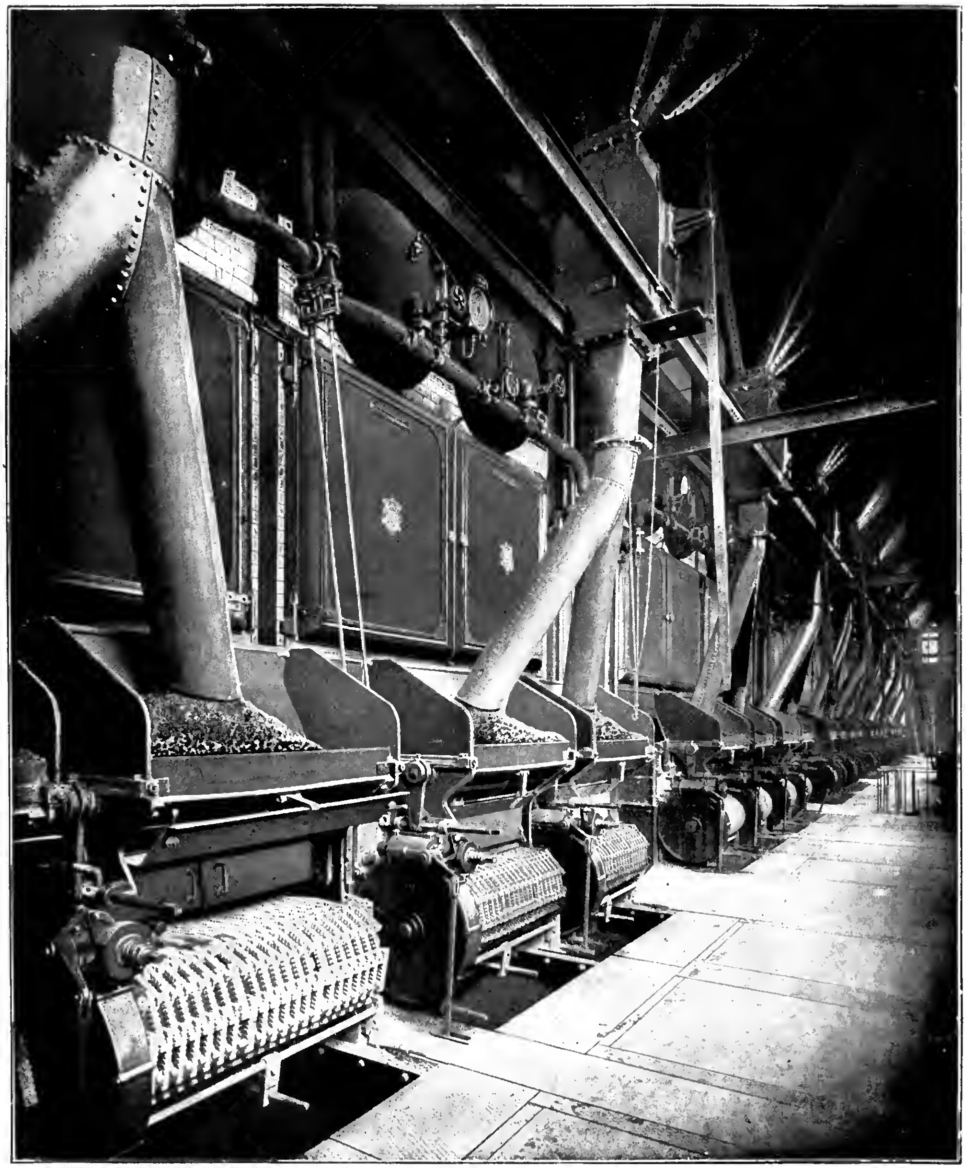
MODERN ENGINES

AND

POWER GENERATORS



MODERN BOILER ROOM, BABCOCK & WILCOX WATER-TUBE BOILERS, COAL CONVEYERS, CHAIN GRATE STOKERS.

Frontispiece.]

MODERN ENGINES

AND

POWER GENERATORS

A PRACTICAL WORK ON PRIME MOVERS
AND THE TRANSMISSION OF POWER
STEAM, ELECTRIC, WATER, AND HOT AIR

BY

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"ELECTRICAL INSTALLATIONS" "ELECTRICAL DISTRIBUTION BY ALTERNATING CURRENTS AND TRANSFORMERS" "PHOTOGRAPHIC AND OPTICAL ELECTRIC LAMPS" AND NUMEROUS SCIENTIFIC ARTICLES AND PAPERS ON MECHANICAL AND ELECTRICAL ENGINEERING

WITH MANY HUNDRED ILLUSTRATIONS

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PREFACE TO VOLUME VI

THIS Volume concludes the subject of the work with reference principally to Steam Generators and Transmission of Power. The steam generator cannot be much further improved upon. Of the many good types in use, it is a matter for judgment by the experienced engineer to select a type of boiler suitable under given circumstances. The steam boiler and engine combined as a prime mover has, of late years, been subjected to keen rivalry by the Gas Engine. The important question is whether the boiler or gas producer is to be the apparatus for the utilisation of fuel for power generation in the future.

It is a significant fact, and one of great importance to all young engineers, that the gas producer is gaining in efficiency and popularity daily, and that small steam engines are not so much used as formerly was the case. In the transmission of power, electricity and compressed air are the chief mediums ; both have their special sphere of successful application. They are briefly considered as accessories to prime movers.

Throughout the whole work an endeavour has been made to present every type of modern and practicable prime mover completely and clearly to the reader. Among them some old types have been given a place. Old machines still find a place where they are appreciated under conditions where newer types would not do so well.

The subject of prime movers is one of never ending interest and importance. Electricity and compressed air as transmitters have made it more generally possible to apply power where animal and manual labour was only applicable hitherto. No prime mover of practical service has been omitted.

The Author's thanks are due to inventors and manufacturers for much information and many illustrations of great interest on recent improvements.

RANKIN KENNEDY.

GLASGOW, *July* 1905.

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CHAPTER I

COLONIAL MINING ENGINES

For power purposes in the Colonies, engines of the greatest simplicity, and capable of shipment and transport overland where the facilities of an old country do not exist, are necessary. The plant must be easily erected, without bricklayers, masons, or plumbers, or other skilled labour, under the supervision of an engineer, with what assistance can be had from the miners, labourers, and natives. Fig. 1 shows a mining plant complete for raising gold quartz in South Africa, and consists of winding, pumping, air compressing, and ventilating machinery. The depth of the shaft is 400 feet. Capacity of engine, 16 cubic feet of quartz in a waggon. Capacity of pumps and pipes, 1000 gallons per minute. Ventilating fan, 1000 cubic feet of air per minute. Compressor, sufficient for three rock drills. Weight of the whole packed for shipment, 22 tons. The boilers are of locomotive type, that type being easily shipped and carried, and requiring no flue building and no brick chimney. Two are used as a minimum number, in order that one may be working if the other requires repair or cleaning.

There are three distinct power plants — the winding engine, the compressed air engine, and the air blowing engine for ventilation of the mine. In some plants there is an electric light engine and dynamo as well.

The winding engine shown has also a bell crank mine pump attached for water raising, if any water exists. It is well to have this attachment, for water may at any time be struck.

The sectional view and plan (Fig. 2) shows clearly the general arrangement and the shaft. The blowing engine is a small vertical high-speed single-cylinder engine, driving a fan by belt for ventilation. The ventilation is assisted by the rock drills worked by compressed air. The drills are worked by the third plant, the compressed air engine —a horizontal engine with a cylindrical compressed air reservoir.

The simple form of the winding engine and drums is shown in Fig. 3. The engines have strong cast-iron bed-plates, the slide bars being cast in one piece with the bed-plates, and bored; the cross-heads are fitted with adjustable brasses, the drum sides and flanges are of cast iron, and the barrels lagged with oak or steel plates. If required, the drums can be driven through spur gearing with an intermediate shaft, and fitted with

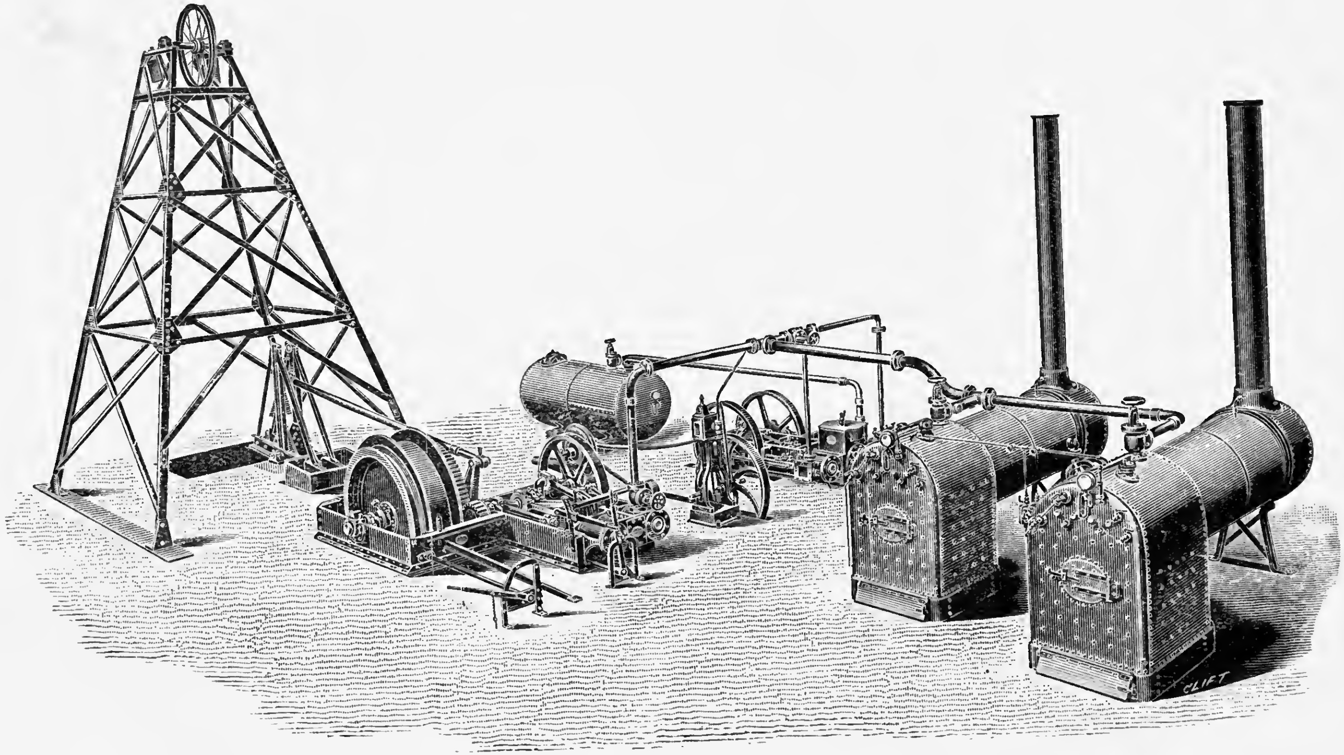


FIG. 1.—Complete Mining Plant.

clutches, pumping crank, etc. The following are standard sizes, and the calculation of loads lifted is based on a boiler pressure of 100 lbs. per square inch, and the assumption that the descending cage and empty tub balance the ascending cage and tub, leaving the nett weight of the material only to be lifted :—

Diameter of Cylinder.	Stroke.	Diameter of Drums.		Maximum Speed of Rope per Minute.	Loads lifted Vertically.	Width of Drums.	Capacity of Drums.
Inches.	Inches.	Feet.	Inches.	Feet.	Cwts.	Inches.	Cubic Feet.
8½	15	4	6	900	12	24	400
9½	15	4	6	900	14	27	400
11	20	5	0	1000	26	34	500
12	20	5	0	1000	29	37	500
14	24	5	6	1100	51	45	600
16	30	6	0	1200	75	53	700

It is good practice now where power is available to use electricity for lighting about the mine, and also for transmitting power for rock drills. Instead of a pump and

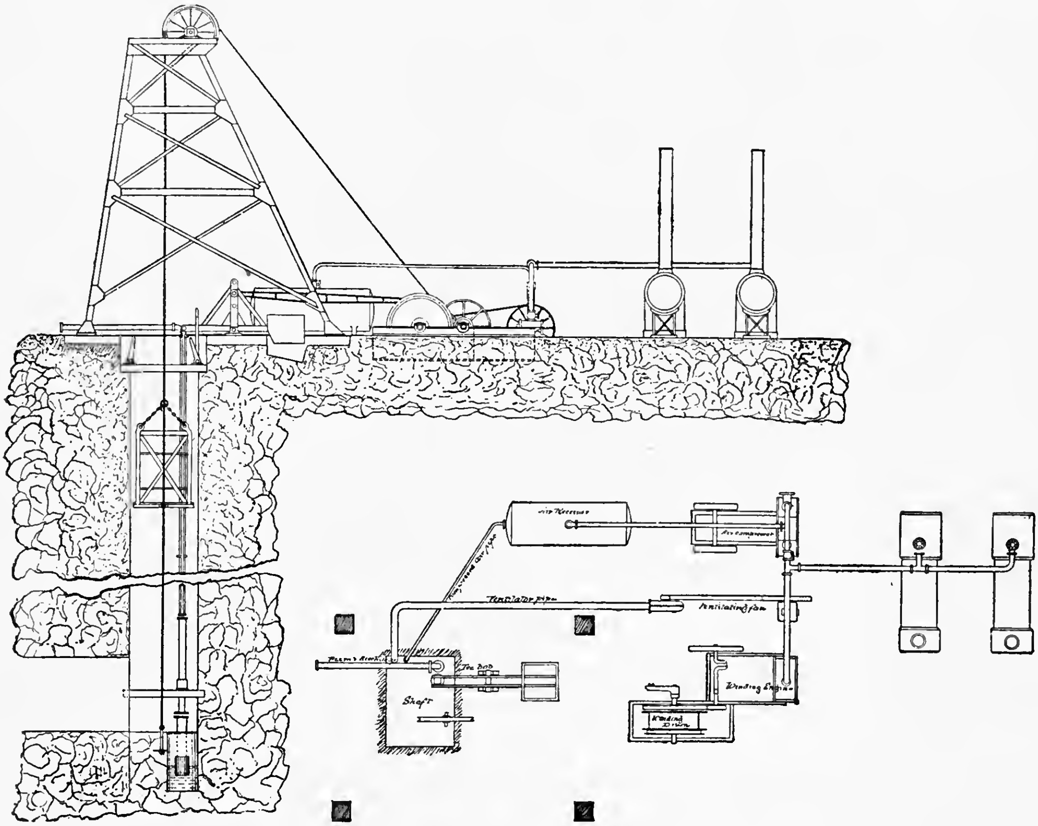


FIG. 2.—Elevation and Plan of Mining Plant.

reservoir at the pit-head, it is better to have an electric driven air pump and reservoir, or two or three such down below, close to the drills, and thus avoid the long lengths of air piping.

