JOHN BROWN AND CO.

LIMITED.

ATLAS WORKS, SHEFFIELD;

SHIPYARD AND ENGINEERING WORKS,

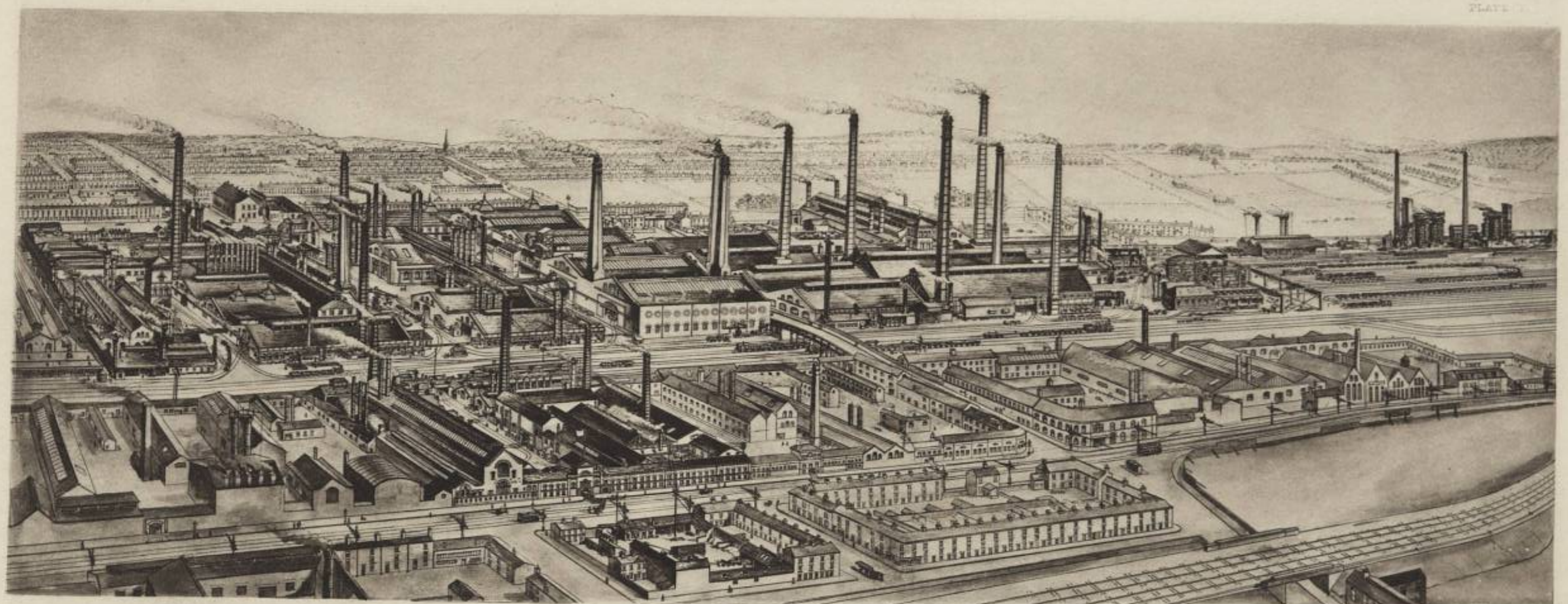
CLYDEBANK.

JOHN BROWN AND CO., LIMITED.

ATLAS WORKS, SHEFFIELD.

SHIPYARD, CLYDEBANK.

PLATE



THE 'ATLAS' WORKS SHEFFIELD. 1903.

JOHN BROWN AND COMPANY,

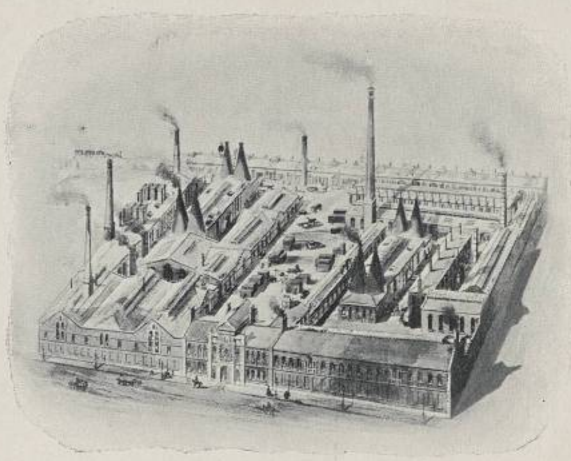
LIMITED:

Atlas Works, Sheffield;

Shipyard and Engineering Works,

Clydebank.

PARTLY REPRINTED FROM "ENGINEERING."



THE ATLAS WORKS IN 1857.

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1903.

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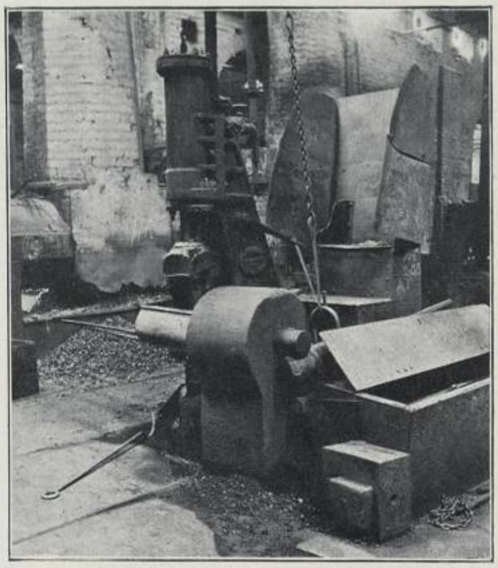
THE ATLAS WORKS.

THE ATLAS WORKS at Sheffield, which were founded about fifty years ago, have acquired a world-wide fame as the birthplace of the British armour-plate industry, as the first works producing steel by the Bessemer process apart from the establishment of the inventor, as the plant from which steel rails were first turned out in great quantity, as well as for the possession now of some of the heaviest forging presses. The works were organised by Messrs. John Brown and Co., and upon Mr. Brown, as head of the establishment, Queen Victoria conferred the dignity of knighthood in 1867, as a recognition of the part which the company had played in the clothing of our great ships of war with armour. Mr. Brown had carried on business at Orchard Street and at Furnival Street, in Sheffield, in a comparatively small way, but it was not until 1854 that he took the tide upon the flood which led to fortune. At that time he acquired what was known as the Queen's Steel Works, previously carried on by Messrs. Armitage, Frankish and Barker. He reorganised the establishment, renamed it the Atlas Works, and secured as partners Mr. John D. Ellis and Mr. William Bragge. In the early years of the history of the works, all three of these gentlemen directed their great skill and energy to the development of the business. Sir John Brown retired in 1870, Mr. Bragge died in 1884, but Mr. Ellis continues as Chairman and Managing Director, displaying the same inventive genius, ripe judgment, and active supervision as of old.

One or two facts will serve to indicate generally what these coadjutors have done for the business. The Atlas Works, when they became the property of the three partners, covered three acres; now the area is 36 acres at Sheffield, 78 acres at Clydebank, and about 150 acres of surface and 7,000 acres below ground at Rotherham Collieries; besides which the company are owners or part-owners of other industrial properties of considerable magnitude. In 1854, the works of the company were valued at £14,050: to-day they are worth 2½ millions sterling.

The greater part of the 36 acres within the boundaries of the Atlas Works are covered with buildings. There are in the works forty-three furnaces for reducing the iron and other metals used in the various processes of manufacture, which necessitate the use of 400 tons of coal and 100 tons of coke each day of the year. There are ten hydraulic presses, including one of 10,000 tons power, and thirty-three steam hammers to work the hot ingots, some of them 80 tons in weight, down to the approximate form of the finished product. For manipulating heavy weights there are ninety-four travelling cranes, two of them having a capacity of 150 tons, one of 100 tons, and most of the others of 50 to 60 tons; in addition, there are fourteen locomotives in the works, for conveying the products from one shop to another on the many miles of railway running like a network through the establishment. There are 307 machine tools, many of them of great power, for planing, turning, boring, and otherwise shaping the forgings and castings to finished dimensions. They are driven by prime movers developing an aggregate of 12,000 horse-power, which is transmitted to the tools largely through the most efficient medium of electricity.



THE FIRST STEAM HAMMER IN USE IN SHEFFIELD.

Although the area occupied by the Atlas Works at Sheffield has increased twelvefold since the works were first commenced, the actual turnover of the company has multiplied one hundredfold, from £30,000 to £3,000,000 sterling per annum; and this fact in itself affords a clear evidence of the beneficial influence of modern mechanical methods. The output fifty years ago probably did not exceed 5,000 tons per annum, whereas to-day it is close upon 100,000 tons. In all the works of the company the 20,000 workers employed earn in wages about £1,250,000 per annum sterling.

When the Atlas Works were commenced, spring steel was made almost entirely from imported iron, mostly of Swedish and Russian manufacture; but the founders recognised that a good English iron could be produced to take the place of the Swedish material, and the first important step taken was the erection of twelve puddling furnaces for making steel-iron. These furnaces had a capacity of 120 tons per week, and there was introduced in connection with them a steam-hammer by Nasmyth, which it is of historical interest to note was the first steam-hammer in use in Sheffield. The production of "J.B.

steel-iron" from this plant practically marked the beginning of the great steel-producing industry of Sheffield from British raw materials. The metal produced proved so satisfactory that a great demand was created. Meanwhile, Brown's original works at Furnival Street and elsewhere had been transferred to the new establishment in Savile Street, and the manufacture of steel springs and buffers was continued with increased diligence and success. It was about this time, too, that Brown introduced his conical spring buffer, which soon became almost universal, owing to the fact that it solved the problem which had troubled railway engineers for the first ten years of the railway era, as it took up the shock due to the violent concussion of wagons with solid buffers and connected by loose chains. To meet the developing trade a second steam-hammer, by Naylor, was acquired, and in 1858 a 12-in. rolling-mill was laid down for working bars. At the same time an extension of the area of the works was found necessary, and ground was acquired from the Duke of Norfolk, on the further or north side of the Midland Railway, which still intersects the works.

In 1858, Sir Henry, then Mr. Bessemer, found in the partners of the Atlas Works that outside encouragement which subsequently helped greatly to overthrow the strong wall of prejudice against his process of manufacturing steel in converters. It is true Sir John Brown was not at first enamoured of the system; but the success in Bessemer's own establishment, which adjoined the Atlas Works, and in which Bessemer steel was made at a cost of £20 per ton, was convincing, and an arrangement was entered into under which Brown and Ellis both became important factors in the ultimate commercial success of the new process. The first order which the firm secured for Bessemer steel rails came from abroad. The difficulty of obtaining a trial in this country is indicated by the fact that a twenty years' guarantee had to be given before the clients would accept the new metal. For years the firm were the greatest steel rail-makers in the world, but the establishment of competitive works near the sea coast, conferring as it did an advantage owing to the absence of overland rates for exported material, ultimately compelled most of the inland establishments to abandon the steel rail trade, which was also given up at the Atlas Works in 1874. Other trades of more importance had meanwhile been adopted.

The firm, too, were among the first to manufacture steel plates for shipbuilding, Bessemer steel being first used for this purpose about 1856, although the introduction of the open-hearth furnace ten years later brought about a change; and, as will be stated further on, Siemens furnaces were laid down to meet the growing demand. For the rolling of Bessemer steel for tyres, plates and angles, and other purposes, mills were put down about 1858.

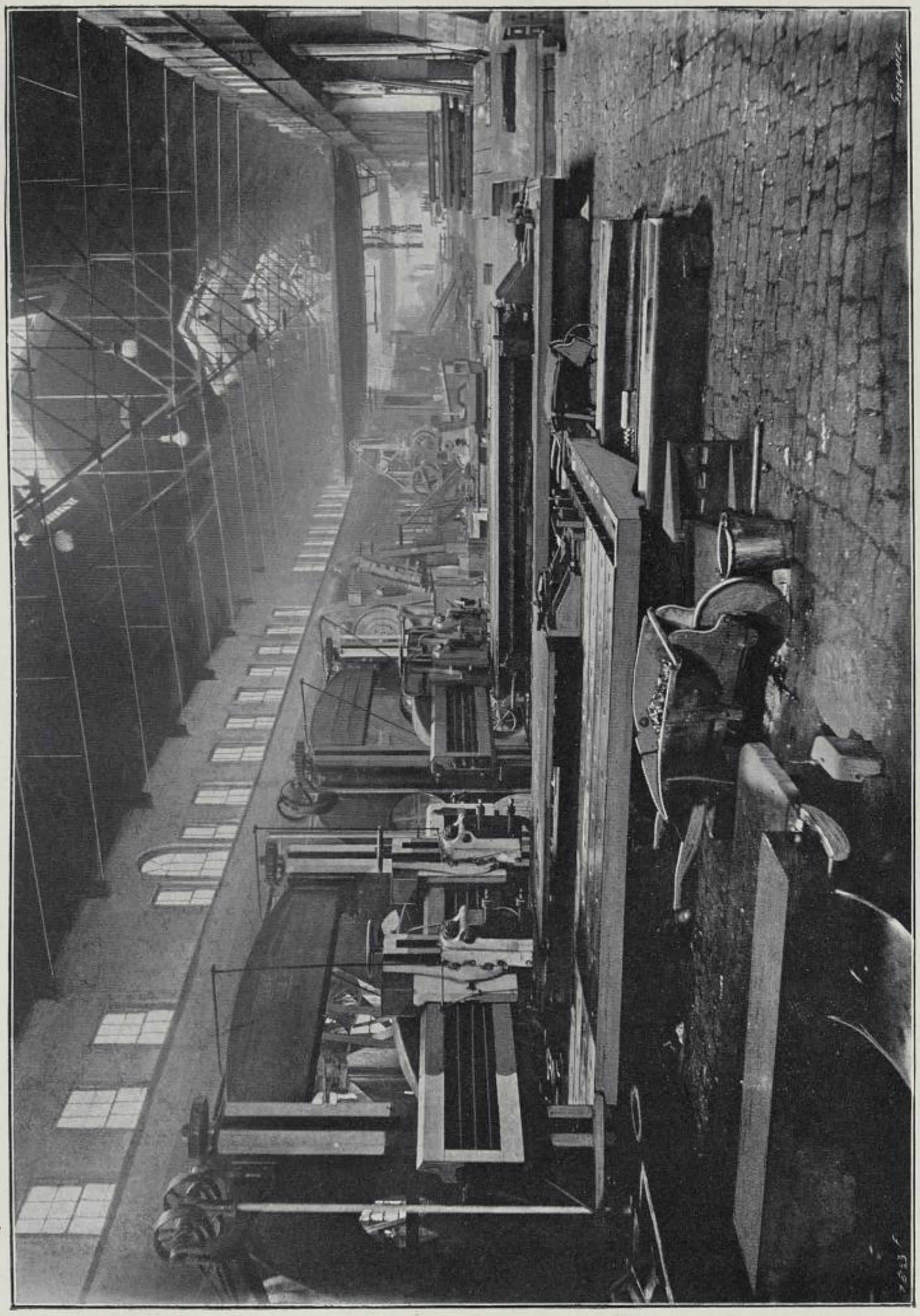
But a greater step forward, and one of national significance, was the commencement of the manufacture of armour plates, and that by an entirely new process. The first experiments were made at the end of 1859; and instead of adopting the practice of hammering the metal in the plate form, as was in vogue abroad for the first armour made, the Atlas Works put down a mill for rolling broad bars to the required width, and these were piled upon each other successively, and the resulting piles re-rolled and welded together in sufficient numbers to make the desired thickness of armour plate. The first mill had rolls 24 in. in diameter, and was actuated by two beam engines of 300 horse-power.

The "Warrior" and "Black Prince," the first vessels of the British Navy to be built with armour, had 4½ in. plates, and the belt, secured to 18 in. teak, extended for 212 ft. of the total length on the water line of 382 ft. As to the resisting power of these plates, which was enormous for those times, but most insignificant when compared with the results of to-day, we shall deal in writing on the evolution of modern armour; but it may be here stated that in the next three ships specially built with armour plates — the "Minotaur," "Northumberland," and "Agincourt"— the thickness was increased to 5½ ins., the total weight of armour being in the earlier ships 1,350 tons and in later vessels 2,100 tons. But in several existing wooden ships, notably the "Royal Oak" and "Royal Alfred," 6-in. plates were bolted on to the "wooden walls." The success of the early plates brought other makers into the field; but in competitive trials where four or five plates from different establishments, including some from the Royal Dockyard, were tried, Atlas plates stood the impact of nine projectiles while the others succumbed at the fourth blow.

The demand of the naval architect was then for increased thickness, as Whitworth and other gun-makers were working diligently to make the attack on the plates more powerful. To meet this there was laid down at the Atlas Works in 1863 a mill with 32-in. rolls driven by powerful engines, and an entirely new shop was erected and equipped with immense tools for machining the heaviest of armour plates. One of the shops, with its modernised machinery of to-day, is illustrated on the Plate facing this page.

Even in 1863, the rolling mills and machine tools installed were in advance of the immediate requirements, for we find that in H.M.S. "Hercules," of 1868, the main belt was only 9 in. thick, and in H.M.S. "Alexandra," of 1877, 12 in.; the "Dreadnought," of 1875, marking almost the maximum reached with a few 14-in. plates on her turrets. The area of each plate was also gradually increasing, but even in this respect the plant at the Atlas Works was equal to the demands, for when the Lords of the Admiralty visited the works on the 9th of April, 1863, to witness the first plates rolled by the new mill, they saw plates 12 in. thick and up to 20 ft. in

PLATE II.



One of the Armour Plate Machine Shops.

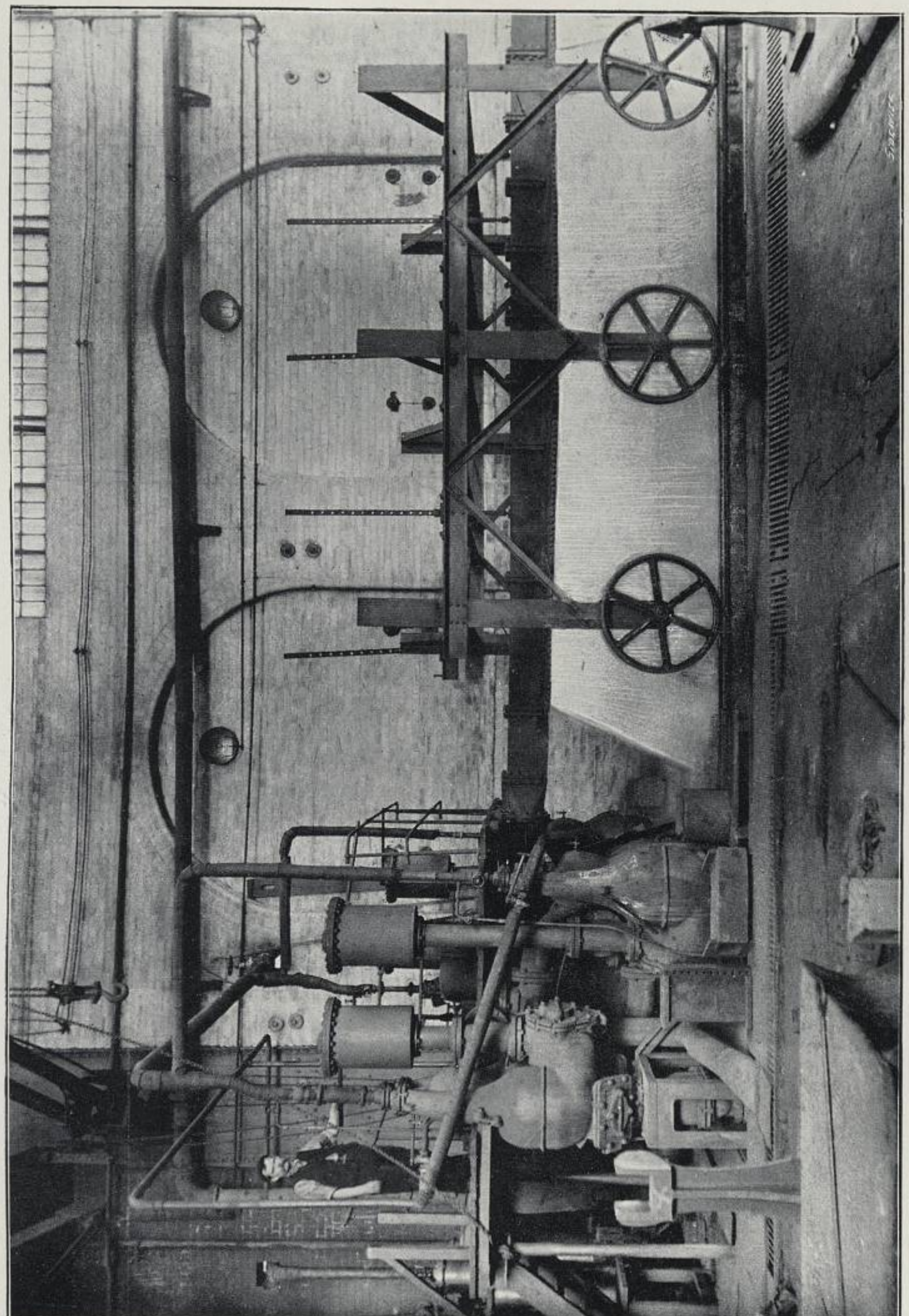
length turned out, and naturally expressed high appreciation for the enterprise of the company, who had in this work spent nearly a quarter of a million sterling. Although the cost of these early wrought-iron plates was naturally much less per ton than that of the plates of to-day, which have to undergo many expensive and complicated processes, their cost per unit of area protected from a given attack (and this is the only reasonable basis of a comparison) was substantially more than the naval architect is now called upon to pay for modern plates. A ship that in the early days would have carried a dead load of 2,500 tons of armour, can now for a smaller expenditure have the same protection for a less weight than 1,000 tons, so that there is set free more than 1,500 tons for extra guns, more powerful engines, greater coal capacity, more armour, or other purpose the naval architect may think expedient.

There have, however, been several intermediate stages in the evolution of the plate of adamantine hardness made to-day, and Mr. John D. Ellis, the chief of the Atlas Works, has taken a prominent part in this process of improvement. About the year 1877, guns had so increased in power that it was considered impossible to produce a wrought-iron plate which, while of reasonable thickness, could withstand the attack from the later 80-ton guns, and the compound plate then came to the front. This was a plate with a steel face and a wrought-iron back (the former representing about one-third of the total thickness), which under Mr. Ellis's patent were united by a process designed to insure not only a perfect weld but a comparatively hard face—an important feature entirely lacking in the wrought-iron armour. This face offered so much initial resistance that the projectiles of the time were broken up, or, if they struck at an angle, they glanced off. The all-steel plates introduced about the same time, offered, perhaps, equal resistance to attack. but lacked toughness, which in the case of the compound plate was supplied by the iron back. As the steel plates were thus more liable to break up, compound plates continued in use where thick armour was required.

As far back as 1871, the idea had occurred to Mr. Ellis of applying to iron armour the principle of cementation, and, a patent having been applied for, a plate so treated was subjected to firing test. The result, however, was not encouraging, owing to the omission of chilling treatment, which at that time was thought impracticable in the case of such large masses as armour-plates. The patent was therefore allowed to lapse, and nothing further was done for the perfection of cemented armour at that time. In 1891, however, Captain Tresidder, a member of the firm of John Brown and Co., devised a method of chilling armour-plates for which various British and foreign patents were taken, in the specifications of which mention was made of the suitability of the process for giving dead hardness to the face of any plate where high carbon was present, whether the face was separately made, as by the Ellis compound process, or super-carburised by cementation, as tried by Mr. Ellis on the occasion above referred to. The engraving facing this page illustrates this method of chilling plates, first introduced at the Atlas Works and now universally adopted.

In connection with this important development in the process of hardening armour, we have a further instance of the many cases wherein scientists in different parts of the world work at the same time, but without knowledge of each other's research, towards the same end with similar issue. Harvey, an American engineer, had been experimenting contemporaneously with Captain Tresidder to produce a cemented and chilled plate, and there was one day between the respective applications for patents, the one in America and the other in England. The Sheffield inventor's date was the earlier, but ultimately, after much negotiation and consulting of lawyers, forces were joined for commercial reasons. This combination of the cementation and chilling processes marked a great advance: a 7-in. plate so treated being a match for a 6-in. shot of 100 lb., striking with a velocity of 1950 foot-seconds; whereas formerly it required a thickness of 10½ in. of all-steel or compound armour to meet this attack. The Krupp process still further increased the resisting power of armour; and almost immediately on its introduction in 1896, the plant at the Atlas Works was altered and extended at great expense to suit this latest system.

But the interesting subject of armour development has carried us somewhat out of our chronological order. The many changes necessitated by the introduction of the Bessemer system in 1858, with its converters, new forge, and rolling mills, the laying down of immense armour-plate rolling-mills and machinery, and other improvements, suggested to the management, in 1864, the expediency of converting the co-partnership into a limited liability company, with a capital of one milllion sterling. Sir John Brown was the first Chairman, but six years later he retired, and by natural selection was succeeded by Mr. John D. Ellis, who continues in the position of Chairman and Managing Director. One of his first acts was to insure for the concern a large measure of independence, by the purchase of iron-ore mines in Spain, Lincolnshire, and Northamptonshire; and also of coal mines, an arrangement which has proved profitable. At the same time, blast furnaces were erected at the Atlas Works, so that the Company were able to convert the raw material from its natural state into the finished product—armour-plates, forgings, ship-building materials, railway plant of all descriptions, &c. The last-named manufacture had enormously increased, and at this time the works produced vast quantities



Armour Chilling Process, First Introduced at the Atlas Works and now Universally Adopted.

of steel rails, while their weldless steel tyres, introduced in 1865, were quickly appreciated.

As to marine work, similar enterprise was shown. A special press for flanging boiler-ends was laid down in 1879, and as soon as the Siemens open-hearth process for making steel was introduced, furnaces were put down, and, in addition to the rolling of plates, the casting of propellers, propeller bosses and the like was undertaken. The triple compounding of steam engines encouraged the use of higher boiler pressures, so that a demand sprang up for heavier shell-plates, as well as for a form of furnace that would offer a greater resistance to collapse than the smooth cylindrical type hitherto used. This led to the production at the Atlas Works, in 1885, of the Purves patent ribbed flue, which rendered very valuable service to the marine engineer. The Serve tube, whereby the evaporation for a given tube surface is increased, adding considerably to the efficiency of the boiler, was introduced in 1890, a new mill being invented for rolling the special strips with the longitudinal ribs: these strips, after being bent and welded, form the tubes.

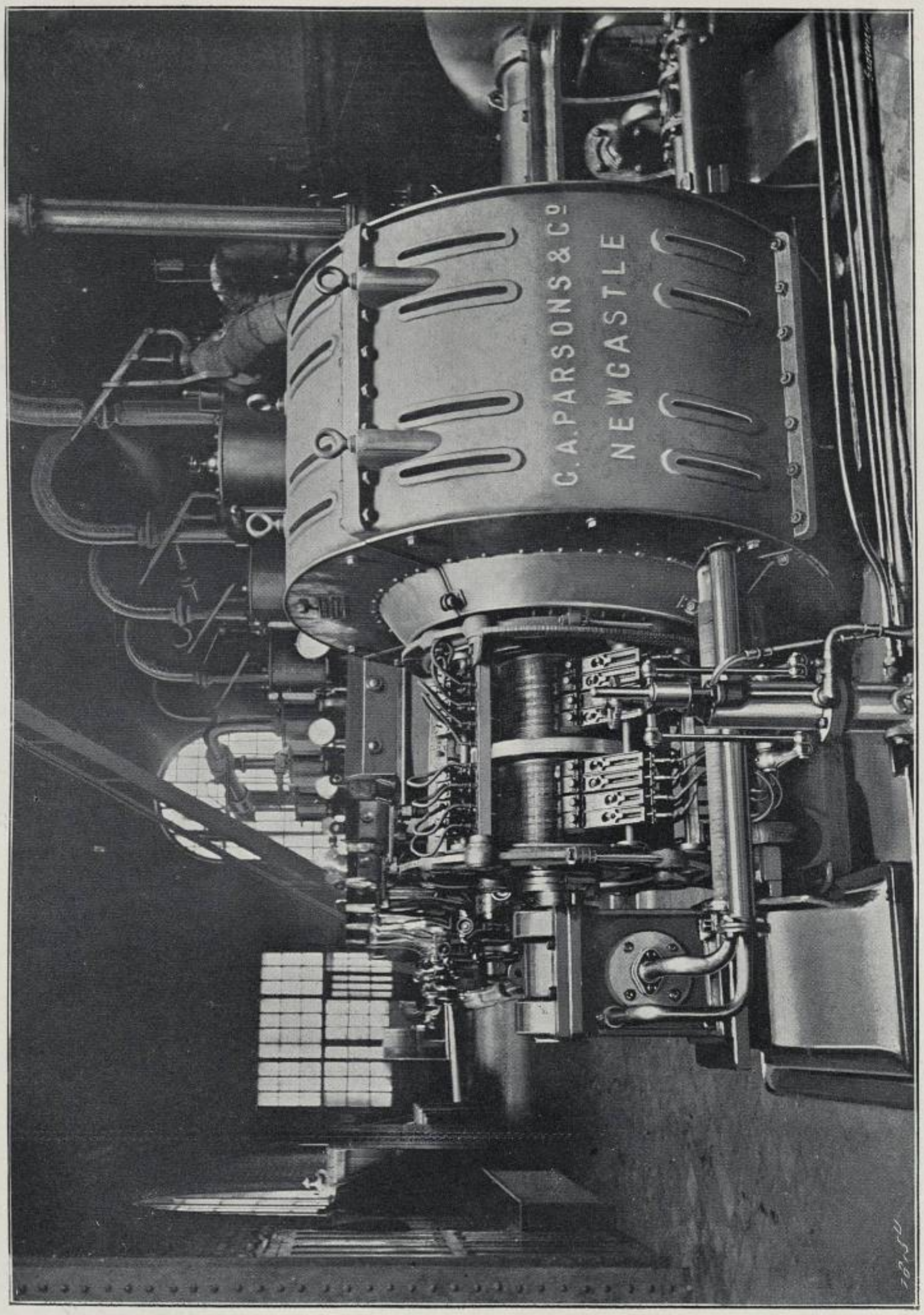
Reference may also be made to the Ellis and Eaves system of draught for boilers of all kinds, both marine and land. This was first introduced in 1893, and, having proved efficient, is widely adopted. The air-heating tubes are arranged in nests on the top of the boiler, so that the waste gases, with much of their heat still unabsorbed, travel along the outside of these tubes on their way to the suction fan at the base of the funnel; while the air to assist combustion in the boiler furnaces enters the tubes from the stokeholds, and passing through them, becomes heated by the waste gases to the extent of between 200 deg. and 290 deg. Fahr., or by over 200 deg. above the temperature in the stokeholds. Thus the heated air entering the furnaces greatly improves the combustion and the economy of steam generation. The "Robert" process of steel casting, which we shall describe later, was introduced in 1889.

These and other similar inventions, as well as the improvements in railway material, have from time to time necessitated the reconstruction of various departments of the works, while increased demand for all manufactures has involved additions to the plant, and thus the resources of the works have been greatly developed. During the past two or three years, for instance, the company have, at an enormous cost, almost doubled their producing capacity, large armour-plate machine shops have been added, and electric power adopted for driving the tools. Generally, the capacity of the works for supplying armour has been increased to about 10,000 tons per annum. During the last ten years, armour has been constructed for fifty British warships, and for naval ships for Japan, Russia, Spain, Norway, Sweden and Holland. Two hydraulic forging presses are in constant use, one of them of 4,000 tons power being employed on marine shafting, gun-forgings, and similar work, while the other, exerting a pressure of 10,000 tons, is employed only on the making of armour-plate. There is alongside it a horizontal press of about 2,500 tons power, while another quick-acting press, just completed, with a power of 3,000 tons, has probably the finest installation yet devised of such accessories as re-heating furnaces, overhead cranes, &c. The machine shops for forgings, &c., are equipped with the most powerful and modern machinery, including lathes up to 80 ft. in length by 60 in. centres, and boring machines to cut a hole 15 in. in diameter out of the solid at 1 in. advance per hour. With this plant the heaviest shaftings and forgings have been produced, not only for British but for many foreign warships and merchantmen.

The fact that the company make many of the requisites for warships and merchant steamers—armour-plate, boiler material, flues, tubes, engine shafting, and forgings generally — prompted the management to acquire the famous Clydebank shipbuilding and marine engineering works, which during their fifty years of previous existence had acquired a high repute, alike for warships, Atlantic "greyhounds," and merchantmen of every type. The works were well equipped, new tools having been added from time to time as the ambition of the shipowner and naval designer called for larger vessels and higher speeds; but, since taking over the establishment in 1899 the company have greatly increased the producing capacity, constructing new shops, and providing modern tools to improve and cheapen the production. The Clydebank yard has seven shipbuilding berths ranging up to 900 ft. in length, while foundations have been provided to permit of the construction of vessels whose launching weight may be 9,000 tons within a limited area. In addition, there are several berths for smaller craft. Practically, everything is done within the establishment fcr the complete equipment of these ships, and the average annual output of new machinery over a period of years has been in excess of 60,000 indicated horse-power.

This historical review of the company and the works owned would certainly be incomplete without a reference to the fact that in 1903 an arrangement was entered into whereby the Norfolk Works, at Sheffield, of Messrs. Thomas Firth and Sons, became practically, although not nominally, allied with John Brown and Co., Limited, so that the latter company thus considerably increased its resources for the supply of ordnance, projectiles, steel castings, forgings, &c.

As supplementary to the narrative we have given, something may be



The Electric Power Station at the Atlas Works.

said as to the general organisation and capacity of the Atlas Works. The works can produce in a year:

	TONS.
Armour-plate	10,000
Forgings	5,000
Flues	2,000
Castings	2,500
Railway material	20,000
Pig iron	45,000
All other	10,000
	94,500

In addition, of course, there is the large output of iron-ore and coal from the mines, of which we shall give a description later.

Reference should also be made to those general arrangements of lighting, heating, and ventilation which are important factors in the efficiency of such an establishment. Light and power for the Atlas Works generally are provided from a central station, in which there are six sets of combined steam engines and dynamos, each capable of generating 165 kilowatts when indicating 250 horse-power, the pressure of the continuous current being 220 volts. This power station is illustrated on the engraving facing page 8. The boilers with which it is equipped, four in number, are of the Ellis and Eaves induced draught type. There is another battery, consisting of four cylindrical and a Babcock and Wilcox water-tube boilers, the latter fitted with Serve tubes for experimental purposes. A fan driven by a Parsons' steam turbine is also installed. It has been the practice at the works, in providing such plant, to arrange for experiments as to steam generation, and the water-tube boiler named was fitted with the special purpose of determining by actual trial the relative advantages of this type, as compared with the ordinary cylindrical boiler, when run with and without Ellis and Eaves draught, and also to ascertain the result of the application of Serve tubes to water-tube boilers generally.

The electric motors employed for driving machine tools are, as far as possible, standardised to reduce the number of spare armatures, &c., kept for emergency. There are several small motors for various duties requiring less than 4 horse-power, but standardisation is applied to motors ranging from 4 horse-power up to 75 horse-power. Enclosed, or partially enclosed, motors were originally adopted; but experience proved that machines of the open type could be worked satisfactorily even in the dust-charged air of a steel works, without prejudicing the efficiency or unduly increasing the repair bill; and they were therefore ultimately preferred, because of their less size and weight per unit of power. The controlling arrangements of the motors are almost exclusively wet switches, which have been found more satisfactory than metallic resistances.

The works generally are lighted by arc lamps running four in series, and the offices by incandescent lamps taking the full pressure of 220 volts.

In the construction of the more modern shops, ventilation involves no trouble because of the size and height of the roof; the frequent opening of large doors for the passage of the traffic affording sufficient fresh air, while louvre and other arrangements in the roof prove satisfactory for the exhaust. But the heating question is always one of great difficulty, especially in the winter season. Almost every possible scheme that had been adopted elsewhere was considered by the management of the Atlas Works, and many plans and estimates were prepared; but, in the end, it was agreed that the best results were obtained by the placing of small stoves at frequent intervals in the shops, each with its own chimney. Most of these stoves are fired with coke, and the remainder with coal-gas produced in the gas-works within the establishment, used for flue-welding, and partly for lighting. Gas cooking-ovens are also provided in all the larger shops, and for a sufficient period before each meal time a man is in attendance to supervise the heating of the workmen's food; so that in this, as in other arrangements, everything is done for the comfort and convenience of the workers.

There are extensive laboratories where all material as it arrives in the raw state, or as it leaves in a complete form, is subject to examination, samples being taken for chemical analysis and mechanical tests. The chemical laboratory, fitted with the usual appliances, has a staff of fourteen chemists, and a great many of the analyses are by combustion. In the case of many of the productions tests are made at frequent stages; in armour manufacture, for instance, there are three or four chemical analyses and five or six mechanical tests. The measure of chemical hardness of armour is determined from drillings taken from the plate, analysed in layers of one-eighth of an inch by the combustion method.

The mechanical testing department has a 50-ton horizontal hydraulic testing machine of the Buckton type, as well as an old-fashioned dead weight testing apparatus, still useful and accurate, although slow. There are two lathes, four planing machines, able to deal with pieces 3 ft. square by 3 ft. 6 in. high, a rotary machine for milling, and other appliances, along with a press of 600 lb. pressure for cold bending. All these machines are practically kept working day and night, the aim being that nothing shall be sent from the works except it be thoroughly reliable. For railway work there is the usual drop-test apparatus; but these and similar appliances will be dealt with when we come to describe the process of manufacturing the various productions of the company.

It will readily be understood that in an establishment equipped with so many mechanical appliances, there is great need for an extensive engineering and repair department; indeed, many of the special tools are constructed as well as designed within the works. The engineers' turning and erecting shop for such purposes includes in its equipment lathes, several planing machines, slotters, and special shaping tools, all of which are driven electrically. The shop is commanded by two cranes, one lifting 12 tons and the other 5 tons. The importance of the department is indicated by the fact that the engineering staff includes six hundred and fifty men. There is also a large boiler shop, about 72 ft. long, for carrying out repair work on the many steam generators within the works. In this shop there are two radial drilling machines, one of them with an arm 5 ft. long; the larger punching machines make $1\frac{1}{2}$ in. holes in 1 in. plates, the bending rolls take plates of similar thickness, and there are two machines for plate- and angle-shearing and punching. There is a 50-ton overhead travelling crane, and four jib cranes of 30-cwt. capacity. In a large pattern shop, a numerous staff is engaged preparing moulds for the armour plates, each of which sometimes requires several of these owing to the variation in form to suit the lines of the ship or the contour of gun-hoods, &c. We may conclude with a list of the manufactures.

AT SHEFFIELD.

Armour plates by the Krupp, Harvey, and other processes.
Marine and other engine crank-shafts.
Shaftings of all kinds.
Gun and other forgings.
Projectiles of all types.
Patent ribbed boiler flues.
Serve patent ribbed boiler tubes.
Ellis and Eaves induced draught apparatus.
Patent deadweight safety valves.
Robert patent and crucible steel castings of all descriptions for engineering and colliery purposes.
Siemens' crucible and all kinds of tool steel.
Rolled and forged bars, angles, iron and steel tee rings, &c.
Railway tyres, axles, springs, buffers, &c.
Patent wrought steel wheels.
Foundry and forge pig iron.
Patent bulkhead doors, with operating mechanism.

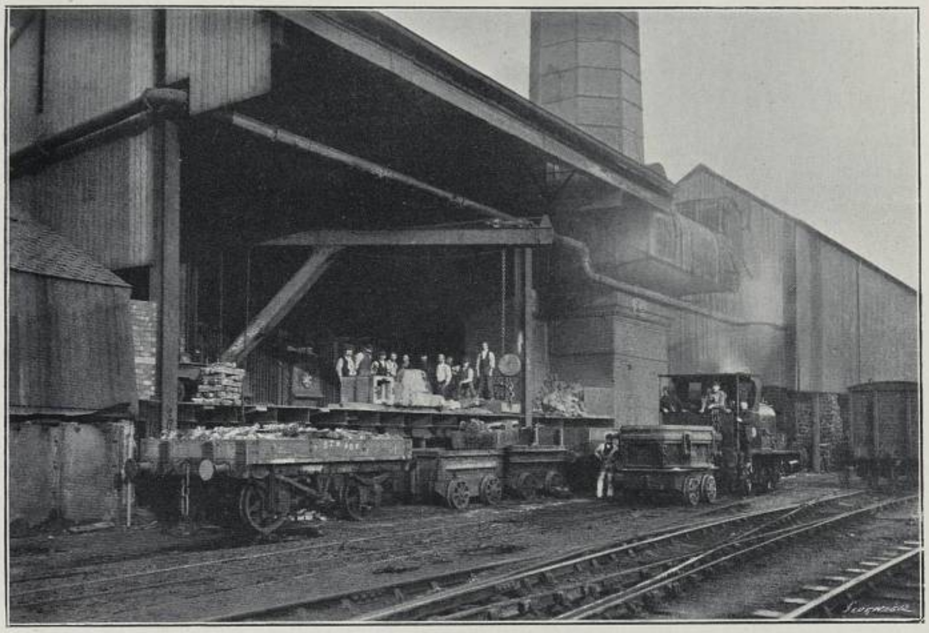
AT CLYDEBANK.

Warships and merchant steamers of all types.
Steam and other yachts.
Marine engines and boilers.
Auxiliary machinery of all types for steamers, &c.

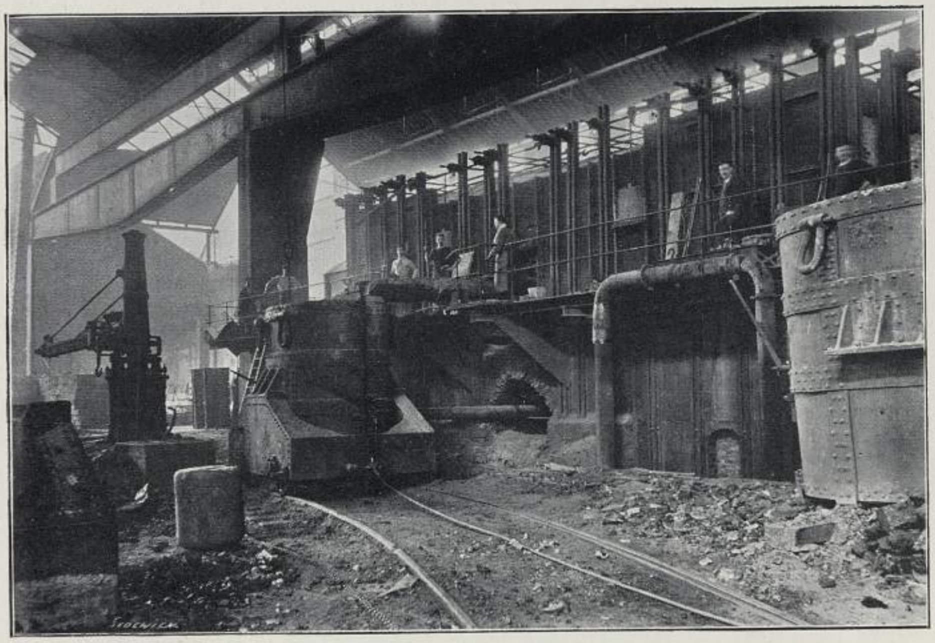
STEEL MANUFACTURE.

STEEL productions, whether cast or forged, have their origin in certain raw materials bountifully supplied by Nature; and Messrs. John Brown and Co., by their possession of collieries, iron mines, blast-furnaces, &c., have the advantage of being to a great extent independent for the supplies of ore, coal, and pig-iron for their steel-melting furnaces. Soon after they developed the manufacture of "steel-iron," in the early years of the history of the works, and thereby put an end to their importation of iron for all steel manufacture, the management recognised the importance of owning iron-ore mines, and of smelting the mineral earth. They, therefore, purchased, in 1871-2, iron-ore mines in Spain, Lincolnshire, and Northamptonshire, and several coal mines in England; and constructed in the north-eastern part of the works in 1873, three blast-furnaces with a producing capacity of 1,000 tons per week. These are partly seen on the engraving given on page 13. These furnaces, which have continued in use and have done good work, will probably be replaced shortly by others of the most approved modern pattern.

For the manufacture of steel, principally for marine forgings and armour-plates, there are six open-hearth furnaces, conveniently arranged with the usual accessories, in a building 480 ft. long with one span of 74 ft. The two engravings on the Plate facing this page illustrate respectively the process of charging and teeming the larger furnaces. The smaller furnaces are used for general work, while those of larger capacity are entirely given over to the melting of steel for armour, experience having shown that better results are obtained, especially with delicate special alloys of metals, by using large furnaces, and thus obviating the necessity of mixing the products of several furnaces. During the last few years, the Siemens foundry at the Atlas Works has been entirely remodelled, and there are several features which merit notice. The safety of the men during the casting of ingots, weighing up to 50 and 60 tons, has had special attention, and the ladle with the molten metal is never suspended from cranes. The alternative method adopted, of running the metal into ladle carriages travelling on rails, which are lifted bodily by means of hydraulic hoists



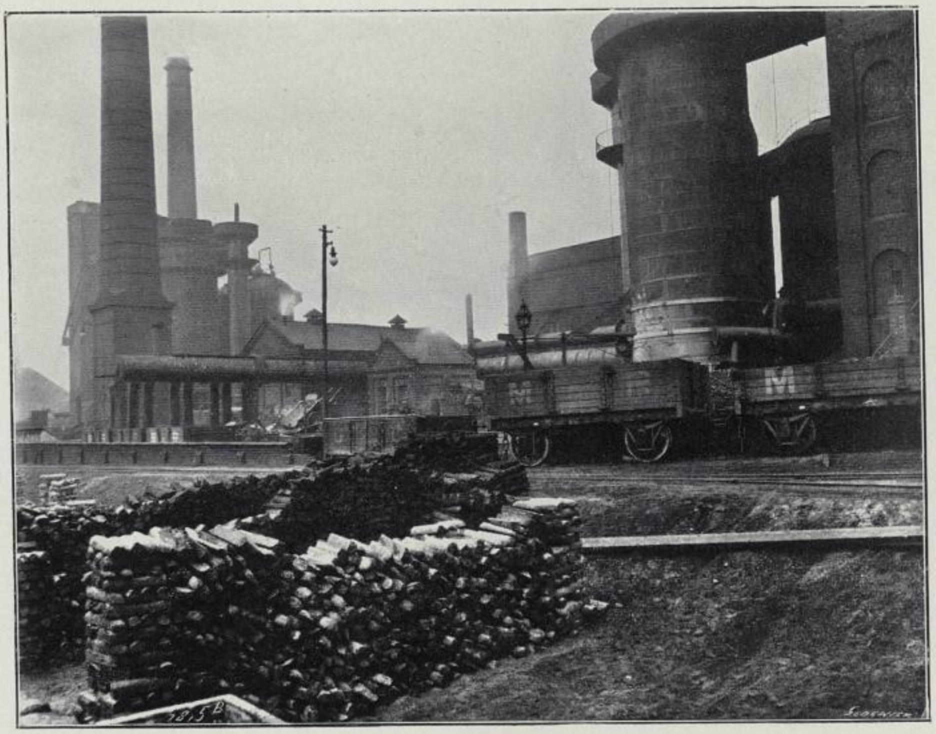
At the Steel Furnaces



Teeming Steel into Ladles.

on to a gantry over the casting pit, is a great safeguard against accident; so that it is not surprising to note that, although 20,000 tons of ingots, varying from 30 to 60 tons, have been made since this arrangement was adopted, no accident of any kind has taken place.

The more modern furnaces were at the time of their erection well equipped with electric charging overhead cranes of 50 tons capacity, and these having proved satisfactory, similar cranes have been fitted in connection with the



At the Blast Furnaces

older furnaces. The whole of the steel-melting department is served by two overhead cranes of 150 tons and 100 tons capacity respectively, the former being steam-driven and the other electrically operated. The gas producers in connection with the open-hearth furnaces are of the Duff design, worked by steam, and the whole arrangement, notwithstanding the frequency of change and improvement to meet developing trade, continues very satisfactory. This steel house is in close proximity to the 10,000 ton forging press, and armour-plate ingots are delivered direct to that press on transfer bogies while yet hot, although, of course, they require to be reheated before being worked. About nine ingots are cast each week for armour alone, and these vary from 30 to 60 tons; those for marine shafting run up to the larger limit; while there are occasionally cast smaller ingots for rolling into bars, plates, &c., and for forging into tyres, axles, and the like. The subsequent operations on these several ingots will be described later.