If the electric plant is of the right kind, moderate in electric pressure and continuous current, it will be found that the transmission of the power by electricity and the working of the pumps below will be of great advantage ; the only possible drawback being that the drills do not then give much assistance to the ventilation.

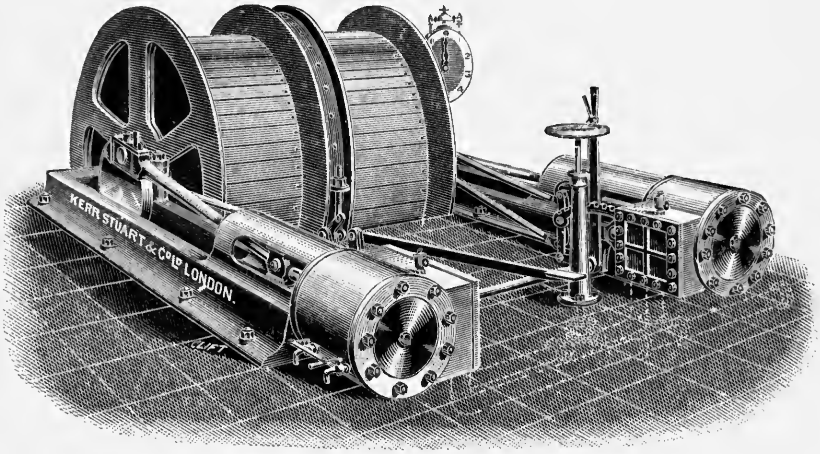


FIG. 3.—Winding Engine for Mining.

We have already described the Reavel air compressor in Volume III., and now show in Fig. 4 the underground mining type mounted on wheels, consisting of two compressors with one electric motor between. The overall dimensions are 6 feet 6 inches by 3 feet 4 inches. Capacity, 550 cubit feet per minute. In order to avoid trouble

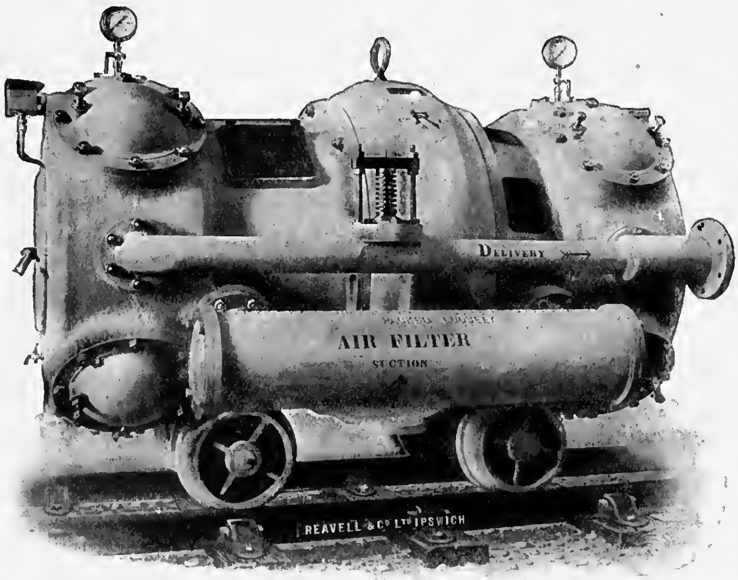


FIG. 4.—Electrically driven Air Compressor for Mining.

from the dust which pervades all mines, a filter is fitted on the suction to intercept the dust.

The air compressor is a double-ended machine, that is to say, there is a set of air compressor cylinders at each end of the motor. Each end of the compressor consists of an independent machine of four cylinders, arranged radially round the crank pin. The cylinders are single acting, and the compressors are of the single stage type.

The compressing pistons (Fig. 5) are provided with balance pistons, which are open to the delivery pressure, and which ensure the parts being maintained in constant thrust, and the result is that the machine is silent in working.

The arrangement of cylinders is such that the torque is practically constant, and therefore it forms an ideal drive for the motor. The armature of the motor, in the machine illustrated, is mounted on the compressor shaft, and the magnet frame is carried by the two compressor housings. This arrangement makes an extremely compact design, and a machine of this kind can very easily be made portable, and is therefore well suited for shipyard work, where the machine might be used in different parts of the yard, and it is also very well suited for colliery work, where the compressor can be taken "in-bye," and can follow up the coal cutting tools as they work forward.

Fig. 5.—Air Compressor Piston.

The compressor has Messrs. Reavel's patent arrangement of suction inlet, by which suction valves are entirely dispensed with. The air is admitted through ports in the connecting rod gudgeons (Fig. 6), which correspond with ports in the piston during the suction stroke. These ports are automatically closed by the movement of the crank pin when the compressing stroke is commenced.

With this type of compressor there are eight cylinders, each delivering air every revolution, and therefore there is practically a constant delivery of air at the desired pressure from the machine. It is not therefore necessary for a large reservoir to be used in order to obtain this constant flow of air.

With this system of working rock drills all that is necessary to follow up the drift or seam or lode as it advances is to pay out electric cable, which may be carried easily on drums.

In places where rails are not used a small type of electric compressor is made which can be moved along by levers and rollers.

Fig. 6.—Connecting Rod.

It has been attempted to employ electric percussion rock drills, and so to render compressed air unnecessary altogether, but without success. Electricity as a transmitter of power by rotary motors is unequalled, but it is utterly useless for reciprocating motors. It does not follow naturally, because an operation or work is done by electricity that it is necessarily better done than by any other means, yet that seems to be the ruling idea among leading electrical engineers. Electricity has its sphere of usefulness in a mine; working percussion drills does not come within that sphere, except only as a means for air compression for air drills.

Colliery or mining winding does not come within its sphere of usefulness. It would be absolute insanity to suppose that by introducing an elaborate switch board, a huge dynamo, and a large motor costing as much as all the other plant together, between the winding engine and the drums in the plant shown on Fig. 1, that anything but a great loss of efficiency could be realised.

Even if mines were worked from a central station, it would be cheaper for a coal mine to use steam direct for winding. But for a gold mine or diamond mine the case is different; they can afford to use electric motors for every purpose. This subject will be more fully discussed in next chapter.

NEW HIGH-SPEED ENGINE OF THE BRUSH COMPANY

Details of this engine have been found since treating the class to which it belongs in Volumes IV. and V. They are exceedingly interesting, as showing the highest development of such prime movers in all the important details which go to make a satisfactory whole. The stiffly designed yet open and accessible box girder bed-plate (Fig. 13), the one-piece standard or column with the fitted guide cylinders (Fig. 12), the simple engine cylinders (Fig. 11), and the cross-head guides (Fig. 10), all show at a glance that every detail has received most painstaking attention of an experienced and highly skilled designer.

This description of the Brush high-speed engine affords a useful summary of the

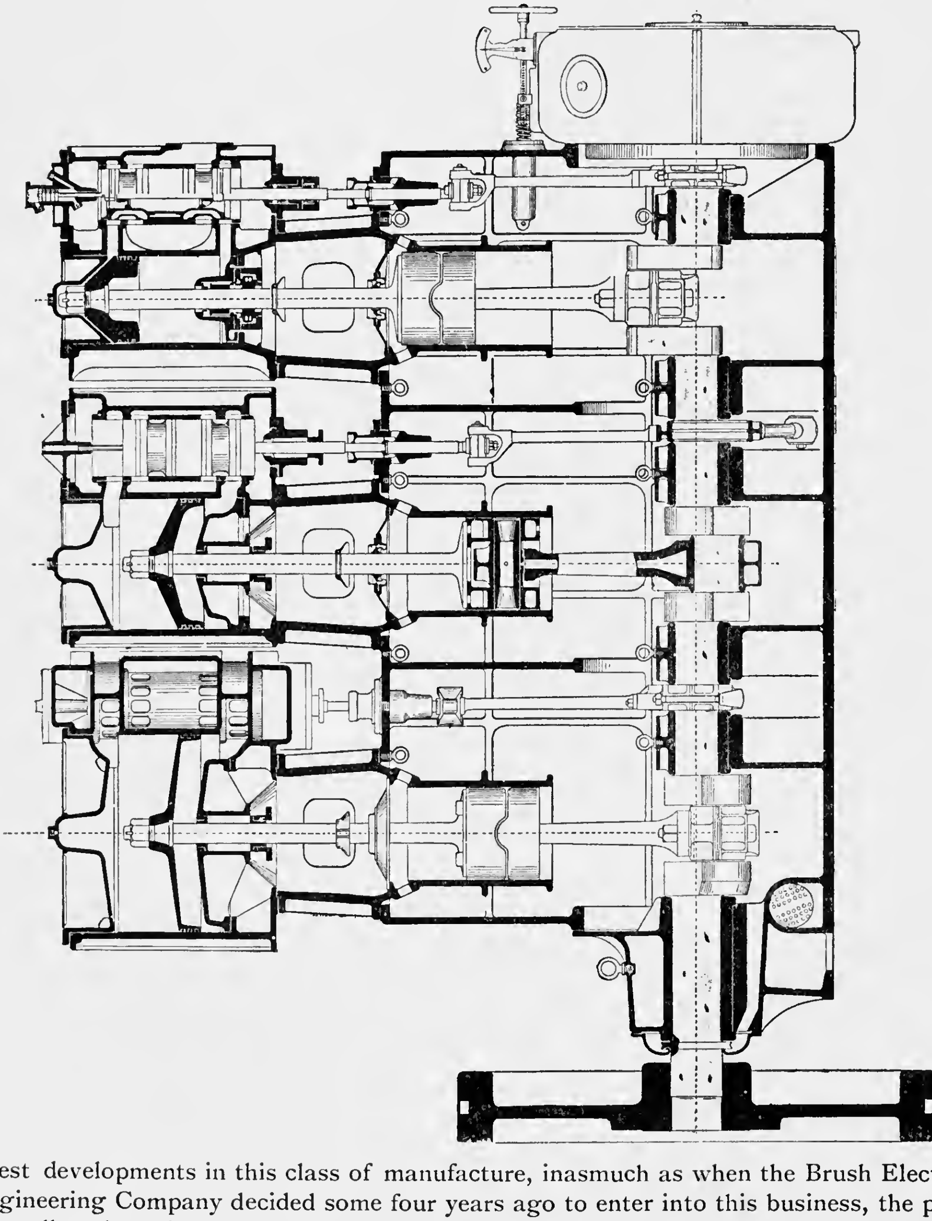


FIG. 7.—Brush Triple-Expansion Engine. Sectional Elevation.

latest developments in this class of manufacture, inasmuch as when the Brush Electrical Engineering Company decided some four years ago to enter into this business, the policy naturally adopted was to begin at the most advanced stage then reached by their competitors.

After very careful investigation it was decided to develop the high-speed double-acting forced-lubrication type of engine side by side with the design and manufacture of the Parson steam turbine.

It was considered that at the present time, taking into account the great efficiency attained by the Parson's turbine, especially in the larger units, the maximum commercially economic size of engines of this type should not exceed 1000 kilowatts, and that this should be the starting-point for the turbine. It may be well, however, before proceeding with the description of their high-speed engine, to state that the company do build turbines of smaller output, and that even with machines of only 250 kilowatts output they have secured very good results.

A recent test of two turbines of this size gave a water consumption on full load of 20 lbs. per kilowatt-hour. The turbine had been in useful operation for three or four months. The steam pressure was 150 lbs. per square inch, superheat about 250° Fahr., and the vacuum 27.25 inches.

As a first step the company determined to build an experimental engine of 500 horse-power, and run it at their works at full load for one year before starting to design and build a complete set of standard engines and generators; and it may be of interest to mention here, as affording evidence of the good wearing qualities of engines of this type, and also as showing the high grade of the workmanship turned out, that this experimental set has been constantly working at nearly full load for over twelve hours a day for about three years, and that not one of the main bearing, crank pin or cross-head pin bushes have been taken up during the whole of this time.