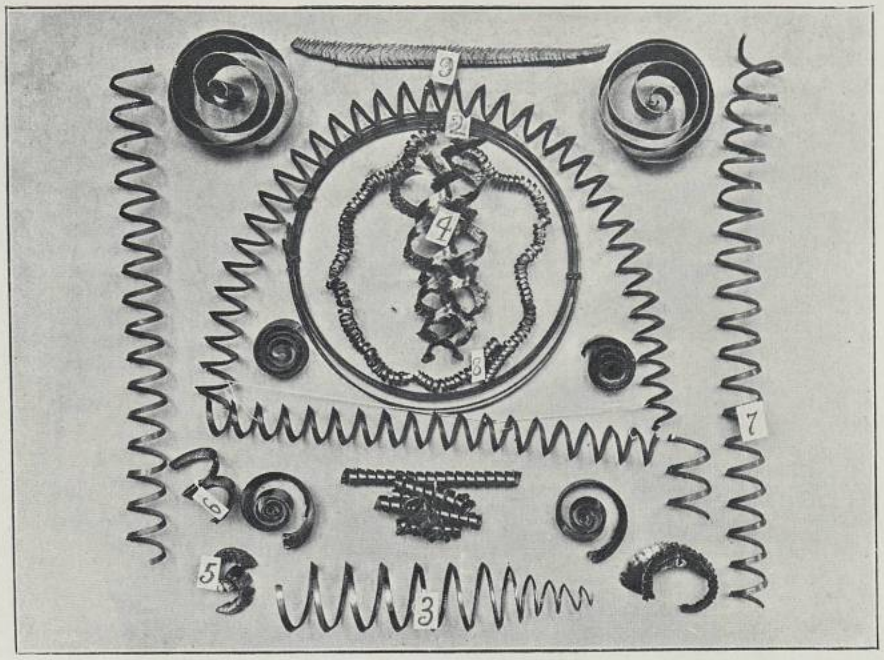
The firm has long been noted for the splendid results got with its crucible steel. In this department there are several melting furnaces which are almost entirely devoted to the manufacture of high-class steel for tools, and with such a success that, although almost every tool-steel in the market is accorded a trial at the works in the search for the very best, the company's own brand is at present unsurpassed. On the Plate opposite there is reproduced a photograph taken of a number of "turnings" from various metals, cut off by tools formed of the company's steel, and used in their ordinary work in lathes, &c. These illustrations, taken in conjunction with the following Table, giving the composition of the steel cut, and the speed, feed, and depth of cut, testify to the value of the company's crucible steel for cutting tools:—

						ft.		in.		in.	
No. 1.	Hard steel,	.5	carbon,	.8	manganese ...	40	per minute,	$\frac{1}{16}$	feed,	$\frac{3}{16}$	cut.
No. 2.	Mild steel,	.25	,,	.5	,, ...	200	,,	$\frac{1}{16}$	,,	$\frac{1}{16}$	,,
No. 3.	Steel,	.3	,,	.6	,, ...	80	,,	$\frac{1}{16}$	,,	$\frac{3}{16}$	,,
No. 4.	Hard steel,	.5	,,	.8	,, ...	21	,,	$\frac{1}{8}$	,,	$\frac{3}{8}$	,,
No. 5.	Very heavy shaft, considerable vibration ...					10	,,	$\frac{1}{4}$	,,	$\frac{5}{8}$	,,
No. 6.	Mild steel,	.25	carbon,	.5	manganese ...	55	,,	$\frac{1}{8}$	,,	$\frac{3}{8}$	,,
No. 7.	Steel,	.3	,,	.6	,, ...	70	,,	$\frac{1}{10}$	,,	$\frac{3}{16}$	,,
No. 8.	Steel,	.25	,,	.5	,, ...	134	,,	$\frac{1}{14}$	,,	$\frac{1}{16}$	,,
No. 9.	Mild steel, heavy shaft					30	,,	$\frac{3}{8}$	,,	$\frac{3}{4}$	,,
	Corner pieces. Armour shavings.										

With the exception of No. 2, the samples of "turning" were taken off dry; Nos. 1, 3, 4, 6, 7, and 8 came off deep blue in colour.

There are five tilt-hammers for working the tool-steel after it has been melted in the crucible pots. These hammers vary in power from 30 cwt. downwards, but such hammers are also utilised for general forging, principally for locomotive work.

In connection with the steel foundries, where such a multiplicity of work is carried out, special references should be made to the "Robert" patent process, in which, by the use of a special type of converter, it is possible to make steel castings of such a mild and tough quality, that they are largely employed for purposes where only forgings were formerly considered permissible. The "Robert" steel foundry is illustrated on the Plate facing this page. These steel castings are being very largely used for locomotive work, wheels, centres, horn blocks, slide motions, eccentric straps, buffers, plungers, &c.; while in electrical work they are admirably adapted for those



Turnings from Various Metals with the Company's Tool Steel.

The "Robert" Steel Foundry.

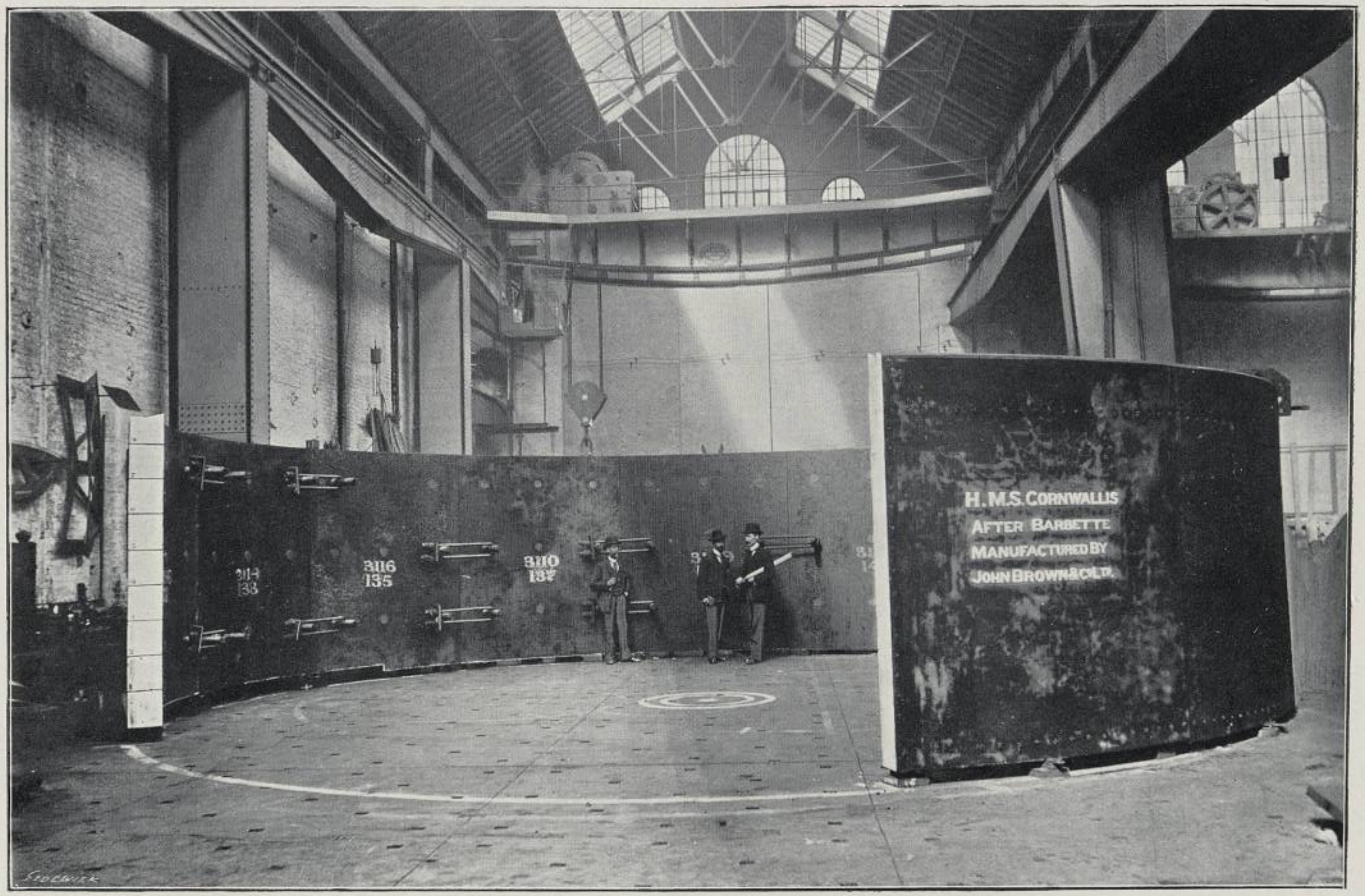
parts of dynamos where high magnetic permeability is necessary. The "Robert" steel has also the advantage that it can easily be welded. After being sufficiently blown in the converters, the steel is teemed into a ladle, and its condition is then such that it maintains its heat for a considerable time, so that a subsequent "blow," or even two, can be used for the same casting. It will thus be understood that a smaller number of converters are required for large castings than would otherwise be the case. The size of each individual converter, too, may be less when several can be used for large operations. The turn-over gear of the converter is driven by an electric motor, which is rapid in its operation and well under control. The "Robert" steel foundry is equipped with a 10-ton and 5-ton electric crane, as well as a large number of differential travelling pulley blocks on swinging jibs, and includes all the latest appliances for cutting runners, &c.

THE EVOLUTION OF THE MODERN ARMOUR PLATE.

A STUDY of the successive stages in the perfection of armour plate, and of the contest waged by the metallurgist against the gun and projectile maker, is as fascinating as the story of armour manufacture, with its many delicate processes for carburising and hardening; and the records of no firm afford fuller scope for such a review than do those of John Brown and Co., for—as has been stated in our first chapter—they were the first to produce plates for the protection of British warships; they succeeded in making a successful compound armour later to meet the harder projectiles fired with increased energy; they were the first to try a cemented plate in England; they were the pioneers of the now universal process of water-quenching, and were equally early in their adoption of the modern process known as the Krupp system, the highest attainment of which, so far as resistance for a given thickness or weight is concerned, is represented in the armour of a modern barbette, as illustrated on the engraving facing this page.

The first plates for H.M S. "Warrior" and other vessels were made by what seems now a simple process, but which, nevertheless, created great interest when first applied. Sir John Brown described the system in a paper read at the Institution of Mechanical Engineers, as follows :—"Several bars of iron were rolled 12 in. broad by 1 in. thick, and were cut 30 in. long. Five of these bars were piled and rolled down to another slab, and these two slabs were then welded and rolled down to a plate 1½ in. thick, which was sheared to 4 ft. square. Four of such plates were then piled and rolled down to one plate, measuring 8 ft. by 4 ft. and 2 in. thick. Lastly, four of these were piled and rolled to form the final and entire plate. There were thus welded together sixteen thicknesses of plate, each of which was originally 1½ in. thick, to form one plate 4½ in. thick. In this operation, from 3,500 to 4,000 square feet of surface had to be perfectly welded by the process of rolling."

The first of the series of armour plates, on the engraving facing page 18, illustrating the evolution of modern armour, shows one of these wrought-iron plates after being tested. It seems to be none the worse, but the attack was feeble, the velocity being comparatively low. The plate had a backing of



THE BARBETTE ARMOUR OF A MODERN BATTLESHIP.

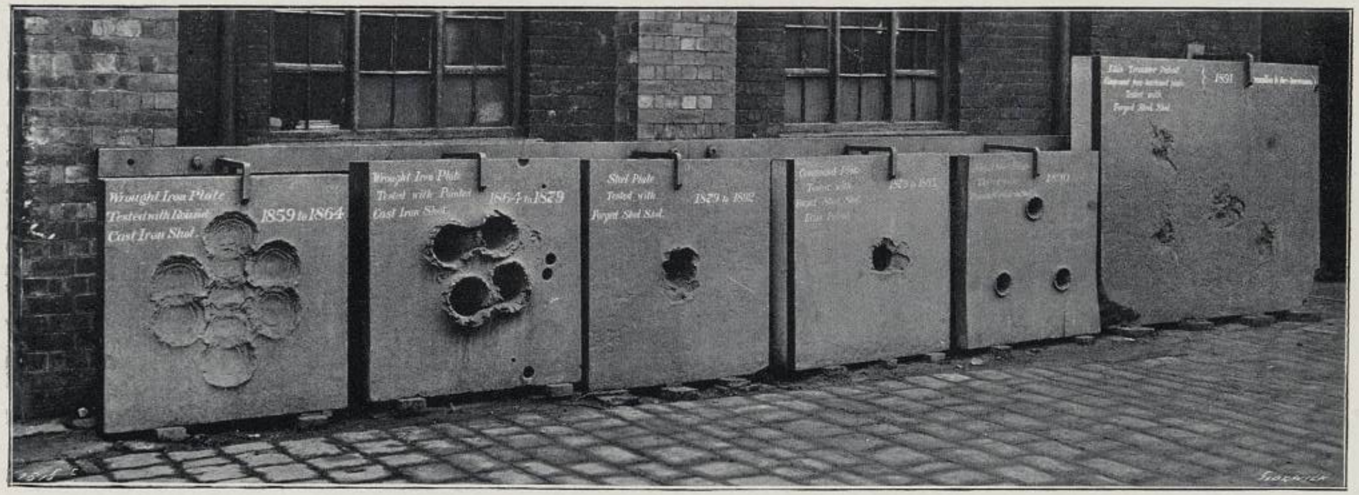
18 in. of teak, and the weapon used was a Whitworth rifled gun, firing an 80-lb. shot. The wrought-iron plates continued to increase in thickness and in area, and with the heavier rolling mills put down in 1863, the number of bars or plates required for the finished product was considerably reduced, and thereby the risk of blisters was lessened. Armstrong, as well as Whitworth, were on the side of the artillerist, and the gun (on the Woolwich system) adopted in the early sixties consisted of a steel barrel with a series of wrought-iron coils shrunk over it. The tube, being of steel, gave a hard surface and a homogeneous material for rifling. Muzzle-loading, however, continued in vogue, the first system of breech-plug proving unsatisfactory. The old 68-pounder guns opposed to the earlier plates used a charge of 16 lb. of powder. The newer weapons were considerably more powerful, their shot ranging up to 400 lb. and their charge to 70 lb. of powder for the 18-ton gun; but even so the 9-in. armour of the period defied these weapons, and, when the "Hercules" wrought-iron armour was made, even a 600-lb. shot was found of little avail.

Ogival-pointed shot of chilled cast iron were introduced. This was the invention of Sir William Palliser, by whose name they have ever since been known. The type is not quite obsolete to-day, being cheap as well as effective so long as the plates attacked have a soft surface. By the 'seventies, the guns had still further increased in weight, a slower-burning powder had been introduced, and an increase in the length of gun enabled higher velocities and a greater striking energy to be developed; the 38-ton guns of the "Devastation" of 1873 were 16 calibres long, and fired an 800-lb. projectile with the initial velocity of 1,540 feet per second, capable of perforating 17 in. of wrought iron at a range of 1,000 yards. This weapon necessitated hydraulic mechanism, which the ingenuity of Armstrong brought into vogue; and the ultimate limit of the old plate was reached in the case of the "Inflexible," which had 24-in. armour in two thicknesses; 12 in. proving quite incapable of resisting the attack of such a weapon. This ship had also 16-in. guns of 80 tons in weight, firing 1,700-lb. shot with a charge of 450 lb. of powder.

Victory, however, did not rest long with the artillerist, as, in 1879, Mr. J. D. Ellis introduced his compound armour with satisfactory results. This armour consisted of a wrought-iron back and a separate hard steel face welded together, the latter being hard enough to wreck the Palliser projectiles, while the former lent toughness and afforded support to the mass. The wrought-iron back and a specially-rolled hard steel plate were first prepared and erected on edge parallel to each other, with a narrow intervening distance-piece between them. The box so formed, having been heated to a high temperature, was held in a vertical position in a pit, where it could be subjected to pressure by an hydraulic ram. Molten steel was then poured into the box, and formed a more or less perfect union between the hard steel face and the wrought-iron back. This hardness was only comparative, as the face plate could easily be punched and even machined, though the latter was a matter of some difficulty. The hardness, at any rate, was enough to break the delicate point of the Palliser shot before it had attained sufficient penetration to receive support from the walls of its own indent; and, as soon as the point was broken, the whole projectile went to pieces and could penetrate no farther. The compound system brought back victory to the armour-maker; a plate thus made, 10 ft. by 5½ ft. and 11 in. thick, received the attack, in 1881, at Shoeburyness, from four projectiles fired from a 9-in. gun, with a total striking energy of 14.869 foot-tons, equal to 1,470 foot-tons per ton of the plate. Three of these projectiles were of chilled iron and one of cast steel; but the plate stood the trial well, for although the steel face was cracked the back continued whole. Two further rounds of cast-steel projectiles were fired at the same plate from a 38-ton 12.5-in. gun, with an energy of 11,824 and 11,695 foot-tons respectively. This very severe punishment only served to prove the satisfactory character of the process.

The era of the compound armour lasted for many years, and one of the most interesting of the tests of the period was a competitive trial in 1889, conducted in Holland, when a "Brown" plate, 11 in. thick, withstood the attack from a Krupp gun of 11-in. calibre and 28-ton weight, firing Krupp forged steel projectiles of 556 lb., with a collective striking energy of 7,078 foot-tons for the three shots. Two of these projectiles broke up "like chilled iron," and the plate, remaining intact, was pronounced the best of the competing targets, which represented the latest products of the leading armour-plate manufacturers of Europe.

The principal competitor of the compound armour as made by two or three firms, was the solid all-steel plate, which, although at first considerably inferior, became a serious rival as knowledge of the metallurgy of steel increased. The all-steel plate was not designed to break the point of the shot, but to offer throughout its mass a greater average resistance than the compound plate, which, in order to avoid cracking, consisted largely of wrought iron of low tenacity, and depended mainly on the power of its hard face to destroy the shot. The two systems, compound and all-steel, were for a long time of about equal resisting power, and the next step was the introduction of ogival-pointed shot, made of very high-grade forged steel, and hardened by a secret process until the point could easily scratch glass. This hardness,



1859-64.
Wrought Iron
attacked by
Round Shot.

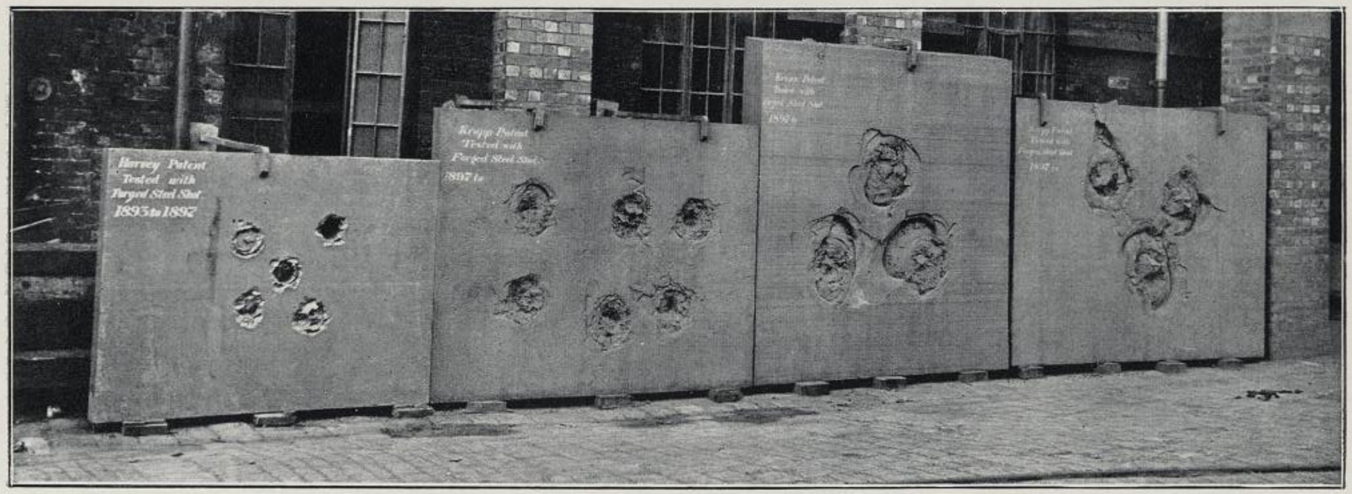
1864-79.
Wrought Iron
attacked by Pointed
Cast-Iron Shot.

1879-92.
Steel attacked by
Forged Steel Shot.

1879-93.
Ellis Compound
Plate attacked by
Forged Steel Shot.

1890.
Nickel Steel
attacked by
Pointed Cast-
Iron Shot.

1891.
Ellis-Tresidder Compound Face Hardened
Plate attacked by
Forged Steel Shot.



1893-97.
Harvey Plate.

1897.
Krupp Plate.

1897.
Krupp 12-in. Plate.

1897.
Krupp 12-in. Plate.

HISTORICAL SERIES OF ARMOUR PLATES.

which exceeded that of the Palliser shot, had the great additional advantage that it was associated with a high strength of cohesion, so that the face of the compound plate, which shattered the original Palliser shot, was no longer able to so deal with the new projectiles; and thus, the chief advantage of the hard face being neutralised, it fell behind in the competition with the all-steel plate of greater average resisting power.

The desideratum was now to restore to the compound plate its lost power of breaking up the point of the projectile before it had time to penetrate any distance and make a support for its own delicate point. Captain Tresidder carried out many experiments at the Atlas Works, with the view of rapidly chilling the face of armour plate to attain the necessary hardness, and, after obtaining fairly satisfactory results with cold air and steam impinging along the face, he tried to effect a uniform chilling by water, driven on to the surface of the plate by a great number of small jets, at a pressure sufficient to prevent the formation of steam globules, which otherwise, he reasoned, would prevent the desired sudden and uniform abstraction of heat from the steel. This it will be recognised, is still one of the primary elements in the latest processes for hardening steel armour ; and the results of several trials made with the Ellis-Tresidder chilled compound plates proved that the research work was in the right direction.

The first plates thus treated were tried at Shoeburyness in 1891. To ascertain the precise effect of the treatment, portions cut from the same plate were treated in different ways, some of them by chilling and others by oil-hardening, and each was subjected to the same attack. The blows which perforated the samples oil-hardened in the ordinary way had little effect on the water-chilled samples. The forged steel projectiles were shattered by the latter, just as the Palliser shots had been in the earlier days. Throughout a series of five comparative tests, the same result was obtained, the projectiles all breaking up without effecting perforation. This system of armour is represented by the sixth plate in the series illustrated on the engraving facing page 18. Hadfield forged steel 100-lb. projectiles were used against a small 9-in. plate, which withstood the attack of five shots having an energy equal to 900 foot-tons per ton of plate ; while a second and larger plate, 9-in. in thickness, similarly withstood an attack amounting to 942 foot-tons of energy per ton of plate. In October of the same year, a 10½-in. plate, measuring 8 ft. by 6 ft. was subjected to trial on H.M.S. "Nettle," under service conditions. Five shots were fired from the 6-in. gun with a charge of 48 lb. of E.X.E. powder; three of the 100-lb. projectiles were of Holtzer steel, and two were Palliser chilled iron shot, the energy developed in each case being

2708 foot-tons; yet the plate, as reported by the late Captain Orde Browne, R.A., stood the test well, so proving the complete success of the chilling process.

Curiously enough, the first Harvey plate was being tried in the United States at the same time as the Ellis-Tresidder plate in England. The latter proved the practicability and utility of rapidly chilling armour plates from a high temperature; the former showed that an all-steel cemented plate was eminently adapted for such treatment. The Harvey system may be said to have combined two processes for application to all-steel plates; of these the one upon which most emphasis was laid in the patent specification was that of cementation or super-carburisation; the other, which the same document dismissed in a few words, referred to a subsequent chilling of the cemented plate, by either dropping water upon it from a perforated tank or by immersing it in a flowing stream. Mr. Harvey was not an armour-plate maker: if he had been he would probably have omitted from his specification all details of the well-known process of cementation, and at the same time elaborated the description of the chilling, where difficulty really existed.

Having obtained success with his process in America, Mr. Harvey approached the European manufacturers with a view to their adoption of his system, and his patent was at once challenged by that of Captain Tresidder. In the end, the Harvey Company bought from Messrs. John Brown and Co., the entire rights for Great Britain and Europe of the Tresidder patents, the Harvey Company of New York similarly acquired the American rights, and the Société Harvey of France purchased the French patents. It thus results that chilling by the Tresidder process has been carried on in all countries, and is still part of the present-day Krupp system.

Probably the best results got with a chilled compound plate were those obtained at a test in August, 1892. The plate in question was 10 in. thick, and measured 8 ft. by 6 ft. It was attacked by five Holtzer forged steel projectiles fired with full charge from a 6-in. gun, the striking energy of each of the five being 2,708 foot-tons, equal to 316 foot-tons per ton of plate. All of the five projectiles were broken up, and the plate, at the termination of the test, "appeared as stiff and strong as at first," as reported by the late Captain Orde Browne, R.A. The centre blow made most impression, principally because of a small blister, which when detected at the works had been investigated by drilling, and the hole subsequently closed with a small screw plug. The blow fell exactly on this defect, but even under those circumstances the penetration was very slight. Several plates of the same manufacture gave similarly satisfactory results, but there was never any question that the cemented all-steel plate was a better subject for chilling than the compound. Therefore, the Harvey plate held the field; and as a measure of the progress made at this time, it may be mentioned that a plate of 10½ in. in thickness could withstand attack from a 9.2-in. 25-ton gun, whereas a 10½-in. compound plate usually succumbed to blows struck by specially hardened forged steel shots from a 6-in. 5-ton gun. In other words, the resisting power in three or four years had increased by 50 per cent.

There was a general feeling, soon after this plate was adopted, that some degree of finality had been reached; but Messrs. Krupp, of Essen, sprang a surprise upon all by perfecting a process, whereby an all-steel plate made of excessively high-grade material could, by a very elaborate course of treatment, be endowed with, not only a face as hard as glass, but also a back as tough as, and much stronger than, wrought iron. The Krupp plate is the plate of to-day, and some idea of its immense resisting power will be formed when it is stated that it is a match for a blow that would conquer a wrought-iron plate of from two-and-a-half to three times its thickness. As a matter of fact, plates made by the Krupp process for the broadside of ships seldom now exceed 9 in. in thickness, but for barbettes the usual thickness in first-class battleships is 12 in.

Before recording the results attained with various thicknesses of Krupp plates, we may indicate briefly the salient features in the process of manufacture. The material used in the latest plates is a multiple alloy of iron and other metals, and is excessively delicate: so much so that a large ingot cast from it, if laid down to cool would almost inevitably fly to pieces. Messrs. John Brown and Co. have their steel furnaces, therefore, close to the hydraulic press. After the steel has been tapped into the ladles, these are hauled along on rails and raised by an hydraulic lift to higher level rails which run over the casting pit. Here the steel is teemed into a trough, and thence direct into the huge ingot moulds. As its melting point is so high, it solidifies upon losing quite a small proportion of its heat, so that it can be taken almost at once to the re-heating furnace preparatory to the treatment under the 10,000-ton press. There it is slabbed down to approximate thickness for rolling in the large mill, special steps being taken to remove a peculiarly adhesive scale that forms upon it. During these several operations the plate frequently requires re-heating, and furnaces for the purpose are provided in convenient positions.

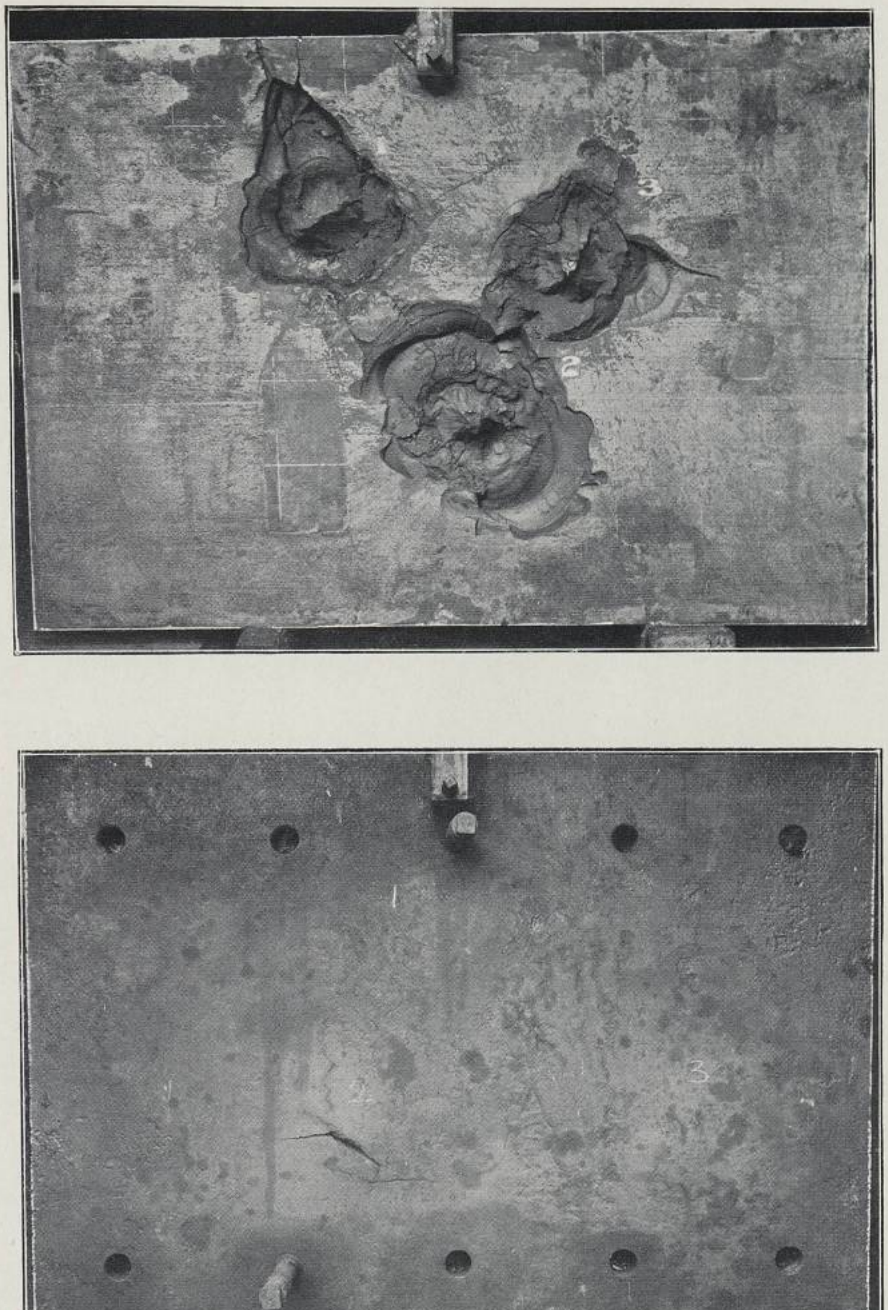
The plate leaves the mill with an allowance for machine surfacing—a process which is most costly and tedious, but which has been less universally insisted on by the British Admiralty since Messrs. Brown submitted rough rolled plates in 1899 to a series of firing trials which demonstrated that the rough face did not in the least degree detract from the resisting power. For this purpose, five 100-lb. shots were fired at a 6-in. plate with the full velocity of 1,960 ft. per second, and the result demonstrated that, from the point of view of resistance to attack, the machining was a waste of time and money. The British Admiralty, however, consider such planing desirable for other reasons;

and in this country armour plates are still machined on the surface, unless there is special arrangement to the contrary.

The plate is not allowed to cool, after being rolled, but is at once passed to the re-heating furnace, and when brought to the required temperature undergoes the first stage of special heat treatment peculiar to the Krupp process, which, if properly conducted, renders it extremely tough. This continuity of treatment and care to avoid cooling is not dictated by economical considerations, but is rendered necessary by the sensitive nature of the material. After the heat treatment, the plate is planed and machined to approximate dimensions, and then is passed to one of the 16 cementation furnaces in the works, where the face becomes chemically harder by absorption of carbon from charcoal, with which its face is kept in contact during a long exposure to high temperature. The plate is further submitted to several heat processes. It is then set under a 6,000-ton bending press, to the approximate form which it will have when fitted on to the ship. Lastly, it undergoes a final heat process, followed by chilling, whereby it acquires intense face hardness. Any alteration or machining subsequent to this last treatment has to be done with powerful electric grinding machines, as no cutting tools can make any impression upon the face. The holes in the back for the bolts, which attach the plates to the ship, are afterwards bored and tapped, and the plate is then finished, and ready for the firing test or for despatch to the Dockyard.

The success of manufacture of modern plates may be indicated by a brief review, with illustrations, of the results of the trial of plates of various thicknesses; and first, we take a 12 in. plate, about the heaviest now made, and used principally for barbettes and conning towers. This plate, illustrated on the engravings facing this page, measured 10 ft. by 7 ft., the precise thickness being $11\frac{11}{16}$ in., and the total weight 15 tons. Three shots were fired from a gun of 12 in., the largest, calibre now adopted in any navy; the projectiles used were of the Holtzer armour-piercing type each weighing 714 lb., and striking with an energy of 17,060 foot-tons, equal to 1,138 foot-tons per ton of the weight of the plate. The engravings afford convincing evidence of the splendid results obtained against an attack which would have made three clean holes in a wrought-iron plate of more than twice the thickness. This test, which was carried out at Shoeburyness on July 21st, 1898, was under British Government direction.

Another plate, illustrated in our Chapter on Warships, is one of those manufactured for the Japanese battleship "Asahi," built by the company at their Clydebank shipyard. In this case the target was 8 ft. square and 8.8 in. thick, cut from a plate selected by the Japanese authorities out of a lot already made for the main broadside belt. The results are peculiarly



FRONT AND BACK OF 12-IN. KRUPP PLATE AFTER ATTACK BY 12-IN. GUN.

interesting, in view of the fact that doubts had sometimes been cast upon the degree of severity of English trials with Holtzer projectiles, the American projectiles being held up as more powerful, and therefore subjecting the plates which they attacked to much greater strain. The plate in question, however, achieved the very marked success shown in our illustrations when fired at with three projectiles made on the most highly-vaunted American process—that known as the Wheeler-Stirling—and thus the results dispose of the doubts referred to. The plate weighed 10.175 tons, and had 12 in. of oak backing, with a skin plate 1½ in. thick. The projectiles were fired from an 8-in. gun, and being of 250 lb. weight, with striking velocities of 1,854, 1,964, and 2,039 foot-seconds respectively, had energies of 5,991, 6,687, and 7,208 foot-tons respectively. The resistance actually exhibited by the plate made it equal to 20½ in. of wrought iron or 2.22 times its own thickness. The projectiles were completely shattered, and the only injury sustained by the plate was the usual splintering of its face round the points of impact, and a few superficial hair cracks on the face, so fine as to be almost invisible. No other cracks whatever could be found, and the only indications on the back that the plate had been subjected to such a severe trial were three smooth bulges, the most prominent being only 1½ in. in height. Such marks on the back, as are shown in our illustration (for instance, across the upper bulge and near the top central bolt), are merely irregularities of the surface, and existed before the plate was fired at.

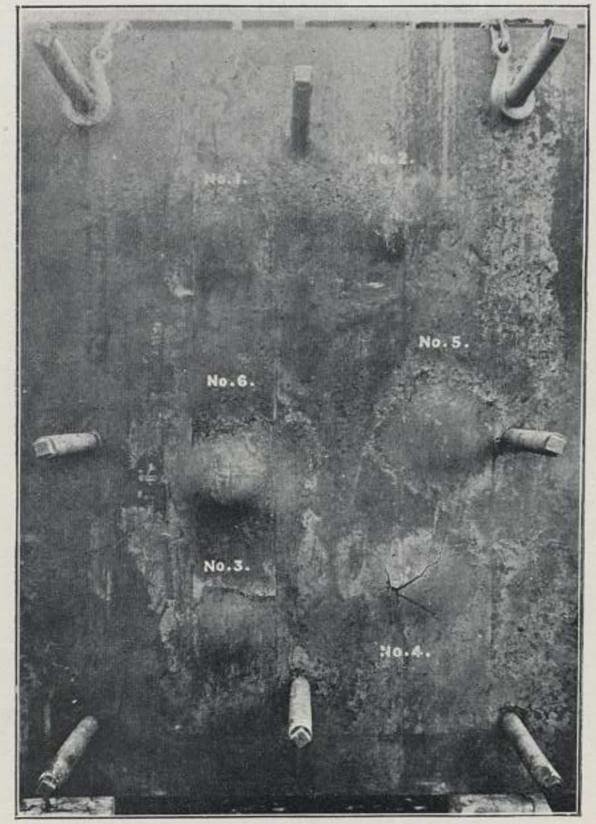
As representing 6-in. armour, which is the most largely adopted, we illustrate, on the Plate facing page 24, the front and back of a plate, 8 ft. by 6 ft., made for two Norwegian coast-defence ships, the exact thickness of the plates being 5.9 in., while the backing was of oak 24 in. thick, with a 1¼-in. skin plate, all arranged to represent the structure of the broadside of the vessel. The tests were made by the Norwegian Government officials, on November 10th, 1899, the gun used being of 6-in. calibre, and here also Wheeler-Stirling projectiles were used, the weight being 102½ lb. The official trial was an attack of four shots, and these were delivered at energies of 2,664 foot-tons. It will be seen that in no instance was there any crack, the perforation being about 3¾ in., while the height of the bulge on the back varied between 1¼ in. and 1⅝ in. It was then agreed, with the consent of the Norwegian authorities, to supplement the attack by two extra rounds at increased velocity, so as to determine the ultimate limit of the plate; but it should be clearly understood that contract conditions had been more than complied with, and the whole of the plates accepted. The fifth projectile was fired to give a striking velocity of 1,997 ft. per second, equal to an energy of 2,834 foot-tons, and the penetration was found to be only 4⅛ in., leaving a dent at the back of the plate of 1½ in. The sixth round was at considerably increased power, the velocity being 2,211 foot-seconds, and the energy 3,392 foot-tons, yet the penetration was but 5 in., the height of the bulge at the back being 2⅝ in. All of the six projectiles were smashed to pieces. The last round, it will be seen, fired at an energy equal to 678 foot-tons per ton of plate, was effectually resisted, and proved that the plate was practically equal to 2.7 times its thickness in wrought iron. As to the mark made on the back of the plate by No. 4 projectile, it was accepted as an example of "a case which occurs in certain rare instances, where the blow is so truly normal to the plate surface and the projectile so good, that the point, instead of being broken, retains much of its sharpness." (See Brassey's *Naval Annual*, 1900 Edition, page 324.)

Our series of test records may be completed by a reference to the official trial of a 4-in. plate on the 3rd July, 1900. This plate was the usual Portsmouth size of 8 ft. by 6 ft., but being only 3$\frac{15}{16}$ in. thick, and opposed to the attack of the 6-in. shot of 100 lb., only two rounds were fired, at a velocity sufficient to perforate 8½ in. of wrought iron. Both of these rounds were defeated, and the face of the plate was not penetrated at all, but driven back locally, just over the area of the impact, to the extent of about 1½ in.

As a record of progress we give a Table showing the figures of merit for the various types of armour, as constructed by the company in the successive stages of the evolution of armour. This shows the relation of the thickness of the wrought iron that would have been perforated by the attack to that of the actual thickness of the plates fired at. Thus, the 6-in. Krupp plate, which we have described, withstood a blow which would have perforated a wrought-iron plate 17 in. thick, or 2¾ times its own thickness. Therefore, its figure of merit was 2.75.

Quality of Plate.	Figure of Merit (being Relative Thickness of Wrought Iron to give Equal Resistance).
Wrought iron	1
Compound or plain steel	1.20 to 1.25
Harvey	1.9 to 2.2
Krupp	2.3 to 2.8

Before departing from the subject of the tests of armour-plates, it may not be without interest to offer a few remarks as to the formulæ in use in different countries for calculating the perforation of armour. In Britain, the formula most generally in vogue—until its inaccuracy at high velocity became apparent a few years ago—was that of Fairbairn, which gave the perforation of wrought iron. The French systems are those of Gavre and De Marre,



FRONT AND BACK OF 6-IN. KRUPP PLATE AFTER ATTACK BY 6-IN. QUICK-FIRING GUN.

also for wrought iron; but the last-named scientist has a new formula for wrought iron and a separate formula for what is called ordinary steel, which is now the standard formula on the Continent. In Germany, up till recently, a formula by Krupp was employed, but it has now been superseded by De Marre's. The most recent formula, and that now adopted in this country, is by Captain Tresidder, of Messrs. John Brown and Co., Limited. De Marre's formula for ordinary steel, which is most largely adopted, except in England, for home trials, is as follows:—

$$\epsilon^{1.4} = \frac{P\,V^2}{1530^2 \times d^{1.5}}$$

where

ϵ = decimetres of *ordinary steel* perforable.
P = weight of shot in kilogrammes.
V = striking velocity in metres-second.
d = diameter of shot in decimetres.

In using this formula, plates are compared by the respective co-efficients required for multiplying the velocity satisfying the formula, when the actual thickness of the plate is substituted for ϵ, to bring it to equal the velocity the plate can actually stand.

But wrought iron is, after all, the most reliable basis of comparison, owing to variations in the quality of other metals; and we may add the Tresidder formula, based on perforation of wrought iron:—

$$\epsilon^2 = \frac{P\,V^3}{816^3 \times d}$$

the notation being as above, except ϵ means decimetres of *wrought iron* perforable. In using this formula, plates are compared by their "figure of merit," which is ϵ divided by actual thickness of plate. Cases in which it is possible to compare the practical accuracy of the formulæ are very rare. One interesting instance was, however, reported from Essen as follows:—Messrs. Krupp had two plates of identical quality; one was 250 millimetres thick, and was found to be just matched (nearly, but not quite, perforated) by the 283-millimetre projectile of 233 kilogrammes, striking at 611 metre-seconds. It was desired to exactly match the other plate, which was 200 millimetres thick, with the 210-millimetre projectile of 95.6 kilogrammes. De Marre's formula was employed to calculate the striking velocity for this purpose, and gave rather more than 652 metre-seconds, which was the observed actual striking velocity, but the shot went completely through, showing that 652 metre-seconds was too much. Tresidder's formula would have given 641 metre-seconds, or about 36 foot-seconds less.

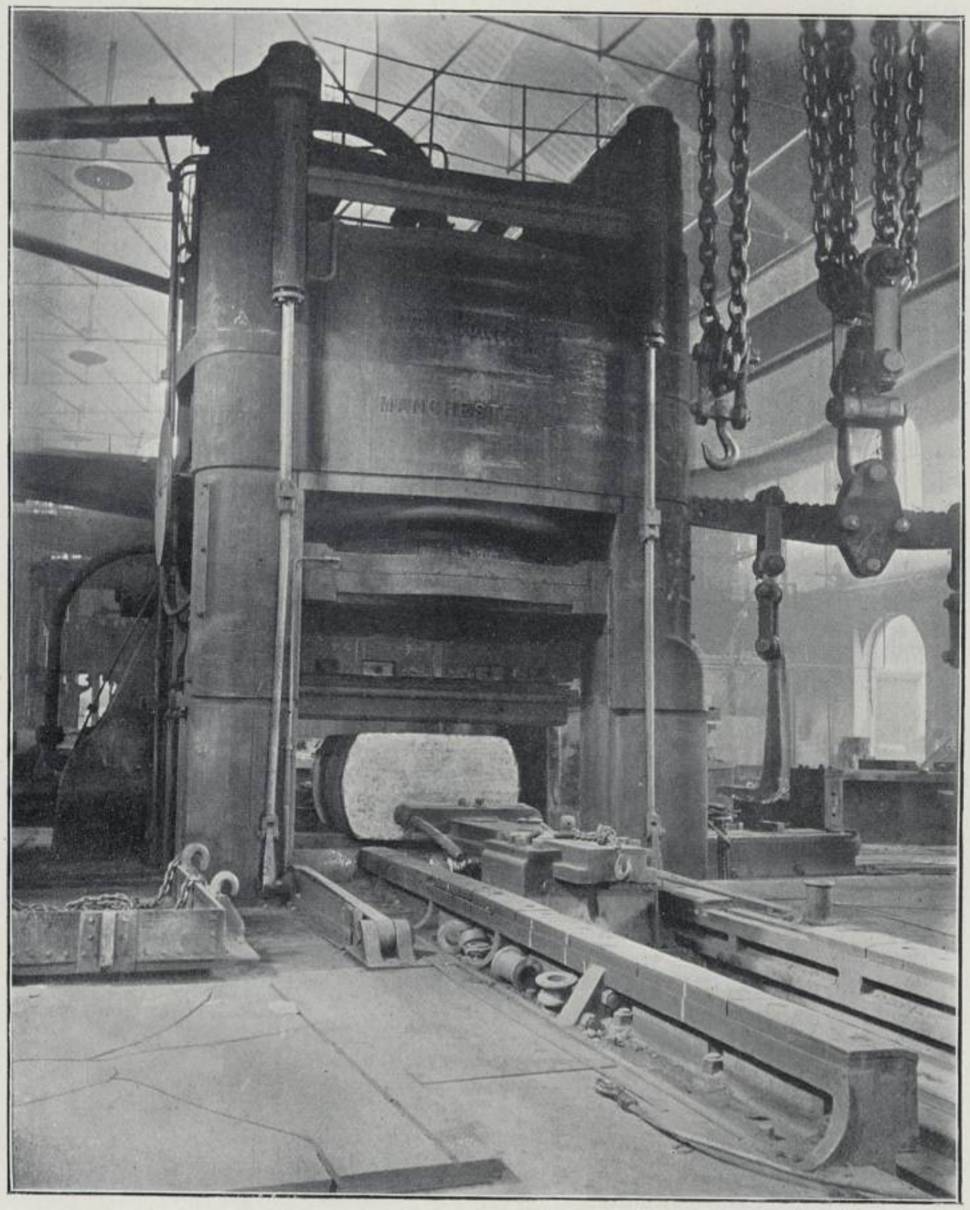
THE MANUFACTURE OF ARMOUR PLATES.

THE large amount of research work resulting in the developments in the processes of manufacturing armour plates, reviewed in the preceding chapter, suggests that in the provision of plant for carrying out the work corresponding enterprise must have been exercised; and an examination of the establishment, and particularly of the recent improvements in plant, supports this idea. We have already written about the open-hearth furnaces for the melting of the steel used in the various departments of the works, and there is no need here to refer further to these, except to remark that the large furnaces of 40 tons capacity for armour-plate work are acid-lined.

The composition of the steel for the specially hard armour plates now manufactured is of such a nature that great precautions are necessary up to a certain stage, as otherwise there would be much risk of disintegration of the mass. Thus, only a very short time is allowed to elapse between the teeming of the metal into its mould, and the removal of the ingot for treatment under the hydraulic press. During the pouring process, too, it is necessary for men to continually stir the liquid steel with long rods, as the melting point is so high that it is ready to solidify almost immediately the metal is at rest. When the mould, which is usually of 40 to 50 tons capacity, is filled, it is allowed to stand for a certain time, according to its dimensions, and is then stripped from the ingot, ere yet the steel has become completely solidified in the interior. In this state the ingot is removed to the re-heating furnaces, there to be prepared for going under the hydraulic ram of 10,000 tons power.

These re-heating furnaces are of the bogie type, the bottom running on rails. The ingot is thus easily lifted on to the furnace bogie by the crane, after which it is run into the furnace. These furnaces are of sufficient capacity to take an ingot 20 ft. long and 12 ft. broad—a measurement which has never yet been reached. One is fired with gas, the other with coal; but experience has not shown any superiority in one system over the other. As soon as the bogie is run into the furnace, the front is bricked up, and a short time suffices to bring the ingot to the required temperature for forging at the 10,000-ton press, illustrated on the engraving facing page 27.

PLATE XI.



10,000-Ton Hydraulic Press.

This splendid hydraulic appliance was laid down in 1895 ; it is the largest of its kind in this country, and is only equalled by one of the same dimensions now at work in America. Its total power, 10,000 tons, is arrived at by multiplying the area of the ram—which is about 4,000 square inches—by the working water pressure of 2½ tons per square inch. This press is in addition to three others now in the Atlas Works, and was provided not only to enable the heaviest of ingots to be slabbed without undue loss in heat, but also to insure a high rate of production and such a duplication of plant as would preclude the possibility of any accident to a press temporarily stopping armour-plate making.

The general construction of this huge machine is very simple. It consists of a heavy cast-iron crosshead at top and bottom, with four massive steel columns, fitted with cast-iron protection slides, which act as guides for the main ram. The cylinder is a steel forging, and is jacketed, and the ram is of cast iron with a cast-steel crosshead. The press is fitted with a pair of horizontal edging cylinders of 2,500 tons power, for lateral squeezing; and, running in line with the anvil, there are horizontal gantreys fitted with hydraulic pushers. These are shown clearly in our engraving on the Plate facing this page. This combination of hydraulic cylinders enables the ingots to be handled quickly with the minimum of labour, and without any chuck or other appliance being connected to them. The ingot is lifted direct from the truck of the re-heating furnaces by one of two 150-ton steam travelling cranes—there is one overhead on each side of the press—and by it placed on one of the horizontal tables. The remainder of the work is done by the hydraulic rams, with much more facility than is possible with overhead cranes pulling about porter bars attached to the ingot. Moreover, the movements are more precise and more under the control of the foreman forger. The work of the hydraulic pushers is further facilitated by the provision of a system of live rollers right up to the anvil.