For outputs from 150 to 250 kilowatts the engines are made of the compound 2-crank pattern, with cranks set opposite one another, and for sizes ranging from 200 up to 1000 kilowatts they are built of the triple-expansion 3-crank type, with cranks set at 120 degrees to one another. The speeds range from 400 to 450 revolutions per minute in the 150 kilowatts to 225 to 250 revolutions per minute in the 1000 kilowatts size.

A sectional elevation of the 3-crank engine is shown in Fig. 7.

In all the engines the cylinders are separate castings. The valve chests are fitted with liners, and the valves (Fig. 8) are made either of the shell type machined all over to ensure even thickness of metal and symmetrical expansion under high temperatures; or are also designed so that they can be fitted with spring rings.

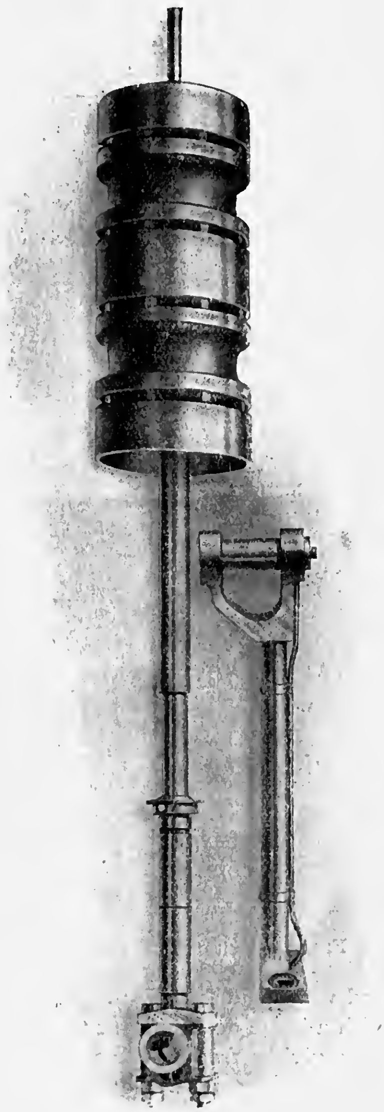


Fig. 8.—Valves and Valve Gear.

The low-pressure cylinders are fitted with pressed steel pistons (Fig. 9) to ensure lightness; the intermediate and high-pressure cylinders with cast-iron pistons, made of the same weight as those for the low-pressure, so that the reciprocating masses on each crank line may be balanced. All the pistons are fitted with rings of the Ramsbottom form.

The cylinders (Fig. 11) are carried on distance pieces, which are cast in one piece with the cross-head guides (Fig. 10). These guides are circular, and cylinders and guides are registered one into the other. The cross-head is also circular, and the piston rod is made to register into it (Fig. 9). In this way the cross-head, piston rod, and piston are made to work in absolute alignment with cross-head, guide, and cylinder by the simple process of assembling, and just as they are delivered to the erecting shop from the machines.

In the earlier days of the enclosed type of engine much trouble was experienced by the oil used in the crank chamber passing into the cylinders by way of the piston rods and glands, and from the cylinders, in the case of the surface condensing sets, into the boilers. To overcome this difficulty the distance pieces mentioned above, which carry the cylinders, and which are bolted to the engine standard or column, are made of such a height that no portion of the piston rods which come into contact with any of the crank chamber oil can enter the cylinders. This oil trouble has by this device been entirely overcome.

The standard or column just referred to, which encloses all the working parts, is a shell of cast iron very strongly ribbed

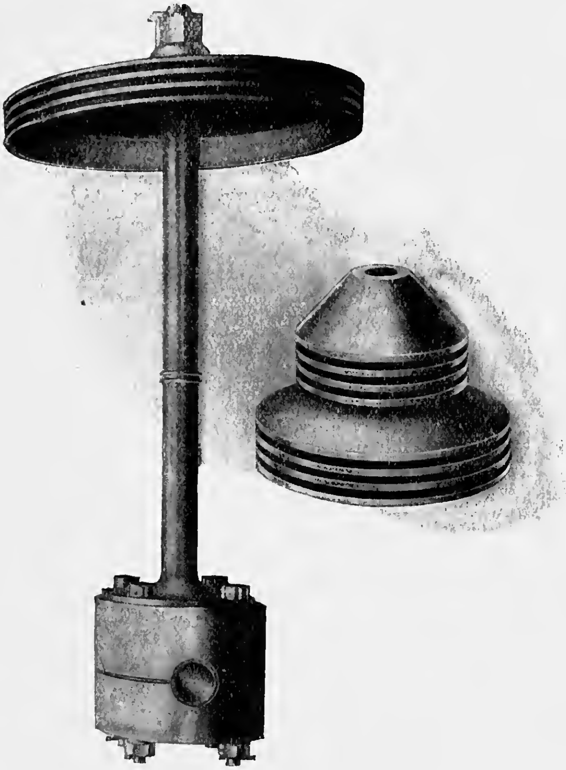


Fig. 9.—Pistons, Piston Rod, and Cross-head.

Fig. 10.—Cross-head Guides.

and very rigid (Fig. 12). It carries the cross-head, guides, and cylinders, and is made with a large door both at the front and at the back of the engine, opposite each crank, thus giving free and easy access to the interior. In addition to this, small hinged doors are fitted to the larger ones on the front of the standard, which can be quickly opened for the examination of bearings, etc., if found necessary.

The engine bed-plate (Fig. 13) is a massive casting of the box girder construction, with the supports for the main bearing cast in. The crank chambers which are formed inside the bed-plate communicate with one another, and form the reservoir for holding the oil used in lubricating the engine parts.

The main bearing supports are bored out true for the reception of the main bearing bushes, the bottom halves of which are circular, so that they can be removed without unshipping or disturbing the crank shaft.

The main bearing and crank pin bushes as well as the eccentric straps are lined with white metal; the cross-head pin and valve rod pin bushes are of bronze.

To ensure a constant supply of oil to all the working surfaces of the engine, including all the governor parts, two pumps are fitted in the case of 3-crank engines, but only one in the 2-crank. They are single-acting, of the valveless type, and driven direct from the eccentrics, and the hand-regulating valve is fitted to some convenient part of the oil main, by which the oil pressure can be varied from about 15 to 30 lbs. per square inch.

The crank shaft (Fig. 14) is of mild Siemens-Martin steel, made to withstand an ultimate tensile stress of about 30 tons per square inch, and an elongation of about 25 per cent. in a 2-inch length. The connecting rod is shown in Fig. 15.

The engines can be fitted with either the throttle valve or the cut off-type of crank-shaft governor; up to the present time they have mostly been fitted with the latter design. As this design presents some novel features we will describe its construction fully. It is shown in Fig. 16 complete, and Fig. 17 shows a sectional elevation and a front elevation.

The governor consists of a carrier A, firmly fixed to the engine crank shaft B, the two governor weights C are centred on bosses cast on this carrier at opposite sides of the centre line. The fulcrum pins D are at right angles to the centre line of the crank shaft, as in the arrangement usually adopted in governors of the throttle-valve type.

This disposition of the governor weights in an automatic expansion governor controlling the cut-off of the steam distribution valve or valves enables a very simple and effective speeding arrangement to be added to the governor, which will be referred to in more detail later.

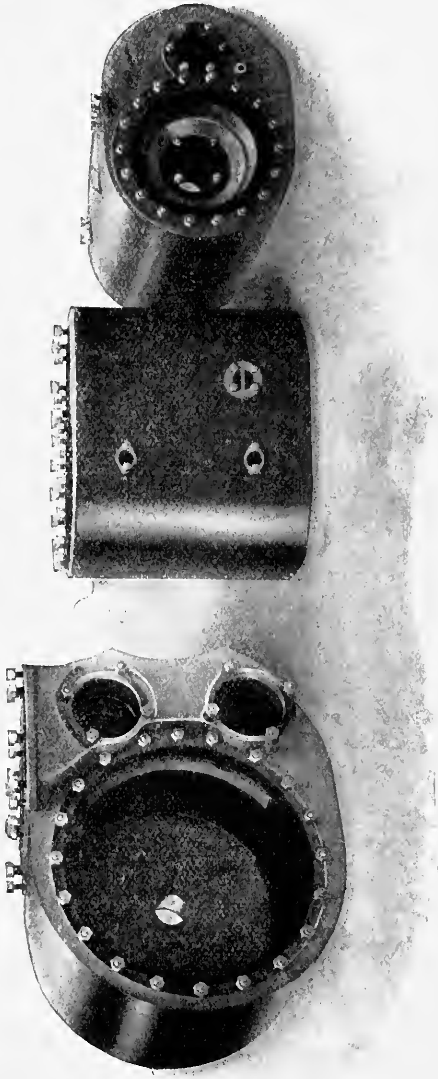


Fig. 11.—Cylinders.

An inertia or oscillating wheel E, centred on the crank shaft, is arranged to swing through a certain maximum angle, and two links F, made with suitable joints, connect the oscillating wheel to the governor weights in such a way that when the weights move outwardly from the centre, or inwardly towards the centre, the inertia wheel has to oscillate through an angle which is proportional to the angle through which the weights move; or reversely, if the inertia wheel swings through any given angle up to the maximum, the weights are compelled to move through angles which are proportional to the angle of swing of the inertia wheel.

On the inertia wheel is fixed an auxiliary eccentric G, which operates the main eccentric H, so that when the inertia wheel and the governor weights take up any new position due to an alteration in the speed of the engine, the travel of the main eccentric is proportionately increased or diminished, this eccentric in its turn acting on the steam distribution valve.

The link U is pivoted at one end to the pin V, which is fixed to the carrier A; at the other end it takes on to the pin W, fixed to the main eccentric H. This link U

Fig. 12.—Standard or Column.

determines the path in which the centre of the main eccentric must move in order to give to the valve the correct cut-off for any given load on the engine.

The position of the weights is controlled by springs K in the usual way.

The governor is fitted with a speeding arrangement, by which the speed of the engine can be adjusted by hand whilst the engine is running.

Attached to each of the governor weights is a lever L, which is connected by a link

M to cross-bars N; these are in turn connected in a suitable way to a sleeve C, which slides on the crank shaft, or an extension of it, in such a way that its position on the shaft is controlled by the weights. A thrust collar or thrust collars P are formed on this sleeve. A ring R, with internal thrust collar or collars, loosely fits round the outside of the

Fig. 13.—Bed-plate.

Fig. 14.—Crank Shaft and Fly-wheel.

sleeve. Levers S are pivoted at Y to any suituble portion of the engine casing. The ring R is suitably attached to one end of these levers, and the other ends of the levers are connected to regulating springs T, the tension of which can be controlled in any suitable way, as, for instance, by the hand wheel X and screw Z. It will be understood, therefore, that the sleeve O rotates inside the non-rotating ring R, while the ring is free to follow the lateral motion of the sleeve imparted to it by the governor weights through the levers, links, and cross-bars already mentioned.

The governor weights, eccentrics, and speeder gear levers are shown in the positions giving the maximum cut-off to the valve; the positions of these same parts giving the minimum cut-off to the valve are shown by the dotted lines. It is claimed that engines fitted with this governor give a little better steam consumption at light loads than they would if fitted with throttle-valve governor, but more especially that it enables the engine when working condensing to do its overload, and when working non-condensing to do its full load, without the use of a bypass, either hand controlled or governor

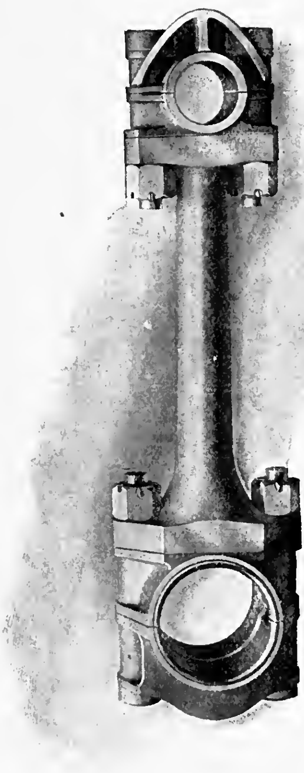


FIG. 15.—Connecting Rod.