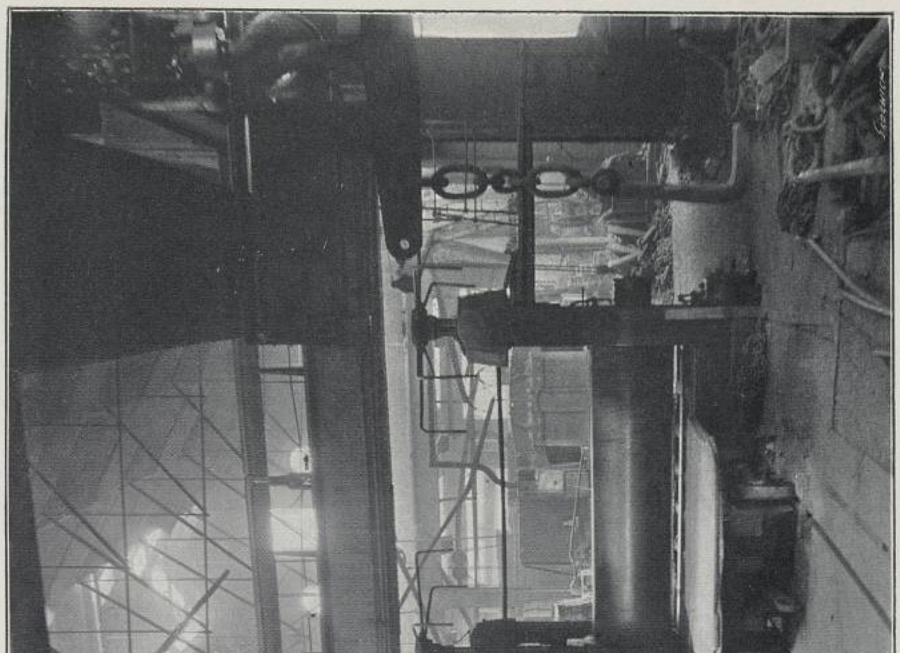
The power for these great hydraulic appliances is developed by a powerful engine of special design, one of the most efficient details being the governing arrangement, necessary owing to the wide variation of the load on the engine, which, in less than a minute, may vary up or down between 150 and 3,000 horse-power; yet, under such severe conditions, the mechanism so controls the engine that one hardly realises that such enormous changes are taking place. Steam is supplied from two of the company's special type of marine boilers; nominally, these are of 1,200 horse-power capacity, but the company's system of induced draught and Serve tubes enables them to meet without inconvenience the frequent, but short, periods of maximum demand,—3,000 horse-power.

The efficiency of the installation is most satisfactory. Ingots received in the press shop, 42 in. thick, are in three heats reduced to from 12 in. to 18 in., according to the finished thickness specified; at the same time the edges are trimmed, the headers and the scrap being cut up into pieces of 15 cwt. to 30 cwt., ready for charging into the Siemens furnace again for re-melting. During the time of the maximum demand for armour, two ingots of from 30 to 50 tons weight were dealt with every 24 hours, giving a production at the rate of from 20,000 to 25,000 tons per annum. A high degree of economy is realised from the mechanical point of view, the steam consumption per unit of power being exceptionally low. The engines work the press direct, without the interposition of accumulators, and by automatic governing the power changes immediately in direct ratio to the resistance offered, which again varies according to the area of metal exposed to the forging tools and the temperature of the mass. The moment the pressure is removed the governor shuts off steam, opening the valve again when the necessity arises.

The ingot, reduced to a slab of not more than 18 in. thick, is taken from the press to the rolling mill shop, and is once more re-heated, the two furnaces provided alongside being able to take in plates 11 ft. wide. These furnaces are also of the bogie type. The truck, with the heated slab, is run on an incline right down to the train of rolls; these are 36 in. diameter by 11 ft. wide, and are driven by engines of sufficient power to deal with plates ranging up to 22 in. in thickness. This rolling mill is illustrated on the engraving facing this page. The plate leaves the rolls when it is reduced to the approximate finished thickness, a little being left in the majority of cases for surface machining—for the removal of the rough face.

In this condition it is passed to the hardening department, where it is subjected to the first stage of the special treatment, and here it is rendered tough but not hard. This first operation requires the use of a furnace of the bogie type, which can take plates up to 37 ft. long by 11 ft. wide, and is constructed on the principle of the Siemens furnace, with regenerative chambers, the current of gas and air being admitted from each side alternately. There are four such furnaces, and they are heated by twelve Dowson gas producers, built under ground level but with 2 ft. at the top above the surface, so that the coal can easily be passed from a truck on to the firing platform at the level of the tops of the producers. After being in one of these furnaces, for a period of time varying with the thickness, the plate is chilled by means of a sprinkler apparatus, as first designed by Captain Tresidder, one of the Directors of the company, and now adopted practically in all countries. This

PLATE XII.



Rolling Mill Shop.

apparatus is illustrated on the engraving (Plate III.) facing page 6. The appliance, it will be seen, is very simple: there is a bottom grid of perforated water pipes, over which the armour plate is laid on supports provided with spiral springs to insure that during the chilling operation the plate will be uniformly supported, notwithstanding any irregularities of shape. A moveable top with corresponding grid is provided for placing over the plate; this upper part travels on rails, and automatically makes a water-tight connection with the pump deliveries. The plate, in its heated state, having been placed over the lower grid, the upper sprinkler is brought over it, and the discharge of four large Pulsometer pumps is suddenly diverted to force a supply of water at 30 lb. pressure through the network of pipes, and from the numerous pin-holes thousands of jets of water impinge forcibly upon both surfaces of the plate. This sprinkling continues for from half an hour to over an hour, according to the thickness of armour being treated.

The plate is now ready for machining, but before this is done, it is "scaled" by pneumatic tools working with an air pressure of about 80 lb.; each tool is mounted upon a standard placed alongside the plate, so as to have a universal swivelling movement, in order that the tool may work at any angle: any number of tools may be used on the same plate at one time. The immense rapidity and deafening noise of the stroke suggested to a humorous workman a name for the machine, which, strange to say, is considered highly descriptive though hardly polite—"the Missus's tongue."

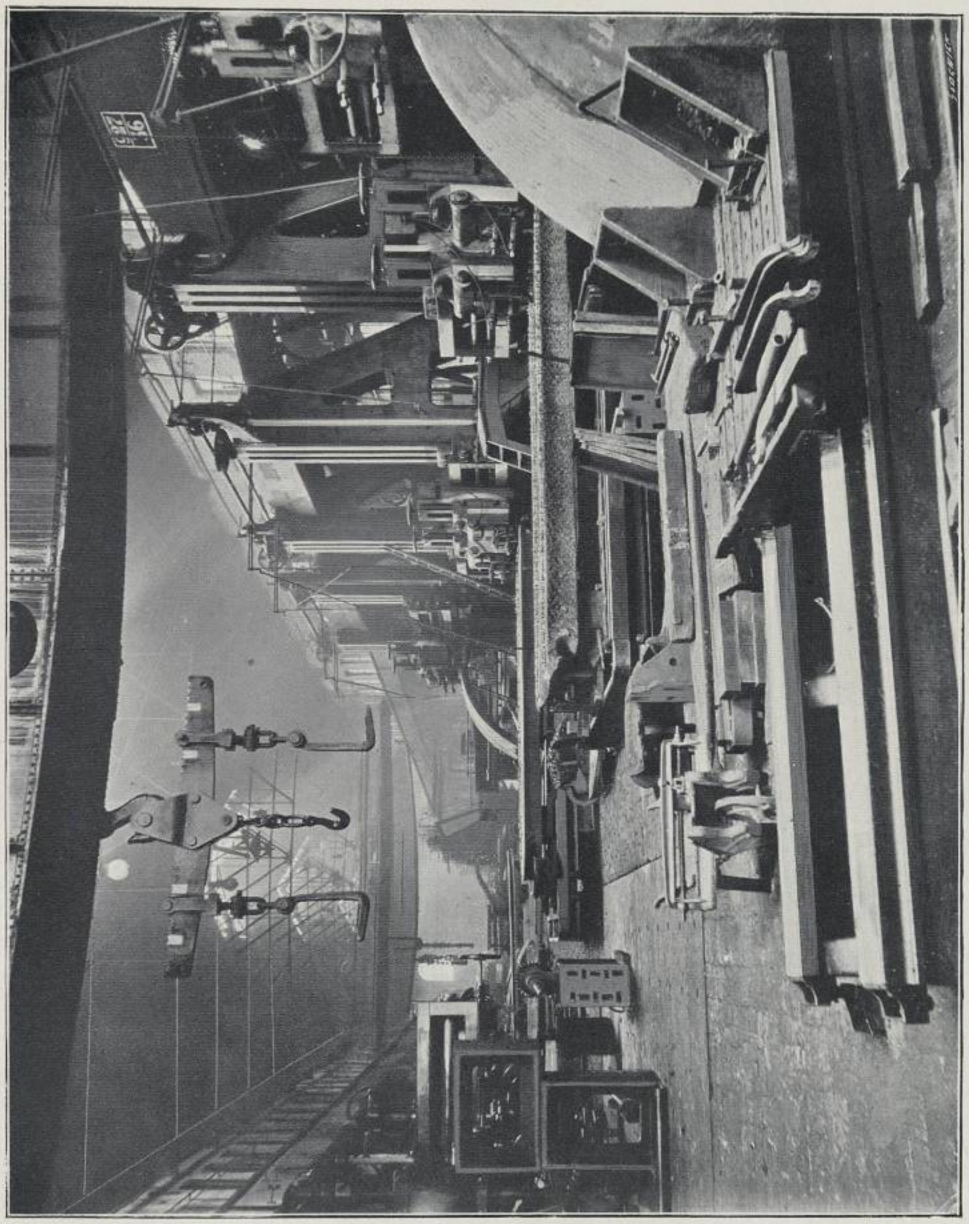
The planing and general machining of the plate is done in one or other of the six shops devoted to armour-plate work, and equipped with 83 machine tools of immense size and power. The shops range up to nearly 600 ft. in length, with a width of 60 ft., and the work is facilitated by the provision in each bay of a crane of 50 or 60-ton lifting capacity; electric power has gradually ousted the original rope drive in all cases. A view of one of these shops is given on Plate II., facing page 4. A most important and tedious operation is the planing of the surfaces of the plates: a practice still insisted upon by the British Naval authorities, because, although it is admitted to have no influence on resistance to attack, it is considered that the rough surface affects the speed of the ship. There are in all 41 planing machines in the works, the largest a screw planer capable of working surfaces 15 ft. wide and about 10 ft. high. Several others take jobs 14 ft. wide. Some of these heavy planers are shown on the illustration of one of the large machine shops, reproduced on Plate XIII., facing page 30. The new tools, as a rule, are screw planers; the rack type is not approved of for such heavy work.

Many ingenious details to ensure economy will attract the attention of the mechanic visiting these shops, apart altogether from the electric driving system which is the result of much experimental work. One noteworthy feature in connection with the planing machinery is a new method for raising and lowering the cross-slides on the planers, without necessitating the continuous running of idle pulleys. This is a great waste of power in ordinary practice; moreover, these pulleys are liable to seize and become fast pulleys at any moment, involving the possibility of a serious breakdown. At the Atlas Works, a swinging countershaft is attached to the wall below the line shaft, with open and cross belts to two fast pulleys on the shaft of the planing machine, which actuates the lifting and lowering of the cross-slide. This countershaft is driven by a belt from the line shafting above it in the usual way; but as it is swung by means of a vertical screw provided for the purpose, and is caused to approach some inches nearer to the line shaft without appreciably affecting its distance from the planing machine, the belt between it and the line shaft continues normally so loose that no driving and no wear takes place. When it is necessary that the cross-slide should be raised or lowered, all that requires to be done is to move the swinging countershaft downwards by means of its screw, whereby the belt is tightened and commences to drive.

Much the same principle is applied in connection with the traverse of one of the large slotting machines. Fast and loose pulleys are usually fitted, the latter running continuously; but at the Atlas Works these are dispensed with. Instead, a very loose belt is employed between the motor shaft and the machine shaft that actuates this power traverse; a jockey pulley is provided on a hinge, so that by pulling over a long lever, the machine attendant can bring the pulley into hard contact with the underside of the loose belt, thereby giving driving tightness to it and causing the table to move. By this means, too, the machinist can more effectually stop the traverse at any point by releasing the lever.

Another improvement is in connection with the use of a magnetic clutch instead of shifting belts, for reversing the motion of side planers and slotting machines. It has been usual in such cases to adopt open and cross belts, which are shifted by a belt striker, so that each in turn comes upon the fast pulley; but belts continually being shifted in this way have a very short life. With the magnetic clutch, which is fast with the shaft, the open and cross belts are not shifted at all, but the clutch, which is wound upon both faces, can have either side energised as a magnet by the automatic movement of a small switch. This magnetism causes it to adhere firmly to the loose pulley on that side, and so gives to the shaft the motion due to the open and cross belt alternately.

But to return to the story of the progress of the armour-plate; after having the surfaces planed, the edges trimmed, and other machining done, the surface is subjected to a shot-blast operated by an air pressure of 80 lb.,



Planing the Surface of Armour Plates.

which drives a hail of very fine cast-iron powder (called shot) against the surface of the plate, removing any dirt and giving a cleaning and polishing action. This shot, it may be incidentally stated, is made by pouring cast-iron, in a molten state, into a stream of water, which simultaneously pulverises it and hardens each particle.

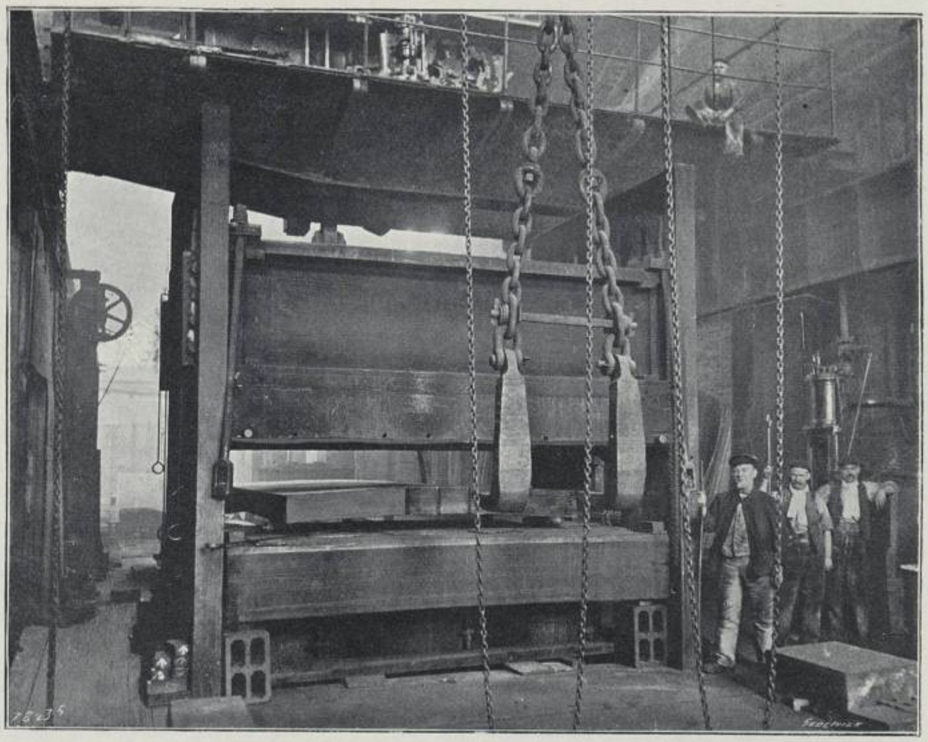
The plate is then ready for another, and important, process in connection with the hardening—for cementation or carburising—which is carried out

SLOTTING MACHINE ENGAGED IN TRIMMING PLATES.

in special furnaces. These, like most of the armour-plate furnaces, are of the bogie type, and are 22 ft. long and 12 ft. wide.

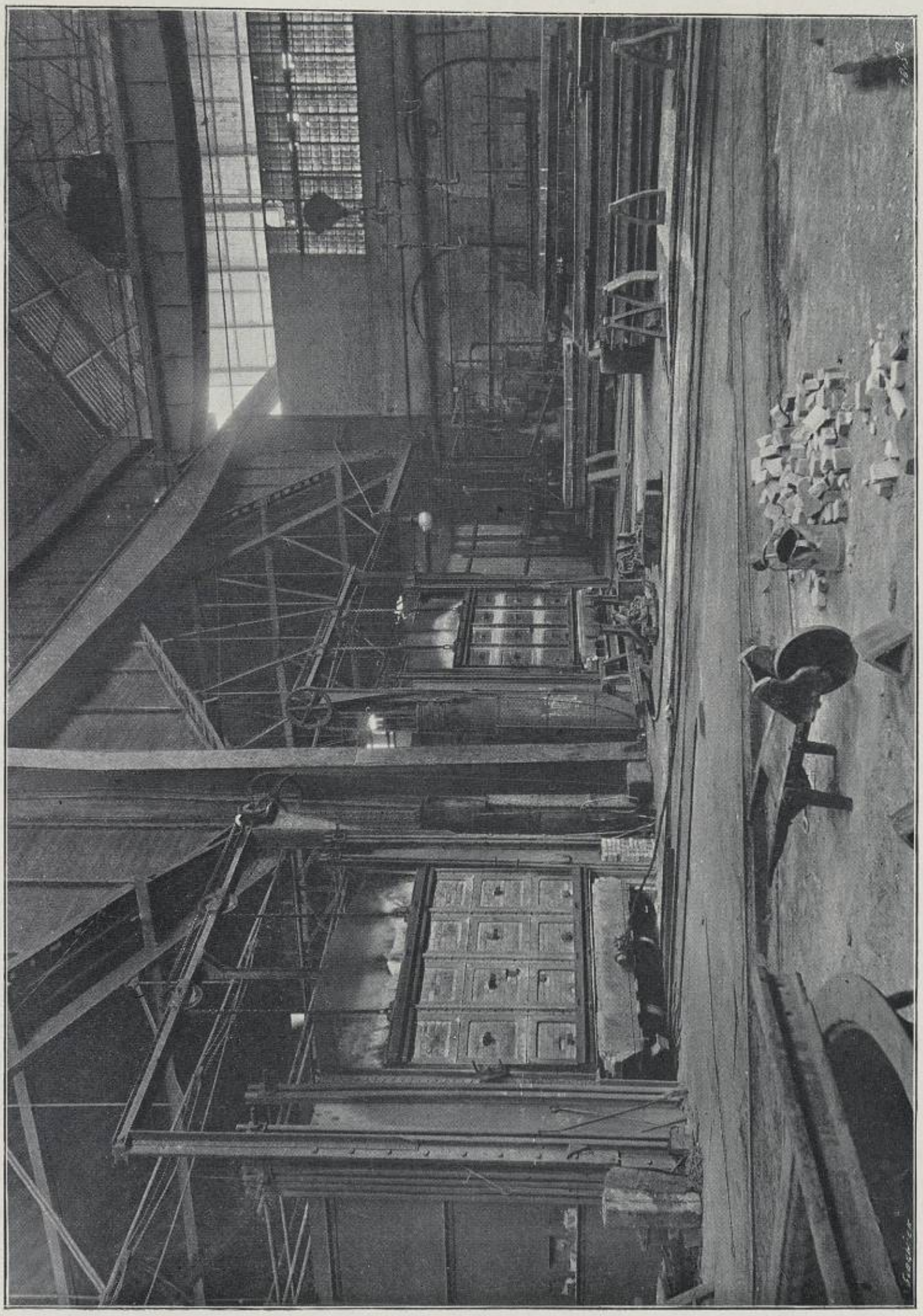
The preparation for carburising may be briefly described. The bogie, which forms the floor of the furnace, is run into the furnace with, as a rule, two armour plates upon it, and with their faces in direct contact with carbon. The front of the furnace is bricked up, the fire lighted, and the two plates are left in the fire for days, great care being taken to maintain the temperature at such a degree that carbon will be absorbed to the desired extent by the front surface of the plates. The furnaces for this carburising process are illustrated on the engraving facing this page.

Upon being withdrawn, each plate has to be bent to the required shape to suit the lines of the ship or the barbette for which it is intended. The press for this purpose is of 6000 tons power, and takes a plate 10½ ft. wide. There are three hydraulic cylinders, each 3 ft. in diameter, with a working stroke of 3 ft. The water pressure is 2 tons per square inch.



Bending Armour in 6000-Ton Hydraulic Press.

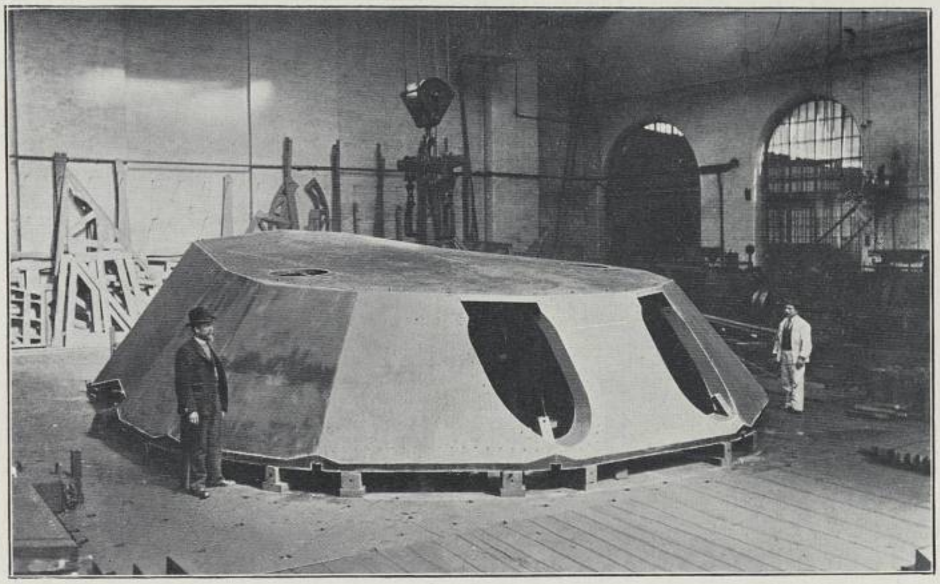
The press is supported by two side standards formed of armour plates, 7 in. thick, 26 ft. high, and 9 ft. wide; they are bedded on ashlar stones laid in concrete. The cylinders, the rams of which work upwards, are supported on a base plate resting on bars fitted into the sides of the standards. The adoption of three separate cylinders enables either the centre cylinder, or the two side ones, to be worked independently, so as to economise water and time when less than the full pressure suffices for the work. The three hydraulic rams have a common head, which weighs about 35 tons. The plate to be bent is supported on packings suitably



Furnaces of the Bogie Type for the Carburising of Armour.

arranged. Any desired variation of height, within the limit of the capacity of the press, is attained by packing blocks being placed in slots in the side standards to make up the distance, and to support the press-head at the level required. The complete press weighs about 200 tons, and with all its accessories occupies a special shop.

The two sets of pumps for maintaining the water pressure have each three steam cylinders, 15-in. in diameter by 12-in. stroke. The pumps have 2-in. pistons, and 1.15-in. rams; their capacity is 30 gallons per minute at 22 cwt. pressure per square inch, or 10 gallons at 66 cwt. per square inch.



Shield for Two 12-In. Guns Mounted on Barbettes.

The pumps work direct on the press. The accessories include a 70-ton electric crane, with a 25-ton electric crane for lighter loads; while alongside there are two reheating furnaces of the bogie type. The extent of bending sometimes required is indicated by the engraving on this page and on Plate VII., facing page 16.

There is a smaller bending press for dealing with thinner armour, the total power being 2,000 tons. This is a separate installation, and can be used for plates up to 6 in. thickness, so that it forms an important adjunct even to the main armour-plate work department. The cylinders are 36 in. diameter and 3 ft. stroke.

After the bending operation, the plate is taken to the machine shop to have its approximately final shape given by edge planers, slotters, and surface planing machines—operations being carried out in the shop which is illustrated on the engraving on Plate XV., facing this page.

The armour is next returned to the hardening shop, to complete the process there. The plate is re-heated in gas-fired bogie furnaces already described, and when brought to a certain uniform temperature, is dipped vertically in a tank of oil, of which there are two in this department, each containing 40 tons of oil, and surrounded by a jacket in which cold water is circulated.

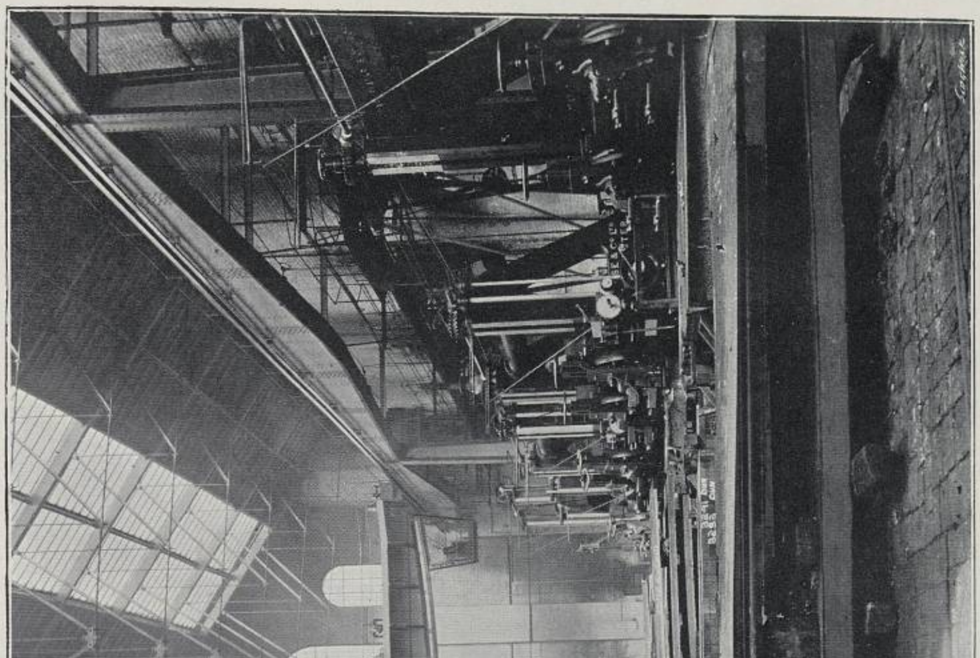
After the oil bath, the plate undergoes further heat treatments, and the inevitable warping thus occasioned has to be corrected by the 6000-ton bending press. After the final heat treatment, change of form can only be given in one direction, as it is quite impossible to stretch the hard face without breaking it. To meet this condition, the tendency in originally bending a plate is to err on the side of increased convexity, so that, in flattening out the plate subsequently, the front surface will actually be compressed instead of stretched.

At various stages of the process the plate is subject to very close examination, and test pieces are taken from it to make certain that it meets the required condition. After its cementation treatment, holes are drilled to ascertain by analysis the amount of carbon taken up, as alluded to at page 10.

The maintenance of a steady and correct temperature in the furnaces employed for the heat treatment is of such great importance, that records have to be taken every half-hour day and night. Many different types of pyrometers have been tried, but experience has shown that the simplest method proved conducive to the greatest accuracy. The system of temperature-taking now adopted is to place in the furnace a hollow cylinder of metal, whose weight is first accurately determined with a chemical balance; when this has attained the temperature of the furnace, it is dropped into an exactly-measured quantity of water; and the extent to which this water is heated, shown by a thermometer and scale suitably divided, indicates to the attendant whether the temperature of the furnace is maintained at the correct degree.

When the shape of the plate has been corrected to conform to the moulds or patterns supplied to govern it (such patterns being in requisition at various earlier stages as well), it is taken to the erecting shop for fitting to its neighbours. Some idea of the extent and equipment of this shop will be formed by reference to the engraving on Plate VII., facing page 16,

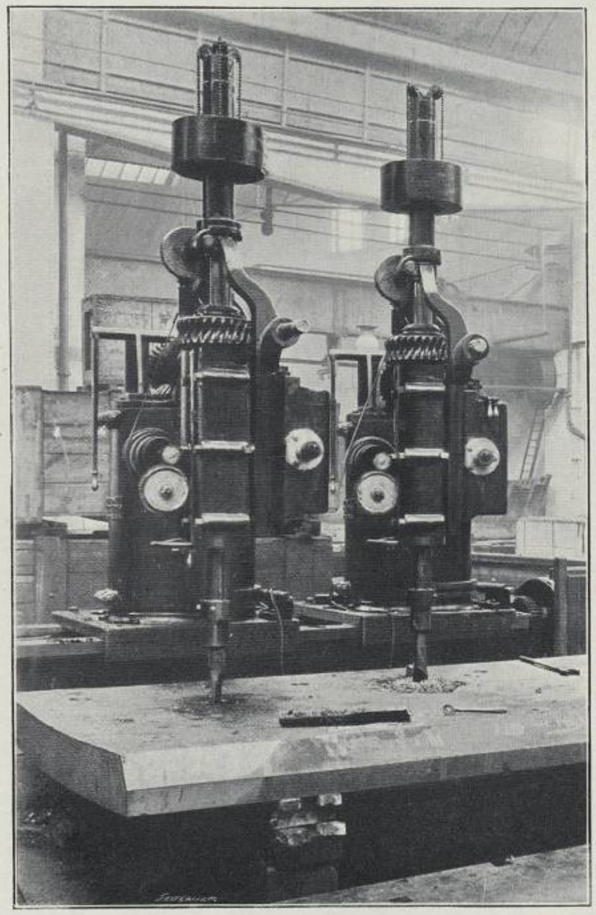
PLATE XV.



Edge-Planing, Slotting, and Surface-Planing Armour.

illustrating the building of a barbette on the floor, and by the illustrations on pages 33 and 37.

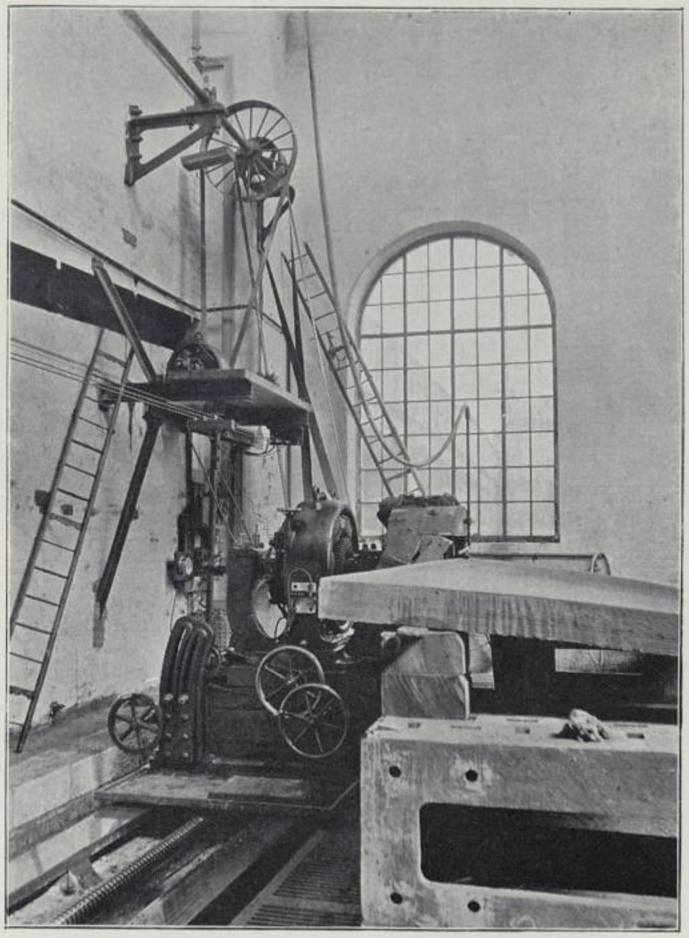
Afterwards, holes are drilled and tapped in the back for the bolts by which the plate is finally to be attached to the ship's side. The engraving on this page illustrates one of the splendid tools used in this work. These



Machine for Drilling and Tapping Holes in Back of Armour Plates.

bolts, which are of special form, are inserted from the interior of the ship, passing through steel plating, wood backing, and into the back of the armour. The company have recently reconstructed the department where these armour-plate bolts, nuts, and washers are made, so as to ensure not only efficient results but rapidity of manufacture and economy, many of the tools being automatic in their action.

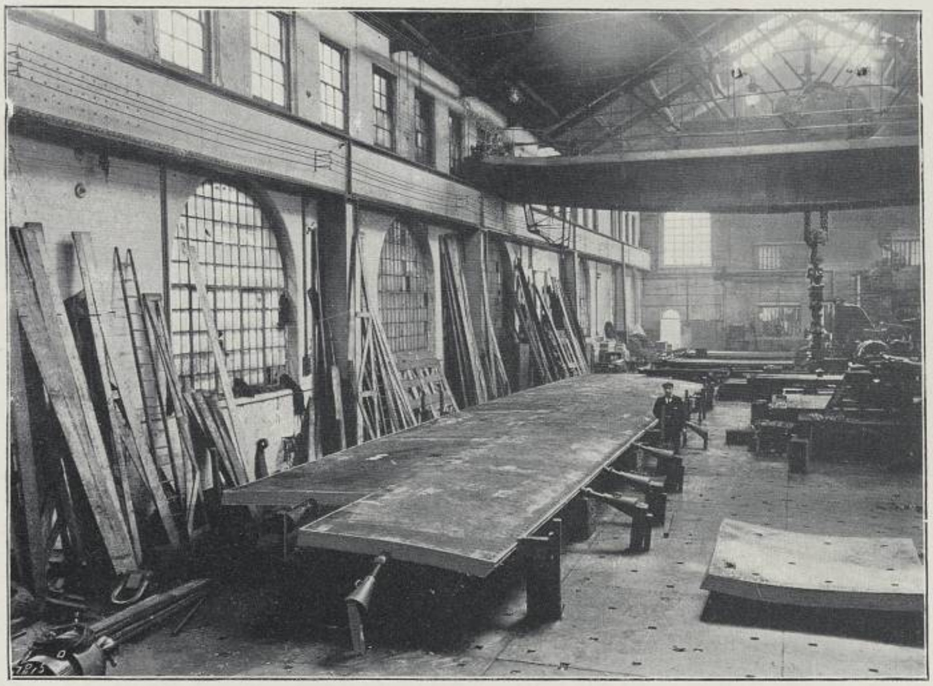
The plates, after they have passed through the successive processes described in the preceding pages, are as hard as the hardest tool, so that ordinary machining is impossible; and thus any trimming that requires to be done is carried out with special grinding machines, one of which is illustrated on this page. These tools are arranged so that they may grind a plate set at



ELECTRICALLY-DRIVEN GRINDING MACHINE FOR TRIMMING EDGES OF HARDENED PLATE.

any angle; and some idea of their size and power may be formed from the fact that the electric motors driving them at a high speed are frequently heavily overloaded, although of 40 horse-power. When it is necessary to alter the surface of the hardened armour-plates, this is done by portable emery wheels driven by electric motor through a flexible shaft.

Most of these modern ship-plates require a large number of small holes in their face for the attachment of torpedo-booms, pipes, &c., and these holes have to be made occasionally after the plate receives its final hardening, while even larger holes sometimes require to be made at the same late stage in the manufacture. For this work, electric annealing plant is employed to locally soften the spots where the holes are to be drilled. This plant consists of an alternating current generator, its exciter, and a stationary transformer. It is driven direct by a 40-horse power motor, and provides an alternating current of 100 amperes at a pressure of 300 volts. This current is passed to



Erecting a Battleship's Broadside Armour.

the transformer which constitutes the annealing apparatus. It has two large copper pole-pieces, which are kept from getting unduly hot by water circulation. The voltage is reduced in the transformer from 300 to 3, and the volume of current increased from 100 to 10,000 amperes, sufficient to rapidly cause a red heat when passing across a portion of the plate from pole to pole of the transformer. The heat is maintained for a few minutes after it has reached a point sufficient to set fire to a stick of pine, and then the current is gradually reduced to allow the heated spot time to cool, without recovering hardness from the chilling effect of the surrounding mass. The whole operation only takes a few minutes. It is then found that the spot between the poles of the transformer—2 in. or 3 in. diameter—has been rendered soft enough to drill, but the points where the pole-pieces have actually rested are even harder than they were before.

The erecting shop has a floor of planed iron plates, and is 217 ft. long by 48 ft. wide, the height being 40 ft.; a 50-ton travelling crane does the work of manipulating the plates. It is one of the four large shops recently added to the establishment, and is used for putting together the belts, casemates, shields, conning-towers, &c., so as to make certain of perfect fit of each plate to its neighbour before being sent to the shipbuilding yards. The iron plates forming the floor rest on concrete foundations so solidly laid that their level has not been thrown out by the huge concentrated weights they carry.

It will thus be seen that, from first to last, great ingenuity and experience, as well as enterprise, is called for in the arrangement and equipment of an armour-plate department, so as to secure reliability as well as economy in the manufacture of armour.

FORGINGS FOR GUNS AND ENGINE SHAFTS.

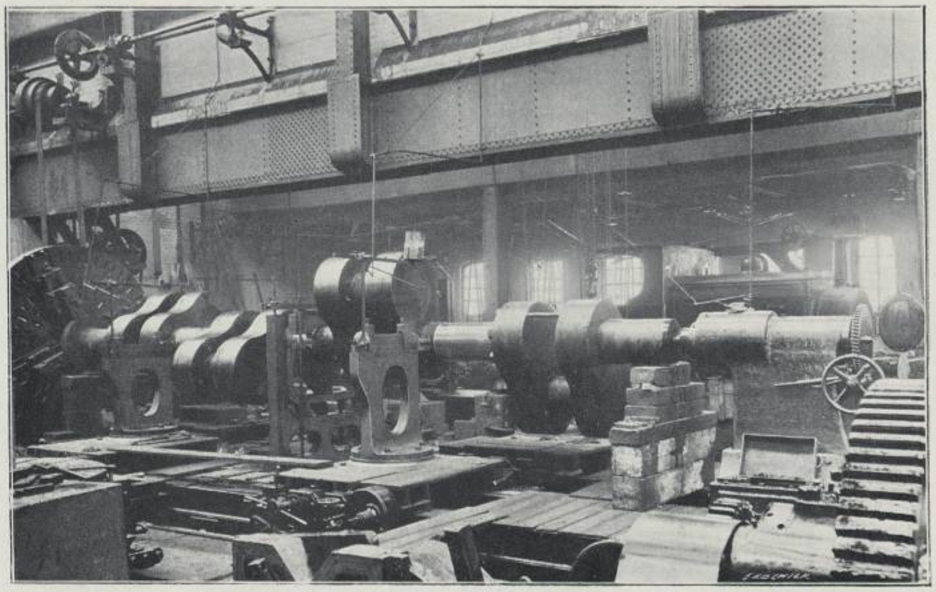
THE superiority of the hydraulic press over the steam-hammer for forging large work has been much discussed for many years, and the importance of the issue has been intensified by the steady increase in the size of shafting, alike for warships and for Atlantic liners. The power to be conveyed to the propeller through one shafting has now reached 20,000 indicated horse-power, while 10,000 to 15,000 indicated horse-power is quite customary; so that the ingots to be forged may require a diameter of 60-in. and more. The largest steam-hammers which may be constructed can scarcely exert a force sufficient to work an ingot of such proportions to its centre; and thus, through force of circumstances, the forging press has become practically a necessity for high-class work. But even apart from this, the gradual squeezing action of the hydraulic press is for all purposes more effectual and less severe on the metal than the sudden blows of a hammer. With hammered shafts unsoundness has often been found in the centre and underneath the collars, due largely to the "drawing" tendency of the hammer; whereas with hydraulic forging the continuous pressure has precisely the opposite effect, and tends to solidify the metal.

When forging operations on a large scale were commenced at the Atlas Works in 1887, the company laid down a forging press of 4,000 tons power, served by two 150-ton overhead cranes, and among the first orders secured was one for the shafting for H.M.S. "Melpomene," and the Hamburg-American Atlantic steamer "Normannia." Since then, with but short interruptions, this department has been working day and night on shafting and on gun forgings.

The largest shaft yet made in this country for a land engine was completed by the company in 1901. It was a crank-shaft of over 80 tons weight, for the engine of an electric traction station. A general indication is afforded of the size of the shafts completed in this department by the illustrations on Plate XVI., facing page 40. These two views show shafts in the process of being turned in heavy lathes. Both shafts were made for electric machinery — one being an ordinary crank shaft, with a straight length for carrying the generator. The diameter in this case is 24 in., and the total weight of the shaft, as shown in the engraving, is 22 tons. In the other illustration, the cranks are of the disc type, and the lathe is shown simultaneously boring the holes for the pins of two discs. The total weight of this shaft is 82 tons.

Of marine shafts a very good example is given on the illustration on this page, which shows a four-crank shaft for a modern steamer, the twin engines of which were designed to develop 30,000 indicated horse-power.

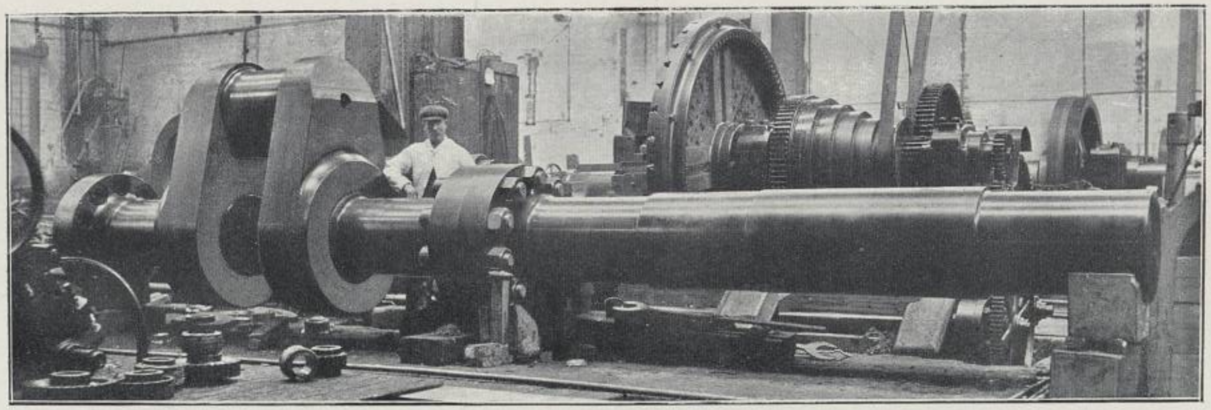
The governments for whom shafting has been made include the British, Japanese, French, Russian, and Spanish. Amongst the ships of note in the



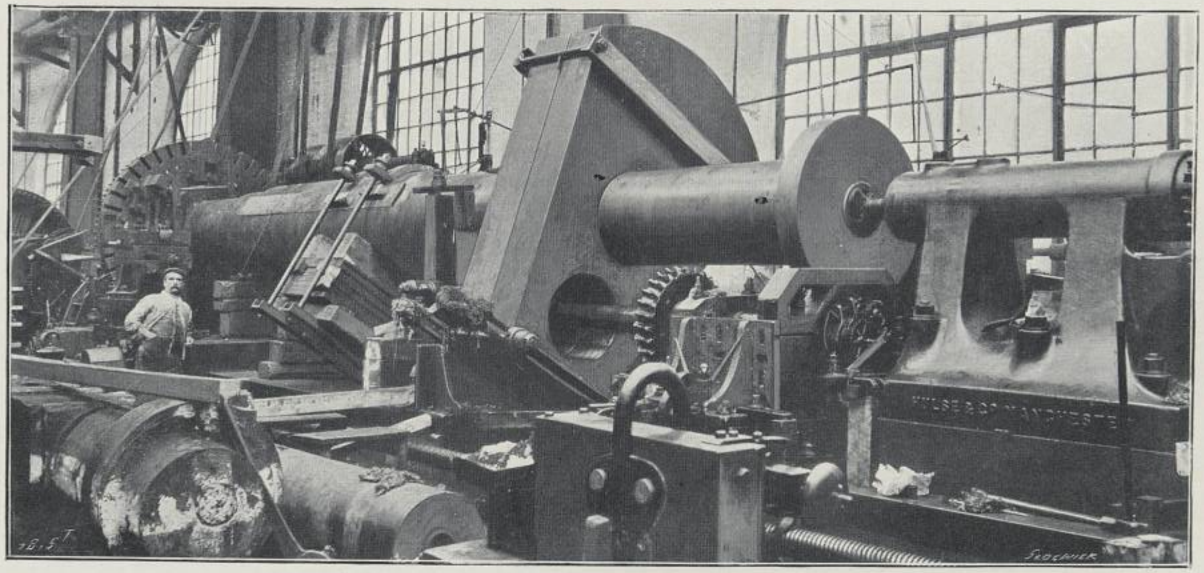
Crank Shaft for Four-Cylinder Engine in Lathe.

merchant marine with John Brown and Co.'s shafting, mention may be made of the Hamburg-American Company's twin-screw steamer "Normannia" the Peninsular and Oriental Co.'s liners "Australia" and "Himalaya"; various South African mail boats; the International Co.'s twin-screw liners "Vaderland" and "Zeeland"; and the Orient-Pacific liners "Orient" and "Orontes."

In view of the fact that the 4,000-ton forging press was commenced when there was little experience in the mechanical world of such hydraulic appliances, the Atlas plant has proved most satisfactory; but in order to avail themselves of the extensive improvements since effected in this branch of engineering, the company decided, at the end of 1900, to establish a completely new press department, embodying all modern accessories. The older press continues



ENGINE SHAFT WITH STRAIGHT SHAFT FOR ELECTRIC GENERATOR (22 TONS).



MACHINE SIMULTANEOUSLY BORING THE HOLE FOR THE PINS OF TWO DISC CRANKS (82-TON SHAFTS).

to do good work; but there is a large demand for comparatively small forgings, which lose their heat rapidly and require a very quick-acting press, and for these the new equipment will be specially utilised. This new equipment has many interesting features, all tending to ensure efficient results.

The new forging shop, of which a view is given on Plate XVII., facing page 42, consists of two bays, 180 ft. long, with a span in each case of 60 ft. The whole of the ground floor is commanded by two cranes of over 100 tons capacity. Electric power is adopted for traversing the crane, while hydraulic mechanism, with heavy and light purchases, is fitted for lifting the loads. Hydraulic gear manipulates the forging when it is being worked in the press. This latter arrangement was adopted, as it is of primary importance in connection with rapid forging to secure that instantaneous movement which hydraulic power gives. Both cranes are controlled from the ground level, there being three positions in the shop where one man can direct all the movements of each of the cranes. The hydraulic power for operating the cranes is obtained from engines, entirely independent of the press pumps, and is transmitted to the crane through a system of walking pipes placed on the outer portion of the crane gantrys. Such walking pipes have frequently been used up to the moderate lengths of 40 ft. to 50 ft.; but there is, in this case, a special arrangement of walking pipes covering a distance of 150 ft., enabling the cranes to operate over a very much larger area than has hitherto been customary. The new forging department is in close proximity to the Siemens furnaces, and the ingots are delivered therefrom direct by railway wagons. The press cranes are so arranged that the block hook comes within a very short distance of the centre of the press, which facilitates rapid manipulation of the job, and avoids the use of excessively heavy balance weights.

The press, which is well shown in the engraving on Plate XVII., facing page 42, has a power of 3,000 tons, there being two hydraulic cylinders, 28 in. in diameter with a 5-ft. stroke, working at a pressure of $2\frac{1}{2}$ tons per square inch. The top and bottom entablatures, as well as the cylinders, are steel castings, and the columns are steel forgings. The press is very rapid in its work, upwards of twenty-five strokes per minute being easily attainable. The main hydraulic pressure is supplied by a three-cylinder high pressure pumping engine in close proximity to the press, and working direct without an accumulator. An air-vessel is fitted to maintain a constant pressure and supply of water to the suction-valves, and thus there is the minimum of noise and vibration, when the engines are running under full pressure at the high rate of 100 revolutions per minute. The periods during which the maximum power is applied to the press are very frequent, owing to the rapidity of its operation;

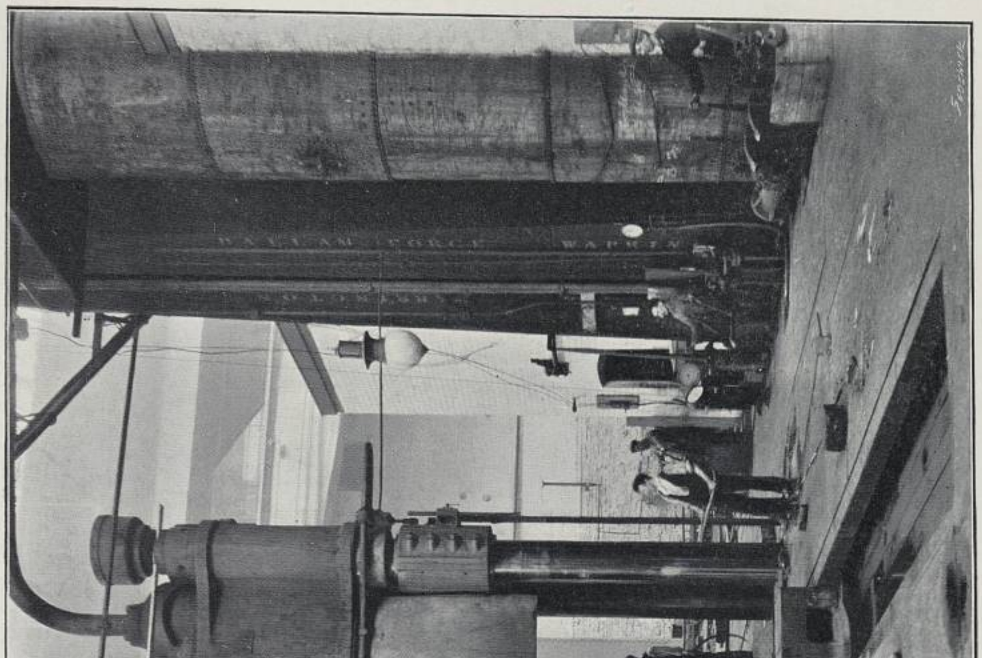
but they are of very short duration. The load on the engines is thus a severely varying one, alike as to degree and frequency; but the governing arrangements are so effective that the influence on the speed of the pumping-engine is reduced to the minimum.

The press is fitted with special hydraulic pushers for working hollow forgings, such as gun-tubes, cylinder-liners, &c., as with such jobs especially good results are obtained by a rapid stroke. The work of forming such hollow

ONE OF THE MACHINE SHOPS FOR COMPLETING SHAFTS.

forgings possesses some special features. The ingot-head is cut off in the lathe, and a hole made through the centre in a horizontal machine by a D-bit. The ingot is then re-heated in a furnace at the forge, and afterwards conveyed to the press anvil on the mandril on which it is ultimately to be forged. The forging-press draws the ingot down on the mandril, the job being supported meanwhile from the hydraulic crane. Portions from 5 ft. to 8 ft. in length are thus forged at each heat, and hollow forgings varying in length up to 50 ft. have been produced by the company with very satisfactory mechanical results.

The machine shop associated with this forging department consists of three



NEW FORGING SHOP, WITH 3000-TON HYDRAULIC PRESS.

bays, two of them 160 ft. long and 35 ft. and 31 ft. wide respectively; while the third is 194 ft. long and 52 ft. wide; the height of 34 ft. enabling the 70-ton travelling crane to conveniently manipulate the immense jobs undertaken without interfering with the work being done on the floor. One of the bays of this shop is illustrated on page 42, and this view, together with the engravings on Plate XVI., and on page 40, demonstrate that the shops are well equipped with the heaviest class of machine-tools, nearly all the well-known makers being represented in the department. There are about fifteen lathes, varying from a length of 80 ft. by 48 in. centres to a length of 50 ft. by 66 in. centres, and all are triple- or quadruple-geared. Some of the tools recently introduced have exceptionally wide pulleys for high-belt speeds, in order to obtain the necessary power for utilising to the utmost the special tool-steel made and used by the company for heavy cutting at high speed. The boring machines are of massive proportions: a 15-in. hole can be bored out of the solid to form a gun-tube, at a speed of 1 in. per hour. The boring of shafts with holes of 8 in. to 10 in. diameter is done at the rate of from 3 in. to 5 in. per hour.

Amongst the interesting tools in this department is the crank "pinning" machine. When the Admiralty and some foreign governments commenced using double-throw crank-shafts in large engines, so as to bring the balancing forces of the reciprocating parts as near to each other as possible, with the view of reducing vibration, it was found impossible, in turning the crank-pins in an ordinary lathe, to overcome a certain amount of spring which made it difficult to maintain true centres. A large crank-pinning machine was therefore erected at the Atlas Works at great expense. In this machine the crank, instead of rotating, as in the ordinary lathe, lies in a rigid position while the cutting tool rotates; and thus the pin can be made absolutely round and perfectly true with the axis of the crank in every direction. This splendid tool consists of longitudinal and cross-girders, supporting a large frame free to be moved along the girders and fitted with an internal wheel, carrying the tool-boxes. These boxes can be advanced to, or retired from, the crank-pin centre, and at the same time are narrow, so as to be able to work between the crank-webs. The crank rests upon, and is bolted securely to, the girders of the machine; while the wheel revolves and the tools operate on the pin and on the ends and sides of the web without necessitating any re-setting of the job.

The other tools of the department consist of several large slotting machines: one of them having a stroke of 8 ft., and the necessary drilling and boring machines. Special loading arrangements are provided for the despatch of the productions.

MARINE DEPARTMENT.

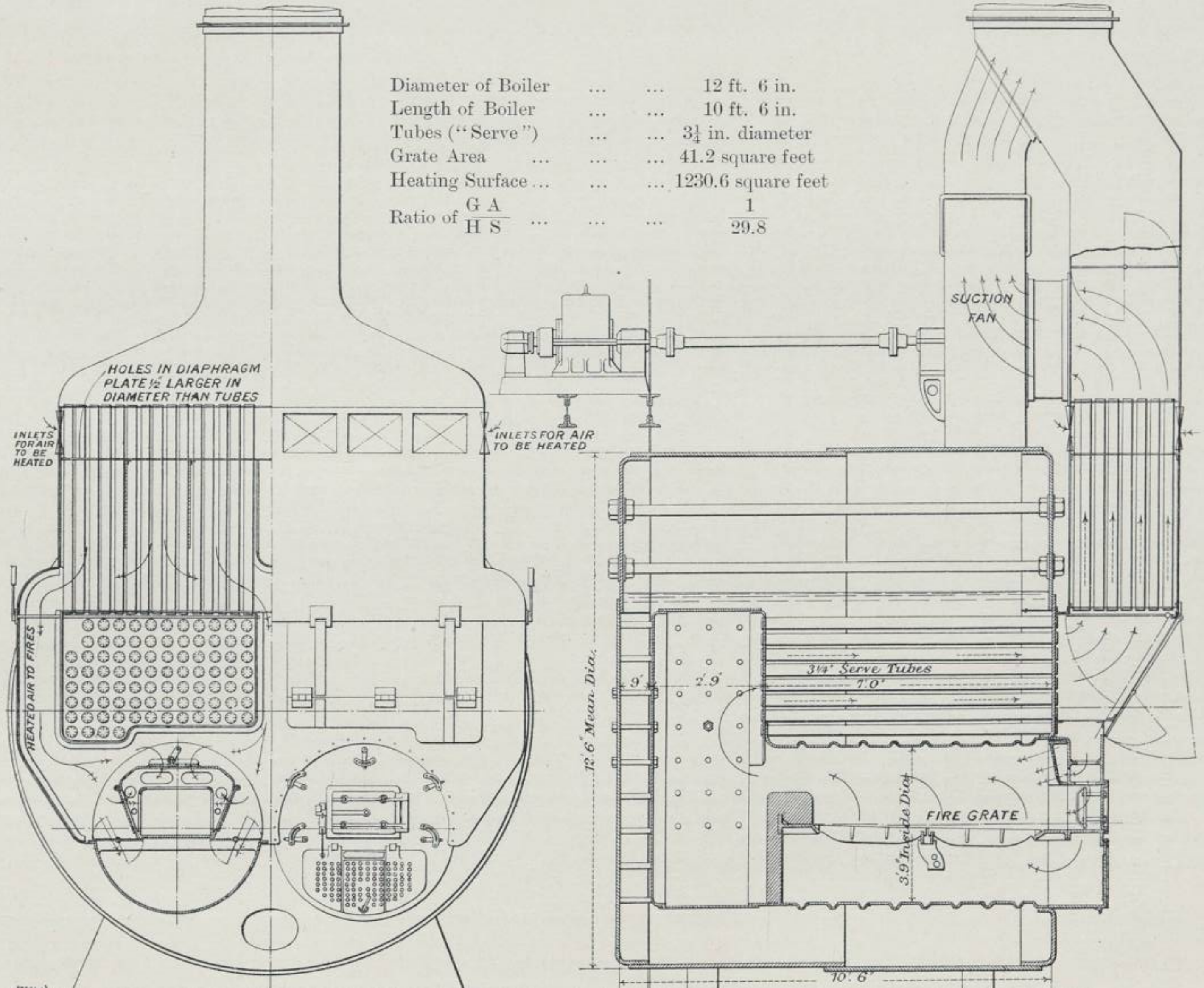
THE Atlas Works have long had a close association with marine engineering, apart altogether from that developed in connection with the manufacture of armour-plates: a result probably attributable to the tendency towards research work in connection with steam plant and machinery generally Experiments with the boilers in the works, in order to reduce as much as possible the smoke nuisance, led Mr. J. D. Ellis, the Managing Director, and the Company's engineer, to design a system of mechanical draught which, insuring more perfect combustion—the primary solution of the smoke problem, necessarily added to the efficiency of the steam generator; and this, the Ellis and Eaves system of induced draught, is now largely applied on shipboard as well as in land stations. The outstanding features of the arrangement are the placing of an exhausting fan at the base of the funnel to induce draught, and the interposition of an air-heating system between the smoke box and the fan inlet, so that a large proportion of the heat in the waste gases is utilised to raise the temperatures of the incoming air, which passes along ducts placed on either side of the smoke box, and is discharged both above the fire-bars and through the ash-pit into the fire.

The arrangement secures all the general advantages of mechanical draught, and has several additional recommendations peculiar to itself. With a well designed and carefully proportioned boiler—and Messrs. Brown wisely lay down conditions under which the maximum efficiency is assured—it is possible to add to the generating capacity per unit of weight and size of boiler to the extent of from 30 to 40 per cent., giving a proportionately higher horse-power for a given weight, or reducing the weight for a corresponding horse-power. There is also, as we shall presently show, increased economy; and it is usually possible to burn an inferior quality of coal than where natural draught is relied upon. In the closed stokehold system of forced draught there is the great disadvantage that all ingress and egress is stopped; while in passenger ships dust is driven out of the stokeholds through the decks and into the cabins, owing to the high air pressure in the boiler compartment. The induced hot-air feed not only overcomes these objections, but ensures a more perfect combustion within the furnace, as hot air unites more freely than cold air with the gases given off by the fuel. There is thus less chance of the gases finding their way up the funnel without ignition within the boiler, which means that there is a considerably reduced quantity of carbon emitted from the funnel in volumes of smoke. Again, less of the heated air is required per pound of coal consumed for complete combustion than when cold air is used. It is possible, also, that the draught in the closed stokehold system, travelling in pockets of cold air, may do harm to the junction of the tubes and tube-plate, owing to sudden variations in temperature; but with heated air there is no possibility of such injury. In the Ellis and Eaves system, with an induced, instead of a forced, draught, there is no tendency of dust to be driven into the stokehold from the ashpits or through the fire-doors and smoke-box seams; nor is there any likelihood of accident to firemen from the opening of doors without due regard to air-pressure valves.

In earlier arrangements of induced draught, one great obstacle was that the high temperature of the furnace gases at the base of the funnel destroyed the fan, but with the Ellis and Eaves system this disadvantage is overcome by the abstraction from the waste gases, before they reach the fan, of a large proportion of their heat, which is then used for raising the temperature of the air delivered to the furnace. Thus, in one instance, where the Ellis and Eaves arrangement is fitted, carefully collected data showed that while the temperature in the stokehold was 74 deg., the air drawn from the stokehold through the air-heating system for use in the furnace was raised to 350 deg.; while the temperature of the waste gases, which, when measured at the smoke-box was 650 deg., was reduced by passing first through steam superheaters, and afterwards through the air-heaters, to 380 deg. There was thus absorbed from the waste heat going up the funnel, 275 deg., which was converted into useful work—(1) in the superheating of the steam; and (2) in the heating of the air before it entered the furnace to assist combustion.

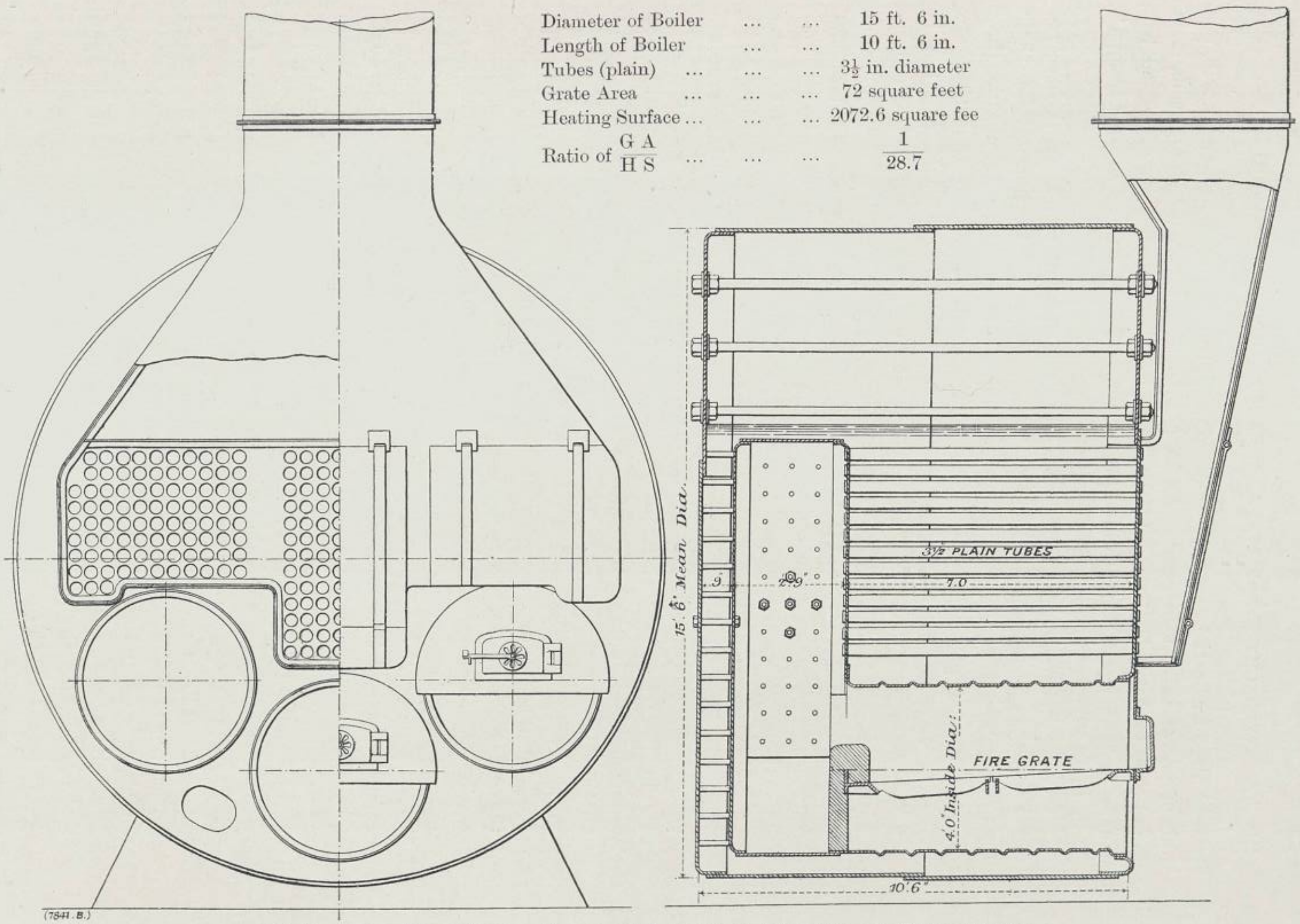
These results were obtained on board the S.S. "Inchkeith," which has the Ellis and Eaves boiler system, and has in combination with it superheaters for increasing the temperature of the steam driving quadruple expansion engines. By this arrangement, probably the highest economy in steam propulsion yet realised was attained, and the results are therefore of interest. The "Inchkeith" has a dead-weight carrying capacity, when loaded, of 5700 tons, and when steaming on the North Atlantic at 1259 indicated horse-power, the coal consumption per hour was at the rate of 0.98 lb. per unit of power developed by the main engines throughout the prolonged trial. The quantity of water evaporated from and at 212 deg. Fahr. was 12.72 lb. per pound of coal, 82 per cent. of the calorific value of the fuel being utilised, showing that the efficiency of the boiler, as a steam-generator, was exceptionally high. In ordinary practice, *i.e.*, without superheating and with triple-expansion engines, the results have

Diameter of Boiler	... ...	12 ft. 6 in.
Length of Boiler	... ...	10 ft. 6 in.
Tubes ("Serve")	... ...	$3\frac{1}{4}$ in. diameter
Grate Area	... ...	41.2 square feet
Heating Surface ...	... ...	1230.6 square feet
Ratio of $\frac{G\ A}{H\ S}$	... ...	$\frac{1}{29.8}$



750 Indicated Horse-Power Boiler, with Ellis and Eaves Induced Draught and "Serve" Tubes.

Diameter of Boiler	... ...	15 ft. 6 in.
Length of Boiler	... ...	10 ft. 6 in.
Tubes (plain)	... ...	$3\frac{1}{2}$ in. diameter
Grate Area	... ...	72 square feet
Heating Surface	... ...	2072.6 square fee
Ratio of $\frac{G\,A}{H\,S}$	... ...	$\frac{1}{28.7}$



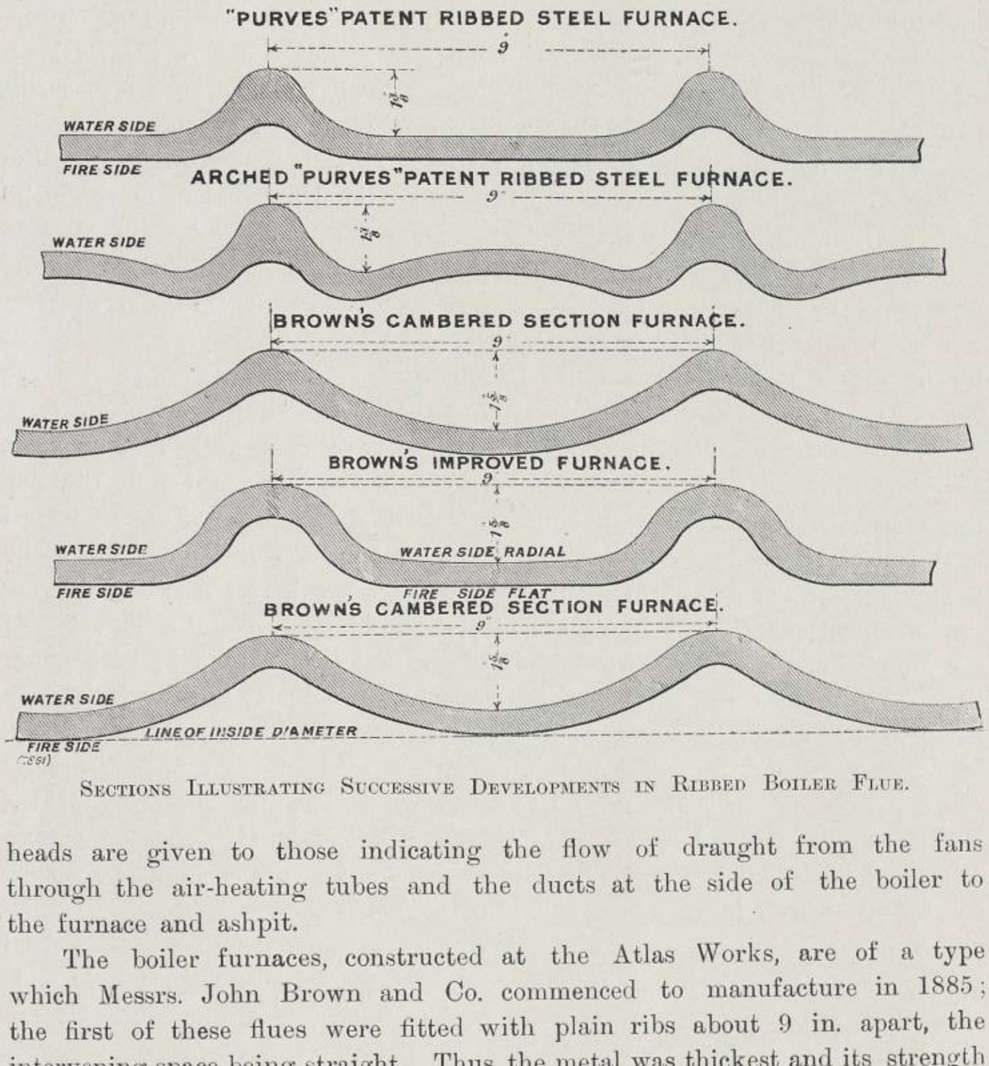
750 Indicated Horse-Power Boiler with Natural Draught and Plain Tubes.

proved almost as satisfactory, the coal consumption being 1.3 lb. and 1.4 lb. per unit of power in certain cases. As to the increased rate of combustion, it is found that in Atlantic liners, 28 lb. to 30 lb. can be economically consumed per square foot of grate, in intermediate steamers 25 lb., and in ocean "tramps" 20 lb. to 22 lb. per square foot of grate.

The arrangement of the induced draught appliances on board involves the least inconvenience. While the fans are placed in the uptake, their driving engines are removed entirely from the stokehold. As a rule, they are placed on a platform in a recess in the engine-room, so that they are always in view of the engineers; the shaft from the engine to the fan is well supported with water-cooled bearing blocks. The system, too, admits of an easy regulation of the draught to secure the required rate of combustion for any quality of coal used; the passage of air to any one furnace can be temporarily shut off to enable the furnace to be cleaned; and the pressure of air may be increased separately in any boiler, to compensate for one boiler being temporarily shut down for repairs. In addition to the induced draught drawing all dust with it into the boiler, it promotes a circulation of air down through the ventilation cowls, so that the temperature is, as a rule, cooler in the stokehold than in the engine-room. Recently the Ellis and Eaves system of induced draught has been applied to both Lancashire and water-tube boilers, with most marked success as regards increased economy, steam-producing capacity, and freedom from smoke.

With the adoption of the Serve tube, which is another of the manufactures of the Atlas Works, and is formed with a number of internal ribs, greatly increasing the efficiency of the tube surface, the ratio of heating surface to the grate area may be very considerably reduced, and the size and weight of the boilers lessened. A combination of the Ellis and Eaves draught system with its economy, and of Serve tubes with their high steam-generating efficiency, is doubly advantageous in the case of channel steamers and ocean liners, where space as well as weight must be economised to reduce the size of the ship and its displacement tonnage, or to add to the accommodation for passengers. The combination gives the same volume of steam for over 30 per cent. less heating surface; the saving in weight per 10,000 indicated horse-power being about 140 tons. As every square foot of passenger space on an Atlantic liner is worth much, the importance of this reduction is at once evident.

On pages 46 and 47 there is reproduced sectional diagrammatic drawings of two boilers, one constructed on the ordinary systems for natural draught, and the other, on the same scale, for Ellis and Eaves draught and with Serve tubes; and the sections, in juxtaposition, show at once the economy in space occupied, while the figures given indicate the difference in weight per horse-power developed. The diameter of the ordinary boiler is 15 ft. 6 in., as compared with 12 ft. 6 in. in the case of the company's steam generator; the relative heating surface being 2072.6 square feet and 1230.6 square feet, and the ratio of heating to grate area 29.8 to 1, as compared with 28.7 to 1, but all the important dimensions are given on the diagrammatic drawings reproduced. The only explanation necessary is that while the arrows marking the course of the products of combustion have single heads double



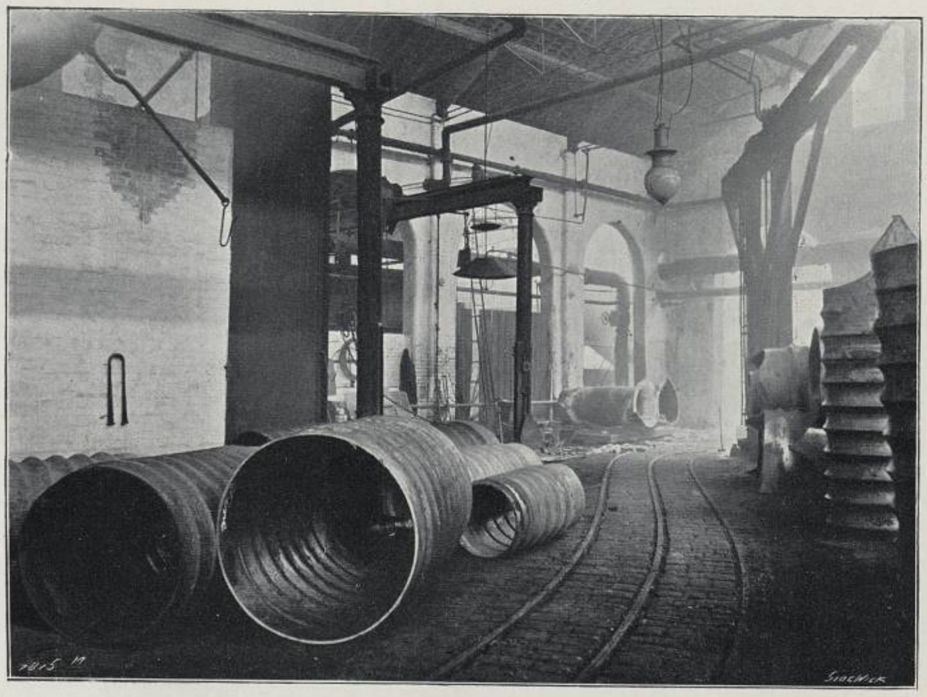
Sections Illustrating Successive Developments in Ribbed Boiler Flue.

heads are given to those indicating the flow of draught from the fans through the air-heating tubes and the ducts at the side of the boiler to the furnace and ashpit.

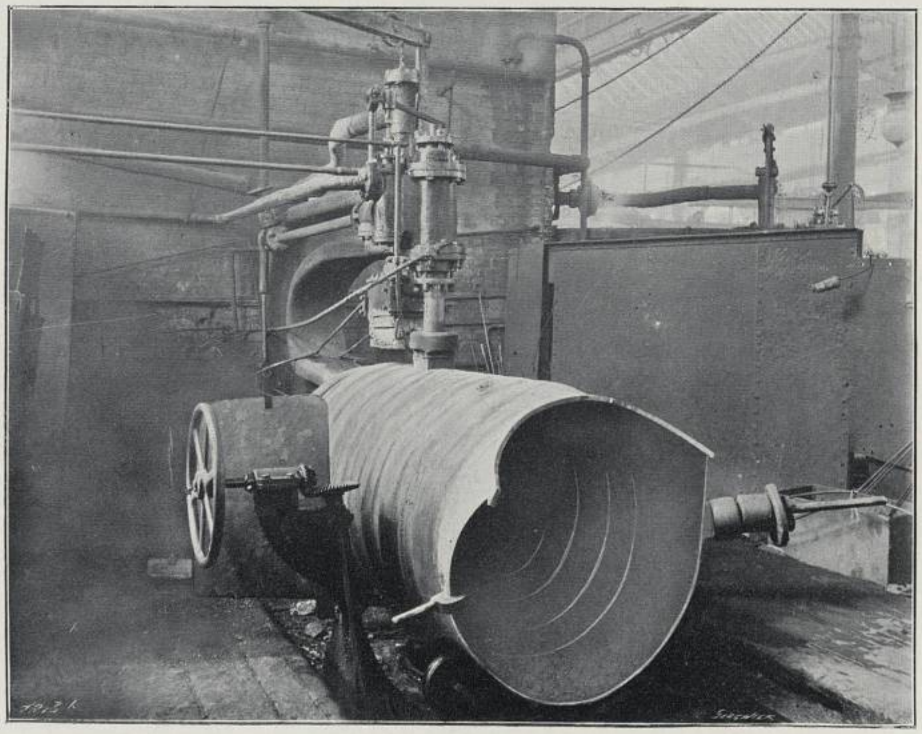
The boiler furnaces, constructed at the Atlas Works, are of a type which Messrs. John Brown and Co. commenced to manufacture in 1885; the first of these flues were fitted with plain ribs about 9 in. apart, the intervening space being straight. Thus the metal was thickest and its strength greatest at the point of largest circumference—an arrangement which offered great resistance to collapse. About 1896, a further development was made in the design, the intervening space between the ribs being slightly curved to reduce longitudinal stiffness. A third improvement was made in the section in 1898, to make the change from the thickest part to the thinnest part more gradual, the curve from the apex of one rib to the apex of the other being of uniform radius, forming a camber. A fourth modification has been made in the form of the rib, while maintaining that straight line of the original flue which facilitated the work of stoking, and a fifth modification has been introduced to combine the advantages of the cambered type, number three, with a gradually increasing thickness. The sections reproduced on page 49 show the progressive steps whereby a uniformity in the thickness of the metal is now obtained, giving a gradually thickening rib, ensuring equable expansion and contraction, with the maximum of strength.

The plant for the manufacture of these flues includes many specially-designed appliances, the whole aim being to minimise stress upon the metal and ensure absolute reliability. The ingots are usually cast in sizes to enable two flues to be rolled from each; they are slabbed down in the roughing mill, and the finishing rolls form the ribs. Both mills are driven from the same engines as the armour-plate rolls, and the reversing gear is worked by hydraulic power. Cranes of 10-ton and 20-ton lifting power serve the mills, which have other useful accessories, including a pair of shears with 14-ft. blades for cutting the plates after they have been rolled. The plates thus cut to approximate dimensions are taken from the mill into the flue department, a building 358 ft. long, with two spans each 43 ft. wide, and with a height of 26 ft. A corner of this shop is shown on one of the engravings on the Plate facing this page. There are here ten cranes ranging up to 3-tons power, conveniently arranged alongside the several machines used for completing the flues. Two flue-plates are first placed back to back under a slotting machine, and shaped at the ends to be flanged; this work is done in pairs, so that the plates will form right and left-handed furnaces respectively. The pieces cut off the plates at this operation are used for test purposes by the engineers of the company's customers, and by examining boards, such as the Admiralty, the Board of Trade, Lloyds, British Corporation, Bureau Veritas, Germanischer Lloyd, &c., all of whom grant the highest formulæ for the company's furnaces, &c.

The plates are then bent at an hydraulic press—one of the special appliances of the firm. This machine consists of a table carrying adjustable ribs, on which the part of the plate to be bent rests, while under it are three cylinders used in the bending operation. A "fuller," or heavy bar, is fixed rigidly to the framework of the machine, but is removeable for the withdrawal of the flue when curved. The flat flue-plate is placed between the



IN THE BOILER FLUE DEPARTMENT.



WELDING BOILER FLUES.

fuller above and the supporting ribs below, and the latter, rising by the operation of the hydraulic power, bend the plate in successive widths to a curve, the radius of which is regulated by the distance apart of the supporting ribs and the duration of the pressing action. As soon as the curvature conforms to the template prepared, the pressure is removed, the plate advanced to bring a new portion under the fuller, and the bending operation repeated.

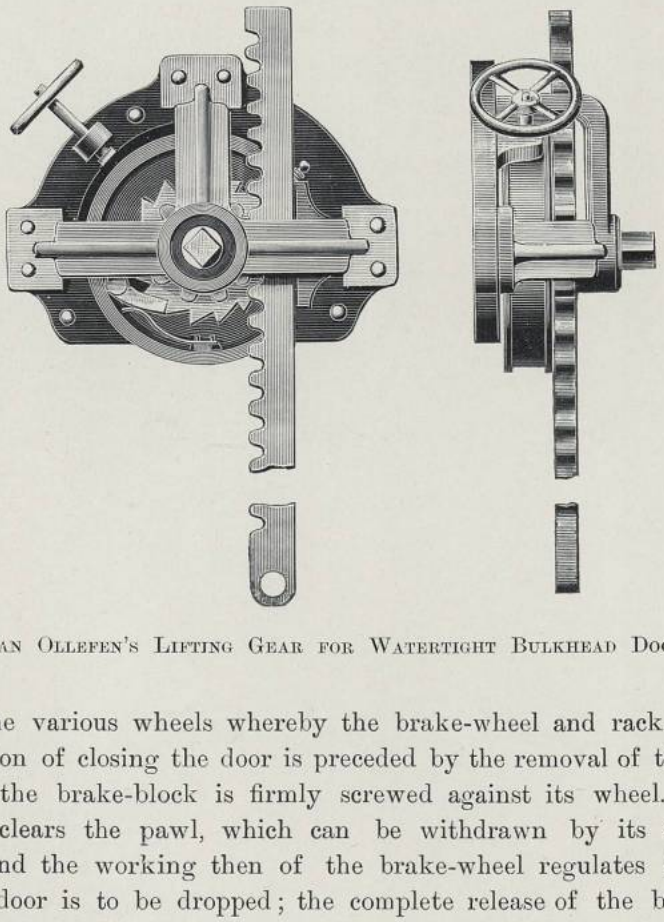
Thus formed to circular shape, the flue is taken to the welding machine. The edges to be welded together are cut on the bevel, but at the ends of the flue, where flanges have to be formed for connection with the front of the boiler and with the combustion chamber at the back, square edges are left, while at the same time the thickness is there slightly greater than in the ribbed portion. The weld is made with a glut in the case of the ribbed flue, and cambered. The welding machine is a cleverly-devised tool, and is illustrated by one of the engravings on the Plate facing page 50. The anvil is carried on one large bracket, the steam-hammer over it on another; and arrangements are provided to enable any length or diameter of flue to be supported immediately on the anvil, the position of which is fixed. Thus, for lateral movement the platform on which the flue is carried can be traversed by means of gear on the rails placed under the floor level. For vertical movement, to suit different diameters of flue, the platform with rails, &c., can be raised or lowered, and for rotary movement side-bearing wheels are fitted to the movable platform. Both of the arms carry gas-furnaces and blowers, coal-gas being preferred because it is considered "easier" on the material. For the purposes of this process, there is a large coal-gas producing plant within the works, with all the auxiliaries, including retorts, purifiers, and two gas-holders with large storage capacity. The gas in the welding machine is perfectly mixed within the blower, and not at the point of contact, as is the usual practice—a difference in method which tends to more uniform temperature at the point of welding. The hammer is operated by steam, and the work is very quickly and effectually carried out, the flue with its carriage being traversed along immediately under the gas-fires and hammer.

The flue is next taken to the rounding machine, also operated hydraulically. This tool has a central column, against which the flue is pressed by suitable shaping blocks conforming to the various flue sections. The outside block is given a reciprocating motion by hydraulic cylinders, and the pressing of the flue in this way against the inner column, takes out any irregularities due to welding, &c. The heat at which this shaping operation takes place is between 1100 deg. Fahr. and 1200 deg. Fahr. The flanges for securing the flue to the shell-plate and combustion chamber are next formed in hydraulic presses. The flue is then trimmed to its exact dimensions by cold band-saws, with specially-designed tables which can be moved in any direction, radially, vertically, or horizontally. Slotting machines of special design are used to trim edges which it is not possible to reach with saws. The flue is pickled at a suitable stage in the proceedings, usually before flanging and dressing; and after this operation it is finally annealed in an upright furnace with a movable truck floor. The furnace is air-cooled, so that there is no chance of alteration in form. Thus completed, the flue is passed to the boiler-maker.

The maximum width of plate worked into flues is 10 ft. 6 in., which constitutes the length of the furnace, while the maximum internal diameter of the finished furnace is 54 in. and the minimum 26 in. The plates range from $\frac{7}{16}$ in. to $\frac{23}{32}$ in. in thickness. Board of Trade test results show that the breaking loads of the material per square inch range between 25.89 tons with an elongation of 30.3 per cent. in 10 in. and 28.06 tons with an elongation of 27.3 per cent. under normal conditions. Board of Trade requirements are from 26 to 30 tons, with 20 per cent. elongation.

Serve tubes, to the efficiency of which we have already referred, were introduced in 1888, and are manufactured in sizes varying from $3\frac{1}{4}$ in. upwards for marine purposes, while for locomotive purposes the sizes recommended are from $2\frac{1}{2}$ in. to $2\frac{3}{4}$ in. These tubes are very largely adopted, not only in British ships, but in the French Navy and Merchant Service, and in several of the North German Lloyd vessels. The shop for the manufacture of these tubes is 234 ft. long, with three bays, giving a width of 134 ft. and a height of 26 ft. The tubes are rolled from slabs with special rollers for forming the ribs. To prepare the tube for welding, there are trumpet-shaped funnelled rollers, with a special mandril having grooves to suit the ribs of the tube. The welding is also done in the tube mill, after which the tube goes through a mangle for straightening and smoothing it. It is then cut to length, bored at the ends to remove the ribs for a short distance so as to enable it to be expanded into the tube plate. In the case of stay tubes the ends are further staved up by an hydraulic ram, while the tube is secured by two dies at top and bottom. Stoppers are also made at the Atlas Works for closing the tube when necessary, and special scrapers are provided with groves to fit the ribs. These latter are made in two pieces, welded together at one end, and plied out at the other with slots to suit the ribs.

Another notable marine auxiliary is the Van Ollefen lifting gear for doors fitted to water-tight bulkheads in machinery and other compartments of steamers. The engraving on the opposite page shows the general mechanism. It consists of a rack and pinion, ratchet and pawl, with brake-gear, and is made partly of malleable iron and partly of steel, and machined in the usual way. It will be seen that the pinion wheel for operating the rack, secured to the vertical door, is mounted on the same shaft as the ratchet and brake-wheels, and that this shaft is operated by a hand-wheel, which, however, is not shown on the square end of the shaft prepared for it. In opening the door, the brake is first put on lightly, and while the hand-wheel is turned, the pawl prevents the door from dropping backwards. The door being fully opened, the brake is screwed tight, and a safety-pin is placed in position, through a series of



Van Ollefen's Lifting Gear for Watertight Bulkhead Doors.

holes in the various wheels whereby the brake-wheel and rack are locked. The operation of closing the door is preceded by the removal of the safety-pin while yet the brake-block is firmly screwed against its wheel. A turn of the shaft clears the pawl, which can be withdrawn by its spring being released; and the working then of the brake-wheel regulates the speed at which the door is to be dropped; the complete release of the brake causing the door to fall instantly. The gear is made to work right- or left-handed: that illustrated is for left-hand. One advantage of this Van Ollefen system is, that should a piece of coal or other obstruction prevent the door from completely closing, the automatic mechanism does not interfere with the door being forced down by stokers, or others in the vicinity, working the wheel operating on the pinion-wheel shaft.

Several other marine specialities are manufactured by the company in addition to these described, as, for instance, steel chequered plates for engine cylinder tops, engine room and stokehold floors, plates, companion ladders, &c.; but it is scarcely necessary to refer to these in detail.

RAILWAY MATERIAL.

IT was for the production of railway material—wheels, tyres, axles and springs, as well as rails, &c.—that the Atlas Works were first organised; and although other departments—notably armour-plate manufacture, the forging of shafts, guns, &c., and the making of the accessories of marine engineering—have long since developed an importance which far surpasses that associated with the original productions, a great volume of railway work is still done and must continue, in view of the popularity of many specialities produced by the company. The annual production of railway materials, including castings, totals 20,000 tons, and embraces all types of tyres, engine and wagon axles, cranks, crank-pins, slide-bars, piston, coupling, and connecting-rods, laminated springs of every description, buffers with volute, conical, and spiral springs, rope pulleys and mining wheels, and many different forms of forgings and castings. For this work, in addition to the open-hearth foundry, there are several shops, the most important, perhaps, being that in which the tyre mill is placed, together with the steam-hammers. This building is 193 ft. long, with three bays of 59 ft., 46 ft., and 58 ft. span respectively, the height of the roof being 27 ft. There are several cranes, ranging up to 10-tons capacity, all driven by electric power. Many of the 30 steam-hammers in the works are utilised in connection with this department.

Tyres for railway and tramway vehicles, representing in their finished state an aggregate weight of close upon 5000 tons, are made each year. For the casting of the ingots, which are now square in form in place of the once universal cheese shape, several moulds are mounted upon a cast-iron bed fitted with a central funnel, into which the metal from the open-hearth furnace is teemed, and from which it flows through fire-brick channels to the bottom of each ingot mould, whence in filling it rises to the top. This arrangement obviates the chances of blow-holes forming in the centre of the ingot. Chemical and mechanical test-pieces are taken from each cast, and if the results are satisfactory, the work of manufacture proceeds. The head is cut off under the hammer, and the weight of the ingot taken: it averages about 18 cwt. After being reheated in one of four furnaces adjoining the tyre mill, the ingot is forged down under an 8-ton hammer to a round bloom, a central hole is punched, and through this a mandril is put for convenience in subsequent manipulation. This is the operation in progress under the steam hammer in the foreground of the upper illustration on the Plate facing this page.

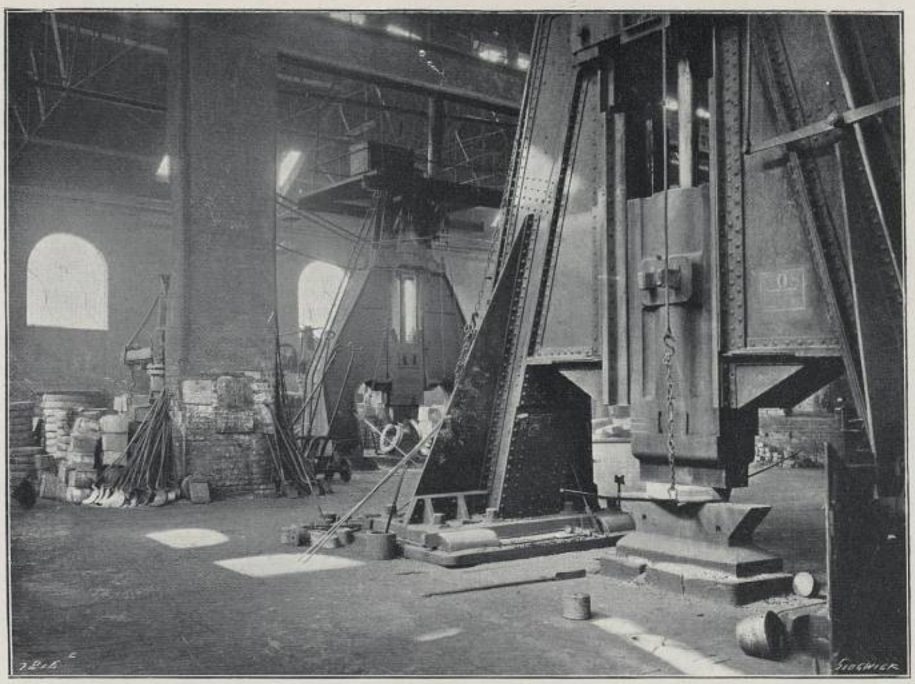
The bloom is next hammered round its edge to consolidate the metal, and to ensure that the edge will be concentric with the hole. It is then placed on a "beak horn" under the hammer, while suitably shaped tools roughly form the flange, the diameter of the hole in the same process being increased. The hammer in the distance in the upper view on Plate XIX. is shown forming the flange.

After being flattened out, the roughly-formed hoop is reheated and passed to the tyre mill, which is capable of finishing to exact dimensions hoops ranging up to 14 ft. 3 in. in diameter; but the plant, although it has been used for the supply of nearly every railway in this country and on the Continent, has never been taxed to its fullest capacity as to size, the diameter of tyre seldom exceeding 8 ft. For preparing rolls for the mill the company have an ingeniously arranged slide lathe with 5 ft. face plate. In addition to the mill, there is in this department a useful 7-ton hammer, for cogging small ingots and for general forge work.

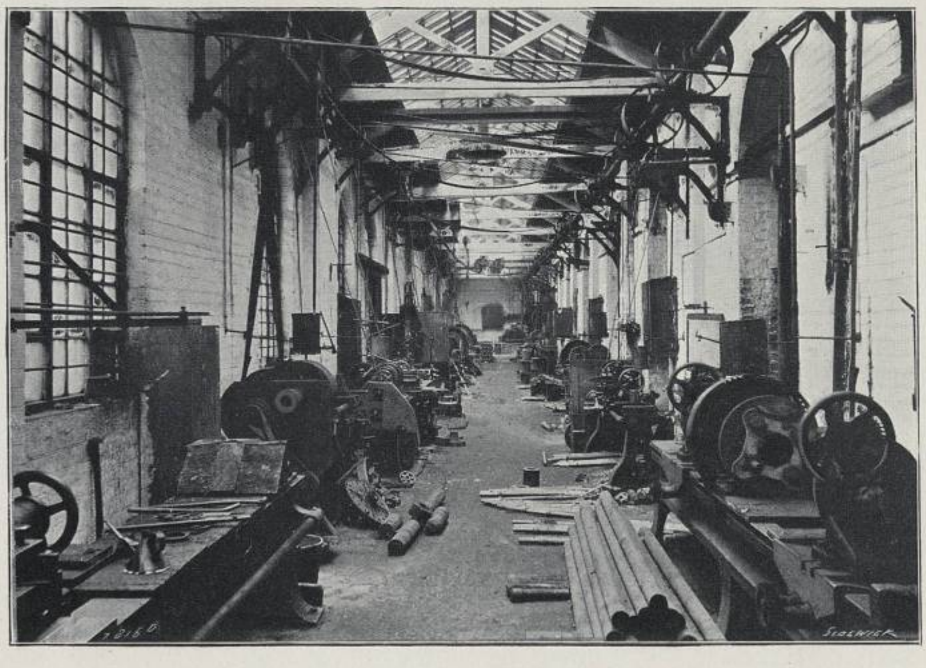
After oil treatment, and in some cases annealing, 2 per cent. of the tyres made are subjected to severe tests, either under an hydraulic press, with a 30-in. ram exerting a pressure of 135 tons, or under a 1-ton tup, dropped from heights varying up to 45 ft., until the desired compression is obtained—one-sixth or one-eighth of the diameter of the tyre. The latter method of testing is more largely adopted. Mechanical test-pieces are sawn from the tyres subjected to this compression test, and for this purpose a special saw has been provided. There is a wide range in the requirements of railway engineers as to the strength of metal used: from 30 to 50 tons per square inch, with an elongation, in the case of the milder steel, of 25 per cent. in 3 in., and with high-tensile material of 15 per cent. in 2 in.

Axle ingots are also cast in groups, the bed for the moulds in this case being able to accommodate some thirteen or fourteen moulds; the ingots usually give 18 cwt. of sound material after the head has been removed. But before proceeding with the rolling of the ingots, a representative ingot from each blow is analysed, and thoroughly tested. Should the result be satisfactory, the work on all the remaining ingots is proceeded with. They are either rolled in an ordinary mill, or knocked down by one of two 3-ton steam hammers, using suitably-shaped tools to form the variations in diameter on the axle constituting the collar, the journal bearing, and the wheel seat. One in every 50 axles thus made is tested under the 1-ton tup, the axle, for this purpose, being placed on bearing surfaces of from 3 ft. 6 in.

PLATE XIX.



Steam Hammers in the Tyre Department.



One of the Machine Shops for Finishing Railway Materials.

to 5 ft. apart ; whilst the height from which the tup is dropped varies from 18 ft. to 30 ft. ; the material usually stands a tensile stress of from 25 to 40 tons per square inch, with corresponding elongations. An engraving on Plate XIX., facing page 56, illustrates one of the machine shops for finishing axles, &c.

The laminated springs are manufactured in all lengths and sizes, in some cases being only a few inches, and in others as much as 8 ft. long, and varying in weight from about 6 lb. to 7 cwt. All descriptions of springs come within these sizes, such as locomotive, carriage, elliptic, van-door stop, check, wagon, and buffer springs.

Locomotive springs are placed first, as these are made a special feature in this department, of which an illustration is given on Plate XX., facing page 58. The material comes to the department from the mill as rolled bars, slightly concave in the transverse section on both sides, so that the edges will always lie close together. The bars are cut to the required lengths in a special shearing machine, the spear-point end being formed by punching. The hole in the centre of the plate is then either punched or drilled, according to size. Where the ends of the plates have to be tapered, they are heated, and run between a pair of eccentric rolls, which gives the required taper, whereupon the plate is "swung off" from the centre under a pair of shears, and the end made quite square, and the plate formed to the exact length at the same time. Whilst still hot, the slits and studs are formed on the plate under the same machine. The studs on the one plate work in a slot in the plate above to prevent lateral slip, while at the same time the slit is long enough to permit of longitudinal movement. This end is obtained in most foreign work by having a rib and groove rolled in the bars.

At the other end of the forging shop, there are seven vertical drilling machines for drilling the spring hoops, the solid-head engine and carriage backs, and the hole in the centre of the plates. A grinding wheel is placed at the end of this shop, mainly for the purpose of grinding the hoops and rounding the ends of the plates. In the smith's shop all the engine and carriage top plates, scrolls, eye-plate, half-moon and rolled eyes are made, and all engine, carriage, wagon, and buffer hoops also.

All springs made are fitted by hand, which gives the best results. Two men work together—a fitter and viceman—and the plates are heated in three large furnaces. The first plate of the series forming the laminated spring, after being heated, is brought to the proper curve and camber with the assistance of a plate or crib of the right curvature, and is subsequently quenched in water to harden it. After being hardened, it is placed in the furnace again until it is a dark red heat to temper it, and whilst in this state any alteration the water has made in the curve is corrected by hammering on a hollow anvil; if twisted, the plate is straightened in a vice. The next plate is then brought out of the furnace, and after being bedded to the first plate, the two are both fastened at one end in a vice, and the men, standing one on each side, press the hot plate to the first one, working along the whole length of both edges with special tongs, so as to make the second fit well to the first plate. It is then similarly hardened and tempered, and corrected by hammering. The shop in which this fitting work is done forms the subject of the upper engraving on the Plate facing this page. The spring is finally bolted up and tested.

The testing is done by placing both ends against bearings on a table, while steam pressure applied to the centre flattens out the spring repeatedly, in most cases quite straight, in others for suitable distances according to the strength and camber. Any plate that is hard breaks, and one too soft separates from the next at the ends; the former is destroyed and the latter re-hardened. The spring is further examined to see that the fitting of the plates is quite close, and that the spring stands at the proper camber.

In most cases, a subsequent test is made to ascertain the carrying power of the spring. Hoops are then put on, securing the spring in the centre, and after being finally examined and painted, the springs are ready to be despatched, and only leaving the works after their reliability has thus been severely put to the test.

In the buffer department there are 9 shops, having in all 61 tools, including lathes, planing machines, drills, milling machine, slotters, boring and screwing tools, cold saws, &c., besides 12 hammers, ranging up to 5 tons power, and 2 spring coiling machines, 1 scragg, eccentric rolls and drop. In addition to the making of the buffers and their springs, the same tools are utilised for the forging and turning, &c., of the bolts, nuts, sleeves, sockets, &c., required for securing armour plates on warships.