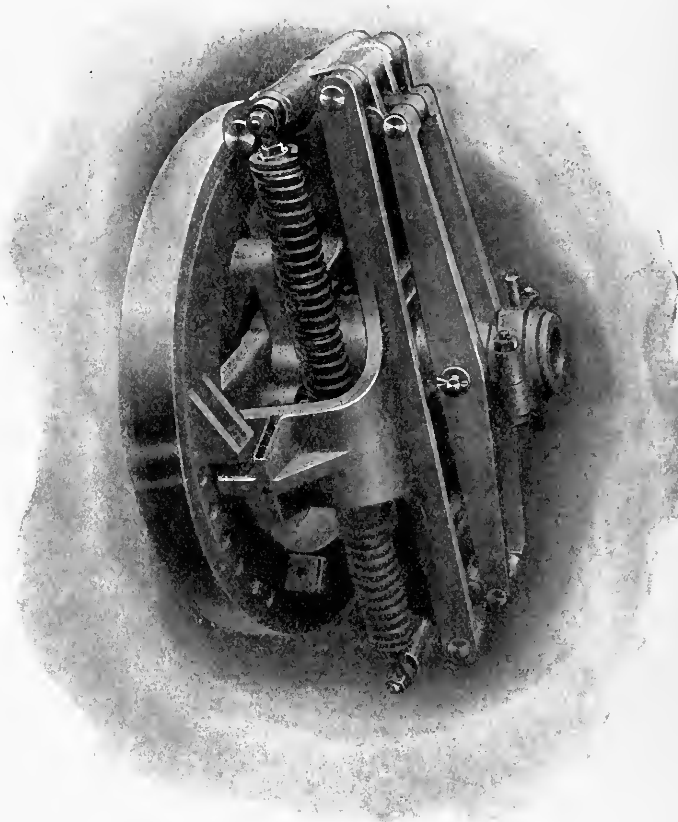


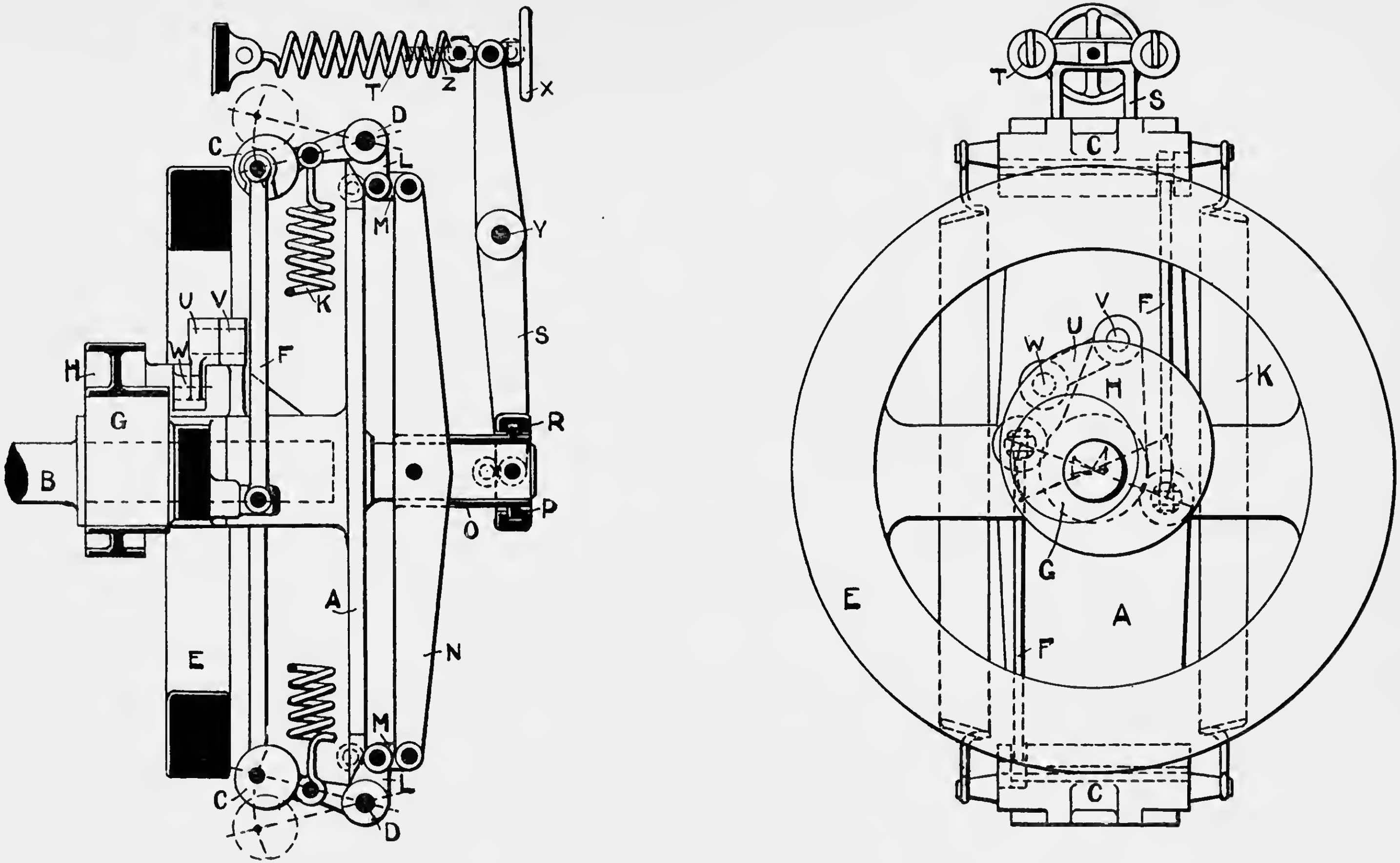
FIG. 16.—Governor.

controlled, and that therefore the engine is under the control of the governor under all conditions of working and of load.

The section shown in Fig. 7 is of one of the standard triple-expansion 3-crank sets, and is taken from the working drawing of a 500-kilowatt engine, and Fig. 18 shows the engine complete.

In high-speed engine work the design of every one of the details, as well as the qualities of the materials used and the workmanship, are of the utmost importance.

The commercial efficiencies of the Brush generating sets, that is $\frac{\text{E.H.P.}}{\text{I.H.P.}}$, are very



Sectional Elevation.

Front View.

FIG. 17.—Governor of Brush Companies Engine.

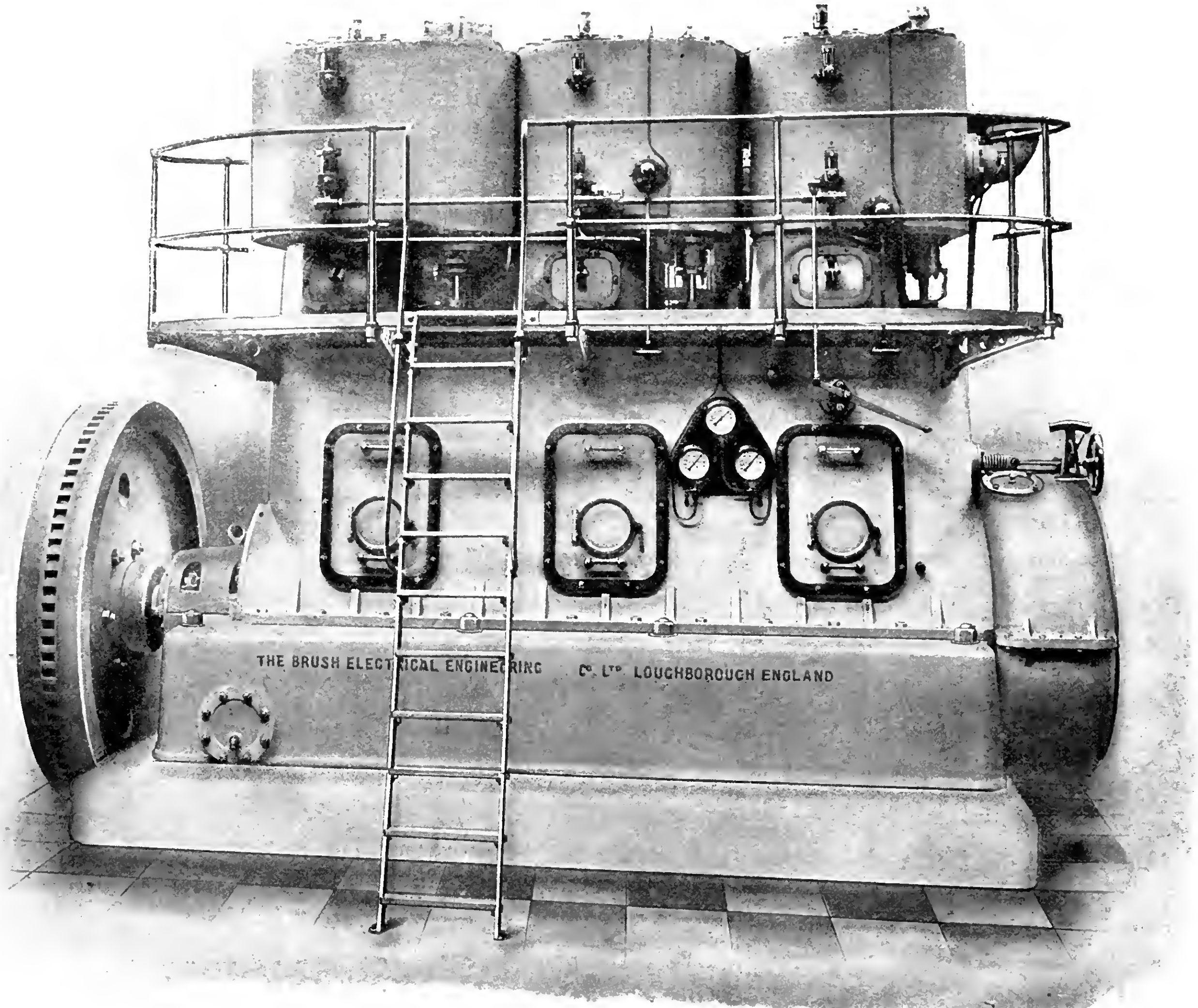


Fig. 18.—Brush Triple-Expansion Engine.

high—the following results being commonly obtained immediately after the plant has been erected, and often after only one day's run :—

Full load—88 to 90 per cent.
Three-quarter load—85 to 87 per cent.
Half load—83 to 84 per cent.
Quarter load—69 to 71 per cent.

With regard to steam consumption, taking a typical case of a plant of 500 kilowatts output, in which the steam pressure at the stop valve is about 150 lbs. per square inch, and the boiler pressure only from 5 to 10 per cent. higher, with superheat of about 100° Fahr., and vacuum from 25 to 26 inches of mercury, the water per kilowatt-hour, as measured by weighing the quantity discharged by the air pump, would be—

Full load—20 lbs.
Three-quarter load—29.25 lbs.
Half load—21.5 lbs.
Quarter load—25 lbs.

THE BROWETT & LINDLEY HIGH-SPEED VERTICAL ENGINE

This engine is shown in sectional drawings and photographs (Fig. 19) of their latest type of enclosed forced lubrication engines.

The engines are lubricated on the now well-known principle of oil forced into all

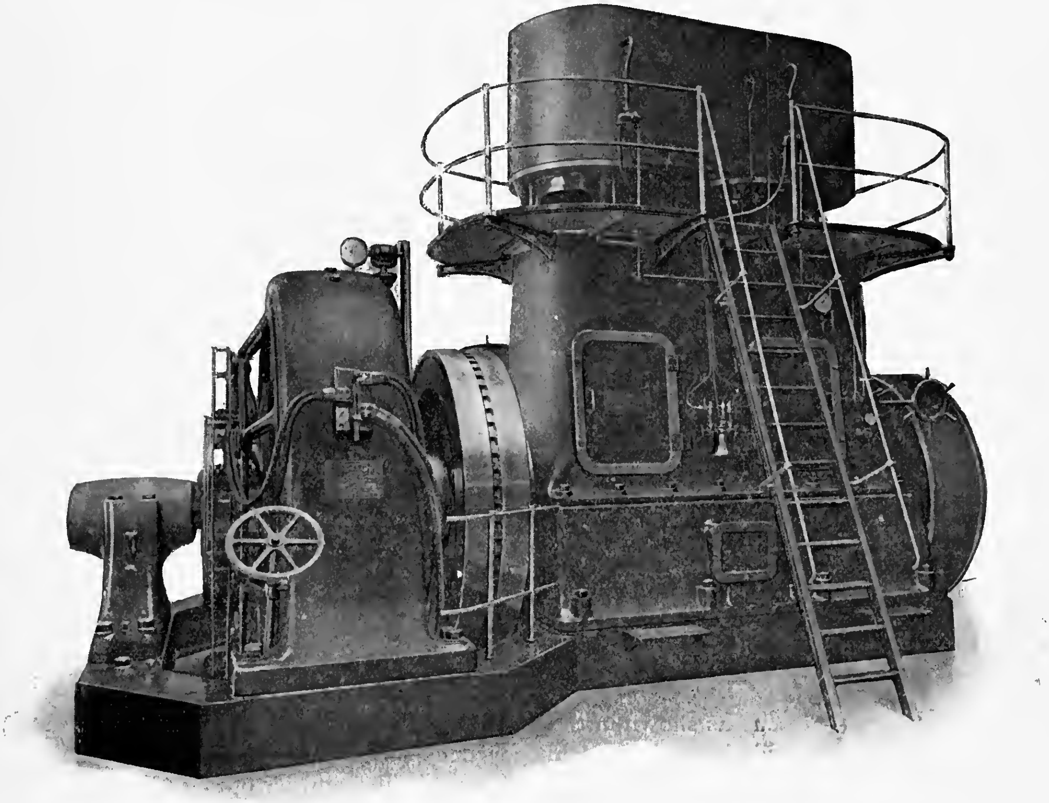


FIG. 19.—Browett & Lindley Engine.

bearings by means of a simple valveless pump (Fig. 20), which is located in the lower portion of the engine bed, and worked off one of the main eccentrics. The speed of the engine is controlled in all cases by throttle governor, acting direct on a double-beat throttle valve (Fig. 21).

The compound engine shown in Fig. 19 is usually made with cylinders about

21 and 36 inches diameter, and is run at a speed of 250 revolutions per minute, developing an indicated horse-power of about 1000, depending on the steam pressure.

The details of the oil pump are shown in the drawings to scale. The oscillating cylinder works over ports on a trunion, thus obviating the use of valves. The governor is also shown in the drawing to scale, and, like the rest of the engine, is forced lubricated.