The buffers consist of (1) a round box, with a flange for securing it to the carriage framing; (2) a spring, either of conical, volute, or spiral form, to take up the concussion due to two carriages coming together; and (3) a plunger, with its outer flange for striking against its opposing buffer, and an inner flange connected with the spring placed within the box. This spring buffer, it will be remembered, proved of enormous advantage in the early years of the railway era. Here also we find that same difference of opinion amongst railway engineers as to the character of the metal to be used as was noted in connection with tyres; for the plunger some prefer wrought iron, others cast steel or mild forged steel, while for the box cast iron is sometimes

Forming Locomotive and other Springs.

Machine Shop for Finishing Wagon Wheels, &c.

used, but more frequently cast steel or wrought iron. Where such workable metal is adopted the plate is bent over in the hammer to a circular form and welded, the shape being subsequently improved by swaging between two half-round hollow tools under the steam-hammer; the splay-out is done on a mandril of trumpet shape, and at the same time a flange is formed at the bottom. The plunger is constructed in a similar manner, the head and bottom being welded on; a hole is made in the bottom for securing the spring. Both box and plunger thus formed are sent to the machine shop, there to be turned and planed to the exact dimensions.

Another type of buffer, known as the rod buffer, is manufactured and largely used. The plunger is made out of a bloom, either of mild steel or iron, drawn out and headed, and is thus in one piece; the boxes are treated in the ordinary manner.

The springs for use within the boxes are made from bars. A hole formed at one end serves to attach the bar to a winding mandril, which, when set in motion in the coiling machine, twists the heated bar, an attendant meanwhile keeping it pressed against the mandril. The spring is hardened in oil at the same heat, and afterwards tempered; but where the ends have to be shaped by a smith, the spring is re-heated for subsequent hardening and tempering. Spiral springs are wound on a special mandril, like a square-threaded screw. The springs are tested by a piston operating in a steam cylinder, driving the spring until it is perfectly flat against a stop. The three items forming the buffer are then fitted together.

Wheels for various purposes, and especially for collieries, are made of forged steel, according to the Eyre patent, and they have proved very popular, owing to their combining great strength with lightness. They are forged from solid blocks of steel, and are practically unbreakable—a fact proved quite unintentionally by an accident which recently happened in a Scotch colliery, where a train of wagons ran away from the top of a steep incline. Although the wagons were smashed to pieces, the Eyre wheels, with which some of them were fitted, remained uninjured, while ordinary cast-steel wheels were completely destroyed.

In the process of manufacture the material is first hammered into a bloom, and then flattened out with special shaping tools to form a disc, with bosses on the top and bottom for centring, and four spragging holes, equidistant from each other. It is next blocked to shape, and the flanges formed, while the inner part of the disc is bent outwards, so that the flange and this bend together form a reverse curve; the wheel is then bored for the axle through the bosses originally left in the centre, and the flange or tread is turned in an ordinary lathe. The machine shop for finishing wagon wheels is illustrated on Plate XX., facing page 58. Finally, the wheel is contracted or pressed on to the axles, which are also constructed in this department. The hole bored for the axle, as well as the bearing-piece of the axle, is oval in section—an arrangement which proves of great advantage in colliery work. Usually both are round, and the spragging of the wheels in the mine involves such wear as to ultimately loosen the axle; but with the oval axle in the Eyre wheel there is no chance of such loosening. The projecting end of the axle is riveted over, except where there are outside bearings, when the ordinary system of keying is adopted.

In the course of a series of tests, made independently, an Eyre solid forged steel wheel, 14 in. diameter, with a 13-ton load, only compressed to the extent of $\frac{1}{64}$ part of an inch, while a cast steel wheel of similar diameter, when tested with the same load, compressed to the extent of $\frac{5}{16}$ in., or twenty times more. The forged steel wheel only compressed to this extent ($\frac{5}{16}$ in.) when bearing a load of $34\frac{1}{4}$ tons. The cast steel wheel had one of its spokes broken with a load of 19 tons, while the forged steel wheel, with the same load, compressed only to the extent of $\frac{1}{16}$ in.

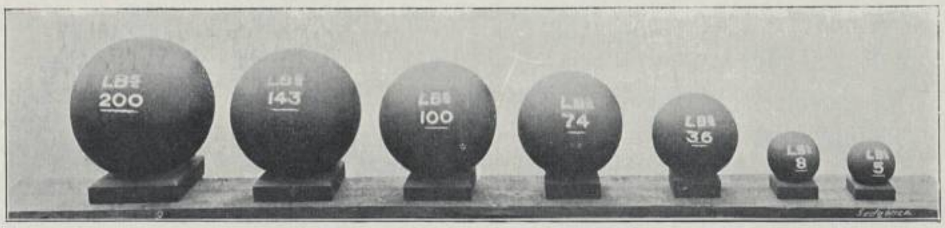
PROJECTILES.

AS we have already said in our introductory chapter, Messrs. John Brown and Co. entered into an arrangement, in 1903, with Messrs. Thomas Firth and Sons, Limited, whereby the Norfolk Works of the latter company became practically, although not nominally, allied with the Atlas Works, so that the resources of the company were thus considerably increased, one or two manufactures being added to their already long list of productions.

The Norfolk Works, which adjoin Messrs. Brown's establishment, have a productive capacity of 40,000 tons of steel per annum. The manufactures are, for the most part, similar to those of the Atlas Works, consisting of forgings for ordnance work, shafting, &c., steel of every kind (including crucible steel of the highest quality for tools), and railway materials, with the important addition of projectiles. The machine tools in use are able to deal with the largest forgings that the engineer may require; but as the processes of manufacture are more or less the same as those carried out at the Atlas Works, and described in the preceding chapters, we do not propose to deal completely with the plant at the Norfolk Works. We make an exception, however, of projectiles, as they are not manufactured at the Atlas Works. Indeed, it was partly the desire to be able to produce this important element in the completion of a warship for fighting service that induced Messrs. John Brown and Co., Limited, to acquire the Norfolk Works, which have for many years been prominently and favourably known for their shot and shell. Messrs. Firth's connection with this department of industry dates from the days of the old round shot, which they produced from crucible steel with the assistance of dies. They have since taken a leading part in all the succeeding stages culminating in the modern capped armour-piercing shell, with its great penetrating power: the contrast offered in the illustration on the next page, and those on Plate XXI., is therefore interesting.

Perhaps the greatest step made was in connection with armour-piercing shot, in which interest was first awakened about the year 1886, when the compound armour had successfully resisted the attack of the ordinary forms of pointed projectile. In that year chrome-steel shot, made in France, and treated under a secret process, pierced the hard face of compound plates, and passed through the wrought-iron back without being broken up. Several projectiles made according to this process were brought to England,

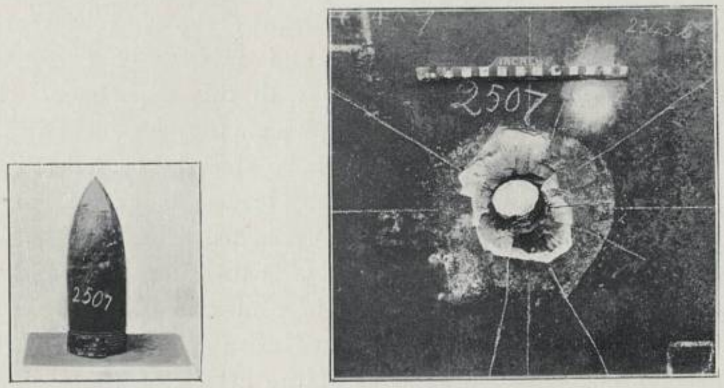
and tested by the Government authorities, who, convinced of the superiority of the shot, decided to encourage British makers to undertake their manufacture. Messrs. Firth thereupon commenced a course of research work, which resulted in the production of projectiles which gave even better results in some instances than those obtained under the French process, and ultimately they acquired the manufacturing rights of this system from the owners—the Firminy Company of St. Etienne. Large orders were obtained



ROUND SHOT OF 50 YEARS AGO.

almost immediately from the British Government, as well as from Spain, Japan, and other countries, and so successful were the company that they passed upwards of 2000 shot within a year without a single definite failure.

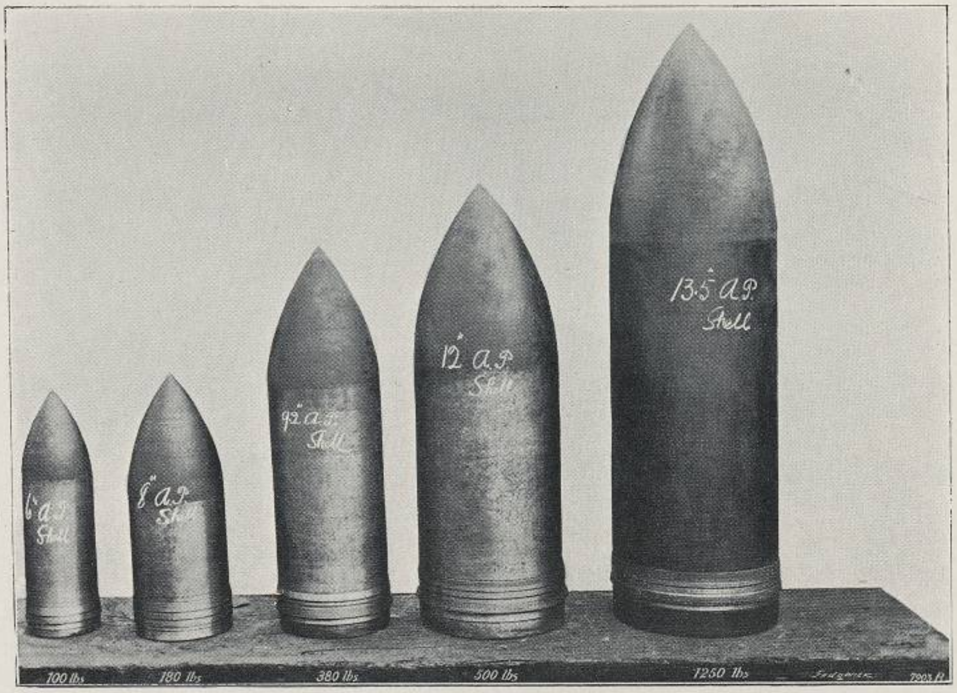
We reproduce below, and on page 63, photographs of several representative compound plates after attack by such armour-piercing shot, the projectile as it appeared after perforating the plate being shown with the armour. A complete triumph was thus established over the compound plate. The ballistic information regarding each test illustrated is also given :—



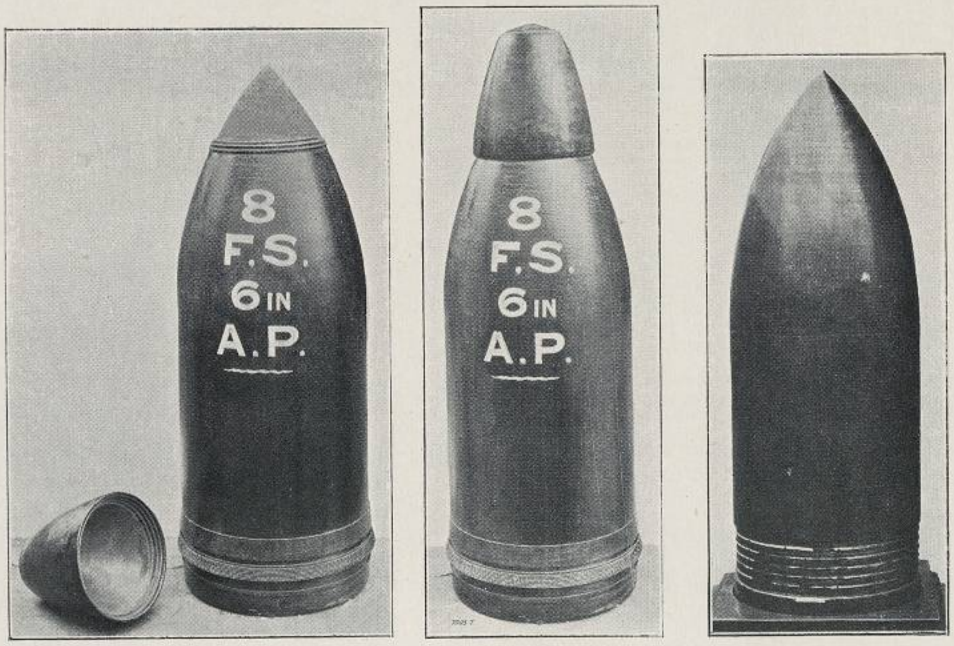
6-IN. ARMOUR-PIERCING SHOT *versus* 9-IN. COMPOUND PLATE.

(Fired December 14th, 1888.)

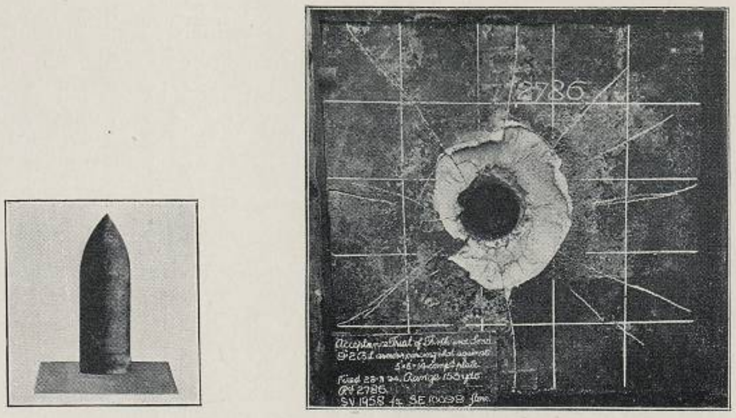
Shot struck $1\frac{1}{2}$ in. left of centre and penetrated, recovered from second layer of backing whole, set up in upper part of body to 6.248 in. Weight 100 lb., range $82\frac{2}{3}$ yards, striking velocity, 1,811 ft. per second, striking energy 2,230 foot-tons.



Modern Armour-Piercing Shell

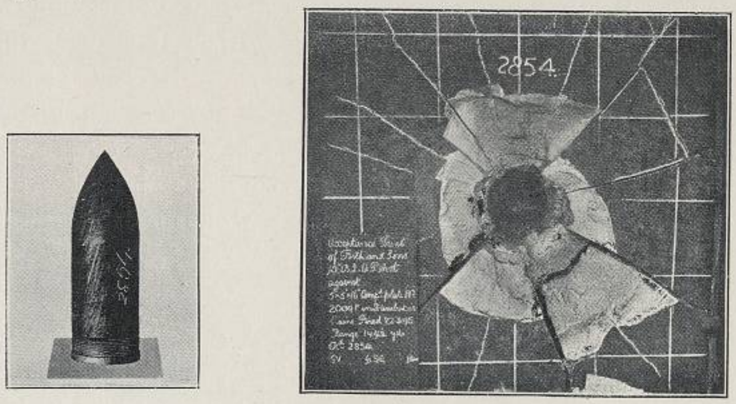


I. and II. Method of Securing Capped Shot
III. Shot after Penetrating Krupp Armour.



9.2-IN. ARMOUR-PIERCING SHOT *versus* 14-IN. COMPOUND PLATE.

9.2-in. shot, fired March 28th, 1894, against 14-in. compound plate, penetrated whole without cracks, but slightly set up in body. Diameter of shot-hole in plate 9.3 in. Weight 380 lb., range 153 yards. Striking velocity 1,958 ft. per second, striking energy 10,099 foot-tons.



10-IN. ARMOUR-PIERCING SHOT *versus* 16-IN. COMPOUND PLATE.

10-in. shot, fired March 22nd, 1895, against 16-in. compound plate, penetrated plate and butt, and recovered whole, uncracked. Diameter of shot-hole 10.2 in. Weight 503 lb., range 144½ yards, striking velocity 1,958 ft. per second, striking energy 13,368 foot-tons.

With the introduction of all-steel, cemented and chilled, armour, the shot-maker was no longer able to penetrate plates whose thickness was one and a-half times the diameter of the projectile, as was the case with compound armour. With the ordnance then available, it was even difficult to penetrate plates equal in thickness to one calibre. This disability, however, only served as an incentive to improve the manufacture of projectiles; and the company set about a series of experiments which led to considerable modifications in the composition of the steel of which the shot was manufactured, as well as to changes in the method of treatment by annealing, hardening, and tempering; while at the same time an alteration was made in the form of the projectile, as the result of experience gained during trials.

The conditions of contracts then were that the shot should pass entirely through a plate equal in thickness to the calibre of the gun—the diameter of the projectile—without being broken up. Even with these modifications it was found that this result was impossible of realisation against the specially-hardened Harvey plates; and, as many ordnance authorities were of opinion that the projectile would do more damage in a warship if it broke in passing through the hull, battery, or protective deck armour plating—provided the particles also passed through—it was decided that projectiles would be accepted if they met this amended condition.

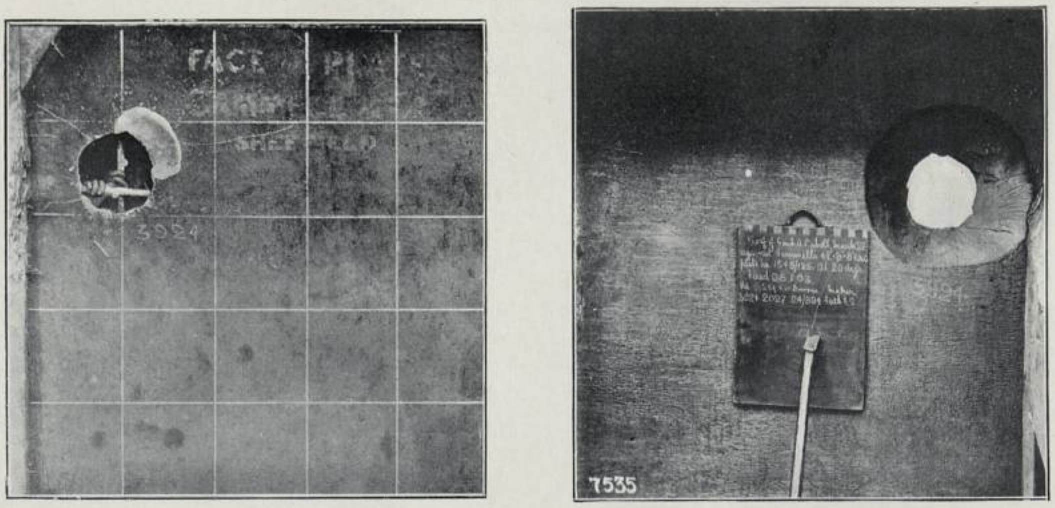
The first method tried to attain this end was the insertion of a bursting charge in the core of the projectile; but experiments demonstrated that the force of impact against the plate frequently caused premature explosion of the bursting charge, so that the projectile failed to effect the maximum damage even to the armour, apart altogether from destruction within the ship. This difficulty was overcome by still further improving the quality; but the authorities then increased the severity of the test by determining that the projectile should be fired against the plate at an angle of from 20 deg. to 30 deg. from the normal line of fire.

With the object of still further increasing the penetrative power of armour-piercing projectiles, other developments took place, which culminated in the fixing of a cap on the point of the projectile. As far back as 1889, experiments were tried in different countries to determine the efficiency of the oft-repeated proposal of fixing on the nose or point of the shot a cap of soft iron, or very mild steel, to minimise the full force of impact, and enable the point to remain more or less in contact, so as to do its work of perforation more effectually. The cap served also in some sense as a lubricant. Plates which could not be penetrated by an uncapped shot were completely traversed by a shot fired with one of these wrought-iron caps. The Russian naval authorities first called prominent attention to the efficiency of capping the shot, in the course of trials at Ochta in 1894. The opinion publicly entertained then was that the caps were secured to the shot by magnetic attraction; but this was found on experiments by some manufacturers to be fallacious. Messrs. Firth were the first to offer capped shot to the British Government—a few weeks after the Ochta trials. The 6-in. shot first tried easily passed through a 6-in. specially-hardened plate. The maximum effect is attained when the capped shot strikes the plate at right angles,

7-in. Krupp Armour, after Attack by 10-in. Shell.

9-in. Krupp Armour, after Attack by 13.5-in. Shell.

PLATE XXII B.



$4\frac{1}{2}$-IN. KRUPP ARMOUR, AFTER ATTACK BY 6-IN. SHELL.

CRUCIBLE SHOP FOR CASTING PROJECTILE INGOTS.

the advantage diminishing in the case of angle fire, and disappearing at about 30 deg.

The company make their caps out of the best wrought-scrap iron, and their form is well shown in illustrations on the Plate facing page 62. The cap for a 6-in. projectile weighs 4 lb., and the method of fixing it to the projectile is not only simple, but involves very little preparation upon the projectile, so that it may be applied to ammunition already manufactured. The attachment is made to a ring of solder sweated on near to the point of the projectile, as shown, and subsequently screwed with a thread to correspond with the one turned on the inside of the cap, also shown in the cap lying alongside the projectile. A right-handed thread is preferred, so that the gyration of the projectile in its flight tends only to tighten the cap in place. This system of fitting is not only efficient, but has the advantage that it can be carried out in a few minutes on any projectile already in service.

The success of the capped shot, and its power to completely perforate armour, increased the desire of the authorities to have such a projectile as would break in pieces when passing through the hardest of plates; and, in 1900, armour-piercing shell to carry a bursting charge were first ordered by the British Government. It was at one time considered better for the shell to break up into many small fragments after passing through the plate, in order to effect the greatest damage to mechanism and *personnel* in the interior of a ship, within casemates and gun-houses, or under the protective deck of fast cruisers; but the tendency now is to secure a shell which breaks into a few large fragments, as each unit is then more destructive. Probably, in the future, it will be the aim to secure armour-piercing shell which will remain whole until after they pass completely through the plate, breaking up afterwards owing to the ignition of the bursting charge.

We illustrate on the Plates facing pages 64 and 65, the front and back of a number of typical armour plates after they were attacked by armour-piercing shells during 1903. These tests were made against Krupp non-cemented plates, ranging from 4½ in. to 9 in. in thickness, and established the great success of the armour-piercing shell made by the company, and illustrated on the Plate facing page 62. The particulars of the trials follow :—

13.5-IN. ARMOUR-PIERCING SHELL *versus* 9-IN. KRUPP ARMOUR.—13.5-in. armour-piercing shell, fired March 6th, 1903, against 9-in. Krupp non-cemented plate at 30 deg. to normal to line of fire. Penetrated. Weight 1,250 lb., striking velocity 1,753 ft. per second, striking energy 26,628 foot-tons. (See bottom views on Plate facing page 64.)

12-IN. LIGHT ARMOUR-PIERCING SHELL *versus* 7-IN. KRUPP ARMOUR.—12-in. (light) armour-piercing shell, fired March 25th, 1903, against 7-in. Krupp non-cemented plate at 30 deg. to normal to line of fire. Penetrated. Weight 714 lb., striking velocity 1,832 ft. per second, striking energy 16,612 foot-tons.

10-IN. ARMOUR-PIERCING SHELL *versus* 7-IN. KRUPP ARMOUR.—10-in. armour-piercing shell, fired April 28th, 1903, against 7-in. Krupp non-cemented plate at 30 deg. to normal to line of fire. Penetrated. Weight 500 lb., striking velocity 1,878 ft. per second, striking energy 12,224 foot-tons. (See top views on Plate facing page 64.)

9.2-IN. ARMOUR-PIERCING SHELL *versus* 7-IN. KRUPP ARMOUR.—9.2-in. armour-piercing shell, fired March 5th, 1903, against 7-in. Krupp non-cemented plate at 30 deg. to normal to line of fire. Penetrated. Weight 380 lb., striking velocity 1,931 ft. per second, striking energy 9,822 foot-tons.

8-IN. ARMOUR-PIERCING SHELL *versus* 4½-IN. KRUPP ARMOUR.—8-in. armour-piercing shell, fired April 16th, 1903, against 4½-in. Krupp non-cemented plate at 30 deg. to normal to line of fire. Penetrated. Weight 180 lb., striking velocity 1,765 ft. per second, striking energy 3,887 foot-tons.

6-IN. ARMOUR-PIERCING SHELL *versus* 4½-IN. KRUPP ARMOUR.—6-in. armour-piercing shell, fired January 28th, 1903, against 4½-in. Krupp non-cemented plate at 20 deg. to normal to line of fire. Penetrated. Weight 100 lb., striking velocity 2,027 ft. per second, striking energy 2,848 foot-tons. (See top views on Plate facing page 65).

As a further indication of the success achieved by the company's armour-piercing shot, without the cap, we reproduce on the Plate facing page 62 an engraving of a 6-in. shot, which weighed 101 lb., and attained a striking velocity of 1,930 ft. per second, developing a striking energy of 2,609 foot-tons. The projectile is illustrated as it appeared after it had passed through the plate, and indicates that little damage was done to it, and that it justifies its description as being of "superior quality." The following is from the official report:—

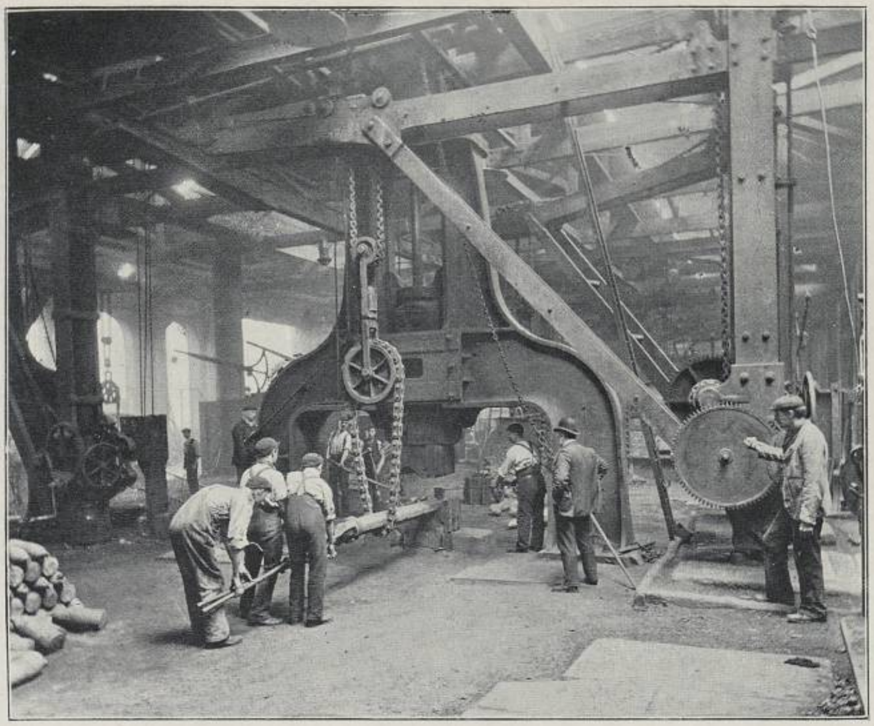
Effect produced on Front of Plate.—Punching action, but approaching perforation. Size of hole 6.1-in. horizontally by 5.9-in. vertically (this measurement has been carefully verified); damage 8.4-in. by 7.0 in. Face metal removed over an area of 9.5 in. by 8.5 in. No dish. Hole coppered all round. One radial crack on each side of shot-hole.

Effect produced on Projectile.—Recovered projectile whole. Passed through plate with ease sufficient to admit of no movement of plug. No appreciable setting up, passes gauge easily. Point perfect. Small piece chipped off rim of base. Scored on one side to about 4.0 in. Hole in card circular at 44.23 yards from plate.

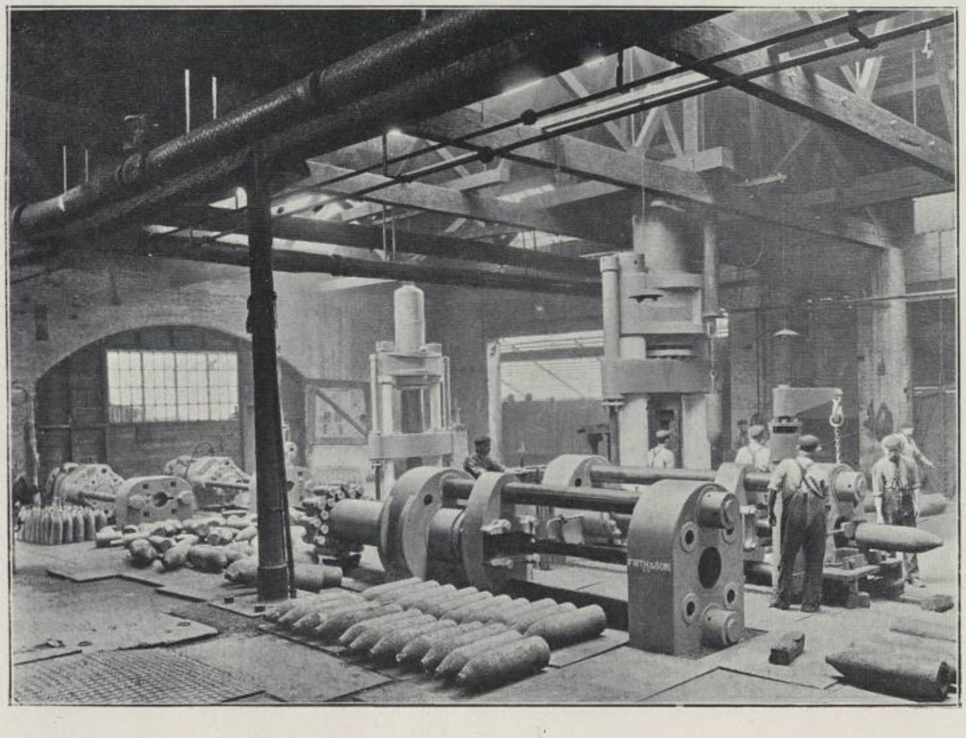
The penetration of this shot was thus theoretically determined as equal to 5.471 in. in the case of Harveyed steel armour, and 5.273 in. in Krupp cemented armour—results eminently satisfactory against modern armour.

The company manufacture all forms of projectiles for all guns, and also ammunition for the smaller quick-firing weapons.

The manufacturing departments of the Norfolk Works utilised for the production of projectiles include the steel producing plant, the forge and press departments, and extensive machine shops. For the melting of steel for projectiles and similar purposes—tool steel, &c.—there are 196 crucible holes, each accommodating two crucible pots; the capacity is over 5,000 tons per annum. The lower engraving on the Plate facing page 65 illustrates the crucible shop. All projectiles were at one time made from crucible steel; but in the more modern systems of manufacture, especially where special alloys are utilised, it has been found as convenient and efficient to utilise the Siemens-Martin open-hearth furnaces at the works for this as for other

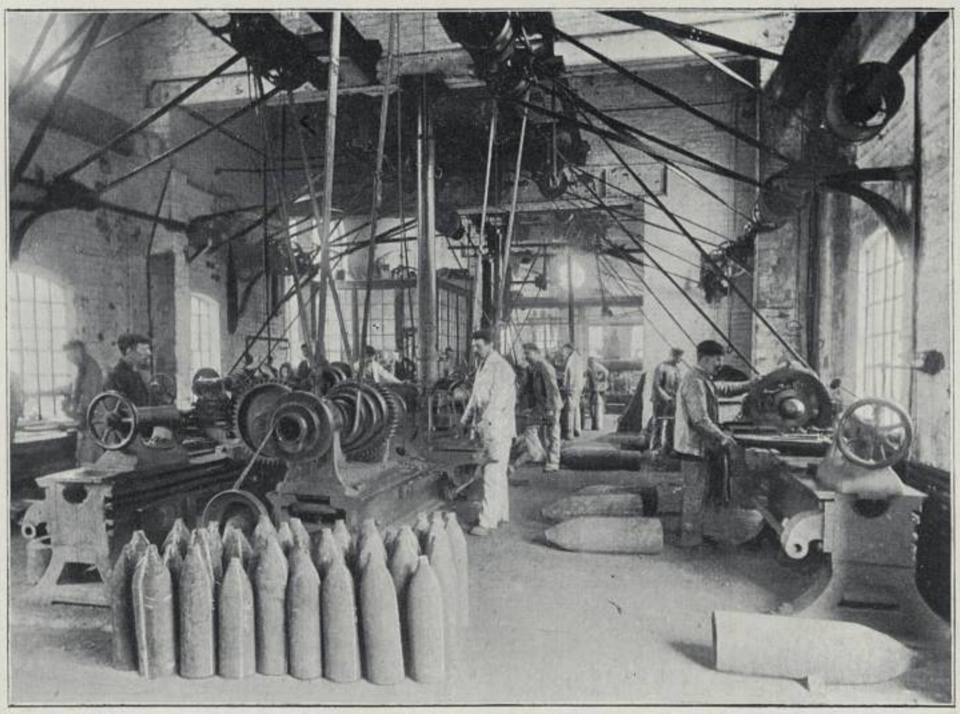


Steam Hammer for Forging Projectiles



Hydraulic Presses for Making Shells.

MACHINING PROJECTILES.



FINISHING PROJECTILES.

purposes. There are four of these in the Norfolk Works, one of them having a capacity of 45 tons, two of 25 tons, and one of 10 tons; so that with the combined capacity of these furnaces it would be possible to meet any emergency demands for projectile work without interfering much with the ordinary peace productions of the company. Ingots from the steel-melting department are sent to the forge, where they are worked into bars under hammers, ranging from 12 to 3 tons in power.

The process of manufacture differs according to the final form which the projectile is to take. When it is intended to make armour-piercing shot, the blanks—as the embryo projectiles are called—are bored and turned, then hardened and tempered, gas checks or copper bands being subsequently fitted on. Blanks to be manufactured into armour-piercing shell are sent to the punching and drawing shop, where they are dealt with by a series of hydraulic presses, varying from 500 tons to 100 tons in power. The first process consists in the formation of a cup at the base of the pointed blank, to facilitate the subsequent drawing down into a hollow cylindrical form. The press for the latter purpose, illustrated on the Plate facing page 66, is of the horizontal double-headed type, of 300 tons power, having a cylinder 16 in. in diameter, and a stroke of 72 in. The shell cylinder is next machined, hardened, tempered, examined and tested. As a rule, two shells out of every lot of 400 are selected for proving: one for firing over water, to be recovered on the receding of the tide for examination, while the other is fired at armour plate. The lyddite shell of forged steel is manufactured pretty much in the same way as the armour-piercing shell.

An important part of the work is done in the forge, which is fitted with a modern 12-ton hammer, as illustrated on the Plate facing page 66. This hammer has a large furnace on each side of it; there are also two 7-ton hammers, with two furnaces each, a 5-ton hammer with three furnaces, and a 3-ton hammer with two furnaces. All these furnaces are for reheating the blanks.

For the machining of the projectiles to the correct finished form there are five machine shops, some of them arranged for doing special work upon all sizes of shot, in order to concentrate as far as possible the experience gained. Two of these shops are illustrated on the Plate facing this page. In these several machine shops there are 146 machine tools, many of them of special type. The tool for forming the ogival, or pointed nose, is a particular pointing lathe, the cutting tool accommodating itself to the lessening diameter of the nose by means of a radius bar, secured at one end to a fixture on the frame, and at the other end operating a cross-slide, which again actuates the cutting tool. One of these machines is shown to the right of the bottom engraving on the Plate facing this page. The groove for the copper band is cut in an ordinary lathe, with ribs in wavy lines, so as to prevent the band from rotating independently of the projectile in its passage through the rifled bore of the gun. This band is pressed into the groove on the projectile in a special hydraulic press of the horizontal type with a 15-in. cylinder. For this special duty there is mounted on the crosshead of the ram a die representing half the circumference of the ring, while the head of the press carries a similar die corresponding to the other half; the projectile, with its ring, having been placed in position, the hydraulic pressure exerted through the dies forces the ring at all points of contact into the groove prepared for it.

The projectile, after being hardened, is finished to its ultimate true diameter by means of grinding machines, of which there is a large collection specially devised for the varied work of the company. These machines are fitted with horizontal spindles for holding the projectile in front of the grinder. The spindle is provided with a hand-traversing slide, so that the machinist has complete control over the operation, and can ensure that the grinding is done to suit the gauge. All so-called solid shot have a small hole bored down the centre, and even shell drawn down hollow in the press are sometimes turned internally. This work is done in boring mills of the horizontal type. The shells are steam-heated internally, prior to the process of lacquering, and the time- and percussion-fuse blocks are screwed at the base in the ordinary way.

It will thus be seen that the company's facilities for the manufacture of projectiles are not only modern, but have been developed by the best of all possible processes—during a long and successful experience.

PLATE XXIV

THE CLYDEBANK SHIPYARD OF JOHN BROWN & CO LIMITED.

(See page 88).

WARSHIP CONSTRUCTION.

JOHN BROWN AND CO., Limited, decided in 1899 that, as the firm constructed so many of the most essential components of ships of war and of commerce, as described in the articles on the preceding pages, they should also build the ships and their propelling machinery. An examination into the equipment and reputation of several establishments resulted in the acquisition of the Clydebank Works. Since it was constructed in 1873, this establishment, situated on the Clyde, near Glasgow, has added to the naval and merchant fleets of several nations a long line of vessels of the highest standard and success. Beginning with the smallest class, the sloop of war, advance has been made, step by step, to the largest battleships and cruisers in the world, with the result that the management and staff have accumulated an experience which enables them to undertake naval work with an assurance of absolute success; and at the same time inspires the naval authorities of Britain and foreign countries with confidence in ordering such work. They also possess an experimental tank in which to conduct ship-model tests according to the system first introduced by Dr. Froude, by which means it is easy to determine the design that will give the greatest propulsive efficiency, and ensure the highest speed for a given weight and power. As the company are alone among warship-building firms in the world to own such a department, they are in an exceptionally favourable position to undertake the design of foreign warships. This tank is described in a special article later (page 111). By the aid of the special plant in use, the work of naval construction can be effected expeditiously, efficiently, and cheaply.

Before giving a description of the shipbuilding and engineering works some reference may be made to the warships built at the Clydebank establishment. All need not be referred to, for the number constructed or engined is now about 60, measuring 180,000 tons displacement, while the machinery aggregates nearly 500,000 indicated horse-power. Several large battleships are included in the number: H.M.S. "Ramillies," is now the flag-ship of the officer second in command of the Mediterranean squadron; H.M.S. "Jupiter" is one of the ships in the Channel squadron; H.M.S.

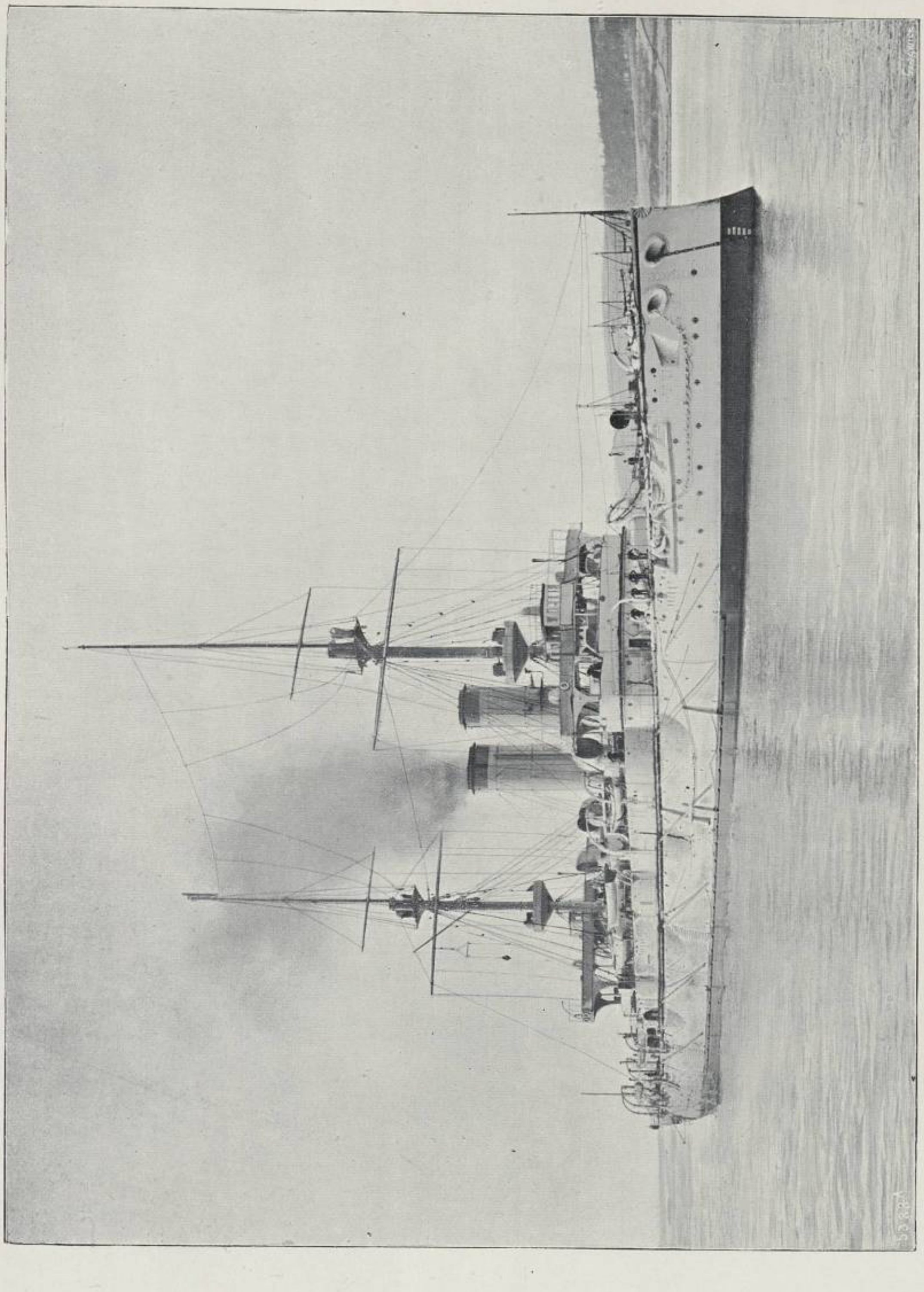
"Hindustan" is the largest warship yet ordered; while the Japanese battleship "Asahi," is amongst the largest in the navy of the Island Empire of the Pacific.

In describing these battleships, one is tempted to glance retrospectively at the successive stages in design due to the developments in armour in which John Brown and Co. have taken a prominent part. The 4½ in. and 6 in. armour of wrought iron made in the early days at the Atlas Works enabled a belt to be constructed practically for the whole length of the ship. Later, with thicker armour, it was found necessary, owing to considerations of weight, to concentrate the guns within a central battery, so as to afford them the maximum of protection alike in depth of belt and thickness of plate. To increase the arc of training of the guns, a recess was at the same time formed for guns at each of the corners of the citadel, and this practice, developed in the "Hercules" and "Alexandra," brought into prominence the principle, of bow- and stern-fire. The further development of gun power as well as of armour necessitated a still greater concentration, and forced the adoption of the turret which was fitted to the "Devastation," 1873, for her 35-ton guns; a breastwork being formed to enclose engines and funnel hatches as well as to protect the base of the turrets, while the broadside belt was narrowed down and the freeboard limited to 3 ft. In the "Inflexible," everything for the fighting of the ship was concentrated within the citadel, which had to be of 24 in. wrought-iron in view of the high power guns then available, so that only one-third of the length of the vessel could be protected, the ends being left unarmoured.

The introduction of compound armour greatly influenced battle-ship design, and the vessels of the "Admiral" class (1887-8) formed a new departure, which was carried still further in the battle-ships built under the Naval Defence Act, of which the "Ramillies," of 1893, was one. In this case the main belt was of 18 in. armour, with 4 in. of nickel steel on the strake above it extending to the main deck, so that the depth of broadside protected was 14 ft. 9 in., enabling the freeboard and the gun platform to be considerably higher. This armour, too, extended for 65.2 per cent. of the ship's length.

By the adoption of the processes of cementation and water sprinkling which greatly hardened the surface of the plate, a further increase in the armoured area was made possible without adding to weight; the whole of the belt of about 15 ft. in depth in subsequent ships was made of 9 in. armour, as it was found almost equal in resistance to the 18 in. armour in the preceding ships. This was the arrangement in the "Majestic" class, to which the "Jupiter" belongs; and thus, although the total armour decreased in weight from 4,633 to 4,260 tons, the later ships were more effectually protected, owing to greater area of armour.

PLATE XXV.

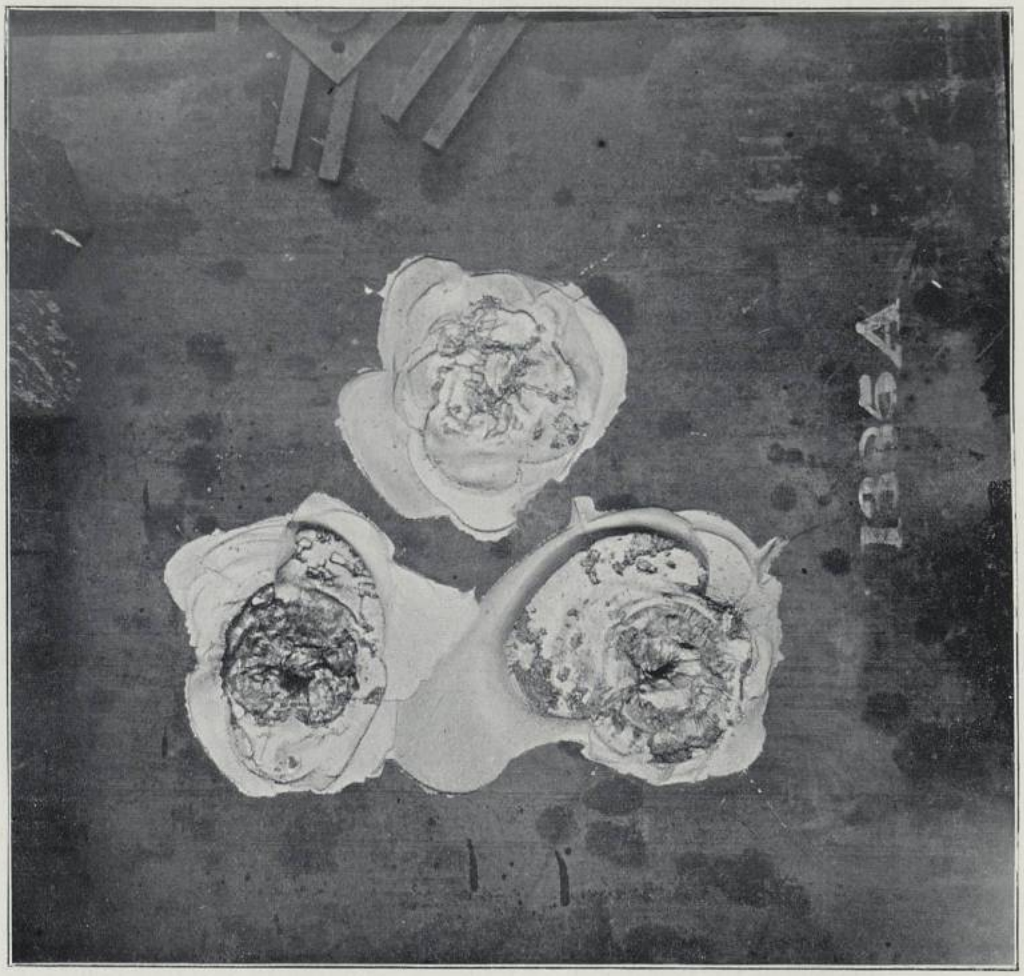


THE IMPERIAL JAPANESE BATTLESHIP "ASAHI."

With the introduction later of the Krupp process, improving the protective power of plates for a given thickness, the depth and length of the broadside protection was still further increased. Thus as the power of the gun developed, the naval architect had first to contract the armoured area. because greater thickness of plate was required to protect the vital parts, of the ship; but each successive improvement in the hardening of the armour, giving greater resistance to penetration per unit of weight, made it possible to provide wider and longer belts. Thus the "Hindustan," the third of the modern British battleships built at Clydebank, has practically the whole of her broadside clad in cemented armour, the water-line strake being for the greater part of the length of 9 in. in thickness, thinning to 4 in. towards the ends, while the upper strakes are of 8 in. and 7 in. in armour. The guns within the battery are separated by armoured partitions. The number of guns has been increased, there being four of 12-in. calibre and four of the 9.2-in. type—all in barbettes, with ten 6-in. quick-firers. The displacement has gone up from the 14,150 tons of the "Ramillies" to 16,350 tons. The speed is 18½ knots, as compared with the 18 knots of previous ships.

The Japanese ship "Asahi," one of the finest battleships built, presents several interesting features. In the first place, the vessel was completed and tried within 30 months of the laying of the keel, and some suggestion of the immense work involved in the design and construction carried out in this period is afforded by the fact that no fewer than 2,500 drawings and tracings were required for the guidance of those engaged in the putting together of this mass weighing 15,200 tons. Her length is 426 ft. 6 in over all, and 400 ft. between perpendiculars; the extreme breadth is 75 ft. 2½ in., the moulded depth 43 ft. 7½ in.: ready for war with 1,200 tons of coal in her bunkers, her draught is 27 ft. 3 in.

As to protection, the side plating is 9 in. thick, and all of it was supplied from the Atlas Works of the company. The engravings on the next pages are interesting in this connection, as they have been prepared from photographs taken from a section of the "Asahi" submitted for firing trial on December 2nd, 1898: the results are set out in detail under the engravings. This armour extends for a length of 250 ft. amidships, and the central citadel thus formed is completed by traverses or bulkheads extending obliquely to the centre line of the ship, and enclosing the bases of the barbettes which protect the mountings of the heavy guns. At the ends of the ship there is side armour, varying in thickness from 7 in. to 4 in. The upper part of the citadel is protected by 6-in. armour, and the middle deck as well as the protective deck proper are armoured. For the protection of the mountings of the pairs of 12-in. guns at each end of the citadel,



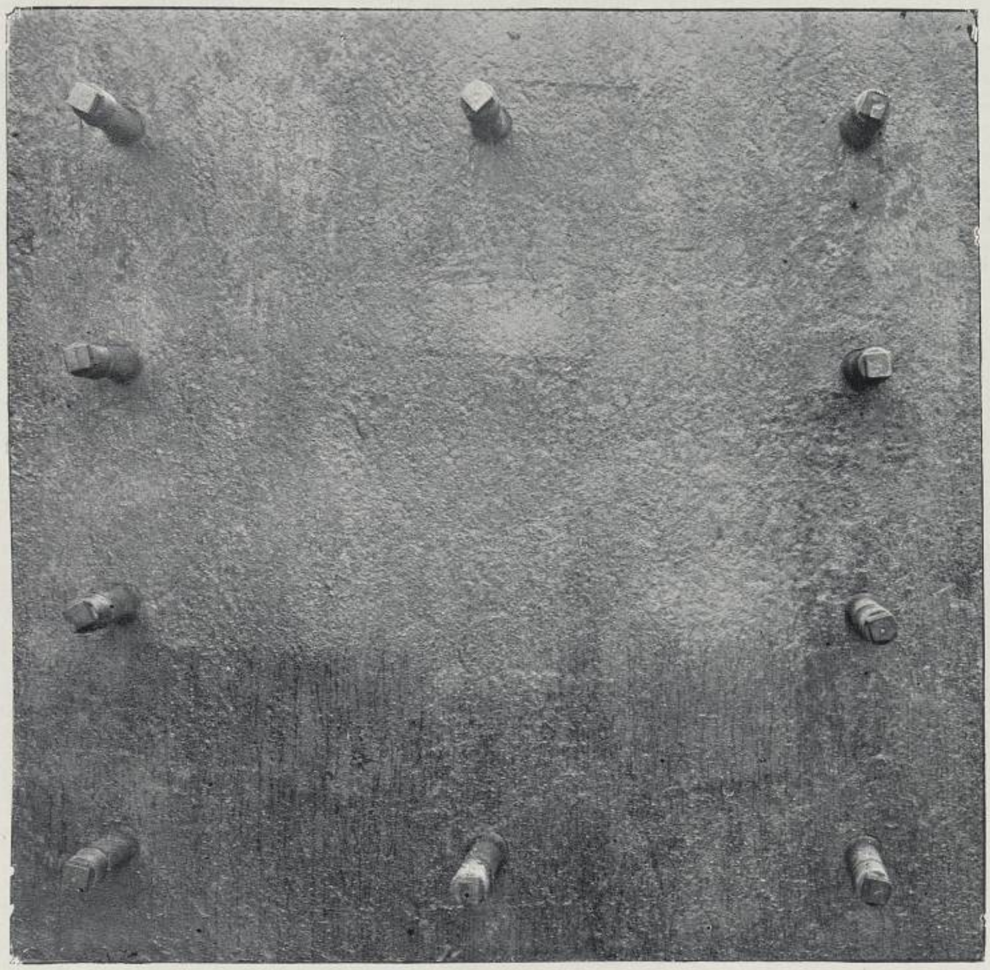
TESTS OF ARMOUR-PLATES FOR THE JAPANESE BATTLESHIP "ASAHI."

The above engraving has been made from a photograph of the front of a plate, and the illustration on the opposite page from one of the back of the same plate made for the Japanese battleship "Asahi," after the gun attack prescribed by specification of the Imperial Japanese Navy.

Doubts have sometimes been cast upon the severity of armour-plate trials made in England, on the ground that Holtzer shot are usually employed; that the Holtzer process of manufacture is an old one; and that the Americans in particular have so improved upon it that shot made by their processes are far more formidable, and so confer more credit on the plate that succeeds in defeating them. It was therefore decided to use the most highly-vaunted "Wheeler-Sterling," projectiles as shown in the following particulars of the test:—

Dimensions of plate	...8 ft. by 8 ft. by 8.8 in.
Weight	... 10.175 tons
Nature of backing	...12 in. of oak, and a skin plate 1¼ in. thick
Number of blows	... Three
Projectiles ...	...8 in. armour-piercing steel of 250 lb. weight, made by Messrs. Sir W. G. Armstrong, Whitworth and Co., Limited, on the "Wheeler-Sterling" process.

The results shown by the engravings prove that the doubts expressed are groundless. The following Table gives the ballistics of each of the three



TESTS OF ARMOUR-PLATES FOR THE JAPANESE BATTLESHIP "ASAHI."

shots with their calculated penetrating power on wrought iron :—

—	First Round.	Second Round.	Third Round.
Striking velocities, foot-seconds ..	1859	1964	2039
Striking energies, foot-tons ..	5991	6687	7208
Calculated thickness of wrought iron perforable, inches ..	17	18½	19½
Proportional thickness of wrought iron perforable, taking thickness of test plate as unity ..	1.93	2.10	2.22

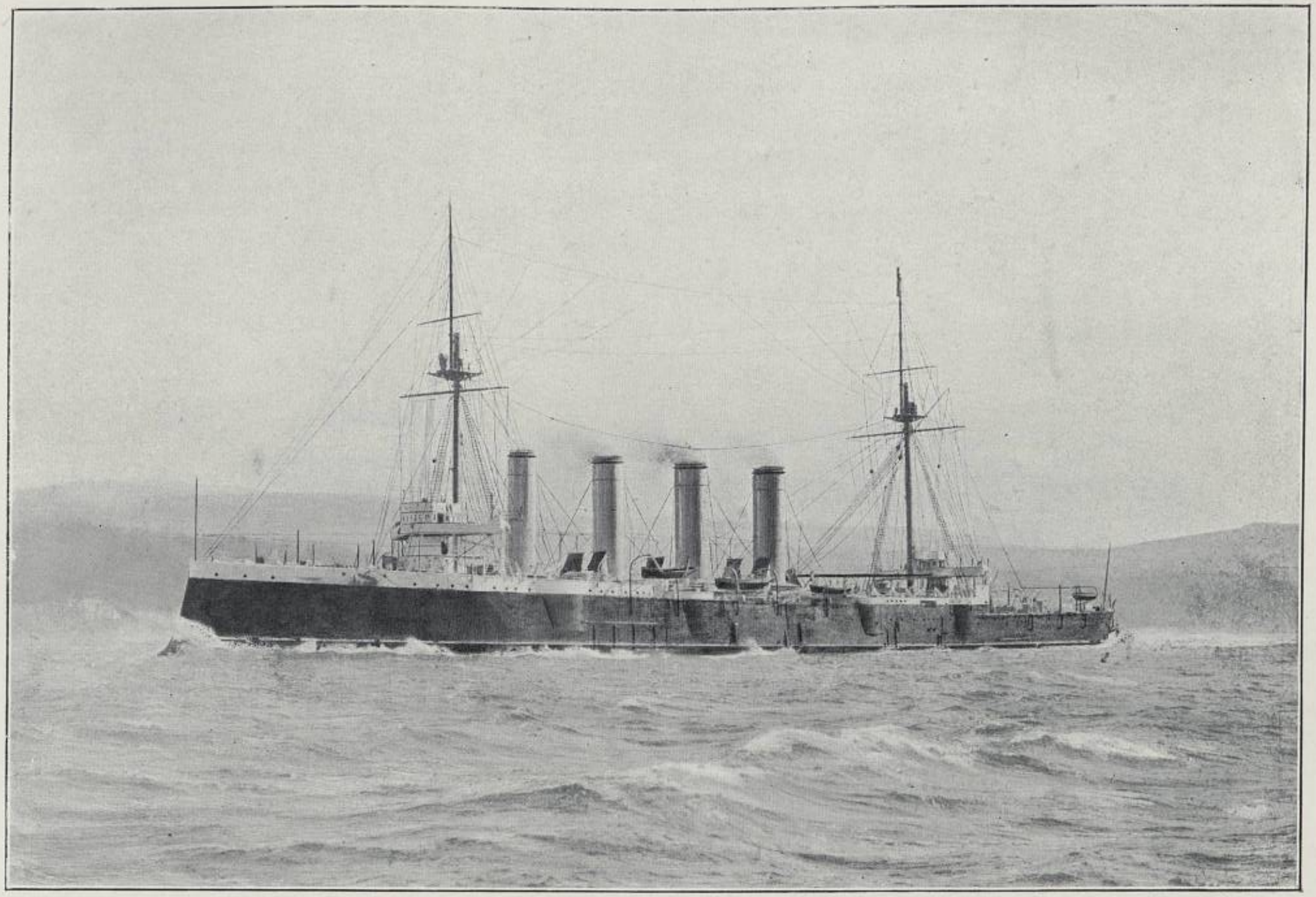
It will be seen that all the projectiles were completely shattered, and that the injury sustained by the plate was confined to the usual splintering of its face round the points of impact, and a few superficial hair cracks in the face so fine as to be almost invisible. No cracks whatever beyond these could be found in any part, and the attack left no mark on the back except the three smooth bulges, of which the most prominent measured 1½ in. in height. Such marks in the back as the illustration shows (for instance, across the upper bulge and near top central bolt) are merely irregularities of the surface, and existed before the plate was fired at. They are shown up more by the reflection of light from above. The Japanese Government was represented at the trial by Admiral Matsunaga, Captain Mukoyama (Naval Attaché), and Constructor Captain Kondo.

there are built circular barbettes, rising from the level of the protective deck to a height of 22 ft. 4 in. above the normal water-line, the thickness of the plating being 14 in. The guns themselves are shielded by a 6-in. hood, which of course revolves with the weapons and their machinery. Each of the fourteen 6-in. guns arranged along the broadside is placed within a casemate, having 6 in. armour on the front and 2-in. plating at the rear.

The 12-in. guns have an arc of training of 120 deg. on each side of the fore-and-aft line of the ship: all four can thus be used on either broadside. Two of them, and four 6-in. guns fire ahead, and the same number astern, and the ship is thus able to fire upon an enemy which she may be chasing four projectiles of 850-lb. weight and thirty-two 100-lb. shots per minute, representing a total weight of 6,600 lb. Four 12-in. guns and seven 6-in. quick-firers may engage in a broadside action, and thus eight projectiles of 850 lb. and fifty-six shot, 100 lb. in weight, can be discharged each minute. The total weight of shot per minute from the broadside is nearly six tons, with a collective striking energy of nearly a million foot-tons. In addition, there is a large installation of small guns, including twenty 12-pounders, eight 3-pounders, four $2\frac{1}{2}$-pounders, and several Maxim rifles. The total weight of metal discharged per minute from all guns is $11\frac{1}{2}$ tons, representing a collective striking energy of 1,337,130 foot-tons. Four submerged tubes are carried in two rooms, one at each end of the vessel, the tubes being arranged for 18-in. torpedoes, of which 16 are carried. The vedette boats, which have the high speed of 16 knots, are fitted with tubes for discharging 14-in. torpedoes. The stowage of ammunition has been arranged so as to minimise transport, and to avoid any crossing of the lines of supply to guns of different calibre, while adequate hoists are provided for all the guns. It is in the perfecting of such details, which greatly influence the efficiency of a ship in action, that long experience in warship design and construction carry their full value.

The "Asahi" proved not only a well-protected and efficiently armed vessel, but a fast and economical steamer. The triple-expansion engines with which she is fitted developed on the full-power trial, 16,360 indicated horse-power, which gave the vessel a speed of 18.3 knots, notwithstanding that at the time of the trial she had an extra load on board, so that her displacement tonnage was 15,340 tons. This fact ensures that the designed speed of 18 knots can be maintained when the vessel is overloaded with war supplies, as must certainly be the case when going into action. As to the economy on a long-distance trial, she ran at a speed of 17.5 knots on a coal consumption of 1.6 lb. of fuel per indicated horse-power per hour. In other words, the vessel, notwithstanding her immense displacement of 15,340 tons, was

PLATE XXVI.



THE BRITISH ARMOURED CRUISER "LEVIATHAN," OF 23¼ KNOTS SPEED.

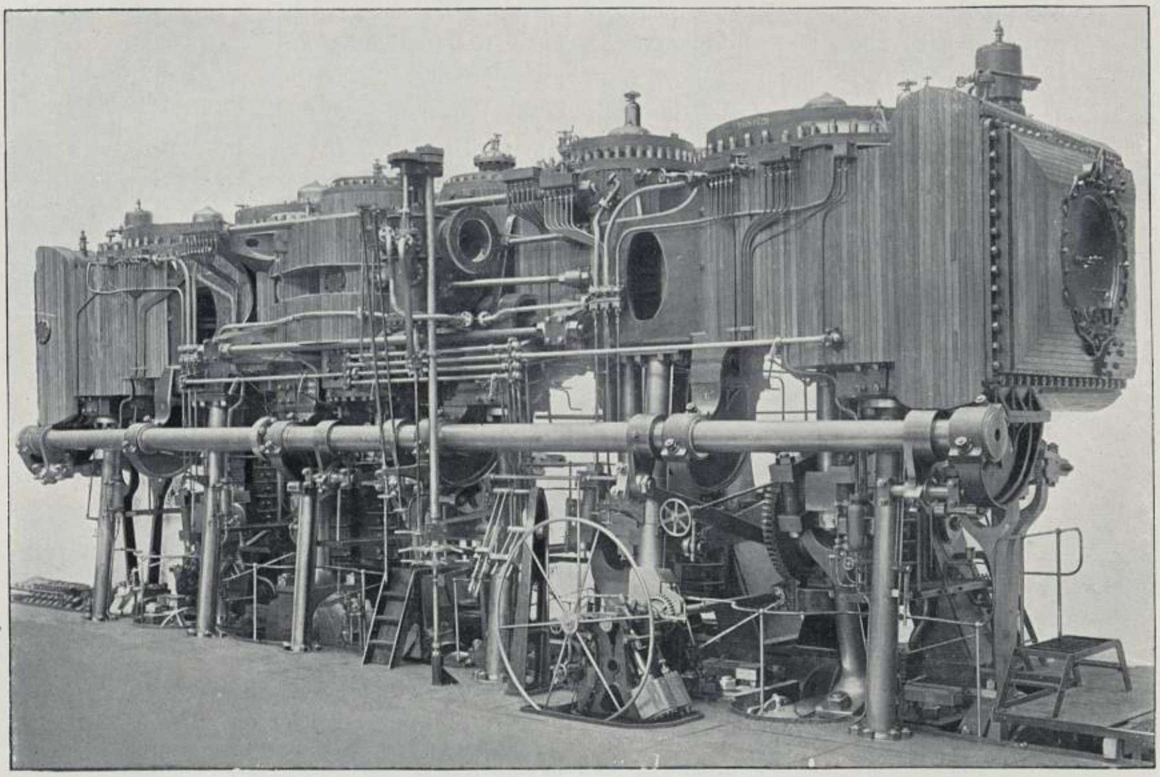
propelled at this high rate of speed for $9\frac{1}{4}$ tons of fuel per hour, equal to 1180 lb. per mile travelled.

The Clydebank Works have produced a great fleet of cruisers of almost every class, and have taken no inconsiderable share in the evolution of the modern type when designing vessels for foreign governments; their list includes the small craft which "police" the distant islands of our great Empire; the "scouts" that serve upon the fleet of fighting units; the fast cruisers which patrol the great highways of commerce; and the powerful armoured cruisers which can oppose the commerce destroyer of the enemy, or even take their place in the line of battle with some chance of doing effective service. Here as in the case of battleships, it is instructive to glance at the influence on design resulting from the development of armour.

In the days of St. Vincent, the Nile and of Trafalgar, all ships, whether 3-deckers or frigates, could afford to dispense with protection, because the opposing guns were not of great penetrating power, the general aim being to capture prizes rather than to sink the enemy's ship. With the introduction of more powerful guns, armour was found necessary, but the enormous weight of effective broadsides so reduced the speed that difference of opinion prevailed as to the merit of the protection afforded by such armoured belt as the weight conditions made possible as against the advantage of the higher speed attained by the utilisation of the weight in augmenting the power of machinery. In 1889, there were built for the British Navy several belted cruisers known as the "Australia" class, one of which—the Aurora—was engined at Clydebank. Their narrow 10-in. belts of compound armour, extending for about two-thirds of the length of the vessel, conferred advantage; but the weight involved such a reduction in the size and power of the propelling machinery, that the speed was less by about two nautical miles per hour than it might otherwise have been.

This was demonstrated at the time by the design and construction at the Clydebank Works of a high-speed cruiser for the Spanish Navy. On a length of 318 ft. 6 in., and with a displacement of 5,000 tons, it was found possible to accommodate machinery of 12,000 indicated horse-power, which gave a speed to this Spanish cruiser of $20\frac{1}{2}$ knots, as compared with the 18 knots of the Aurora. The essential difference was that the one ship had an armoured broadside belt, the other depended for protection upon a deck varying in thickness from $3\frac{1}{4}$ in. to $4\frac{3}{4}$ in. which covered in the "vitals."

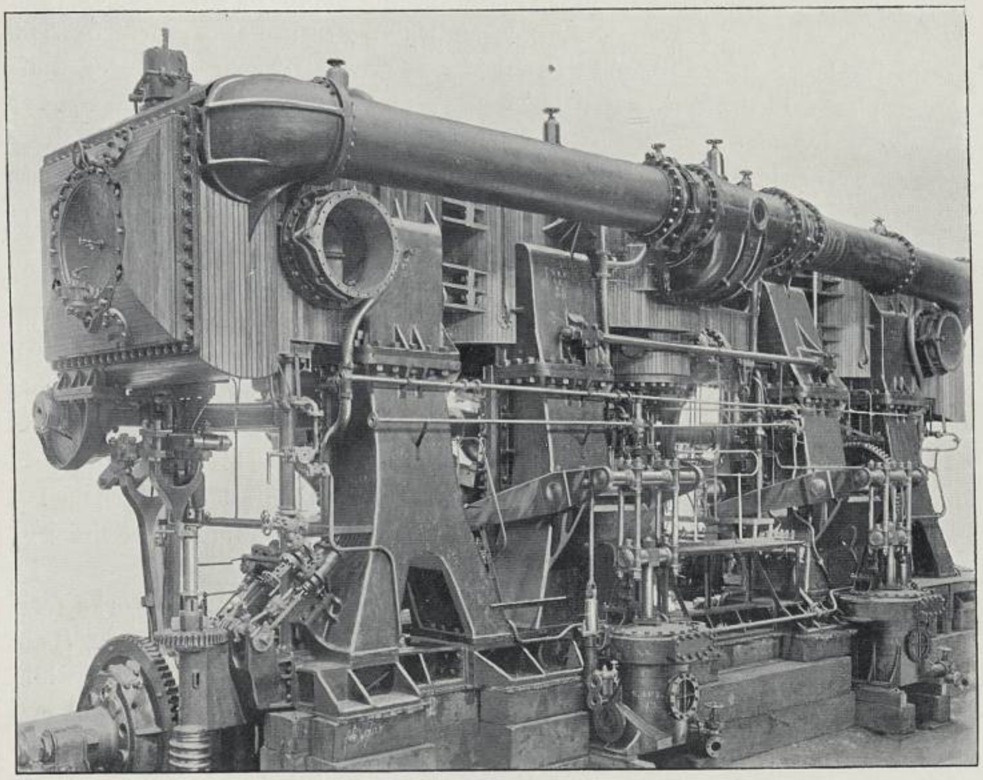
The gain in speed settled the day in favour of the protective deck type, the available quality of armour rendering broadside protection too costly in weight to admit of the thickness of the plating on the ship being sufficient to ward off attack by the high-power quick-firing guns then in use. Besides, foreign navies were favouring commerce-destroying cruisers in which reliance was placed on high speed and rapidity of gun fire rather than on armour protection. The British and other navies were reinforced by cruisers of this protective deck class, and quite a succession of vessels were launched at Clydebank, including the "Terrible," of 14,200 tons, which, with machinery of 25,000 indicated horse-power, developed a speed of 22¼ knots; and the "Europa" and



FRONT VIEW OF ONE SET OF ENGINES OF A MODERN CRUISER (30,000 INDICATED HORSE POWER).

"Ariadne" of 11,000 tons, which, having engines of 18,000 indicated horse-power, steamed at 20¾ knots. The protective deck in those vessels was formed with very considerable rise of arch, so that the real resistance presented to sidelong shots was greater than would be the case were the same thickness (6 in. to 4 in.) placed at right angles to the line of fire. These protective decks rise from a point on the broadside 7 ft. below the load line to about the water line in the centre, so that even with the ship rolling there is little chance of exposure of the part of the hull under this deck.

The design of cruisers, however, was completely changed by the introduction of the system of hardening armour, rendering 6-in. plates more than equal to the 10-in. compound armour of the former cruisers in resistance to penetration by shot. It became possible without a great demand on weight to effectually armour the broadside, and thus the later large cruisers have been so designed. The "Sutlej," and "Bacchante," built at the Clydebank Works for the British



BACK VIEW OF ENGINES OF ONE OF THE LARGEST AND SWIFTEST CRUISERS IN THE BRITISH NAVY.

Navy, resemble the "Europa" and "Ariadne," but differ in having 6 in. of hardened steel on the broadside for more than three-fifths of the length, and for a depth of 11 ft. 6 in., while at the forward end there is 2-in. nickel steel reinforcing the ordinary shell plating of the ship. Armoured bulkheads of 5-in. steel form something approximating the citadel of a battleship, while all the quick-firing guns are in separate casemates of 6-in. hardened steel. A further improvement was made in fitting these vessels with a bow-and stern-chasing gun of 9.2-in. calibre, in place of a pair of 6-in. guns fitted in the earlier ships of the "Europa" and "Ariadne" type. Without any increase in length, the defensive and offensive qualities were thus greatly improved, while the speed was slightly greater: 21 knots being attained with engines developing 21,000 horse-power, although the displacement of the ship was 12,000 tons.

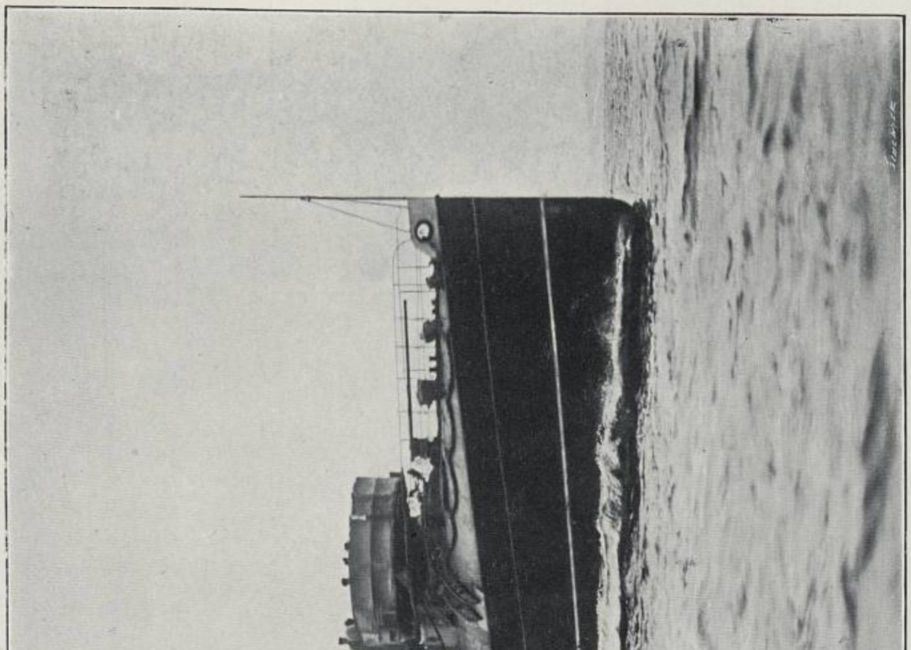
The "Leviathan," which marks the highest point of present-day success in cruiser work, includes the best characteristics of the "Terrible," but has a 6-in. armour belt for 320 ft. of her length, the depth of this armour being 11 ft. 6 in., while armoured bulkheads and casemates are also provided. This vessel is 500 ft. in length and 71 ft. beam, and, when drawing 26 ft. of water she displaces 14,100 tons. Her machinery, of 30,000 indicated horse-power, illustrated by views on the two preceding pages, are supplied with steam from 43 water-tube boilers, and on trial a speed of 23¼ knots was attained. With her pair of 9.2-in. guns, sixteen 6-in. quick-firers, and seventeen smaller guns, she undoubtedly constitutes a formidable addition to the British Fleet.

On the same lines, a smaller ship with proportionate fighting qualities has been adopted, and to this class the Clydebank works are contributing the "Antrim." The length is 450 ft., the displacement 10,200 tons, and with engines of 22,000 horse-power a speed of 23 knots is to be realised. The side belt is of 6-in. hardened steel, the bow- and stern-chasing guns are of 7.5 in. calibre, and there are five 6-in. guns on each broadside. This class of ship is much superior to the protective deck cruiser of ten years ago, which had a speed of only 20 knots, and had guns less effective in rapidity of fire and striking energy.

In the development of such armoured cruisers, the Clydebank Works took an early part. In their Japanese cruiser "Chiyoda," built in 1889, there was side armour of 4½ in. thick to keep out small explosive shells, while the protective deck was of chrome steel, 1 in. thick; in this arrangement one finds a suggestion of the modern armoured cruiser. But it is not possible within limited space to describe all the many varied types of war-vessels built at the Clydebank Works, so that we must content ourselves with a passing reference to second-class cruisers and torpedo-boat destroyers. Under the Naval Defence Act, there were built the "Thetis," "Terpsichore," and "Tribune," of 3,400 tons, which, with engines developing 9,000 indicated horse-power, attained a speed of 20 knots. Two cruisers of similar type were also built for the Australian Fleet, the "Ringarooma" and the "Tauranga," of 19 knots speed. Seven "scout" cruisers were completed within eighteen months in 1884-5, and continue to do effective duty. Seven gun-boats were built for Spain, in connection with the Cuban revolt of 1895, within three months of the signing of the order.

In the evolution of the modern torpedo craft, the works have likewise taken

PLATE XXVII.



A 32-Knot Torpedo-Boat Destroyer.

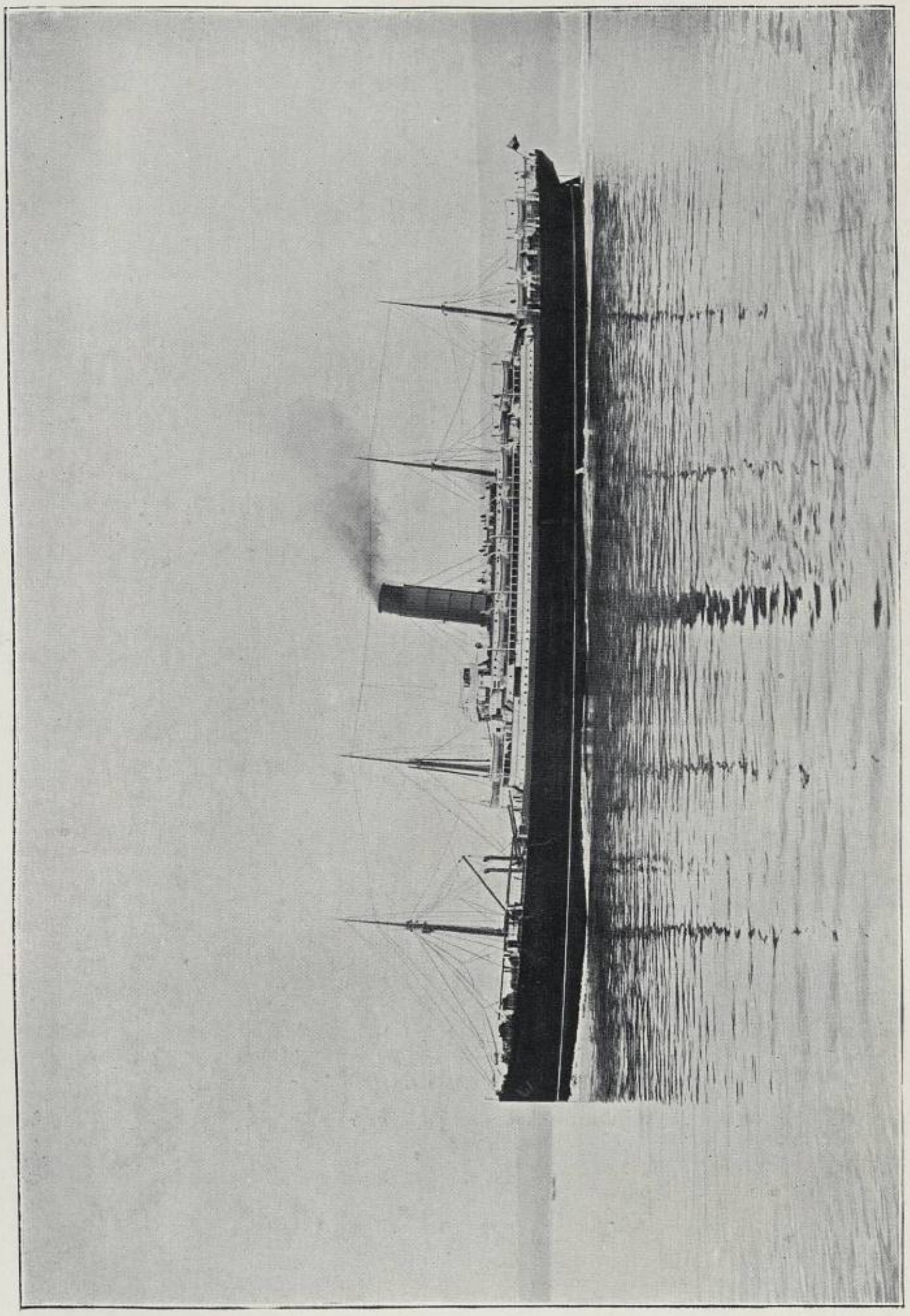
an important part. In 1886 the torpedo boat "Wiborg" was constructed for the Russian Navy. The "Destructor," built in the same year for the Spanish Navy, was intended primarily for destroying torpedo boats, and the speed of 21½ knots was developed with the use of triple-expansion engines of 3,500 indicated horse-power. The success of this vessel encouraged the management to enter confidently upon the construction of later torpedo-boat destroyers. The first three easily developed their speed of 27 knots with 4,000 indicated horse-power; while since then eight vessels of 30 knots and one of 32 knots have been built for the British Navy.

Although not a warship in the usual acceptance of the word, the twin-screw steamer "Moskva" built for the Russian Volunteer Fleet in 1898, may be referred to in this chapter, because, while used for merchant service between the Black Sea and the Russian ports in the Far East during peace time, she has been built, like all vessels of the fleet, so that she can be utilised for cruiser duty in the event of war. She is of 7,300 tons gross, her length over all being 508 ft. State rooms have been provided for 74 first-class and 50 third-class passengers or officers, on the upper and main decks respectively; while on the main and lower decks, 1,536 emigrants or troops may be carried. She is a smart-looking vessel, and her speed of 20 knots, maintained on a long-distance trial, when the twin screw engines were developing 15,500 indicated horse-power, will enable her to do good service in war. Arrangements have been made for carrying eight guns of 4¾-in. calibre, and an equal number of 3-in. weapons. The magazines are arranged under the water-line, with hoists for serving the guns; the coal bunkers are fitted alongside the machinery space, and afford protection at the water-line against gunfire. Very large hospitals are arranged; heavy derricks may enable the ship, with her large engine shop, to be of service in repairing small craft, when associated with a fighting fleet; and in the destruction of commerce she, acting separately, may do considerable damage with her rapid-firing guns. She has bunker capacity for 1,600 tons of coal, which, at full speed, gives her a radius of action of 2,700 sea miles.

NOTABLE MERCHANT VESSELS BUILT AT THE CLYDEBANK WORKS.

THE Clydebank Works began with engineering in 1846, and the shipbuilding yard was laid down in 1851; but operations were not commenced on the site now occupied until 1873, the marine engineering branch being removed from Glasgow ten years later. Almost from the first the establishment achieved a prominent place, largely by its success in the production of Atlantic liners; thus the annals contain many creditable entries associated with such historical vessels as the Cunard liner "Russia" of 1867—the first of the screw steamers of that fleet, the "Bothnia" of 1874, the "Servia," the largest ship in 1881, the "Aurania" which participated in the first of the high-speed contests engaged in by a succession of Clydebank steamers, including the "America," "New York," "Paris," and others. But there is no need to enlarge upon the creative ability of the establishment so far as high-speed steamships are concerned, in view of what we have written on 21-knot, 22-knot, and 23-knot warships, because the attainment of speed in a warship involves even more difficult problems than those associated with high-speed merchantmen. There is, first, the necessity of minimising the length of a warship, so as to reduce as far as possible the target area presented to the guns of an enemy, and length is one of the dimensions conducive to high speed; similarly, the weight of naval machinery must be cut down to the lowest limit, in view of the equally important claims of defensive armour and of the guns that give the fighting power. Thus, in modern cruisers the machinery weight is so reduced that 12 horse-power must be developed for each ton allowed, whereas in modern high-speed merchant steamers the ratio of power to weight is only from 6 to 7 horse-power per ton. Moreover, cruiser machinery has to be accommodated within about 75 per cent. of the superficial area allowed for the engines and boilers of merchant vessels. It is thus a comparatively simple matter to build a 23-knot or 24-knot merchant steamer where speed is the first consideration, alike as regards weight and space available.

The latest ship completed for the Cunard line, and apart from the work in hand, is the "Saxonia," illustrated in the engraving opposite, and combining



The Cunard Liner "Saxonia."

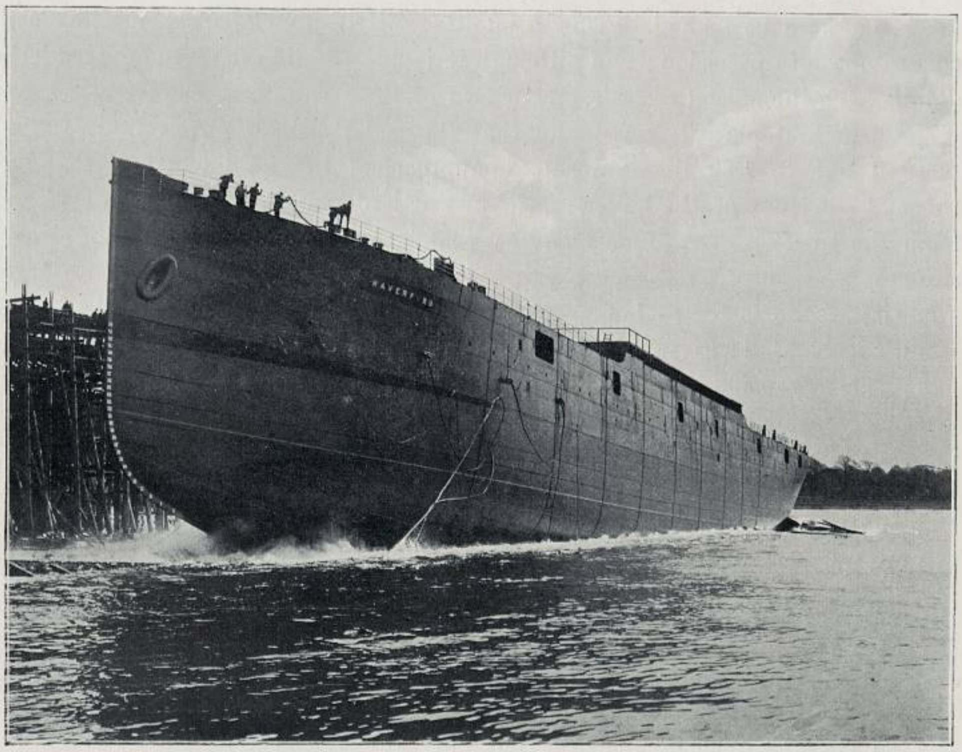
passenger and cargo carrying, and with high economy. The "Saxonia," is 600 ft. long, 13,960 tons gross register, and accommodates 188 first, 200 second, and 428 third-class passengers, and has a cargo measurement capacity of 20,000 tons, and a dead-weight capacity of 12,700 tons. This vessel has proved exceptionally economical; we have results ascertained by a committee of engineering experts, appointed by the British Admiralty to make exhaustive tests as to the efficiency of her boilers and machinery, for comparison with the results attained in warships. The cruisers tried for comparison were not built at Clydebank, and need not here be named. This committee fitted up elaborate appliances to ensure absolute precision; and although it is not possible here to quote all the details from the official records, one or two of the results may be given.

In the first place, it was found that the coal consumption in the "Saxonia" worked out to 1.29 lb.—a result unapproached in the naval service. The thermal efficiency of the boilers, "the proportion of heat or energy developed from the fuel," proved to be 82.3 per cent., whereas in the case of the Naval ships it was only 65 to 68 per cent. The boilers, too, supplied a larger quantity of steam for each pound of coal burned—12.33 lb. as compared with from 9½ lb. to 11 lb. in the naval ships. The engines, which are of the quadruple expansion type, as designed at Clydebank, also gave a high efficiency: each horse-power was developed from 13.47 lb. of steam, whereas the experience in the warships was that 14 lb. to 16 lb. of steam was necessary at full power; and thus the thermal efficiency of the main engines comes out at 17.2 per cent., as compared with 13 to 15 per cent. in the naval ships.

As an indication also of the satisfactory character of the workmanship, it may be said that the water lost by the boilers and machinery in this vessel, developing about 10,000 horse-power, was only 2.76 tons per hour: a fact which proves that there was practically no leakage. These results, which are the outcome of most careful independent investigation by highly experienced engineers, at once attest not only the satisfactory character of the design, but of the work carried out at Clydebank. For we have here a ship which carries a large population of passengers and heavy cargo, for an expenditure in fuel equal to 3¾ lb. per hundred ton-miles.

This is a most popular type of vessel at the present time, attaining a moderate speed with high economy, and yielding a large revenue alike from passengers and cargo. Four such vessels were constructed for the International Navigation Company's service between New York and Antwerp. The engraving on the next page shows one of these vessels, the "Haverford," being launched. These steamers take 11,000 tons of cargo, as well as 342 first, 194 second, and 626 third-class passengers, travel at a speed of 16 knots, which is enough for most purposes; and yet, by reason of the adoption of the company's Ellis and Eaves system of induced heated draught, and of Serve tubes in the boilers, this satisfactory speed is got with a very low fuel consumption.

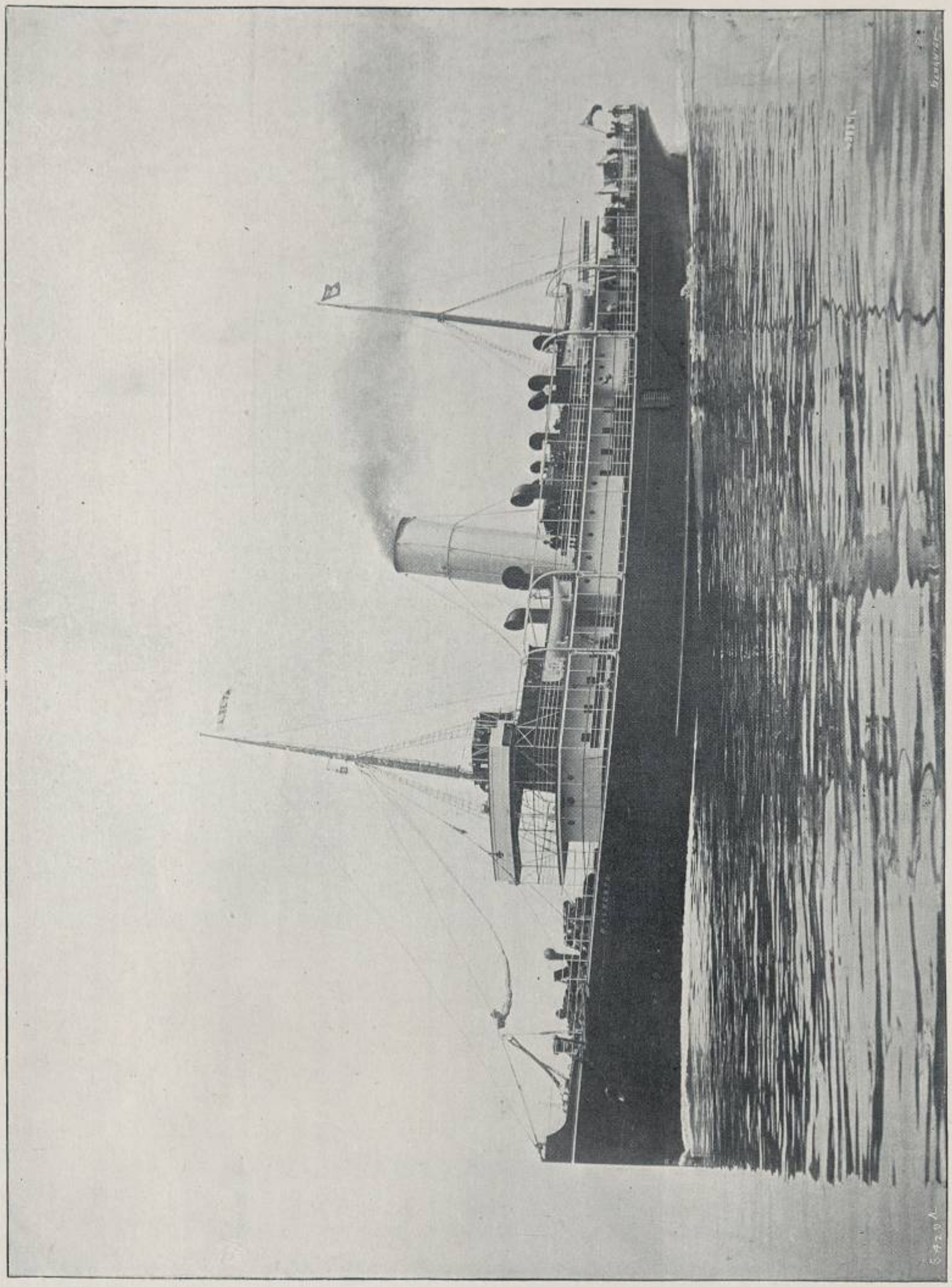
In addition to this economy, there is ensured absolute safety so far as this can be realised by the minute subdivision of the interior, the duplication of all machinery, and the inclusion of the shafting within the ship structure for facility of inspection. As to comfort, the arrangements are equal to



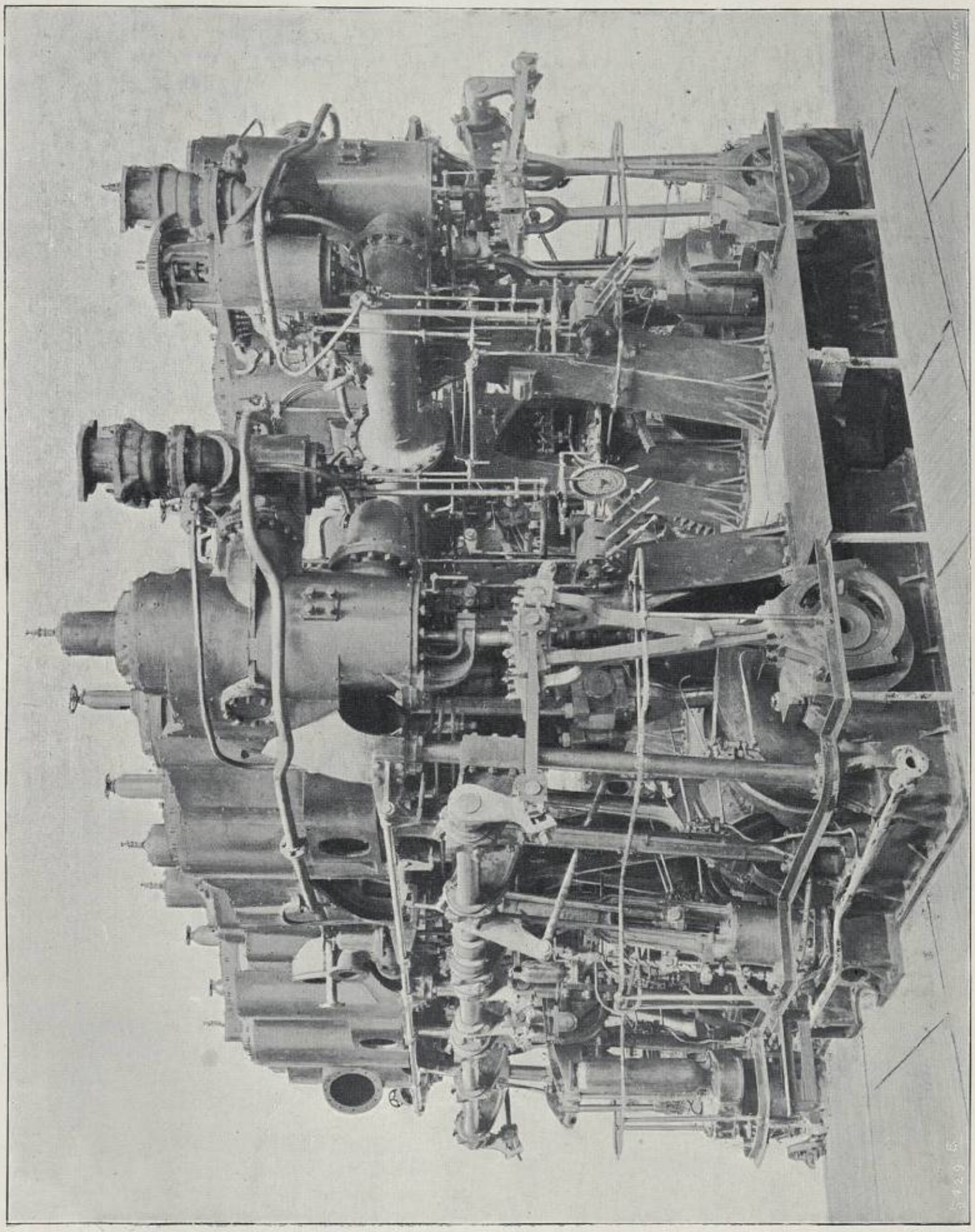
LAUNCH OF THE "HAVERFORD."

those on the best of modern ships. The dining-room, to seat nearly 200 passengers, occupies the full width of the ship in the centre of its length, and is decorated with oil paintings forming panels, relieved with most beautiful carving. The drawing-room, on the promenade deck, is of large size, 36 ft. wide, and painted in white enamel with panels of striped silk, the upholstery being also of silk; the large square windows are fitted with Cloisonné glass panels, beautiful in their effect by night as well as by day. The smoking room offers sumptuous lounges; the woodwork is of fumed American oak upholstered in red

PLATE XXIX.



THE LONDON AND SOUTH-WESTERN RAILWAY COMPANY'S CHANNEL ISLAND STEAMER "ALBERTA."

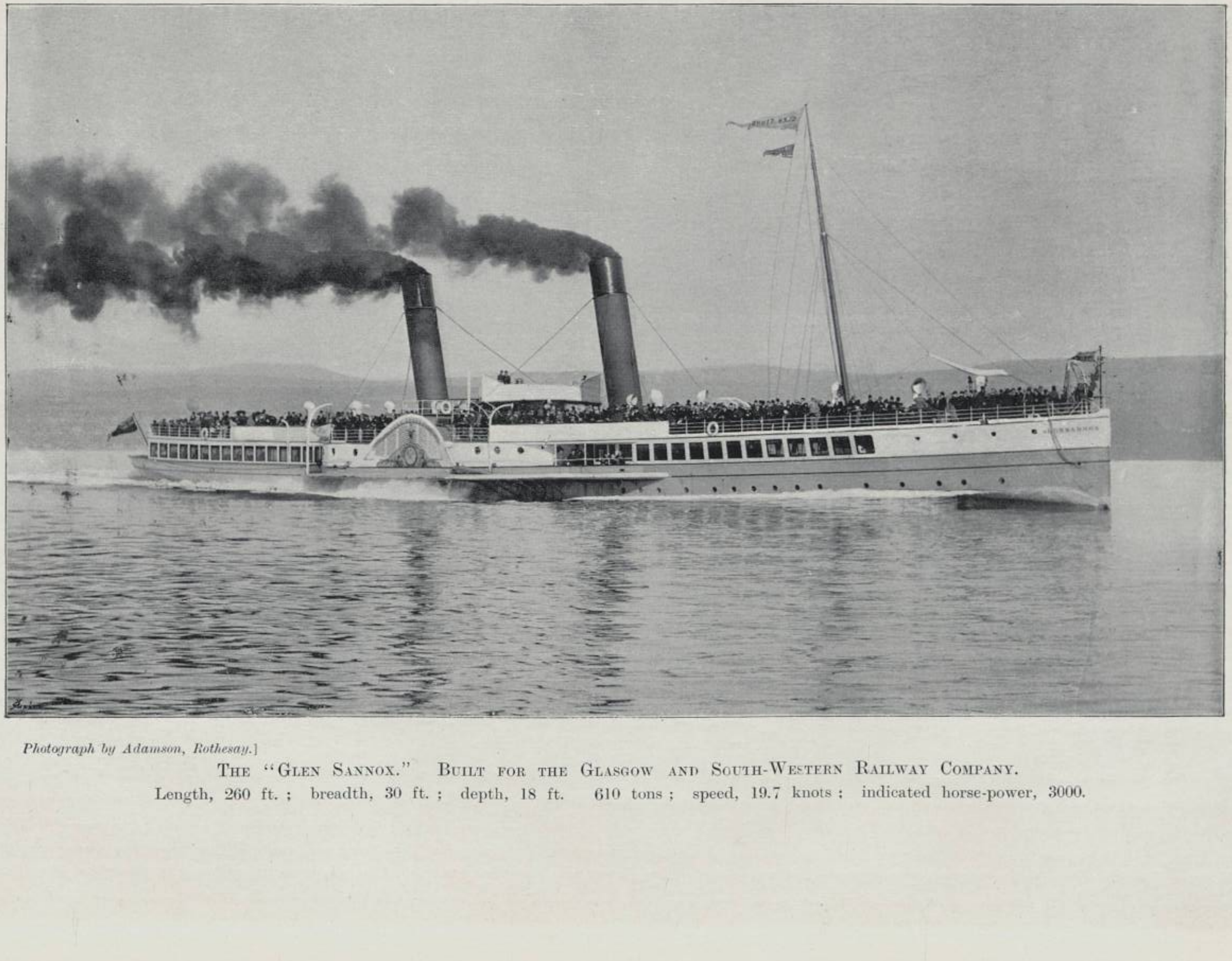


TWIN-SCREW ENGINES OF THE CHANNEL STEAMER 'ALBERTA.'

leather, while the wall panelling has oil paintings representing scenes in the towns of the Low Countries. There are a large number of state-rooms for single passengers, and many family cabins ; so that it will be seen that so far as comfort is concerned, such vessels offer the same attractions as the expensive high-speed liners.