The oil pump details are interesting, as they show completely how simple it is ; and as it is now employed on nearly all high-speed engines, it may here be more fully described

The pump barrel oscillates upon a large hollow pin in which two ports—a suction

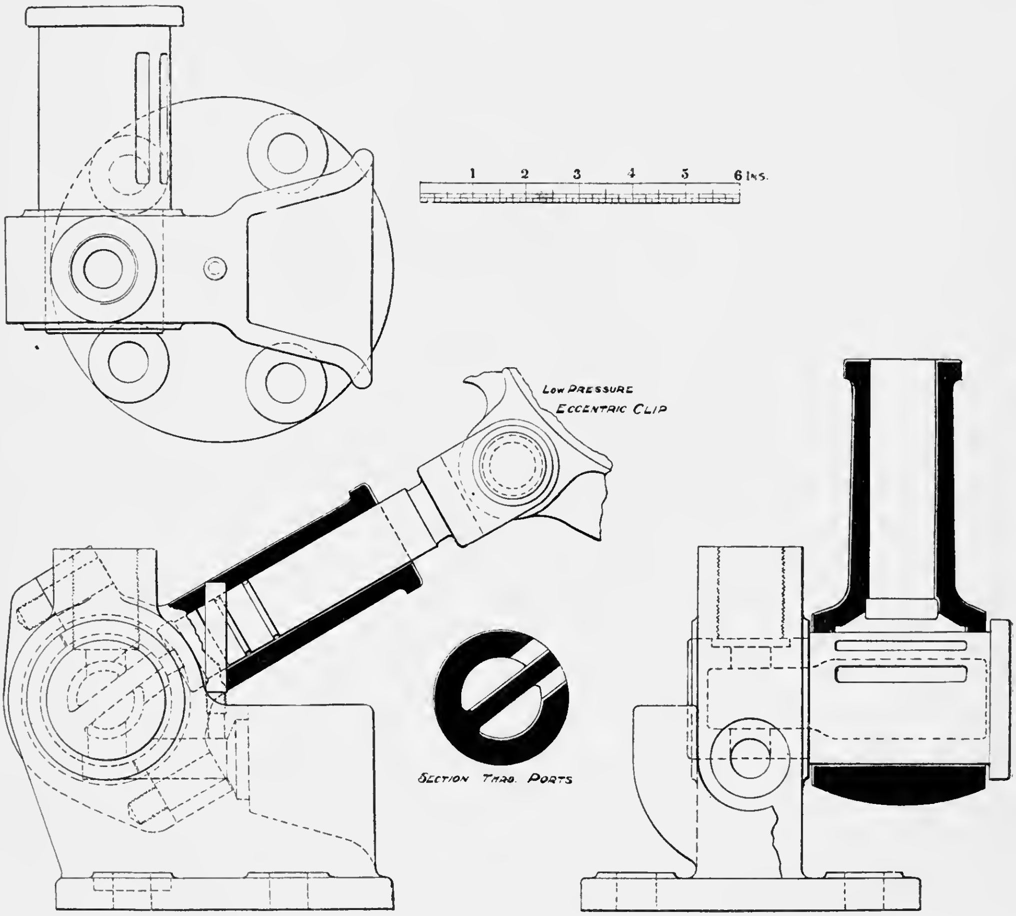


FIG. 20.—Valveless Pump.

and delivery port—are cut as shown in the section. In the bottom of the pump barrel is cut one port. As the cylinder oscillates this port comes over the suction port on the pin when the piston is on the out-stroke and draws in the oil from the bottom of the crank case; on the in-stroke of the piston the cylinder port is over the delivery port on the hollow pin, and the oil is forced out through the whole lubricating system. It will be seen that no valves are necessary, and that the motion is of the simplest and most direct kind—all wear being confined to two pinned joints.

The governor (Fig. 21) is fixed to the end of the crank shaft, which is hollow and contains the lubricating oil under pressure, so that by coupling the governor joints by pipes to this oil supply it also is thoroughly well lubricated.

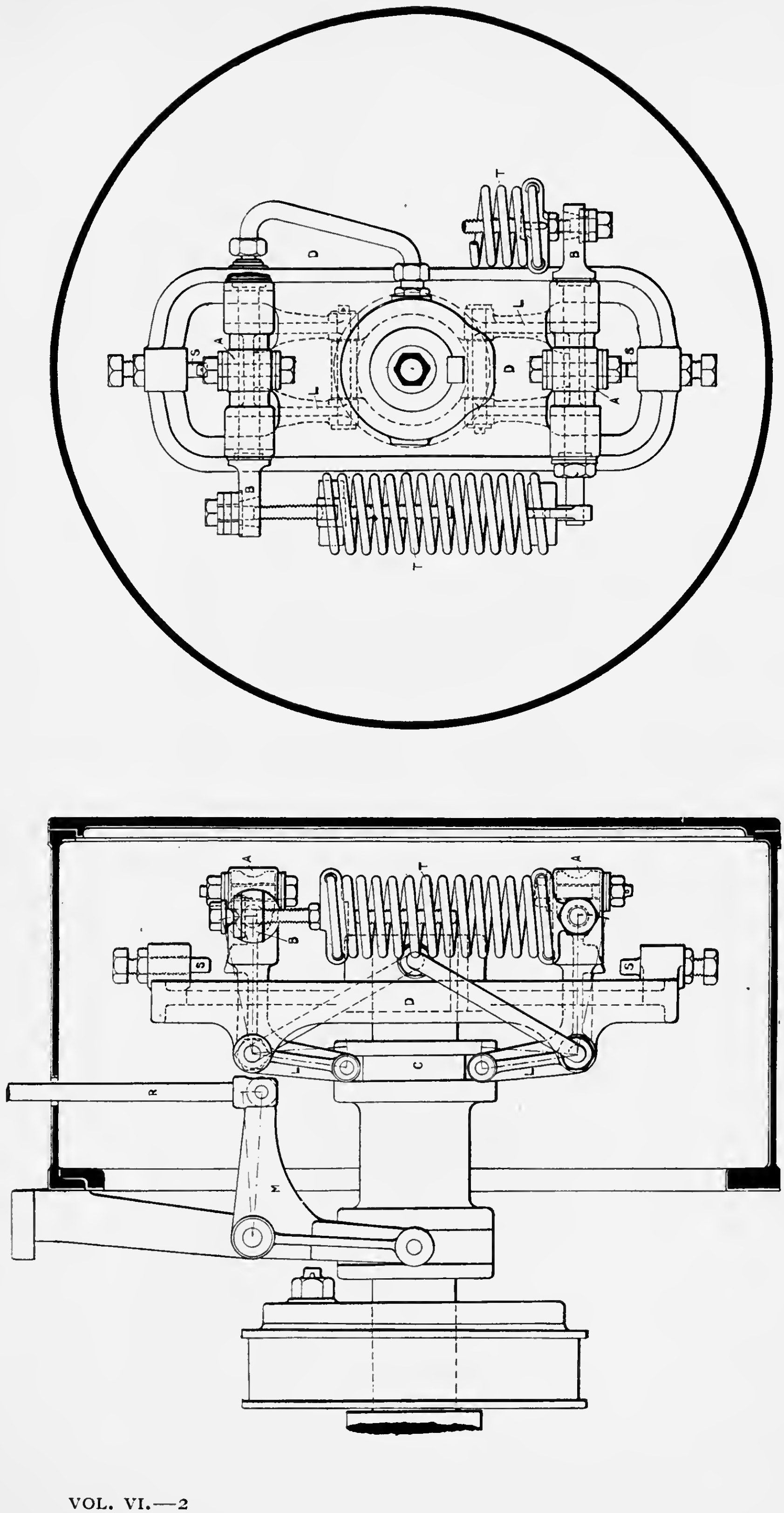


FIG. 21.—Throttle Governor.

The two governor weights are carried on bell crank levers L, L, and are directly connected by the governor springs T, T. The bell cranks operate upon a sleeve C sliding on the crank shaft, and this same sleeve operates the bell crank M and valve rod R. This rod R is shown in the longitudinal sectional view, fitted with a spring and adjustable screw for varying the speed while the engine is in motion.

The governor valve is of the usual equilibrium or Cornish valve type.

The engines have been largely used in electricity works for dynamo and alternator driving.

DESCRIPTION OF LATEST TYPE OF BRUSH-PARSONS TURBINE

The Brush turbine is of the Parsons horizontal type. The rotor (Fig. 22) consists of a steel drum, to which the brass blades, separated by suitable distance pieces, are held by caulking in parallel grooves turned in its circumference, to permit of efficient steam expansion. The diameter of the rotor is increased in four steps from steam inlet to exhaust; and on the other side of steam inlet the rotor is also stepped to form dummy pistons of suitable area to balance the end thrust on the blades. In the smaller turbines the rotor is built up of three pieces: a central barrel and two end spindles, on which it rotates; in the larger turbines, of six pieces.

At the exhaust end of the rotor is attached a flexible coupling, while the other end carries a helical wheel for driving the governor and oil pump; also an adjustable thrust block for taking that part of the end thrust not balanced by the dummy pistons.

The dummy pistons have rings turned out of the solid metal, which rotate very close to but not in contact with rings fixed to the cylinder.

Steam leaks slowly past these, and escapes through passages cast in the cylinder, which equalise the pressure on each piston and that at the corresponding point in the blade system.

The rotor spindle is supported on bearings which rest in spherical seats, and are abundantly lubricated by means of a rotary oil pump, which draws from an oil reservoir through a strainer, and forces the oil through a cooler on its way to the bearing. The oil reservoir and cooler are contained in the cast-iron bed-plate.

The cylinder material is dense cast iron, and is made in two halves, which are joined along a horizontal plane passing through the rotor axis. Each half is built up of three sections permanently bolted together.

Cast solid with the bottom half of cylinder are the supports for the bearings, with the necessary oil passages. The blades are fixed in the cylinder as in the rotor, by caulking in grooves turned in its inner surface.

Bolted to the bottom half of cylinder is the valve box containing the governing valve and stop valve. The former is worked by a steam relay controller by the governor, and is given a periodic motion, from an eccentric attached to the oil pump spindle.

The governor is of the spring controller centrifugal type; and is pivoted on knife edges. A speeder spring is fitted so that the speed may be varied while the turbine is running.

An emergency governor is attached to the main governor spindle, and is arranged to cut off the steam supply to the turbine when the speed rises beyond a given limit.

The main points distinguishing this from the older and more generally adopted design are the following:—

1. Greatly decreased length.
2. Higher peripheral speeds.
3. Modified position of the steam inlet on bottom half of cylinder casting, thus permitting the cylinder cover to be removed at any time without breaking steam pipe joints.

FIG. 22.—Rotor of Brush Company's Turbine.

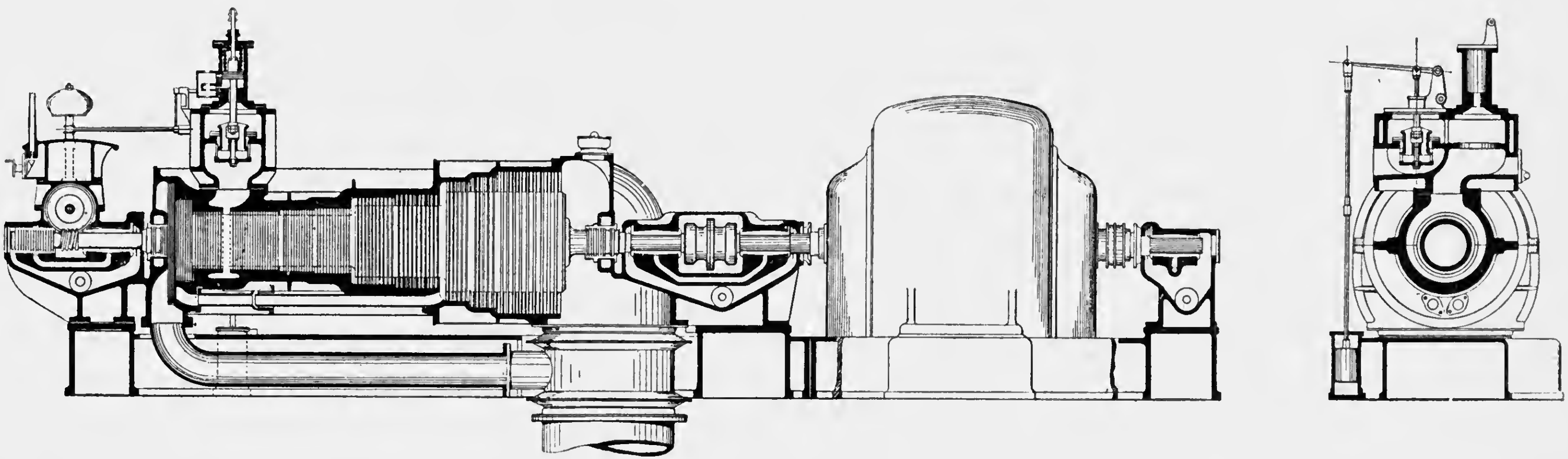


FIG. 23.—Section of Brush Steam Turbine.

4. A special powerful and sensitive governor and simplified governor gear.
5. Combined bed-plate eliminating any chance of accident through careless erecting.
6. Specially large exhaust passages.
7. Rotary oil pump.
8. Adjustable thrust.
9. Adjustable bearings on spherical seats.

Fig. 22 is a photograph of a turbine rotor of the older design, at the Loughborough Electricity Work, which has just been equipped with two 250-kilowatt turbines of Brush Company manufacture, and gave on test a steam consumption of 19.9 lbs. per kilowatt-hour, a result which, considering the fact that the units are only 250-kilowatt capacity, is an exceptionally good one.

Referring to Figs. 24 and 25, the double-beat valve is attached to the piston of a steam relay cylinder, which is continuously supplied with a small amount of throttled steam on the under side of its piston.

A strong spiral spring on the upper side of the piston tends to keep the valve down on its seat against the upward pressure of the steam on the under side of the piston.

The small piston valve of the steam relay controls the exhaust of this cylinder. When the relay opens to exhaust the steam under the piston is free to escape, and the spring can close the double-beat valve. When the exhaust is throttled or closed by the piston valve the steam pressure overcomes the push of the spring, and the valve is lifted.

The relay piston valve receives an intermittent reciprocating motion from a cam on the shaft.

The position of the relay piston valve in relation to its exhaust port passage is controlled by an ordinary centrifugal spring governor, in such a way that at light loads and at no load the exhaust is more fully open than at the higher loads, and consequently the regulating valve is open to steam for shorter periods at the lighter than at the heavier loads. At full and overload the valve is almost continuously full open.

One advantage of the reciprocating motion given to the valve and gear is that the whole of the governing mechanism is always on the go, and is therefore ever ready to respond to even the slightest changes in the load.

Although at first sight this gear may seem to be of the cut-off type, an examination of the curves of total water consumption show that these follow the Willans straight line law, which is the characteristic of throttle-governed engines.

A second governor, exactly similar to the first, controls a second double-beat emergency valve, which only comes into play if, perchance, the main governor fails to act. The emergency valve can also be controlled by hand.

The throttled steam mentioned above, which works the steam relay cylinder, is used after exhaust from this cylinder to supply the glands with the steam necessary to prevent air leakage into the vacuum chambers.

The crank shaft is driven by the worm-reducing gear. It drives, as well as the cam already mentioned, the two governors by means of bevel gears, and also the oil pump.

In all machines designed to abstract kinetic energy from a moving mass in an efficient way it is most important that the mass should glide on to that portion of the machine, generally a rotating wheel, whose function it is to absorb kinetic energy, absolutely without shock.

That this may be so in the steam turbines we are considering, it is necessary to observe certain relations between the path of the steam and the angles of the blades, and also between the velocity of the steam and the speed of the blades.

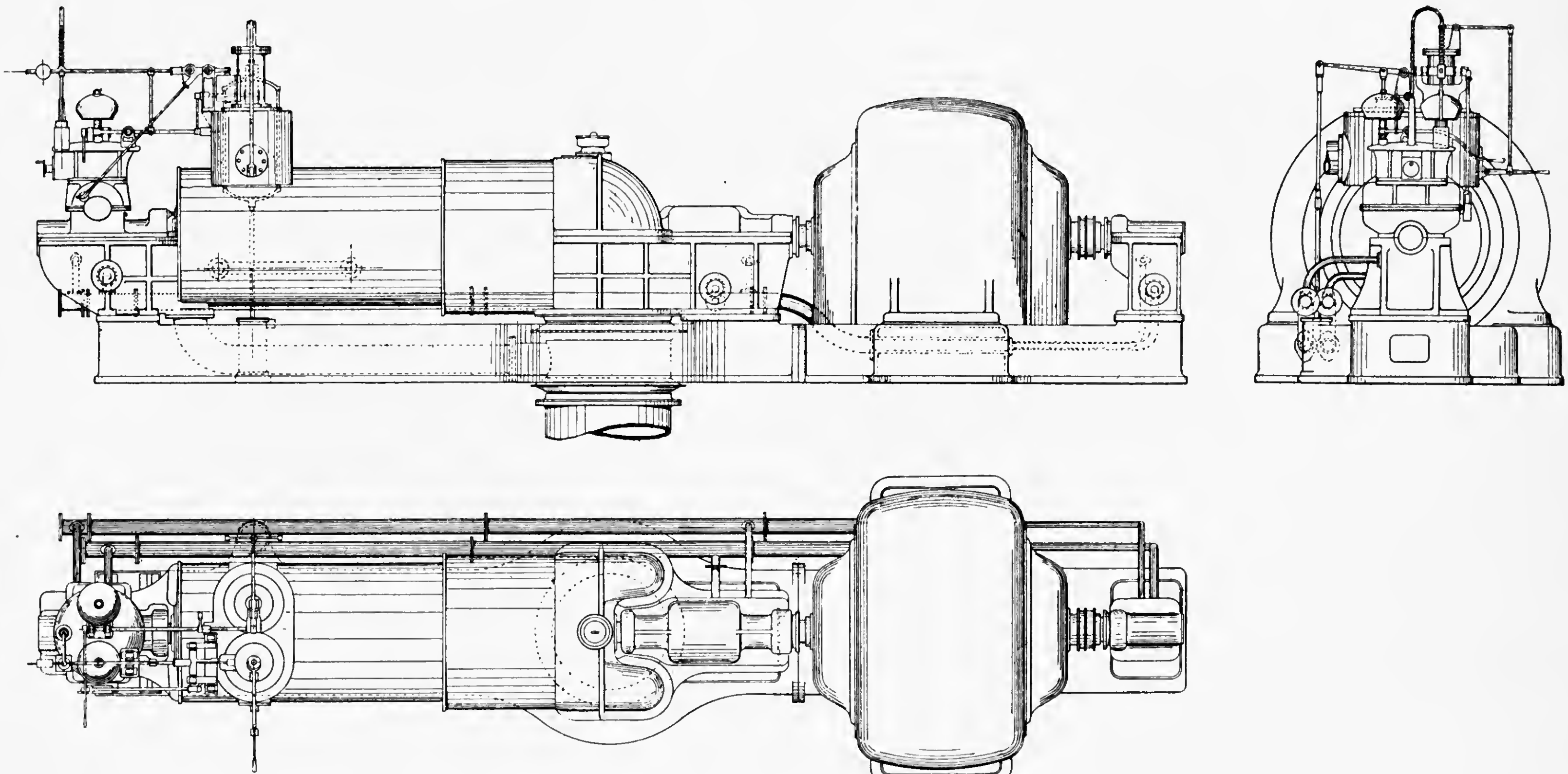


FIG. 24.—Plan, Elevation, and End View of Brush Steam Turbine.

An important relation is that between the absolute velocity of the steam before it enters the moving blades and the speed of the moving blades themselves. This latter is always a fraction of V, and, generally, the larger this fraction the higher the efficiency of the turbine.

In practice the velocity of the moving blades is often one-half of the absolute velocity of the steam.

The angle a, the absolute velocity of the steam, and the speed of the blades having been fixed, the entrance angle θ of the moving blades must be formed so that the resultant path of the steam obtained by combining absolute velocity with speed of blades shall be parallel to the surface of the moving blades at entrance.

The steam will now flow along and parallel to the surface of the blade until it reaches the point of exit, making with the line the angle.

If free to choose this angle, we shall naturally make it so as to give as high an efficiency as practicable.

This angle, however, once fixed, the angle θ must be constructed so that the resultant path of the steam, obtained by combining the velocity of the steam at exit relatively to the blades with the speed of the blades, shall be parallel to the surface of the fixed guide blades at entrance.

The shape of the curved portion of the blade between the inlet and outlet surfaces is not of much importance, provided it is smooth and takes the steam from one side to the other by a short and easy path.

With regard to turbines and reciprocating engines, at present there is room for both. For the smaller units, and when working non-condensing, the reciprocator has undoubtedly the advantage; but from 400 to 500 kilowatt output and upwards, and when working condensing with a good vacuum that can be obtained at a small cost, the advantages are often on the side of the turbine. It is for the engineer to study each case on its merits, and then decide which plant he will use.

It is a frequent complaint that comparisons of efficiencies are made between turbines working with very high and reciprocators with lower vacua.

It is, however, well known that the steam efficiency of the ordinary engine only increases to a small extent when the vacuum rises beyond twenty-five inches of mercury, and this is more marked in high-speed than in low-speed engines.

The reason is obvious, as a consideration of the following table will show.

The volumes are here given of 1 lb. of saturated steam at atmospheric pressure, and also at vacua varying from twenty-five to twenty-nine inches of mercury. In the top line are given the actual volumes in cubic feet; in the lower line, for the sake of more easy comparison, the volume at atmospheric pressure is given as unity; the others in multiples of unity.

Vacuum in inches of mercury .	0	25	26	27	28	29
Volume of 1 lb. of saturated steam in cubic feet . .	26.36	145	177.6	237	347.6	709
Comparative volume—volume at 0 inches vacuum = 1 .	1	5.52	6.75	9	13.3	27

The tables show how greatly the volumes increase with each inch drop in the absolute pressure beyond that due to twenty-five inches of mercury, and how great is the volume to be dealt with when the vacuum reaches twenty-eight or twenty-nine inches of mercury.

The following tabular comparison of the condensing plants required for reciprocat-

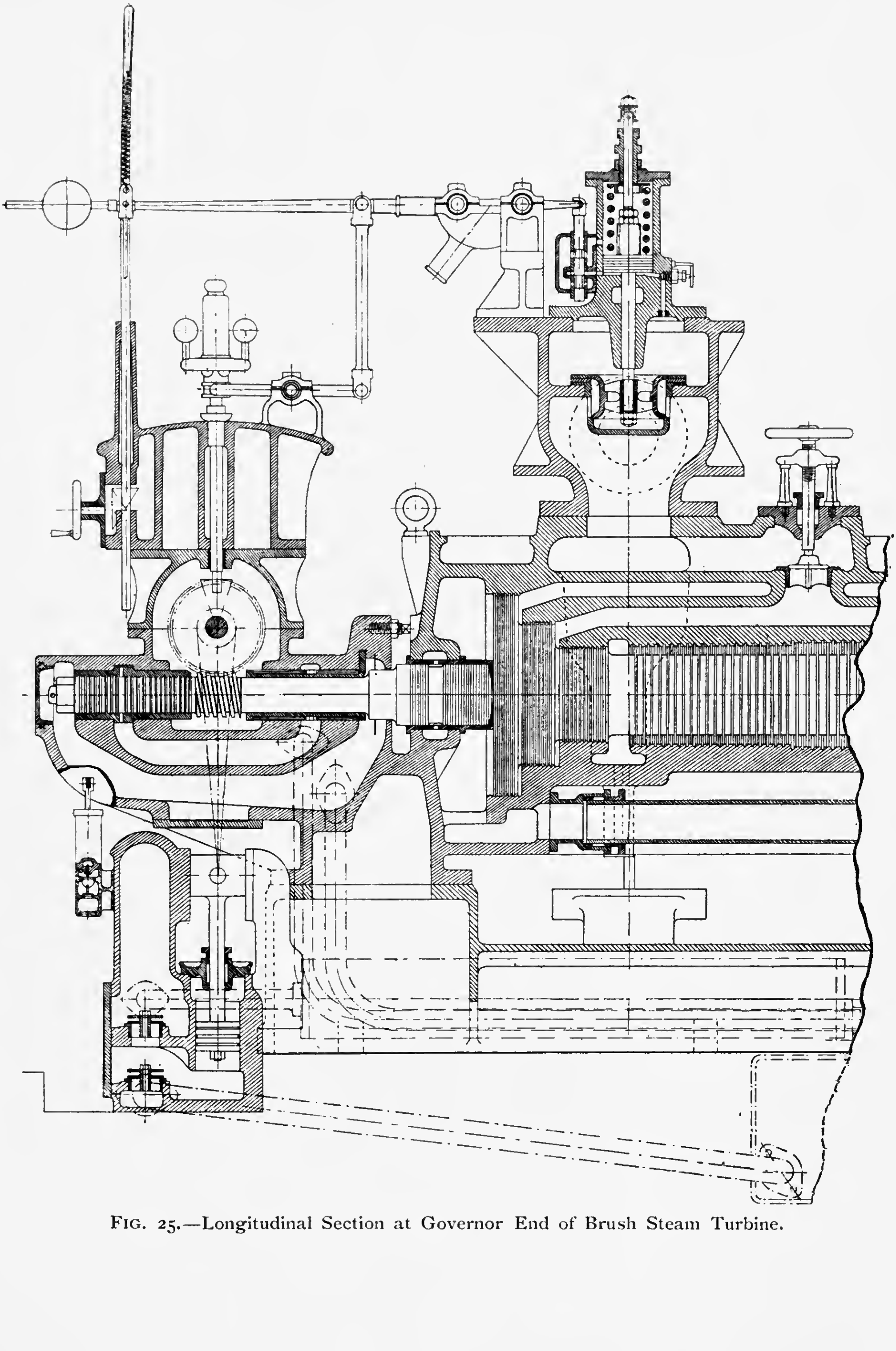


FIG. 25.—Longitudinal Section at Governor End of Brush Steam Turbine.

ing and turbine sets of 500-kilowatt output working with saturated steam will be of interest :—

Particulars.	Reciprocator.	Turbines.
Consumption of steam per kilowatt-hour—lbs.	24	22.5
Steam to be condensed per hour—lbs.	12,000	11,250
Tube surface in square feet	1050	1540
Vacuum in condenser—inches of mercury	26.5	28
Air pump capacity—cubic feet per minute	125	150
Brake horse-power to drive air pump	3.3	3.85
Circulating water—gallons per minute	730	830
Brake horse-power to drive circulating pump	5.5	6.3
Temperature circulating water inlet	65° F.	65° F.
,, ,, ,, outlet	95° F.	90° F.
Mean temperature in condenser	119° F.	100° F.
Cost prime mover and generator	£3250	£3250
Cost condensing plant	£556	£659
Total cost	£3806	£3909

Extra cost of turbo plant over reciprocating plant about 2.7 per cent.; but inasmuch as the engine will probably be fitted with an oil filter for extracting the oil from the exhaust steam, the cost of the turbo plant will probably not be more than the other.