Many of our large companies have had, at one time or other, additions to their fleets from the Clydebank Works—the P. and O., the Hamburg-American, the Royal Mail, the Union Company of South Africa, as well as the International, American, and Red Star lines ; but it is scarcely necessary to enter into details regarding the successes of all such vessels. The latest vessels constructed for the South Atlantic were of 6,060 tons gross register ; and although they had not the speed of the North Atlantic liners, they offered the same luxury for the 214 first and 36 second-class passengers carried. The New York liners in twenty-five years have increased their speed from 15½ to 23½ knots; but commercial considerations operate against a corresponding advance in steamers trading to South American or South African ports. The number of passengers is yet comparatively few, and the necessity of depending upon freight for revenue determines the type of steamer, while the long distance between coaling ports also encourages the minimising of fuel consumption. Thus a vessel of the type of the "Saxonia," burning 7½ cwt. of coal per mile steamed, is for such trade immensely superior to the express liner consuming about a ton of coal per mile steamed. Such high speed on the South Atlantic voyages would not permit of any cargo being carried, and would necessitate coal-bunkers having a capacity of 6,000 tons. There has, however, been progress in these long voyage passenger ship, for in twenty-five years they have increased in tonnage by about 100 per cent., in cargo space by over 150 per cent., and the bunker capacity has also been doubled. At the same time there has been an increase in speed, so that the voyage to the River Plate, with calls at Spain, Portugal, and Brazilian ports, has been reduced from twenty-eight to a little over twenty days ; the trip to the West Indies from thirteen to eleven days, and to the Cape from sixteen to about twelve days.

In recent years, a great change has taken place in the design of Channel steamers. Although the screw propeller was readily adopted in the 'fifties for coasting steamers, the side-paddle wheel was still preferred where high speed was concerned, because, with the limited draught necessary for the shallow waters of most of the Channel ports, difficulty was involved in the adoption of the screw propeller, which requires to be deeply immersed to insure efficiency. The solution came with the adoption of twin-screws and the increased number of revolutions of the modern engine : this the Clydebank



Photograph by Adamson, Rothesay.]

The "Glen Sannox." Built for the Glasgow and South-Western Railway Company.

Length, 260 ft.; breadth, 30 ft.; depth, 18 ft. 610 tons; speed, 19.7 knots; indicated horse-power, 3000.

Works were among the first to recognise. The two factors named enabled the diameter of the propellers to be greatly reduced, so that their efficiency with limited immersion was increased, Most beneficial results have followed. There is not, for instance, the same reduction in speed in rough weather as with side paddles.

Amongst the large number of such high-speed twin-screw Channel steamers built at Clydebank Works, reference may be made to the series of successful ships built for the London and South Western Railway Company, beginning with the "Frederica" in 1891: the latest, the "Alberta," was built in 1900. The vessel, illustrated on Plates XXIX. and XXX., is 270 ft. in length, 35 ft. 6 in. in breadth, and 22 ft. 9 in. in depth, the gross tonnage being 1250. There are 11 water-tight bulkheads, dividing the hull into twelve compartments; and the whole of the internal arrangements are such as to insure the greatest comfort for the 130 first-class passengers, and 50 second-class passengers, dining-saloon, drawing-room, and the other luxuries of the large Atlantic liners being here reproduced for the comfort of those travelling by day or by night. The trip from Southampton to Havre occupies six hours, as compared with the eight and three-quarter hours of the ships of ten years ago. The "Alberta" has made the passage in a little more than five and a-quarter hours the speed of 20 knots being realised with about 5,000 indicated horse-power.

In paddle steamers the Clydebank Works have a splendid record. Amongst the most popular of such vessels are the "Iona," "Grenadier," and "Columba," the last probably the best-known river steamer in the world; and although she is now many years old, she still carries her 2,000 passengers every day of the season, at a speed of 18 knots, with a steadiness, comfort, and economy not equalled by many of the modern boats. Another of the typical steamers is the "Glen Sannox," built, with many other paddle steamers in recent years, for the Glasgow and South Western Company. She is 260 ft. long, and steams 19.7 knots. Several steamers have also been built for the Caledonian Railway Company, for services on the estuary of the Clyde.

A reference may be made to the long series of yachts built, and remarkable alike for their speed and for their internal decorations and comforts. As typical we take the "Mayflower," built for an American yachtsman. It is no mere play of words to say that in the design and construction of this yacht neither pains nor expense were spared to make her a credit to her designers and builders, and a constant source of satisfaction to all fortunate enough to spend any time on board. The length of the "Mayflower" is 275 ft. on the water-line and 321 ft. from fiddle-head to taffrail; the breadth is 36 ft. 6 in., and the depth from the bridge deck 30 ft.; the registered tonnage being 1780 tons. As a brigantine she carries a great stretch of canvas, but for most purposes will

The Steam Yacht "Mayflower."

depend on her twin engines, balanced to reduce vibration, and capable under easy working of developing 4,650 indicated horse-power, to give a speed of 16¼ knots. Her economy is such that she may travel for 2,000 sea-miles at full speed, without re-coaling, or for 6,300 sea-miles at a speed of 12 knots.

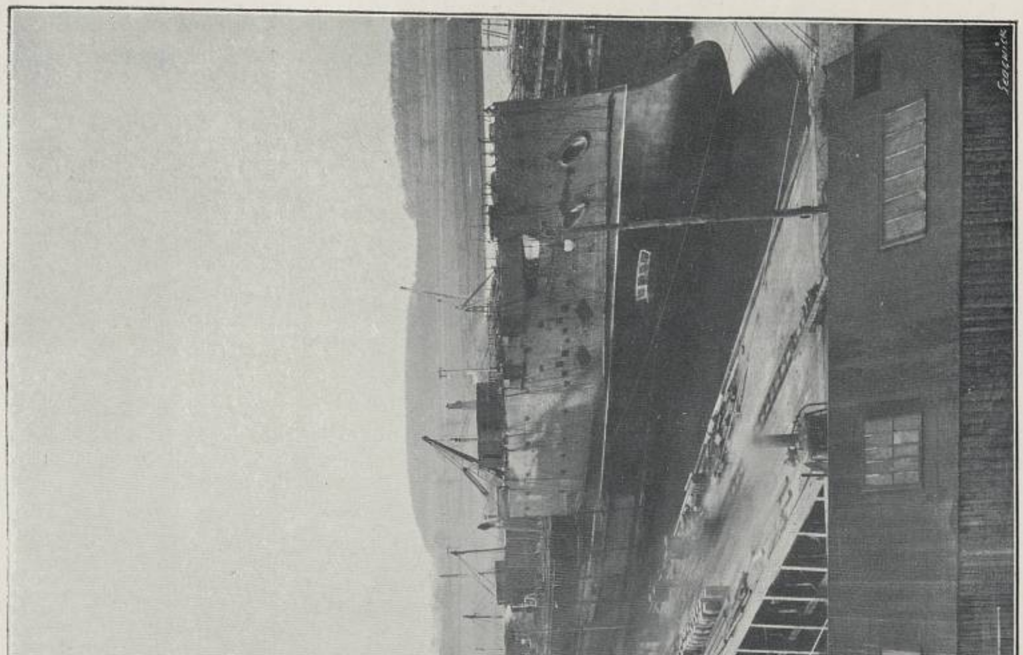
We may describe two of the rooms to convey some idea of the work carried out in such vessels, and also in some modern passenger steamers. The first is a beautiful palm-decked reception-room, arranged around the engine casing; the carved oaken moulding and scrolls being distinctly French in feeling. In the treatment of the engine casings, one might almost say that an unfortunate necessity has become an unquestionable virtue: the otherwise ugly trunk being converted into a beautiful gallery, filled with large clear plate-glass windows, in richly-wrought iron and brass work, which give pleasing light effects, and, when opened, afford the owner's guests an opportunity of watching the working of the engines. The dining-room measures 36 ft. by 22 ft.; the panelling is of beautifully-carved oak of antique design and dull finish, the style being that of the Louis XIV. period. There are ten 14 in. sidelights and two skylights, while a full suggestion of comfort is suggested by the fire in a cosy recessed hearth at the forward end. Twenty-four persons can dine in this apartment. The drawing-room, an apartment 21 ft. long and 32 ft. broad, has also a fireplace, a piano, and card and writing tables; while comfortable chairs and lounges are disposed in a manner more suggestive of a Mayfair mansion than of a ship's saloon. The decorative work is executed in oak, carved and painted white in Louis XVI. style. The decks are 9 ft. apart, and the great headroom thus afforded adds materially to the handsome appearance of all of these public saloons.

THE CLYDEBANK SHIPBUILDING AND ENGINEERING WORKS.

THE Clydebank shipbuilding and engineering establishment of Messrs. John Brown and Co., Limited, is not only one of the largest in the kingdom, covering as it does an area of 80 acres, but it is equipped with the most varied of tools for the production, without sub-contracting, of every type of ship, from the superbly-furnished yacht down to the utilitarian "tramp-steamer" carrying its thousands of tons of cargo; from the "ocean greyhound," of which a large number have been produced in quick succession at the works to the smart, swift Channel steamer; and from great leviathan ironclad warships to high-speed torpedo-boat destroyers.

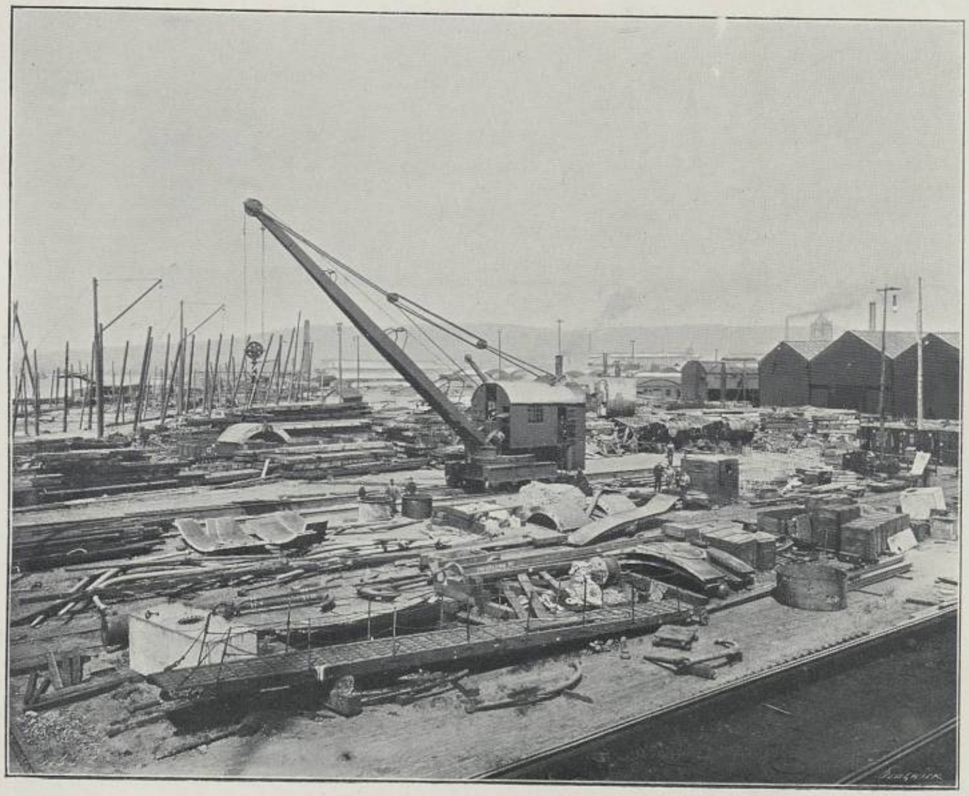
Many shipbuilding firms are content to construct the more important items of the ship, depending largely upon outside establishments where particular items of work are specialised. The principal commendation for this practice is that there is less capital involved in the plant, consequently less loss incurred during those periods of depression which recur regularly. The Clydebank establishment, on the other hand, is laid out with the object of doing the maximum of work upon any ship, purchasing only from outside sources what may be termed "proprietary" items, where inventions are largely involved. The advantage in such case is, that there is not only economy in production under the one management, but that there is less likelihood of the separate items being delivered out of time, and therefore interfering with the consecutive progress of the building of the ship. This is almost a necessity in large important ships, especially naval vessels, where small changes in design are introduced frequently. The necessity for maintaining the works at their fullest producing capacity is, of course, increasingly important, and here the whole question of capitalisation and finance is involved; but we do not propose to enter upon that here; our object in pointing to this distinctive characteristic of the Clydebank works is simply to indicate that this desideratum for prompt delivery is fully realised.

The establishment, which is situated on the north bank of the River Clyde, about seven miles from Glasgow Harbour, was originally laid out in 1873,



FITTING-OUT BASIN WITH BATTLESHIP, ARMOURED CRUISER, AND MERCHANT STEAMER.

but the traditions of the works date back to 1846. The first plan was conceived not only upon a liberal scale so far as "elbow-room" is concerned, but with due appreciation of the possibilities of extension, a large area of ground being reserved to the west of the original works; and since Messrs. John Brown and Co., Limited, took over the establishment, about four years ago, this vacant ground has been incorporated into the works, and new machine-shops



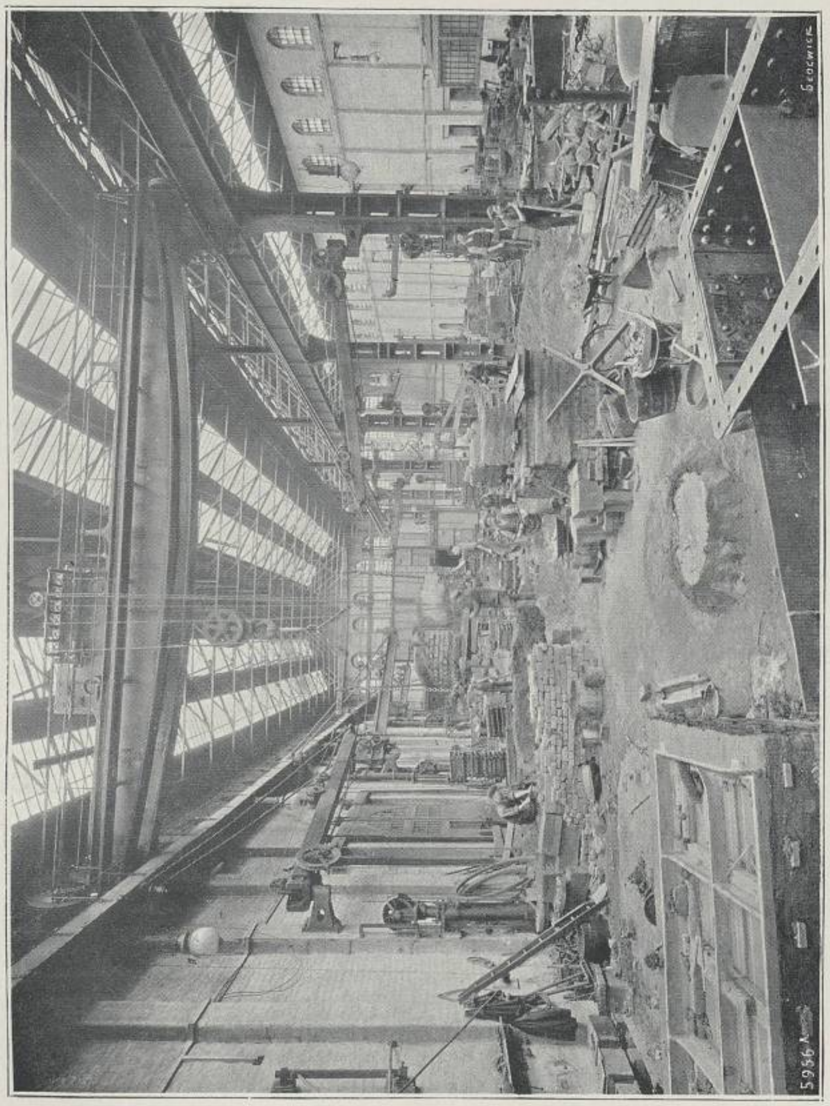
View in West Yard.

and building berths have been laid out, part of this new section being illustrated above. The general arrangement, illustrated on Plate XXIV., facing page 69, includes now six shipbuilding berths in the east yard, and several in the west yard; while between these two series of ship-constructing slips there is a large dock for the fitting out of the vessels after they have been launched. This dock is illustrated on the engraving, Plate XXXI., in which are to be seen a battleship, an armoured cruiser, a large merchant ship and small craft. Angle-iron departments, beam and platers' screeve boards, furnaces and machine-tool shops, are arranged at the head of each series of berths. The carpenters', joiners', cabinet-makers', polishing and wood-workers' departments generally are in the east yard, contiguous to both the dock and building slips, with plumbers' and other auxiliary sections close by the docks. In both sections of the works, too, there are smithies, forges, and light-iron

General Offices and Stackyard for Plates, &c.

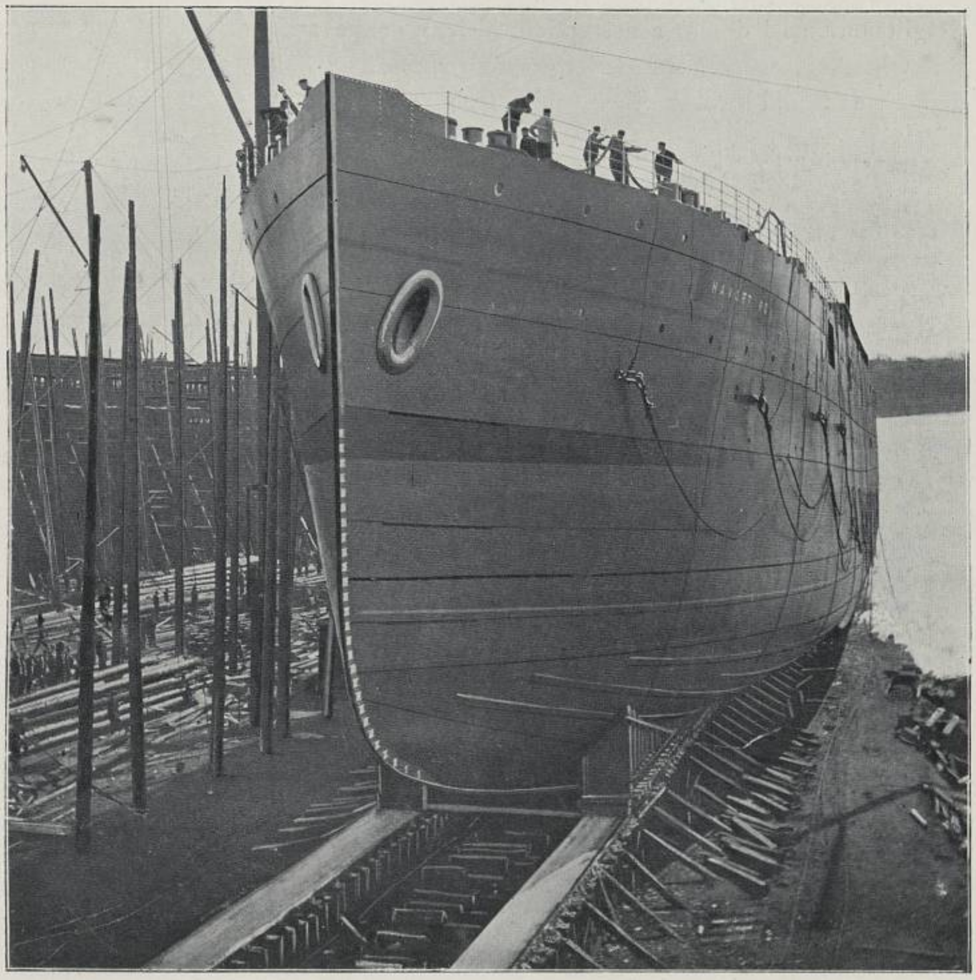
shops, and the other departments associated with shipbuilding. The engineering and boiler works are placed at the end of the fitting-out dock, being thus not only close to the vessels when machinery is being fitted on board, but equidistant from the two series of shipbuilding berths. It thus becomes a simple matter to convey by the yard railway the machinery and boilers in parts to any ship while on the slip or in the dock. The engineering section includes also a large smithy, as well as a brass foundry, copper shops, galvanising department, &c. The brass foundry is illustrated by Plate XXXII., facing this page.

PLATE XXXII.



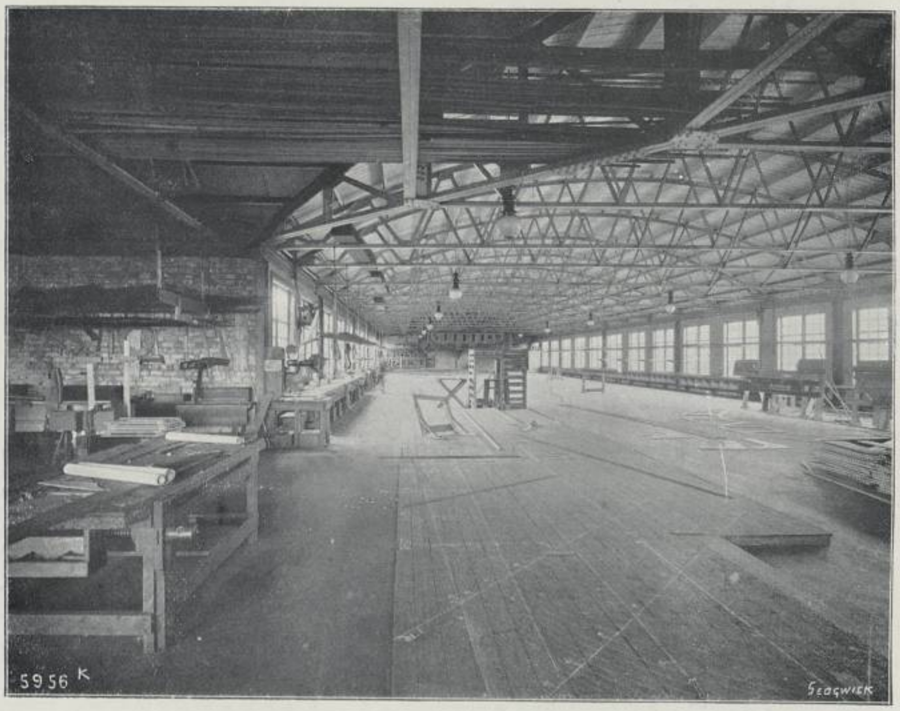
Brass Foundry.

In describing the works it may be more interesting to review the departments and plant in the order of their use and importance in the building of the ship, rather than to adopt an itinerary method; and it may be said at the outset that the works have a frontage to the River Clyde of 3,200 ft.,



VIEW AT THE BUILDING BERTHS.

and that the various building berths have a length varying from 450 ft. to over 800 ft. Several of them have been constructed with the view of supporting the concentrated weight due to the modern armoured battleship and cruiser, the weight per square foot of surface carried by the launching ways amounting in some cases to 3 tons. As regards the waterway, no difficulty has been experienced in sending afloat the immense liners, many of them of historical importance, which have already gone forth from the works; the lines of the building berths in the east yard converge upon the centre of the River Cart, which flows into the River Clyde almost directly opposite the shipbuilding works. The berths, as shown in the illustration on page 91, are equipped with hydraulic 4-ton jib cranes at frequent intervals, for lifting weights on board during construction. There are several portable 10-ton cranes throughout the works. In the large quadrangle immediately inside the entrance, in both east and west sections, where ship-plates, angles, &c., are stored, as



MOULDING LOFT.

shown in the illustration on page 90, there are 10-ton portable cranes for lifting the material on to the racks, or on to the trucks for conveyance to the platers' shed, &c., which again stand between this plate stack-yard and the building berths. To facilitate the conveyance of material, there are in the works five miles of narrow gauge, and six miles of standard gauge railway, in direct connection with both the Caledonian and the North British Companies' systems.

Dealing with the separate departments, one naturally commences with the moulding loft, where the work of construction is begun in the case of all ships. The engraving given above of this department at once establishes not

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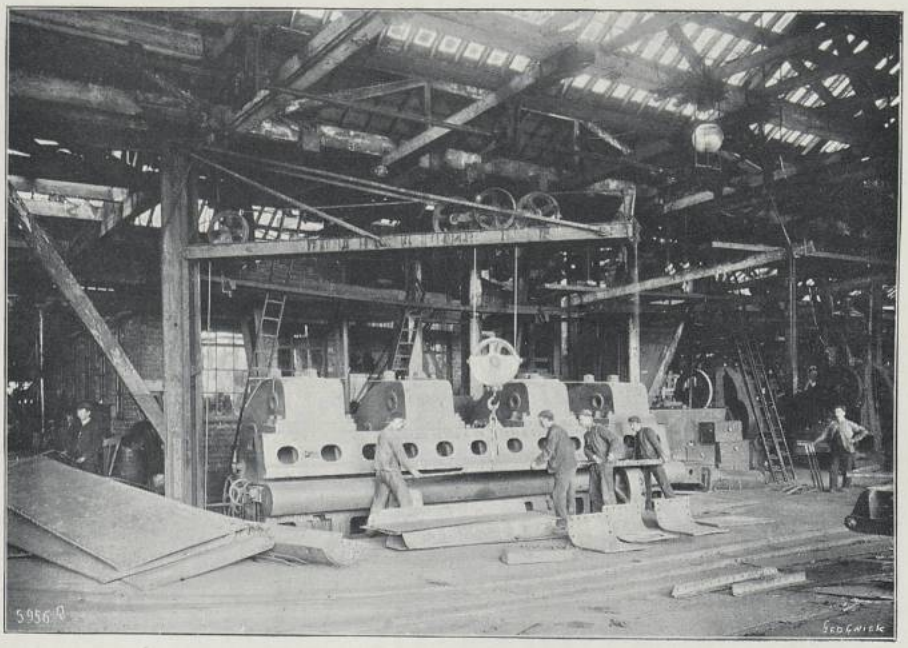
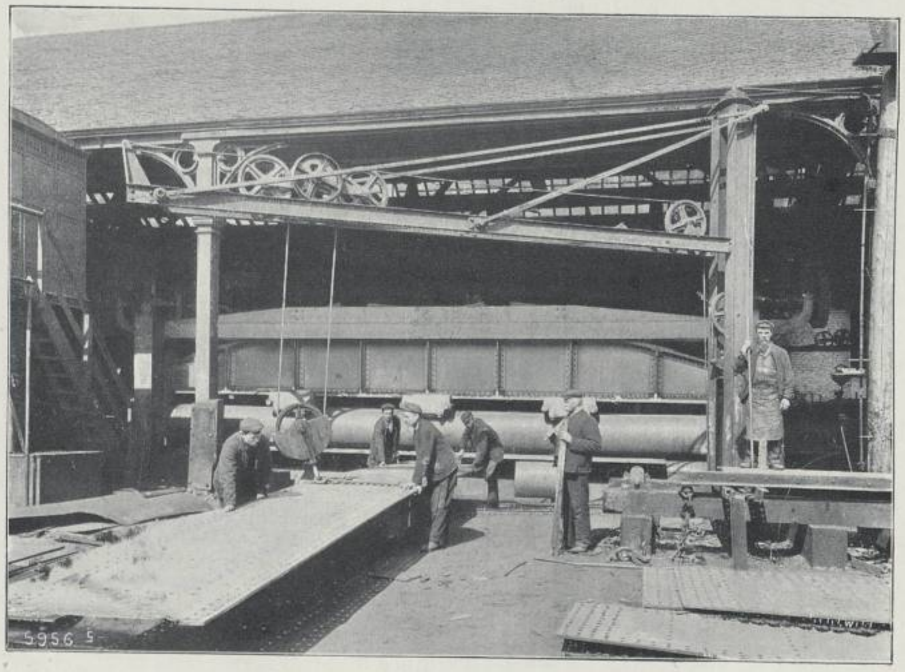
PLATE XXXIII.



Hydraulic Flanging Machine.



35 Ft. Plate-Bending Rolls.

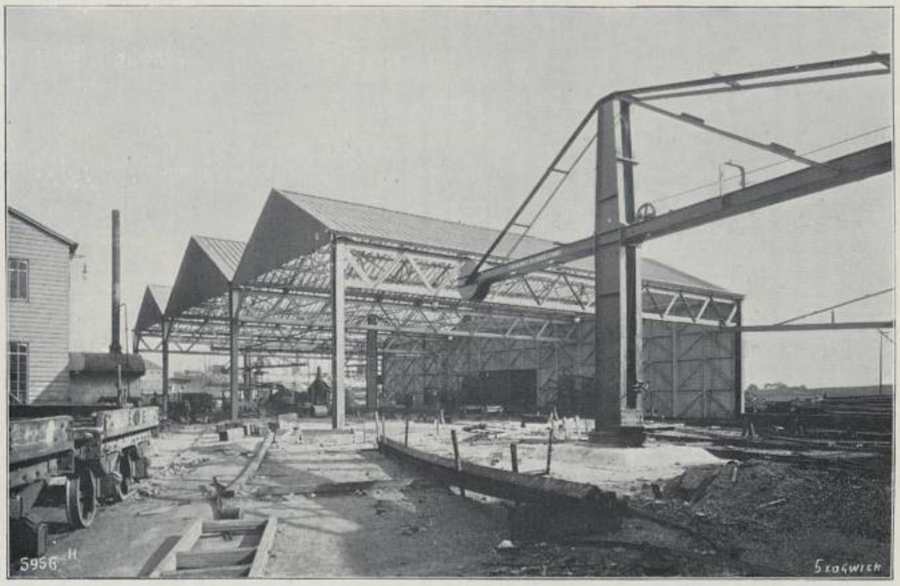
only the size of the loft, but the profusion of daylight admitted. The length of the loft is 250 ft. and its width is 55 ft.; the roof is of light steel principals with corrugated iron on the purlins, and the sides are entirely of glazing.

In the frame-bending shop in the eastern yard, about 250 ft. square, there are three angle-iron furnaces, each 61 ft. long, with a large floor area of cast-iron blocks for setting the frames, as well as screeve boards for laying them out. There are alongside, also under cover, the usual equipment of punches and shears, with a special hydraulic machine for cutting off the ends of channel bars, and a machine for planing both edges of angles at one operation. A specially noteworthy machine is that for setting the flanges of angle-iron frames to the required bevel.

In the east section of the works the ironworkers' machine shed is 350 ft. long by 150 ft. wide, being in three bays, with two lines of shafting for driving the machines. This shed contains very heavy machine tools; there are about thirty punching and shearing machines, ranging up to tools which sheer $1\frac{1}{2}$-in. plates and punch $1\frac{1}{2}$-in. holes in the same thickness, while the gap is 42 in. enabling plates 7 ft. wide to be dealt with. Of special interest are two double punching machines, of the cam and lever pattern, with twin-punches at each side. There are two hydraulic manhole punches, capable of working holes of 36 in. by 22 in., while two other machines of a kindred nature for cutting elliptical and circular manholes are worked with automatic feed. Irregularities in the plates, angles, and channel framing of warships, due to splinter gratings in the air-hatches of protective decks and to other causes, have made necessary the use of band saws for cutting such sections, instead of the ordinary hydraulic shears; and two powerful saws of this type are in constant use at Clydebank, in addition to the ordinary circular saws, of which there are four.

There is an immense hydraulic flanging machine, which is illustrated on Plate XXXIII., facing this page, for setting plates for the keel and garboard strakes, as well as for stiffening flanges in bulkheads. It is capable of dealing with plates of any length, being open-ended, but the machine itself is 25 ft. long.

The tools in the platers' shed, as a rule, are designed to work plates up to 35 ft. long and 7 ft. wide. This is the length of the bending rolls, shown on Plate XXXIII. These rolls deal with plates up to $1\frac{1}{2}$ in. thick, the top roller, a solid steel forging, weighing 45 tons. There are two other sets of rolls of slightly less power in this department. The planing machines number five, and are all of considerable capacity. For straightening plates there is a mangle with solid steel rollers, taking plates 6 ft. wide and $\frac{3}{4}$ in. thick. There are two plate-cutting machines for light work, as, for instance, torpedo-boat destroyers' and river steamers' shell-plating; the machine has two revolving steel discs, the edges of which slightly overlap, so that when a plate is inserted between the discs it is cut to the required form ; the machine is capable of cutting the plates in a curve of very small radius. The shop is well equipped with radial drills, three of which have each three jibs, the arcs described by them intersecting, so that a plate 35 ft. in length may be drilled without re-setting. There are three sets of countersinking machines each with two radial arms and roller tables. The majority of the tools in this shop are worked from shafting driven by a steam engine situated close to the ironworkers' department and, described on pages 109 and 110.



BEAM-BENDING SHED IN WEST YARD.

In the west yard new ironworkers' machine-shops have been and are now being erected, and in some respects they will excel, not only in their arrangement but also in their equipment, those which we have just described. The engraving on this page illustrates the beam-bending shed being built : the roof is entirely of glass. This shed is 150 ft. long by 90 ft. broad, and in it there are now horizontal punching and beam-bending machines, vertical punching and shearing machines, steel circular saws, hydraulic channel cutters, &c., all operated by electric motors. Throughout this shed there are five hydraulic cantilever cranes, with jibs 42 ft. long, and a lifting power in each case of 5 tons. The cranes are so placed that the beams can be taken up at the delivery end of the shop and passed through the machines to the other end, close to the shipbuilding berths, without any other system of transport.

PLATE XXXIV.

Shipyard Smithy.

Shipyard General Store.

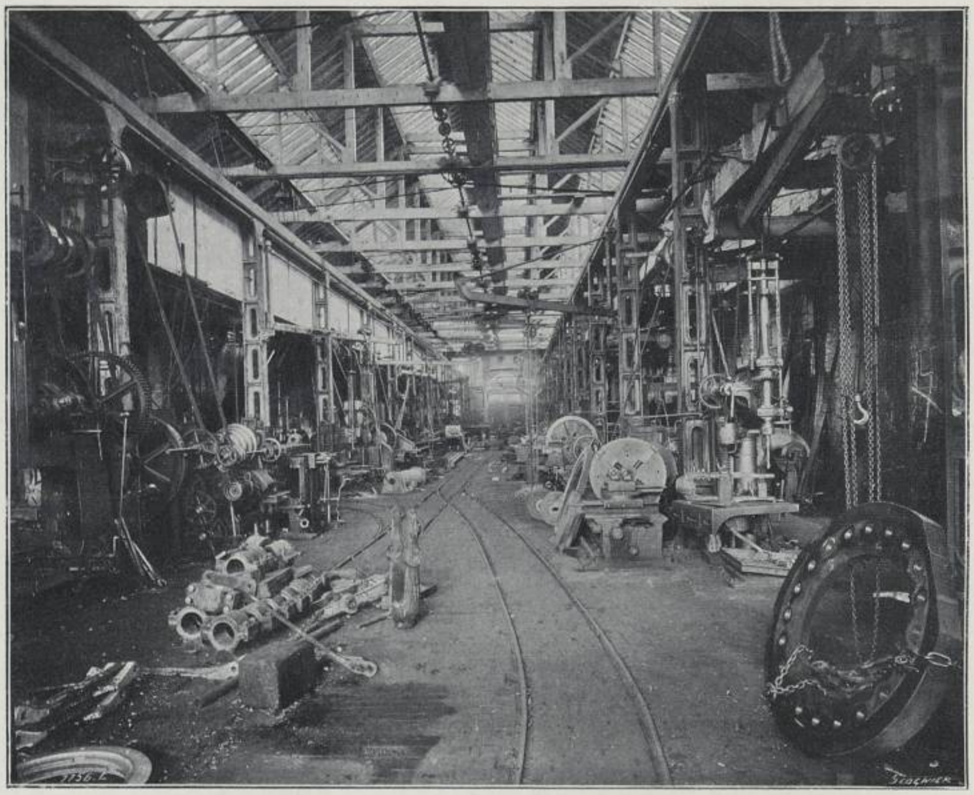
To the west of this new beam-bending shed there is placed a new smithy, and between them three powerful hydraulic cranes, of large radius, are fitted for moving material during various stages of the work. The smithy is so equipped with cranes that the beams can easily be wrought at the fires, and the work in connection with beam knees, &c., is thus greatly simplified.

The new main platers' shed in the west yard is also contiguous to the building berths. It is 360 ft. long by 180 ft. wide, and is built in six bays. It is equipped with large hydraulic swing cranes for the easy handling of material. All the machinery is new and of a powerful type, comprising punching and shearing machines, plate-edge planing machines, plate-bending rolls, plate-straightening rolls, countersinking machines, beam-benders, hydraulic punching and flanging machines, hydraulic channel cutters, and circular steel saws, and all are operated by electric power. There are two gas furnaces placed near the centre of the shed, for heating the bars employed in framing, &c. In connection with these furnaces there are bevelling machines suitable for different sections of steel framing. On both sides of the furnaces there are placed two large screeve boards, 180 ft. long by 60 ft. broad. One bay of the machine shed is laid off for building and riveting the frames, &c., to minimise work in the building berth during inclement seasons of the year, and to facilitate work before the berth is vacated for a new ship, This bay has a four-ton overhead electric travelling crane, which runs out clear of the shed at each end, so that it can pick up the constructive material and lay out the finished frames at the other end.

It will thus be seen that the east and west yards, so far as ironworkers are concerned, are practically in duplicate, but the other departments are more or less concentrated. The general store, which is really the main distributing department, is almost in the centre of the works. It was a wise provision to make this department a prominent feature, and to insure a thoroughly organised system, because in such a large establishment there would otherwise be grave risk of leakage. A view of the store is given on Plate XXXIV., but it would occupy too much space to review the general system, Under the same roof there is a well-equipped dispensary and operating room, and a surgeon is in constant attendance for prompt treatment of any workmen injured. Although accidents are not frequent, this provision is one which gives much satisfaction.

Amongst the departments which utilise this store as a main distributing centre is the shipyard smithy, illustrated on Plate XXXIV. This building forms the eastern boundary of the establishment, having direct communication with the ships on the eastern building slips. There are about 120 smiths' fires, the blast being supplied by a powerful Roots blower; while in the forge there are four furnaces and fifteen steam-hammers, ranging up to 75 cwt., the most powerful being placed between two furnaces, served by two 10-ton hydraulic cranes. Adjacent to the smithy is a testing-house with a machine of 50-tons capacity.

In the modern steamship, particularly for war service, there is a large amount of engineering work independently of the main propelling machinery, such as is connected with stearing gear, capstans, gun-seats, hoists, &c., and at



THE SHIPYARD ENGINEERS' SHOP.

Clydebank these are usually constructed in a department of the shipyard rather than in the engineering works; and thus it comes that there is a shipyard engineers' shop. At Clydebank this department is placed contiguous to the building berths, and the extent of work undertaken is indicated by the fact that on an average 500 men are employed here alone. The shop is 240 ft. long by 75 ft. broad, with a fitting bay 80 ft. long by 70 ft. broad. There is a very complete equipment of fitters' tools, lathes, planing, drilling, and screwing machines, and although none of them are of unusual size, they

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PLATE XXXV.

SAWMILL.

JOINERS' SHOP.

are well worth noting. There is a multiple drilling machine, four wheel-cutting machines, key-seat cutters, and an emery tool-grinder. The fitters' benches are in a gallery, as are also the stores. As a narrow-gauge railway runs through the shops, and as there are two 5-ton overhead travelling cranes, several jib cranes, and a 5-ton hydraulic jib crane at each end, the department is well equipped for handling heavy products.

As can readily be imagined, in an establishment which sends out a large number of high-speed passenger steamers and yachts, the wood-working department is very extensive, occupying about 10 acres of ground, two-thirds of which is covered by drying sheds. The timber for the joiner shop is accommodated in a building measuring about 360 ft. long by 125 ft. broad, and having 112 portable racks and four patent electrically-driven radial cross-cut and ripping saws, for cutting timber to the exact sizes required by the joiners. The store for deck planks is a duplicate of the joiners' shed, the timber being delivered automatically from the planing machines to any part for stacking. There is ample accommodation for storing and seasoning all wood required for the decks of twelve Atlantic liners, and all entirely under cover.

The saw-mill is new, and is situated at the extreme west end of the yard. As shown in the engraving, Plate XXXV., the saw-mill itself consists of two bays, and the roof is of light construction and glazed all over, the effect being to secure the full light of day with ample weather protection; in fact, we have never seen a more adequately lighted and satisfactory structure. The building measures about 200 ft. long by 68 ft. broad. The saw mill is controlled in every part by four overhead electric travelling cranes, which lift the logs direct from the river, and store them or deliver them to the machines as required. The log department is fitted with three vertical log-frames, one German board-cutting saw, and an American band mill, the combined cutting capacity being over 500 logs per week. In the re-conversion and re-sawing of the wood, the principal machines used are one large deck planer, one lining and flooring machine, one American planer, one moulding machine, one deal frame, one improved Casson's bench, two small saw-benches, two large travelling circular benches, one lightning planer, two pendulum cross-cut saws, and two disappearing cross-cut saws. In the saw-room there are seven automatic saw-sharpening machines for band-saws, one automatic circular saw sharpener, one automatic blade grinder, one punching machine, and two hand-sharpening machines.

The wood-drying stove is controlled by a patent thermo tank, by which the temperature can be regulated at will. The entire installation is driven by a 300 indicated horse-power compound condensing engine, supplied with steam by two Lancashire boilers, automatically fired by Henderson's patent stoker for sawdust and chips. The buildings, machinery arrangements, &c., were designed by the company's staff.

The joiners, cabinetmakers, and polishers are accommodated in a two-storey brick building, situated at the head of the building berths in the east yard, and close to the fitting-out basin. This building is 200 ft. long and 150 ft. broad. A view of the interior of the joiners' shop is given on

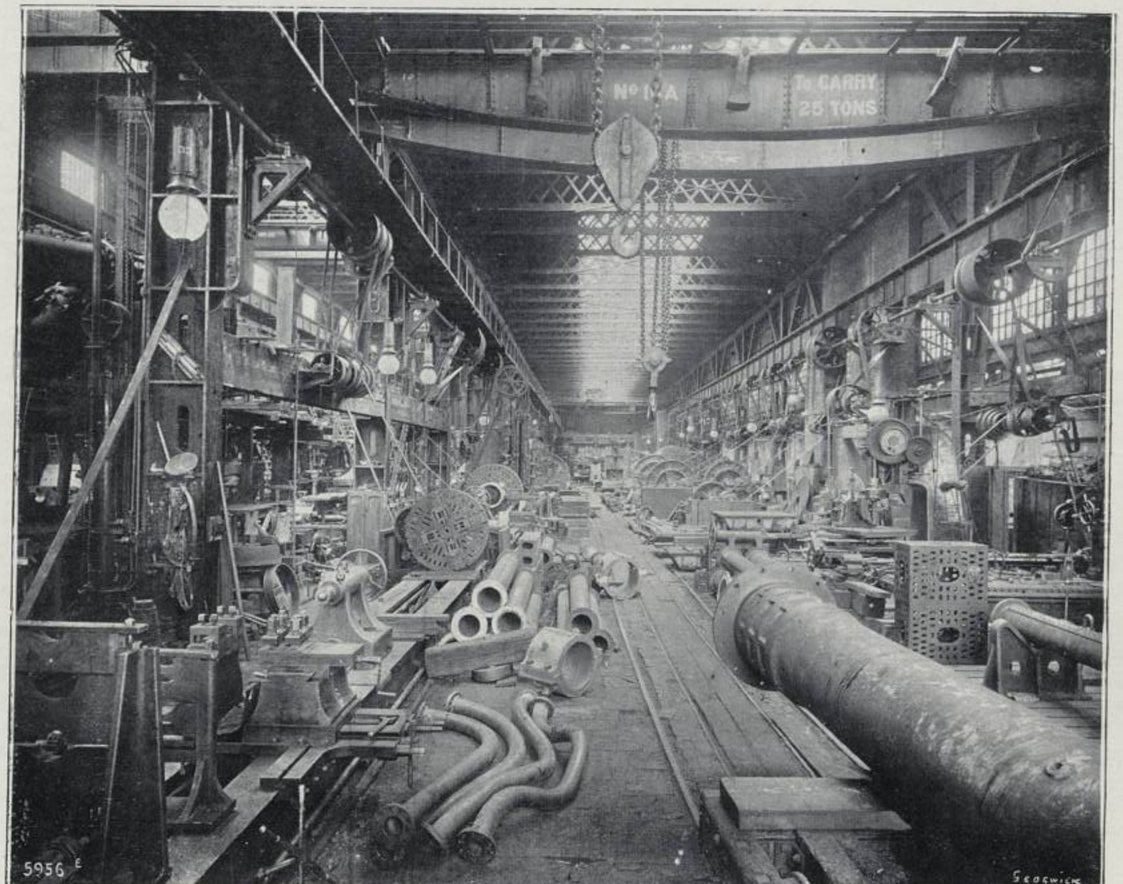
CRANES AT THE FITTING-OUT DOCK.

Plate XXXV., facing page 97. The collection of wood-working tools is complete, and is representative of the best British and American practice. It includes sand-papering machines, dovetailing machines, blind-slotting machines, and special tools for cutting spiral or fluted grooves of balusters, sheerlegs, &c., with the usual planing and moulding machines. The shavings, &c., and sawdust are carried off by a pneumatic conveyor direct into the furnaces of the boilers in an adjacent power station. In the western yard there is a joiners' store, where all the finished furniture and fittings are stored until they are required on board the vessels. The floor over this joiners' store is occupied by the riggers' loft, where all the rigging, ropes, tackles, and other material required by them is prepared. The carpenters' shop, which is also in the eastern yard, contains planing, moulding, and dowelling machines, with band and circular saws, all of the tools having been installed recently.

It may not be uninteresting to introduce here a reference to the dock or fitting-out basin (see Plate XXXI., facing page 88). It occupies the central part of the water frontage, and extends for 750 ft. from the river, while the width of the dock is 320 ft. from cope to cope. The entrance from the river is 137 ft. wide. There is about 2,000 lineal feet of wharfage, and, in addition to this, a jetty 120 ft. long by 22 ft. broad, is run out from the north end of the dock—that furthest from the Clyde—so that it is possible to berth alongside the wharves five vessels of different lengths. The depth of water at low tide is 25 ft., so that the largest ships may be always afloat. The dock is constructed of sheet-piling, driven to a depth of 30 ft. below low-water-level, while above the top of the piling there is a sloping wall with a concrete coping. The facilities for moving ships in the dock include hydraulic and steam capstans, and a powerful steam winch.

The crane arrangements are very complete: on the east wharf, that nearest to the engine works, there are sheerlegs capable of lifting 130 tons, designed and constructed at the works. The front leg is 138 ft. long between centres, and the back leg 180 ft. The back leg is run out by means of a screw, with a nut in the cross-head of the leg, the screw being 76 ft. in length, $9\frac{3}{4}$ in. in diameter outside, and $8\frac{1}{2}$ in. at the bottom of the thread. Separate engines are provided for raising the load and for actuating the screw: and this arrangement enables both operations to proceed simultaneously, and thus the disposal of heavy loads is expedited. The sheerlegs have sufficient overhang to lower a load perpendicularly at a distance 60 ft. from the quay wall; they can place the machinery on board a steamer of 86 ft. beam. On the eastern wharf there are also two 5-ton hydraulic travelling jib cranes. These cranes are shown in the illustration on the opposite page.

The west wharf is traversed by a 20-ton steam travelling crane, with a jib having a radius of 47 ft.; the carriage of the crane has a sliding table which enables the crane to be traversed to any set of parallel rails, and thus it can work at any distance up to 180 ft. from the quay wall, and for the whole length of the wharf. On the jetty, projecting into the dock (as shown on Plate XXXI., facing page 88), there is a 10-ton electric jib crane, built at a high elevation, and of very considerable radius, so as to be able to place loads on ships on either side of the jetty. This jetty and crane are most useful for the fitting out of paddle steamers, torpedo-boats, and small craft.