The turbine requires no holding-down bolts, the foundations and buildings are less costly, and crane capacity required is less ; add to this that no lubricating oil is necessary for cylinder lubrication, and the turbine comes out very favourably in comparison with the reciprocating engine.

With regard to superheat, both types of engines derive great benefit from its use, but for different reasons.

This concludes the consideration of engines as applied to different purposes. Steam still holding the leading position as the working fluid in heat engines, its generation is of great importance, and the construction of boilers a subject for study by all engineers. The steam boiler will now occupy considerable space in its many varied forms.

CHAPTER II

STEAM BOILERS

THE question is often asked, What is the best type of steam boiler? The answer to this question depends upon the purpose to which the boiler is to be put. A boiler suitable for a marine engine is not necessarily the best for a locomotive, and a land engine in a mill or factory may be best suited with a boiler which might not be the best for either a marine or locomotive engine.

There exists a great deal of criticism adverse to cylindrical boilers, on account of unequal heating effects causing racking strains and the inefficient heating by large

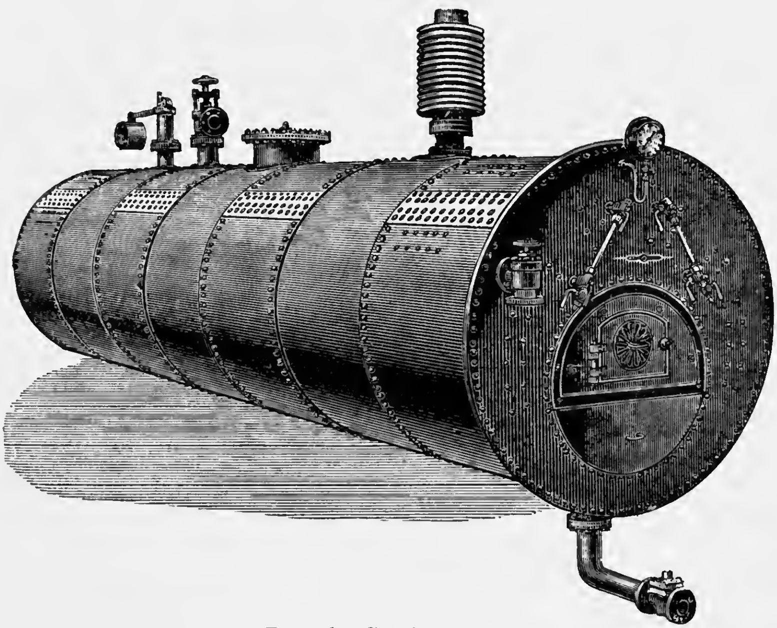


FIG. 26.—Cornish Boiler.

unbroken masses of hot gases, lack of circulation, great bulk and weight, nevertheless they are largely in use, and give considerable satisfaction to the users. A good Lancashire boiler is not out of place in a factory or works.

The Cornish boiler has a single internal flue, and is generally only used for small powers. The hot gases traverse the central flue, in which cross tubes are sometimes placed to increase the heating surface; the gases then pass along the bottom through a brickwork flue, and thence split into two streams flowing each along one side of the boiler back to the chimney. The flat ends require gusset stays for stiffening. This type of boiler is shown in Fig. 26.

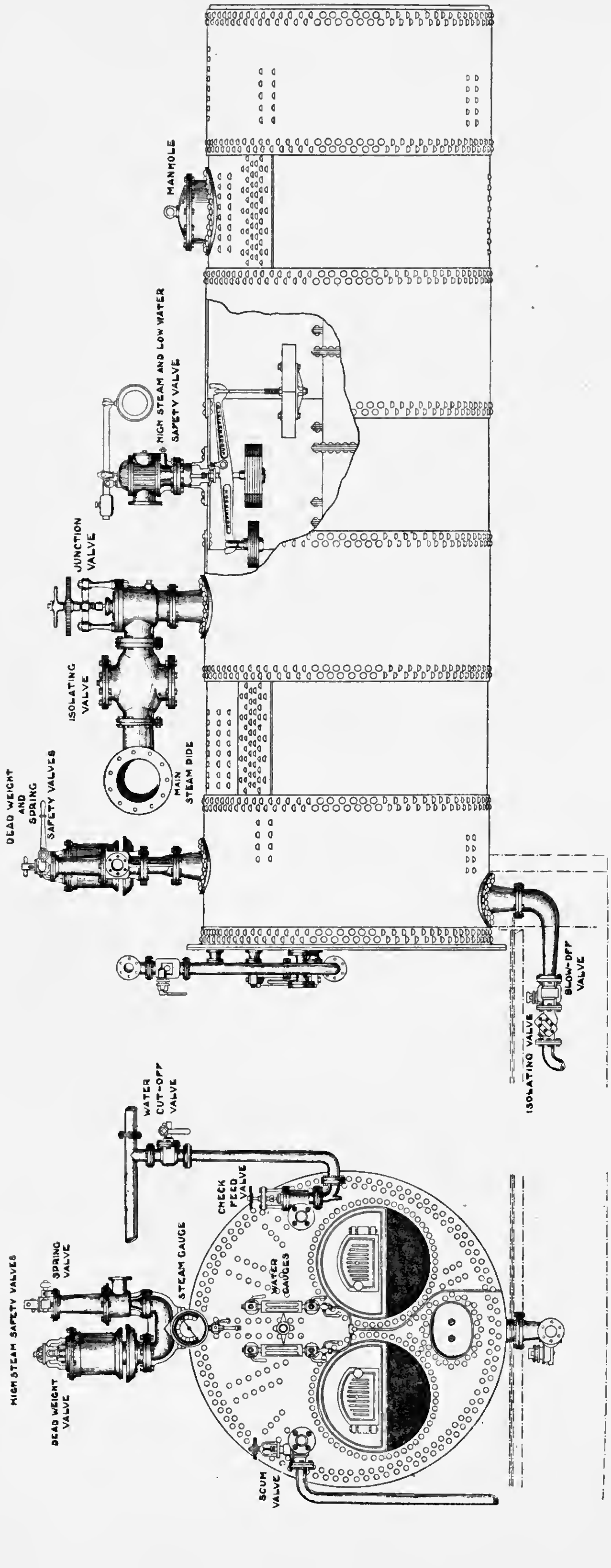


FIG. 27.—Lancashire Boiler.

The Lancashire boiler is of the same construction, but has two furnace flues. It is shown in Fig. 27 complete with all its mountings. First, there is the manhole for providing access to the boiler; then there is the safety valve, which blows off when steam pressure is too high, and blows off also when the water level is too low,—the float hung on the balance sinks as the water falls in level and pulls open the valve. Then we have the main stop valve on the junction of the steam pipe, and an isolating valve to cut off communication automatically from other boilers when by any cause the pressure should fall in this boiler. Then there is the dead weight and spring-safety valve, which are adjusted and locked so that they guard against any tampering with the high and low safety valve. In front there is the pressure gauge and two water gauges, feed-water valve, scum valve, manhole and blow-off valve. The scum valve blows off from the surface all floating impurities, and the blow-off valve is for clearing out mud and sediment collecting at the bottom. The large quantities of water evaporated leave behind the dissolved salts and minerals which all natural waters contain, more or less; hence in time the residue in the water in the boiler becomes salt and muddy, and must be blown away.

Figs. 27 and 28 show the Lancashire boiler in all its details.

The Scotch marine type of boiler with return tubes is shown in Fig. 29. The regular repairs required on board ship where this type is so largely used are: replacing

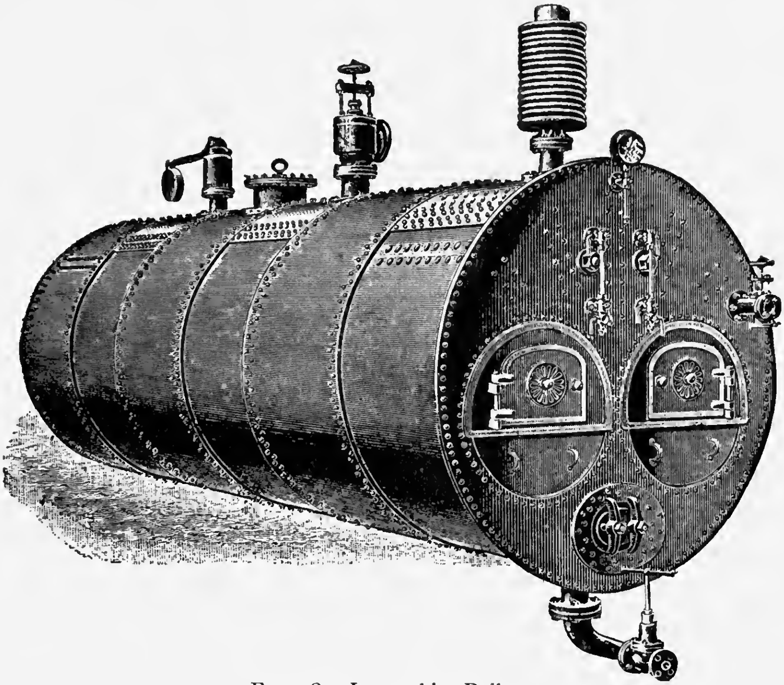


Fig. 28.—Lancashire Boiler.

of combustion chamber stays; repairs to combustion chamber, which gets out of shape; and re-expanding of tubes. These defects are well known to marine engineers, and

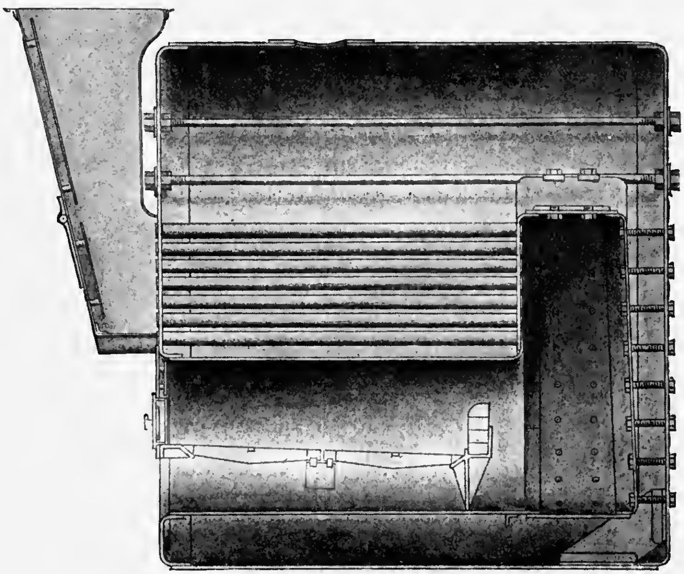


Fig. 29.—Scotch Marine Boiler.

has led, even in marine work, to the adoption of water-tube boilers. It is a boiler, however, which has done good work, and is still largely used in vessels of all sizes, being self-contained and having large capacity and a good steamer.

It is, however, very heavy, requiring a thick shell and the flat ends very heavily stayed.

A modification of this type of boiler with a dry back and two sets of tubes, through one set of which the hot gases return to the back end, is shown in end and side elevation in Figs. 30 and 31, and in its brick setting in Fig. 32.

THE PAXMAN "ECONOMIC" BOILER

The Paxman "Economic" boiler is essentially a flue and tubular boiler set in brickwork, with a combustion chamber in the rear, into which the gases, after escaping over the bridge and passing through the flues, enter, where the regenerative action of the hot combustion chamber ignites all unburnt gases, and the same pass through the small

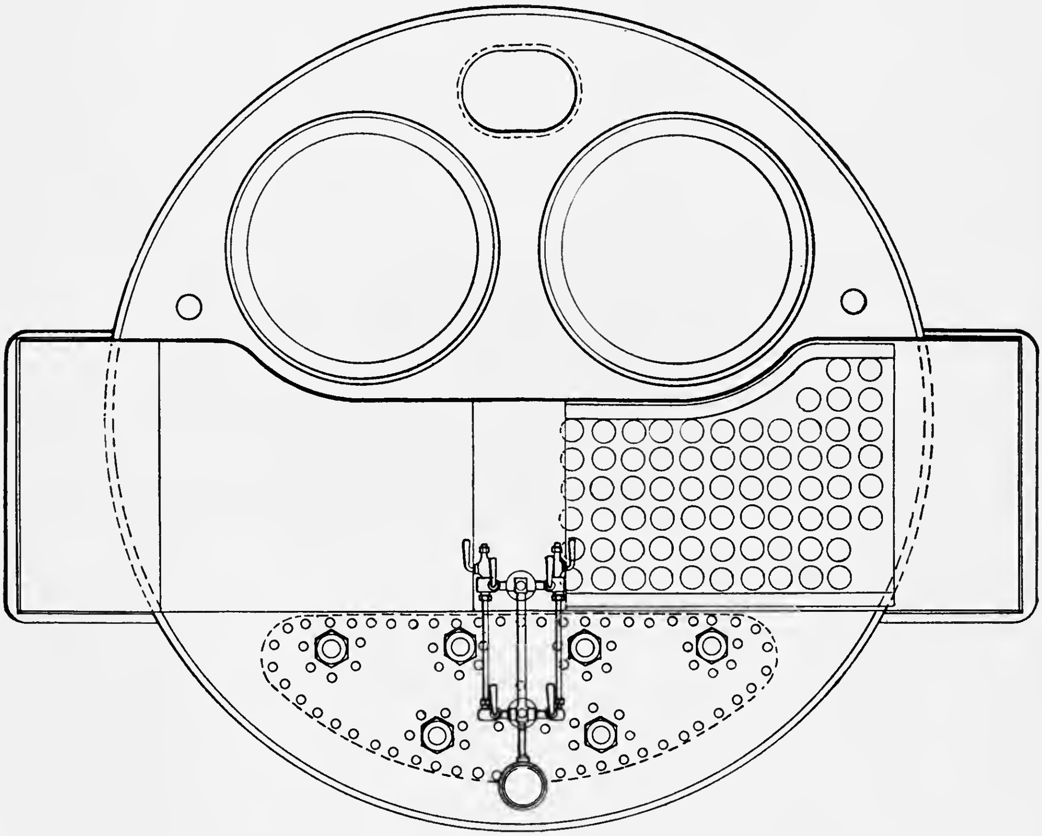


FIG. 30.—Scotch Marine Boiler.

tubes towards the front of the boiler into suitably shaped smoke boxes, from whence they diverted around the sides and bottom of the boiler to the tail flue. The heating surface obtained in this boiler, in proportion to its cubic contents, is more than that of any other class, and consequently its efficiency is a very high one. Under test this boiler has evaporated 12.2 lbs. of water per pound of best Welsh steam coal, from and at 212° Fahr., and this result has been confirmed by Professor Kennedy.