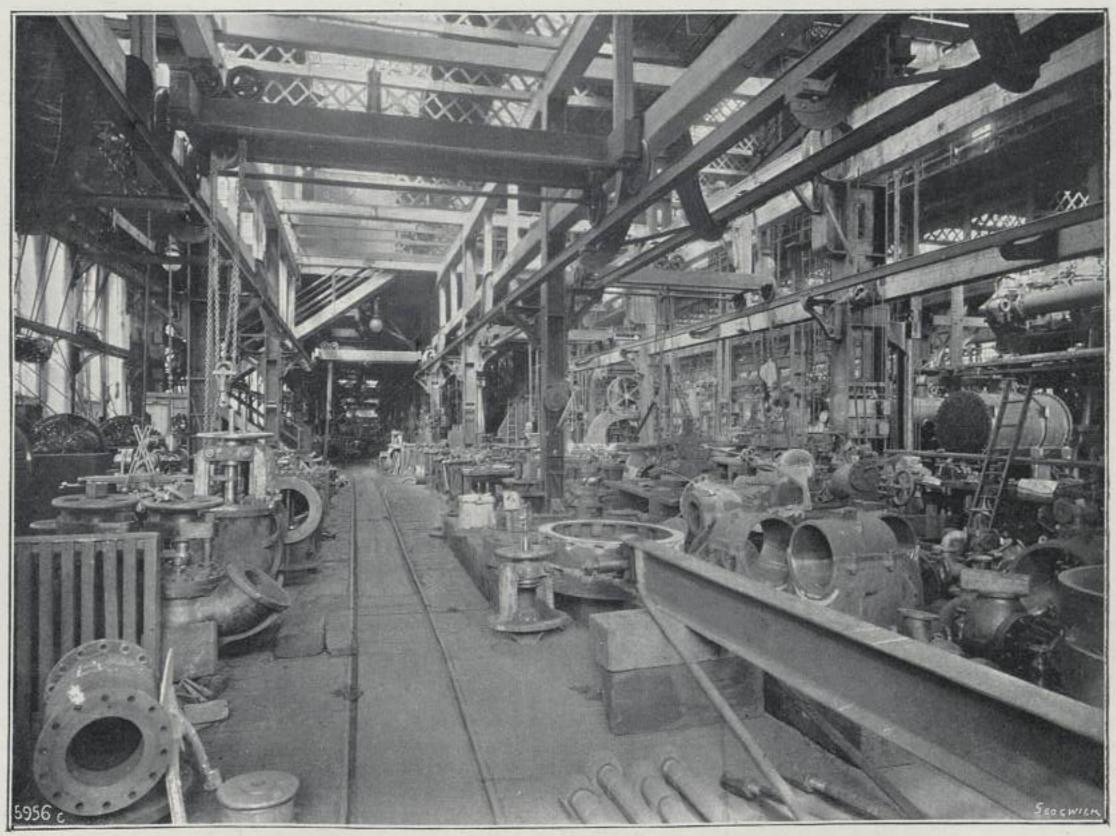


LARGE MACHINE SHOP (ENGINE WORKS).

We now turn to the engineering department of the works, which is compactly arranged near to the head of the fitting-out basin. Some idea of the capacity is provided by the fact that for several years the average output has been over 60,000 indicated horse-power per annum, the number of men engaged in this department alone being from 2,700 to 3,000. A separate entrance for workers and materials is provided, and here there is the same regular method of storing the material in readiness for the various sections. The main engine-shop consists of a building 410 ft. long by 360 ft. wide, divided into four main bays, the height being about 60 ft. The respective bays are utilised as delivery departments, large machine shop, erecting department, and small machine-shops; the erecting bay being placed between the two machine-shop bays, so as to minimise the distance through which the various parts require to be moved.

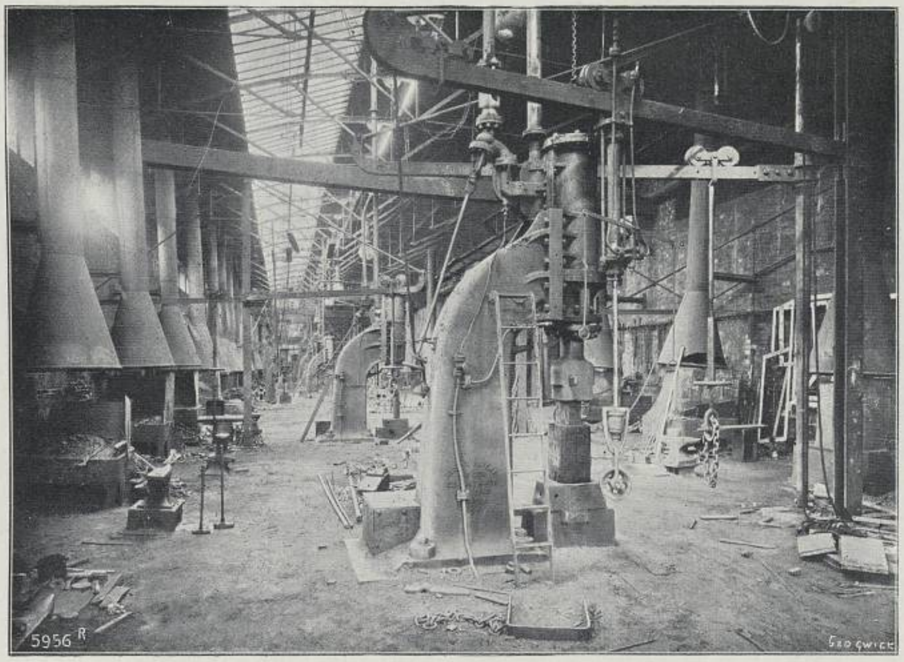
On the opposite page there is a view of the large machine-shop, in which there are many tools of noteworthy dimensions. Included amongst these are two vertical milling machines, the cutters used varying in diameter up to 18 in.: the cross-feed is 6 ft., and the transverse feed is 2 ft. 1 in., the movable circular tables being 4 ft. in diameter. There is a treble-geared miller, capable of milling a surface 10 ft. by 4 ft. 7 in. by 18 in. deep, the table being fitted with a quick-return power motion. Opposite this latter tool is a triple-geared lathe, 20 ft. between centres, with an independent motion by screw; the headstock is 33 in., and is provided with rack motion for quick hand traverse; the saddles are arranged so that they will pass alongside the shifting-head, in order that an extra large job may be faced up. The face-plate is 5 ft. 10 in. in diameter, and can swing 48 in. and 54 in. clear of the back and front saddles respectively. There are two other powerful treble-geared lathes, mounted on one bed, so that a 33 ft. length of shafting can be driven by both heads. Close by is a large radial drill, having a spindle 5 in. in diameter, and fitted with screw and hand gear; the jib has a 3 ft. vertical travel, the drilling spindle traverses 8 ft., and the vertical feed is 2 ft. 6 in.

There are five slotting machines, the larger having a 20-in. stroke, with compound and rotary table, and another with a 16-in. stroke with quick-return motion, admitting articles up to 5 ft. 4 in. in diameter. Adjoining is a large treble-geared face-plate lathe, the plate measuring 11 ft. in diameter. There are together a set of three combined planing and slotting machines, with quick-return motions. One can deal with an area of 21 ft. long by 17½ ft. high, and is arranged to take a cut of cast iron 1 in. deep at a speed of about 15 ft. per minute; a second can slot and plane over a surface 20 ft. 6 in. long by 14 ft. high; the third machine can take a job 15 ft. long by 12 ft. high. At the north end of the bay there is a set of four horizontal universal boring, drilling,



SMALL MACHINE SHOP (ENGINE WORKS).

and tapping machines, and two of these can operate over a continuous vertical surface of about 40 ft. by 10½ ft. These powerful machines have bored cylinders up to 48 in. in diameter, tapping and studding their flanges at a single setting. One of the 5 in. spindles of these machines is fitted with an interchanging wheel arrangement for combing or cutting internal screws of large diameter, by means of a chasing tool held in a small slide on the end of a spindle. Opposite these machines are two powerful treble-geared shafting lathes, whose beds are continuous, and with feeds up to 5 in. per



Engine Works Smithy.

minute. They are 21 in. centres, and each is fitted with two strong duplex sliding saddles, each having front and back duplex rests. The front rests are arranged for tapered work.

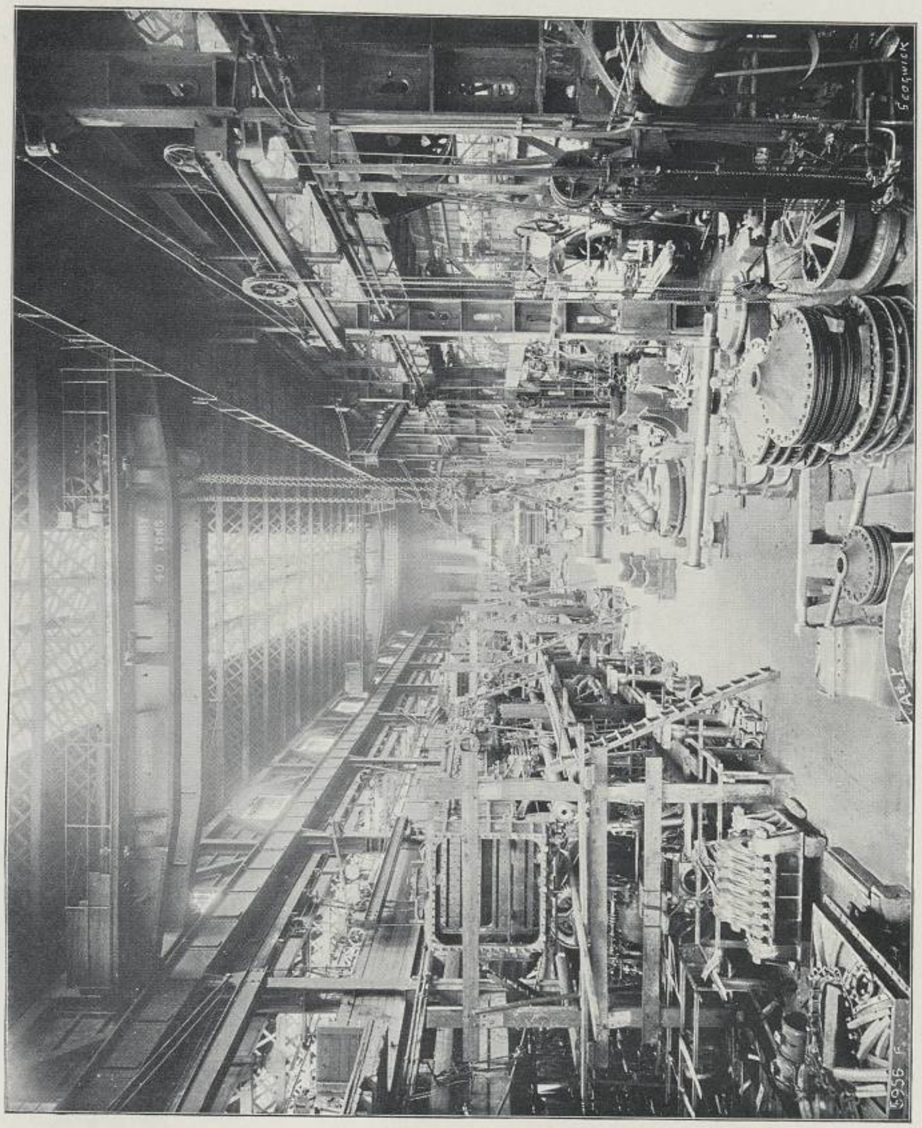
The small machine-shop, illustrated on the opposite page, has a splendid installation of tools, but mention need only be made of three 12½ in. screw-cutting lathes, whose beds are about 16 ft. long; a 7-in. double-geared self-acting hollow-spindle, capstan rest, chasing lathe; an 8-in. universal self-acting open-spindle double-gear chasing lathe, fitted with a capstan rest; two 5 in. self-acting lathes; and 7 lathes ranging from 6 in. to 12 in. centres. About the centre of the bay there are placed a number of drilling and tapping machines, and further southward a multiple drilling machine, arranged to drill holes $1\frac{1}{4}$-in. in diameter by 1 in. deep, at the rate of ten per minute, through steel plates $11\frac{1}{2}$ ft. wide by 15 ft. long, or through drums 4 ft. in diameter by 10 ft. long Amongst other tools, reference may be made to a band-saw for sawing tubes and coupling pieces, &c., admitting pieces 2 ft. 6 in. deep and 4 ft. between the saw and frame.

An important adjunct to these machine shops is the engine works' smithy illustrated on the preceding page. It is a light structure, with 35 hearths arranged on either side, with 13 steam-hammers, and there are several air furnaces. A large number of forgings of considerable size are produced for the engines of ships and for the boiler-shop requirements.

On the Plate facing this page, there is illustrated the erecting shop, which is served by two 40-ton overhead travelling cranes, and many hydraulic jib cranes. At the north end of this bay there is placed a very large surfacing lathe, the face-plate of which is 12 ft. in diameter, the width across the slide bed being 10 ft. 8 in. There are two tool-boxes that traverse on the slide, and suitable gears for longitudinal and transverse feeding are provided. The machine is capable of dealing with very large cylinder covers, parts of condensers, and also for the important work of machining and buffing cylinder liners for naval vessels. Adjacent to this machine, but on the west side of the bay, is a large vertical boring machine, having a 8-in. diameter spindle, and special large table with 10 ft. travel; also two large horizontal boring machines, all capable of dealing efficiently with the heaviest work of the shop, being provided with the most approved means of adjusting the work under operation. Adjoining are two 8-in. spindle vertical boring machines, having a 4-ft. travel. The spindles are fitted with a special arrangement for boring conical holes, such as are usually found in propeller bosses, &c. This arrangement consists of a parallel boring bar with a groove running its entire length, in which the tool-holder slides, and is traversed by a screw fed automatically. The bar carries a cross-head, on which is mounted a traversing top-centre, which engages the socket of the boring spindle ; in the lower end is formed a socket bearing of hard steel, which runs on a corresponding spherical-ended centre, bolted through the frame of the machine, below the level of the bed-plates. The taper of the hole to be machined is adjusted by traversing the top-centre on the crosshead. Further down the erecting shop are four sets of boring, tapping, and studding machines, fitted with a milling arrangement. These have also level iron beds in front, and can drill over an area of 40 ft. by $10\frac{1}{2}$ ft. high. They have 3-in. spindles, having a travel of 3 ft., and form a valuable part of the equipment of the department.

The fourth bay, forming the receiving or delivery shed, has a travelling

PLATE XXXVI.



Erecting Shop (Engine Works).

jib crane which removes materials from the railway company's wagons, depositing them in positions convenient for the travelling cranes in the shops. There is a separate tool-fettling department; and the machines specially set apart for preparing the tools include a universal milling machine, a shaping machine, milling cutter grinders, Morse drill grinders, emery grinders, and a number of ordinary grindstones. The upper portion of this west bay is occupied by the light iron-finishing shop, well supplied with light travelling

Boiler Shop, Centre Bay.

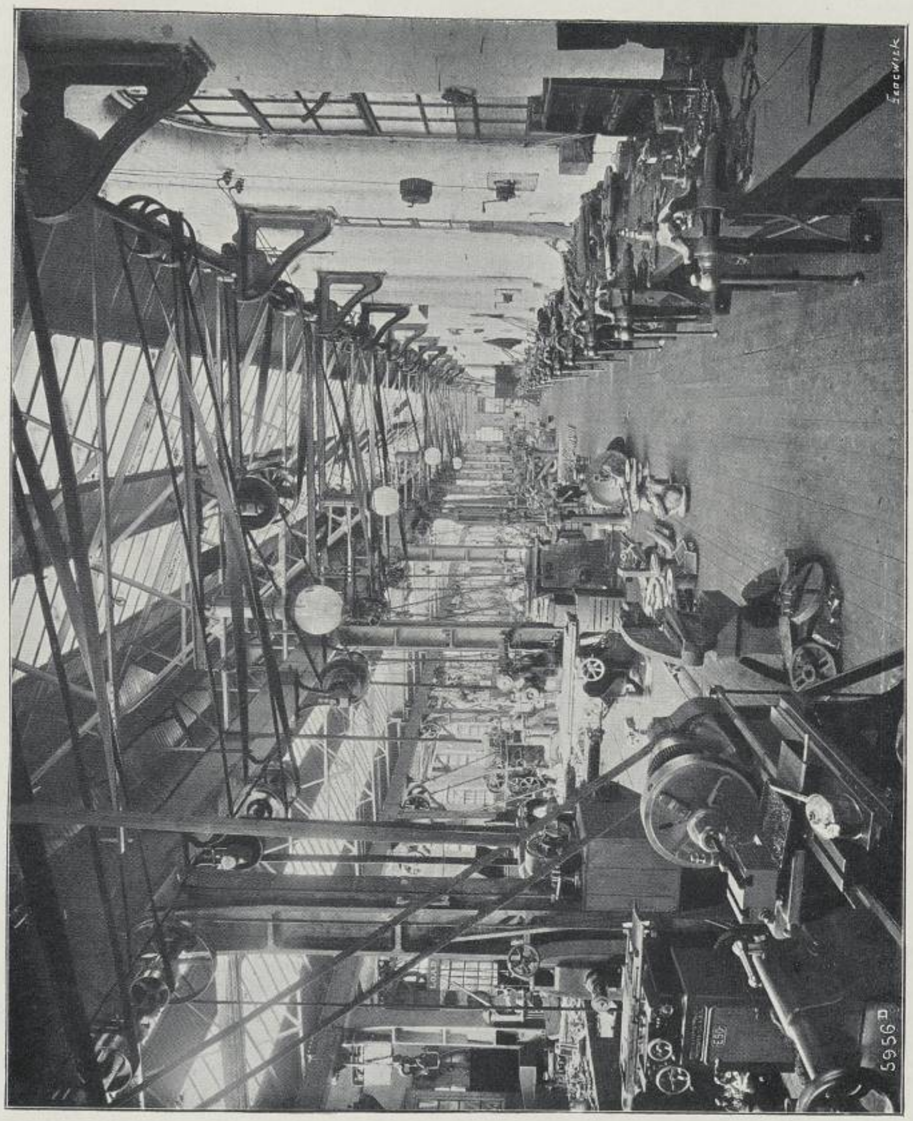
cranes, and the smaller machine tools necessary for this class of work, as well as hydraulic cranes and lifts for promoting despatch to and from the ground floor.

The main boiler works are situated in juxtaposition to the engine shops; the building is divided into three bays, being 410 ft. long, with a total width of 140 ft. In the two largest bays the cylindrical boilers are constructed, and there are several very powerful tools, notably plate-edge planers for dealing with plates 38 ft. long, and a vertical machine for cutting ovals for manholes on cylindrical boilers. In the main bay there is a plate furnace 20 ft. long by 10 ft. wide, with a powerful steam-hammer, the whole set being commanded by an hydraulic crane. There are several powerful flanging machines, multiple boring and drilling machines, vertical cold-plate rolls, taking 12-ft. plates, and many punching, shearing, drilling, and tapping machines, besides several large riveting machines. The third bay is largely utilised for the construction and erection of water-tube boilers, and of this department an illustration is given on the preceding page.

The water-tube boiler shop is situated on the ground floor of a two-storey building immediately to the west of the main engine-shop, and is exclusively devoted to the manufacture of the various parts of such boilers. The machines number in all about 30, and comprise a three-spindle horizontal boring, facing, and tapping machine, which finishes the end boxes into which the tubes are screwed; surfacing lathes for couplings; two milling machines; a number of emery grinders; and a double geared screwing machine. This latter consists of a large hollow spindle mounted on two long bearings, and carrying powerful universal self-centring chucks at each end, which grip the tubes to be screwed. The strong circular frame for holding the six dies employed is mounted on a saddle, and is fitted with micrometer cones for their adjustment. A slide rest is also provided for facing, bevelling, and grooving the ends of the tubes; and a centrifugal pump supplies the necessary lubricant to the dies while screw-cutting. The lower part of the shop is reserved for the building and testing of both steam generator and economiser elements.

The brass foundry is situated to the west of the main engine-shop, the intervening space of 50 ft. being utilised for storing scrap and pig iron, coke, and other foundry requisites. The foundry is 150 ft. wide and 250 ft. long, and is considered one of the largest and finest in the country, having ample plant and every facility for carrying out all classes of work. This foundry is illustrated on Plate XXXII., facing page 90. The equipment includes air furnaces ranging from 16 tons to 5 tons, drying stoves 20 ft. long by 20 ft. wide, heavy overhead travelling cranes, and hydraulic jib cranes, 2½ cwt. air furnaces and 32 crucible furnaces, hydraulic and hand moulding machines, besides rumblers, and circular and band saws. In order to make the foundry self-contained, there is a 3-ton cupola for making the required moulding boxes and plates, core bars and core irons, and the other cast iron necessary for the department. Brass castings up to 25 tons have been dealt with. Adjoining the foundry are the requisite stores for metal, sand, and furnace coal, &c.; and close by is the hydraulic house, in which is a 60 horse-power and 100 horse-power gas engine, driving separate three-throw pumps, and supplying two accumulators 15 in. and 21 in. in diameter respectively, with a stroke of 14 ft.

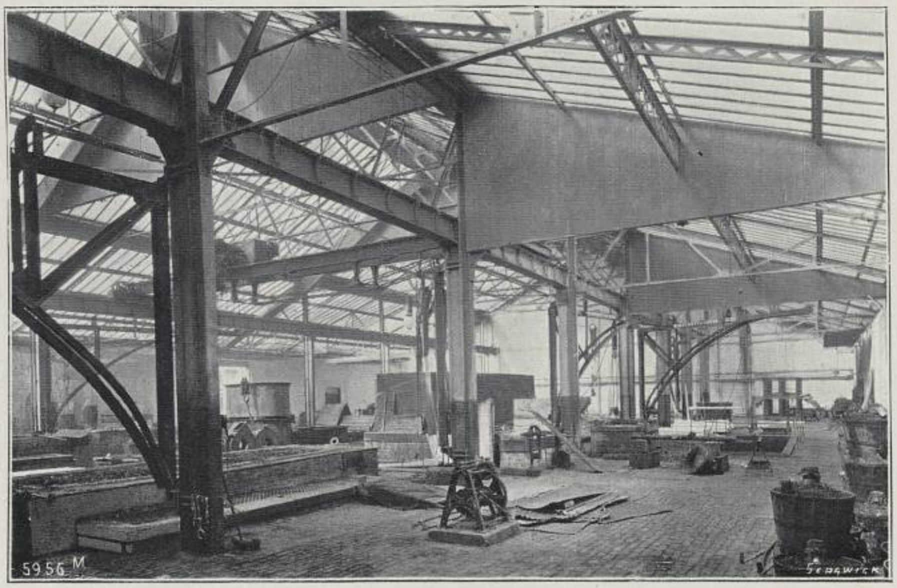
The brass-finishing shop is illustrated on Plate XXXVII. It forms the upper floor of the two-storey building; the ground floor is devoted to water-tube boiler work. The shop is supplied with lathes, milling machines, and screwing



BRASS-FINISHING SHOP.

and grinding machines, a most interesting feature being a number of small English and American machines of ingenious design for the machining of duplicate parts. In both of these shops small longitudinal and transverse overhead travellers are arranged, as well as a powerful hydraulic hoist for the transport of material to and from the brass-finishing department.

There is a galvanising shop, both for the shipbuilding yard and the engine works. The building in which these are arranged has three bays, and is about 150 ft. long by 100 ft. wide; there are three large hot baths and four acid baths, with two large electro-deposition tanks and a powerful sand-blast,



GALVANIZING SHOP.

the power for this latter being supplied by three air-compressors driven by electric motors. An illustration of the galvanising shop is given on this page.

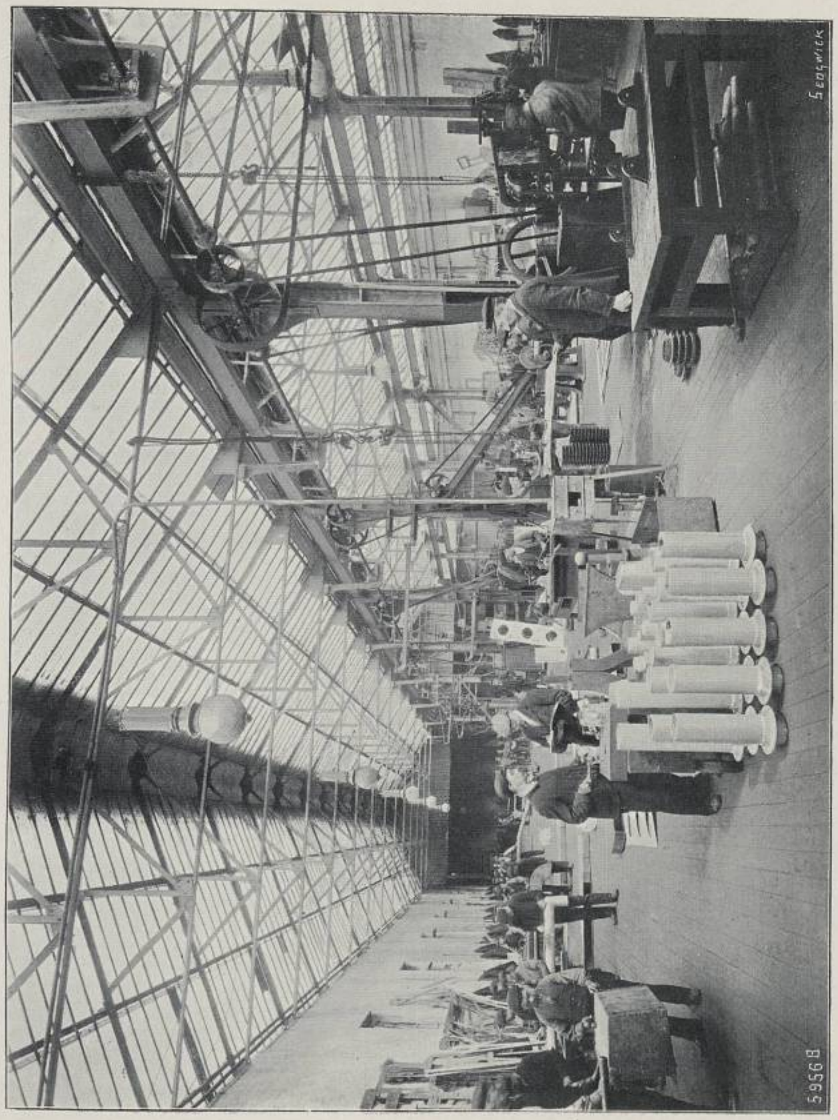
The sheet-iron shop illustrated on the Plate facing page 108, is one of the new buildings in the west yard. The two bays make the shop 100 ft. wide, and the length is 220 ft. The plant in use includes hydraulic stamping presses, mangles, and shearing and drilling machines, capable of forming the holes simultaneously in a complete length of pipe; and as to the extent of work carried out, perhaps the best indication is that there are 200 employés in the department.

A new building, 250 ft. long by 50 ft. span, has been erected in the west yard, to accommodate the coppersmiths, and, as shown on the following page, it is well equipped. Alongside this building is the producer-gas plant, with generators, coolers, and holders.

An interesting item in the arrangement of such a large establishment is the system of generating and distributing power. Electricity is used on an extensive scale, not only for the lighting of workshops, sheds, the interiors of ships under construction, and of the yard generally, but also for the driving of the machine tools. There are three separate power stations : one in the centre of the shipyard, another in the engine and boiler works, and a third close to the saw-mill and wood departments. The shipyard station is equipped

COPPERSMITHS' SHOP.

with six boilers of the Babcock and Wilcox type, which provide steam for the sheerleg engines close by, as well as for running the electric generating sets. They also serve as destructors, being used for disposing of the sawdust, shavings, &c., from the various wood-working shops, and the rubbish collected from the interiors of ships under construction. The station is equipped with a fair representation of the best types of steam engines and dynamos comprising Willans and Robinson's central valve engines, Belliss and Morcom's forced lubrication engines, and Robey's high-speed open engines. The dynamos include such makes as Siemens Brothers, Crompton, W. H. Allen, Sons and Co., Brush Engineering Company, and the



Sheet Iron Shop.

British Schuckert Company. The total engine power is more than 900 horse-power, while the electric output is 700 kilowatts. A large set of Tudor accumulators is provided for supplying current during periods when boilers or generating sets are shut down, so that there is at all times an uninterrupted supply of current.

The engine works generating station differs from that in the shipyard, as the dynamos are run by gas engines, with the intervention of ropes. Four of the engines are by the Premier Gas Engine Company, three of them each driving a generator of 80 kilowatts, the fourth driving a generator of 180 kilowatts, and the other two, by Crossley Brothers, drive generators of 44 kilowatts each; the total is thus about 500 kilowatts. The engines are supplied with gas from Dowson producers.

The sawmill generating station consists of four dynamos, two of 77 kilowatts and two of 44 kilowatts, driven by rope from the main sawmill engine.

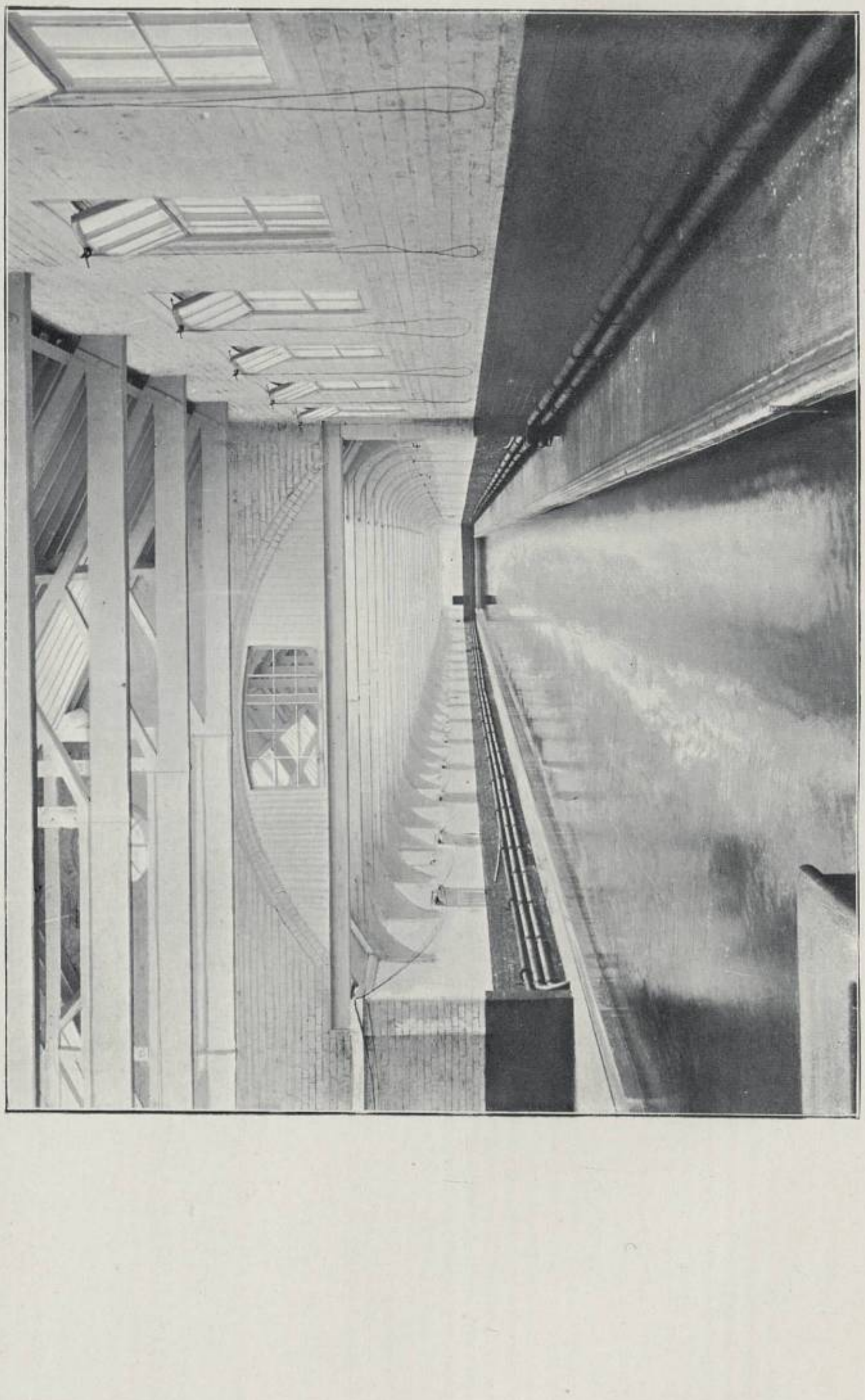
There are in the works about 750 arc lamps of 1,000 to 2,000 candle-power, and about 5,000 incandescent lamps of 16 candle-power. The arc lamps are used principally for outside illumination, and in the interior of the larger sheds and shops. The incandescent lamps are used in all the wood-working departments and offices, and for all bench work. They are also adapted for the internal lighting of ships during construction, replacing the old-time naphtha lamps.

Electricity is largely used for machine-tool driving, the power utilised in motors amounting in all to about 1,050 brake horse-power. There are over 150 motors in use, varying in power from 30 brake horse-power downwards. In the first place, there are a number of high-speed electric overhead travelling cranes in the wood departments, boiler shops, and engine shops; two large electric jib cranes, one of which is capable of lifting 10 tons at 42 ft. radius, and the other 5 tons at 60 ft. radius. A number of motors, again, are applied to general shipyard work, such as shop driving, the new ironworkers' sheds being entirely driven electrically by motors applied directly to each machine—punches and shears, plate-bending rolls, plate-straightening rolls, angle cutters, bevelling machines, countersinking drills, planing machines, squeezers, circular saws, tool grinders, &c. Motors are also applied to the lighter class of work—driving portable drills, pumps, and ventilating fans on board ships under construction, &c. Two powerful electric winches are utilised for lifting armour plates and other heavy work in connection with the construction of warships.

Power is supplied to the majority of the machines in the east yard by a horizontal compound Robey engine, situated at the west end of the iron-workers' shed. The engine has cylinders 18¼ in. and 30 in. in diameter, with a stroke of 40 in., and indicates about 300 horse-power. The engine transmits the power to two main lines of shafting, extending throughout the ironworkers' shed, and also supplies power for the shipyard engineers' shop, which is situated close to the engine. Steam is supplied to the main engine by four large Lancashire boilers. The boilers are fitted with Proctor's patent mechanical stokers, the coal being raised by a steam elevator and distributed by means of a screw worm. These boilers also supply steam to a Tangye engine of about 80 horse-power, used for driving machinery in the joiners' shop, to a small auxiliary engine in the shipyard engineers' shop, and to 15 steam hammers in the forge and smithy.

An hydraulic pressure system is installed throughout the yard, and is used for actuating, amongst other tools, the powerful flanging machine (shown on the engraving, Plate XXXIII., facing page 93), two large manhole punches, several portable riveters, and a number of cranes and capstans. The pressure for this system is 1,000 lb. per square inch. For the portable hydraulic riveters a separate system is used, with a pressure of 1,400 lb. per square inch.

The principal offices are centrally situated, and near the main entrance to the works. They are shown on the illustration on page 90. They include on the ground floor, model-room, counting-house, engine works drawing office, with accommodation for fifty draughtsmen, and, alongside, the manager's office, which is also close to the engine shops. The first floor has the board room, the private offices of the managing directors, &c., shipyard drawing offices, with accommodation for 100 draughtsmen, and the tracers' office ; while on the second floor is a completely-equipped photographic department. There is a suite of offices for Admiralty overseers, &c. ; while distributed throughout the works are the time offices. The shipyard manager has also an office close by the building berths, for consultation with his foremen, &c. ; a system of telephonic communication is in use : so that it will be seen that, vast as is the establishment, its organisation overcomes the disadvantages of distance ; and thus it comes that work can be expeditiously and cheaply done, as the records of the establishment show.



View of the Model Experimental Tank.

THE SHIP MODEL EXPERIMENTAL DEPARTMENT.

A DESCRIPTION of the Clydebank Works would not be complete without an allusion to the latest addition, made in 1903, viz., the new tank for experimenting on ships' models. It is well known that the modern developments in the utilisation of models for ascertaining the resistance of ships were due initially to the late Mr. Wm. Froude, of Torquay. Under his illuminating guidance the Admiralty experimental tank was established; since his death it has been superintended by his son, Mr. R. E. Froude, who is well known in scientific circles, and has placed the whole nation under a deep debt of gratitude in this connection.

The building comprising the new tank and the offices in connection therewith, is situated at the west boundary of the yard, and covers an area of about 2 acres. The basin or tank, which lies due north and south, runs parallel with the boundary wall of the yard, and has an extreme length of about 400 ft., a depth of water of from 8 ft. at one end to 9 ft. at the other, and a width of water of 20 ft. clear. At the end of the tank, where the models are worked, there are dry and wet docks for trimming the miniature ships, capable of accommodating a 20-ft. model. At the south end of the tank a stepped or sloping beach is built for breaking the wash caused by the models. The tank proper is covered for its whole length by a roof of 28-ft. span, thus giving a passage of 4 ft. on either side. It is well glazed, in order to give as much overhead light as possible. This is fully established by the engraving of the tank on the Plate facing this page.

Grouped conveniently round the dry and wet docks is the necessary gear for making the wax models, such as the moulding box, automatic cutting machine and weighing machines ; also an overhead railway for conveying models from one place to another, in order to undergo the different processes preparatory to experiment.

The carriage from which the model is towed through the water runs on rails fixed on each side of the concrete walls of the tank. Electricity is used to drive the carriage, and it may be here mentioned incidentally that this power is used for all mechanical work in connection with the model tank. The electric current is conveyed to the carriage by overhead trolley wires. The dynamometric apparatus is designed entirely to avoid the use of any devices involving the possibility of friction. About the centre of the main tank building an observation room is built out for photographic purposes.

At the north end there is placed a large building, forming an adjunct to the tank buildings, for the accommodation of the model makers. This building is 80 ft. by 40 ft., and is fitted for the construction of finished models.

As temperature is an important factor in the results of model experiments, due regard has been paid to this matter. The buildings are heated by means of hot-water pipes, and the water is heated by calorifiers. The buildings are fitted throughout with electric light.

The main entrance to the tank is situated on the east side of the buildings, and adjoining it are the tracing room, superintendent's room, and drawing and record offices.

IRON ORE, COAL AND COKE.

IN the early 'seventies, when a great demand was experienced for iron and steel, owing partly to railway and shipbuilding development, and to the company's success with armour plate as already narrated, Messrs. John Brown and Company, Limited, acquired iron-ore mines in Spain, Lincolnshire, and Northamptonshire, and purchased the Car House and Aldwarke Main collieries in Yorkshire. Contemporaneously, blast-furnaces were built at the Atlas Works; so that the company became independent of outside sources of supply of raw material, and thus ensured regularity and economy of production.

Little need be said of the iron-ore mines; hematite is got from the Spanish, and clayband ironstone from the English, properties, the total output being about one and a-half million tons per annum.

The collieries have been greatly developed and the mining appliances improved; while the Rotherham Main colliery, to work the same coal seams, was sunk some thirteen years ago, to the south of the town of Rotherham, and three or four miles from Aldwarke; so that the annual production is now 1,500,000 tons as compared with 350,000 tons when the mines were purchased by the company. Some of the best-known seams in South Yorkshire are worked from all of these collieries—the Barnsley, Swallow Wood, and Parkgate seams; the Silkstone seam, underlying the whole of the company's property at Rotherham, is known to be of good quality and thickness by the workings at adjacent collieries. At Aldwarke about 2,800 tons are raised per day, at Car House 400 tons, and at Rotherham Main 3500 tons—a total of 6,700 tons of coal; while 2600 tons of coke are made per week in ovens utilising the small coal separated in screens from the main coal, and thoroughly washed before use in the ovens. Valuable residual products are recovered from the coke-oven gases.

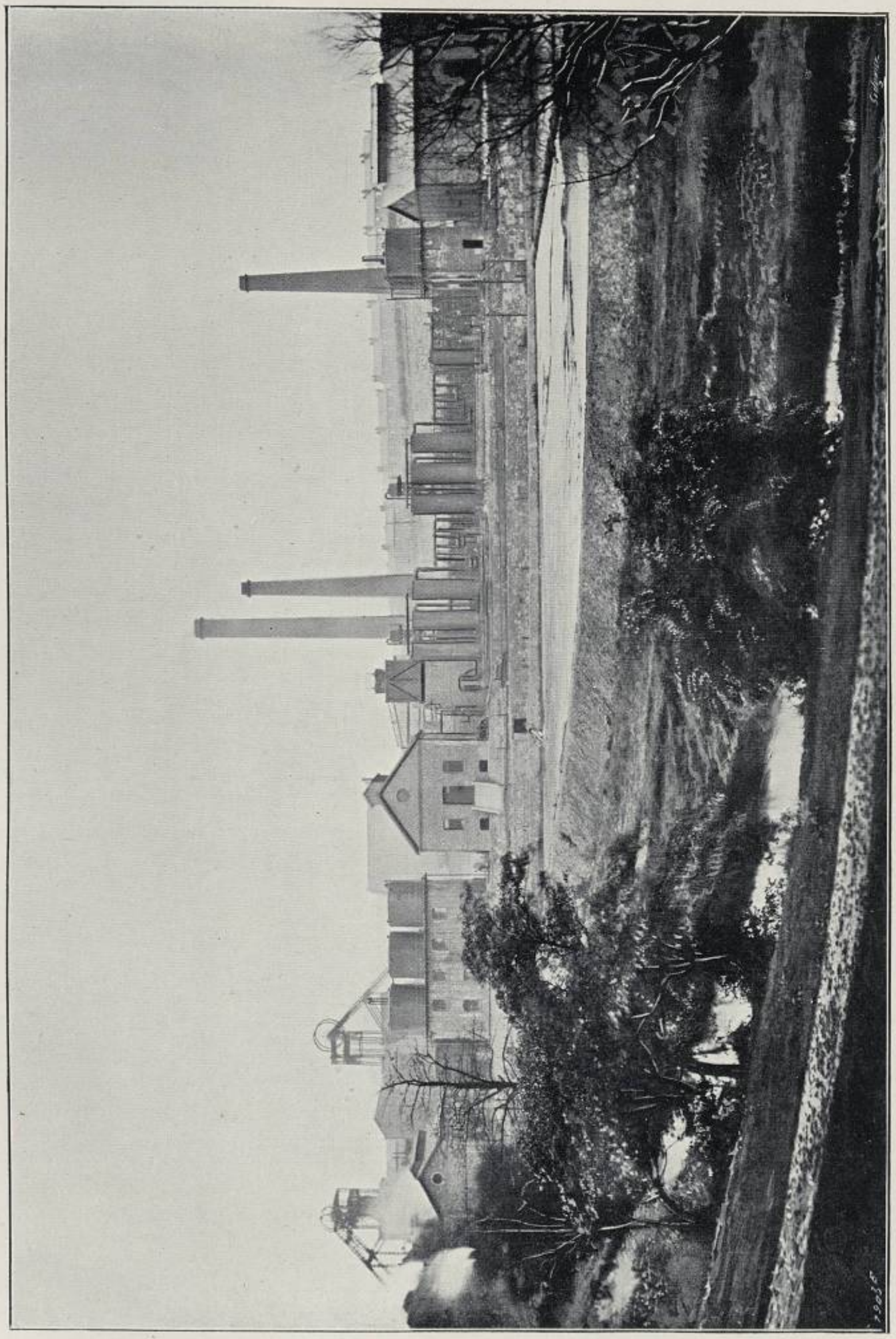
The Barnsley seam yields a coal second only to Welsh fuel for steam-raising, and, like the Swallow Wood seam, it is worked on the "long wall" system, with gates about thirty-five yards apart. The Parkgate seam has for many years had the highest reputation for its gas coal, and all the principal gas companies at home, and a great many works abroad, have utilised it from time to time. It is also, like the Swallow Wood seam, a first-rate household fuel, and yields coke of the best quality. The Parkgate seam is worked by what is known as the "pillar-and-stall" method—narrow stalls eight yards in width alternating with pillars forty yards in width, but the latter are subsequently extracted.

Modern mechanical methods are applied in the raising of the coal at the three collieries, the practice at each differing only in detail. The steam for the various engines for haulage, winding, screening, &c., at Rotherham Main is supplied from twenty Lancashire boilers, many of them fitted with the company's Ellis and Eaves' system of induced draught; and at Aldwarke Main steam is generated for the many engines in use in thirty-one Lancashire boilers, many of them fired with the waste gases from the coke ovens. There is at both centres an electricity-generating station, from which the surface works and a large part of the underground roads are lighted.

At Aldwarke very long lengths of roadways, as the result of about thirty years' mining operations, have to be maintained, and something like twenty miles of cables run along the main engine roads. These ropes are for the most part operated by hauling engines on the surface; but in a few cases air, compressed on the surface, is conveyed down the shafts to pneumatically-driven hauling engines in the workings. In connection with the Aldwarke works there are five shafts, one of them, the Warren House Pit, for ventilation, haulage, pumping, and letting the miners down to the workings, &c., being situated four miles from where the coal is drawn. The shaft at Car House is only for the raising of coal; the underground roadways, being connected with the Aldwarke colliery, are ventilated from the shafts at the latter. At the Rotherham Main colliery there are two winding shafts. To ensure safety, no explosives are used underground, and the lamps are of the most approved type, and are tested before being handed out to the workmen each day. The two ventilating fans at Aldwarke have a capacity of 450,000 cubic feet per minute; and that at Rotherham Main of 400,000 cubic feet.

The coal-screening arrangements at Aldwarke and Rotherham Main collieries are extensive, and are designed to ensure uniformity in a large variety of sizes or qualities of coal. The whole of the coal, after screening, is passed over picking bands for removal of foreign matter. After passing over the bands at Messrs. Brown's collieries the coal is delivered to broad-belt conveyors, the outer end of which can be raised or lowered to suit the level of the coal in the wagon, so that there is practically no drop and consequently no breakage. The coal in the wagon thus represents a close

PLATE XL.



ROTHERHAM MAIN COLLIERY, WITH COKE OVENS AND RESIDUAL RECOVERY PLANT.

approximation to the standard set by the screens. Extensive sidings, arranged in connection with the despatch of coals, are connected at both collieries with the Midland and Great Central Railways. At Rotherham Main there are 19½ miles of sidings, with four locomotives, and at Aldwarke ten miles, with five locomotives. For the export trade there is wharfage at the collieries alongside the canal of the Sheffield and South Yorks Navigation Company, connecting with Hull and other ports.

We turn now to the manufacture of coke from the small coal eliminated from the large coal and nuts, The small coal, after being thoroughly washed, is passed on to the coke ovens. There are extensive batteries of these ovens at Aldwarke and Rotherham Main. The plant at the latter colliery, which includes, in addition to the ovens, residual recovery appliances, is illustrated on Plate XL., facing page 114.

The coking plant illustrated consists, at present, of 35 ovens. This number is about to be doubled. By the Simon-Carves system adopted a much greater yield of coke is obtained than by the old method of manufacture in the bee-hive oven; the carbonisation is performed in half the time; and, more important still, the valuable by-products of tar, ammonia and benzol are recovered. Each ton of coal liberates 10,000 cubic feet of gas and though part of this is used for heating the ovens and for steam-raising in boilers, 30 per cent. is available for general lighting and heating. The quality of the coke is greatly improved by the coal smudge being pressed into a solid mass of the same size as the oven before it is charged into the oven. This operation of stamping, charging and compressing the coke, and of subsequently discharging each oven of coke, can be performed in less than 40 minutes, the only manual labour required being that of a man and a boy. The machine which combines all the apparatus necessary for the above operations is on one base, and is electrically driven.

The method of recovering the by-products, and their subsequent conversion into marketable commodities, is interesting, partly because of its simplicity. The tar is deposited by the cooling of the gas, and it is then in a marketable condition. The ammonia is recovered by taking advantage of its affinity for water; the ammonia-laden gas is therefore passed through washing towers (shown in the engraving), into which either water or acid is slowly fed. The resulting liquid is further treated by steam, when the ammonia gas is liberated and passes through a bath of sulphuric acid, sulphate of ammonia being precipitated. The latter product is one of the most valuable nitrogeneous manures known. The benzol is abstracted practically in the same manner, though in this case creosote oil is used as the absorbing agent. The enriched creosote is heated, whereupon the benzol vapour is liberated and condensed as a liquid, and as such is sold for gas enrichment or for dye-making. The resulting creosote is cooled, and again used as an absorbent.

Out of the large surplus of gas about 50,000 cubic feet per day is, after being enriched to 18 candle-power at a small expense, used in the district for public lamps and cottage lighting, and for illuminating the local engine sheds of the Midland Railway Company.

At both Aldwarke and Rotherham Main collieries there are extensive workshops, joiners' shops, smithies, engine-fitter's department, in which are machine tools for dealing with repair work throughout the collieries. At Aldwarke, too, there is an extensive wagon-making factory, where all the railway trucks utilised by the company in the delivery of their coal throughout England are repaired and manufactured. Twenty such railway wagons, as well as 200 corves of 10-cwt. capacity, as used in raising the coal from the mines, are manufactured each month. There is also a brickmaking department, with a producing capacity of 300,000 bricks per month.

It is scarcely necessary to add that everything is done by the company for the safety and comfort of the 6000 or 7000 men engaged throughout the collieries. In all cases plant is in duplicate. The lamp-cleaning department is regarded as of the greatest importance, and it is fitted up with extensive appliances for cleaning and examination, so that each lamp can be thoroughly cleaned and examined each day before being given out to the workmen. The company have not been remiss in providing suitable housing accommodation for the workers—as at Aldwarke there are about 170 cottages, while at Rotherham Main the number is 340, with school and church, so that from first to last the conveniences are most satisfactory.

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