The boiler occupying but little space (only about half that of the Lancashire type for a given duty), the cost of brickwork is reduced to a minimum, while another feature of value is the facility for cleaning and examining the boiler. The cost of upkeep is very small indeed, and, in addition, owing to the excellent combustion obtained, the boiler is almost smokeless.

The main argument put forward generally in favour of all these types is that they contain a large body of water, and thus are not so liable to sudden fluctuations in pressure as water-tube boilers containing a smaller body of water.

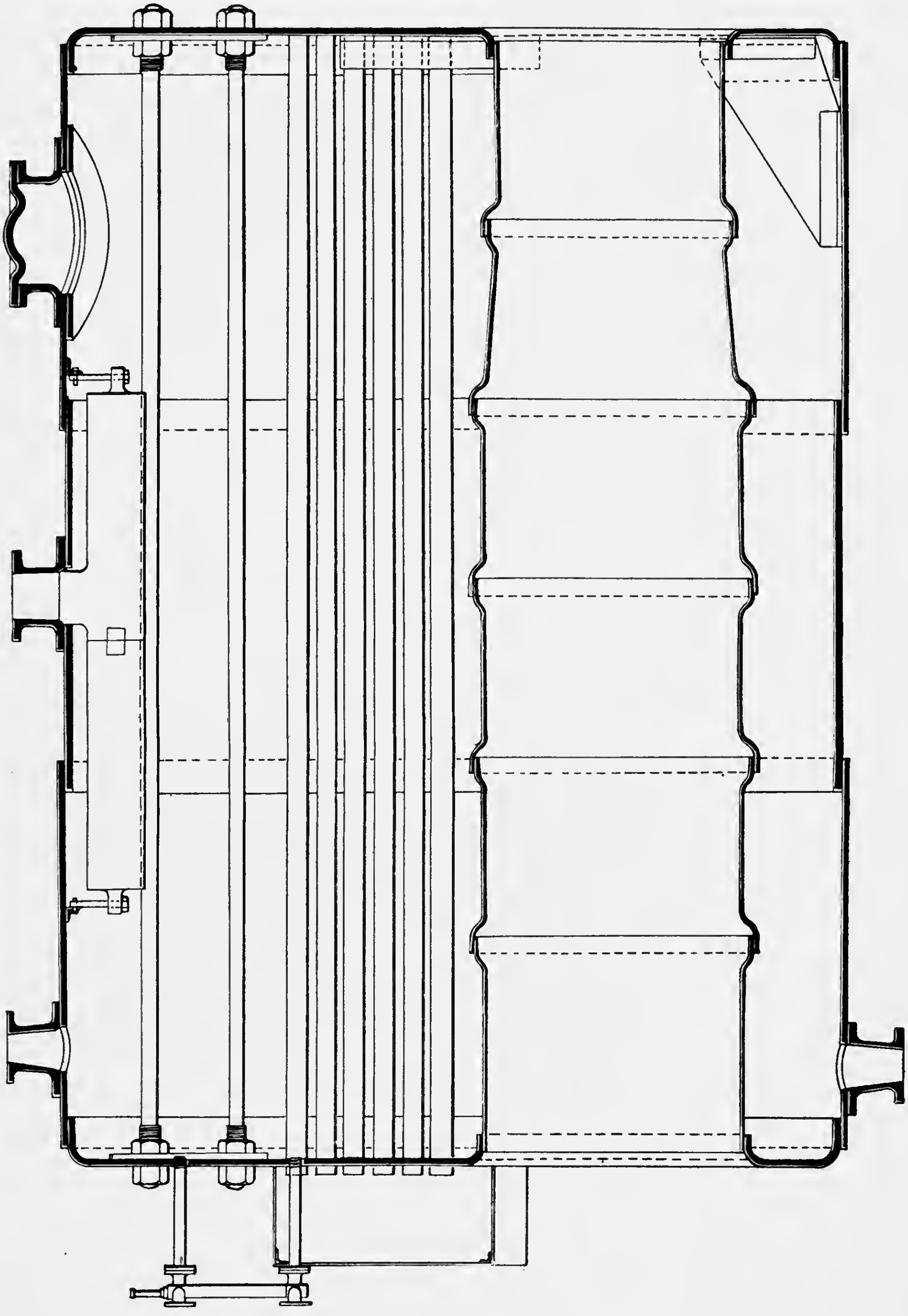


Fig. 31.—Dry Back Boiler.

This argument applies in so far that these types of boilers do contain more water in comparison to the quantity of steam they generate than even the best water-tube boilers, but the practical necessity for such a volume exists only in the rarest cases of manufacturing. Where the steam produced is for motive power, the advantage claimed is somewhat delusive. The rapid generating capacity is of far more importance—in view of the fact that, even in the types of largest water capacity working with a proportionate engine, the pressure would fall in a few minutes if the process of steam generation were not proceeding at the same time.

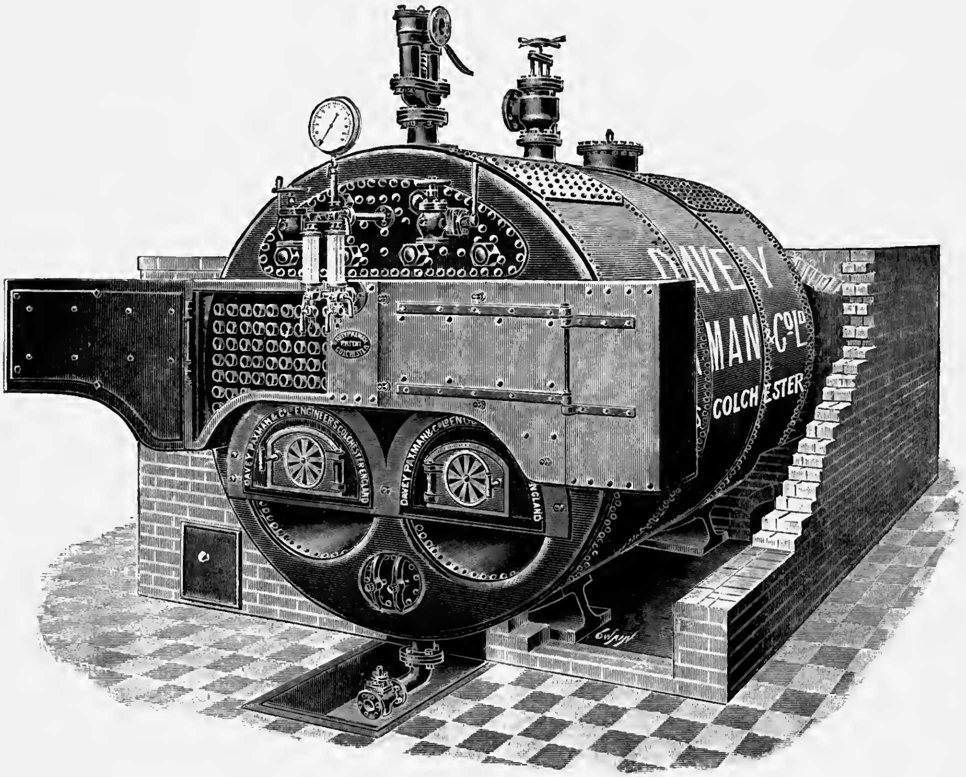


FIG. 32.—Paxman Boiler.

For the requirements of the present day—which are "high pressure," "safety," "efficiency," and "economy in space" per unit of power generated—the shell boiler is gradually giving place to water-tube sectional boilers.

VERTICAL BOILERS

For small powers vertical boilers are much used, requiring little setting and being easily portable.

A good type of this class is that shown in Fig. 33, the Blake boiler. It has a large wet back combustion chamber, without screwed stays, great strength and no brick lining, and provides free circulation.

The circularity of the shell and combustion chamber is not broken into by the introduction of flat tube plates.

A special formation is imparted to the tube plates, whereby round tube holes are obtained and a sound joint ensured by rolling with an ordinary tube expander, while those portions of the tube plates between the tube holes are cylindrically intact.

Blake boilers have been extensively used in steamers for driving winches, etc., and are well known, and the improved design has been most favourably received, and is being largely manufactured under British and foreign surveys.

The superior efficiency, power, and economy of a boiler provided with a wet back combustion chamber is well known to experts. Authorities on this subject reckon every square foot of combustion chamber surface equivalent to 3 square feet of tube surface.

Blake boilers are provided with spacious wet back combustion chambers having from 25 to 75 square feet of heating surface, according to size of boiler, thus adding greatly to the evaporative performance of the boiler.

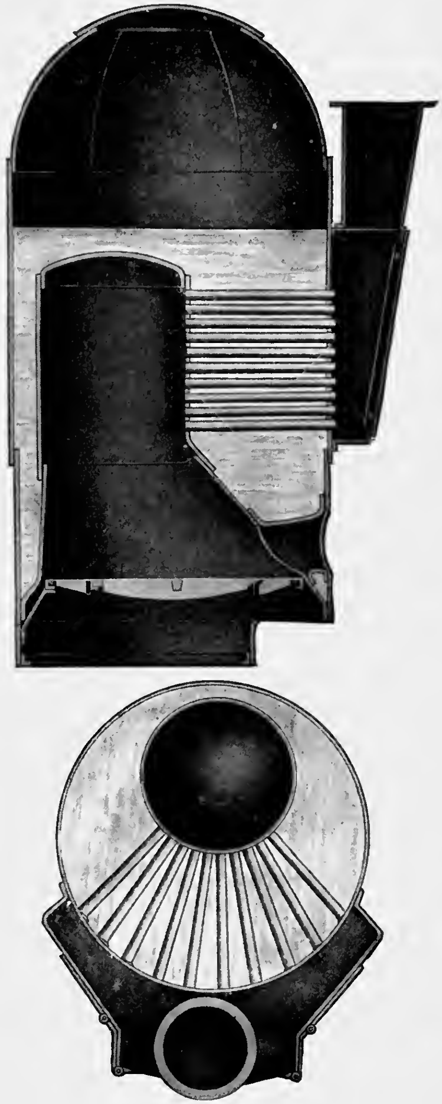


Fig. 33.—Blake Boiler.

TANGYE'S VERTICAL BOILER

This boiler (Figs 34 and 35) is made for steam pressures not exceeding 100 lbs. per square inch, and before leaving the works is tested by hydraulic pressure to 175 lbs. per square inch. It has a greater evaporative efficiency than the ordinary vertical cross-tube boiler.

It is made throughout of best mild steel plates flanged by special machinery and planed on the edges, the plates exposed to the fire being of best "fire-box" quality. The rivet holes are drilled after the plates are bent into position; the rivets, of best mild steel, being closed by hydraulic machinery in all the accessible parts.

The vertical seams in the shell are double chain riveted in the sizes up to 12 horse-power, and triple riveted in the larger sizes.

The sides of fire box and combustion chamber are formed by one inner shell. The furnace crown and bottom tube plate are worked out of one plate, dished for strength and flanged for attachment to inner shell. A short passage of segmental form connects the two chambers together, giving access to combustion chamber from fire box. Between top and bottom tube plates vertical tubes are fitted, their upper ends being swelled in diameter to facilitate withdrawal.

The smoke box (of cast iron in sizes up to 10 horse-power, and of steel above) carries a steel chimney, and is fitted with pipe and bend for exhaust steam. It is also fitted with two doors to facilitate the cleaning of combustion chamber and outside of tubes.

The crown is formed from one plate, swelled to carry the safety valves and steam stop valve, and is flanged to meet the shell. It is stayed to the top tube plate by bar stays, with nuts and washers at each end.

The mountings and fittings are as follow :—Wrought-iron damper plate and handle ; fire-bars on wrought-iron bearing ring ; beaded cast-iron fire-door with wrought-iron baffle plate ; manhole, handholes, and mudholes with wrought-iron lids and cross-bars ; anti-priming pipe ; steam stop valve with gun-metal fittings ; two lever safety

Fig. 34.—Sectional Elevation.

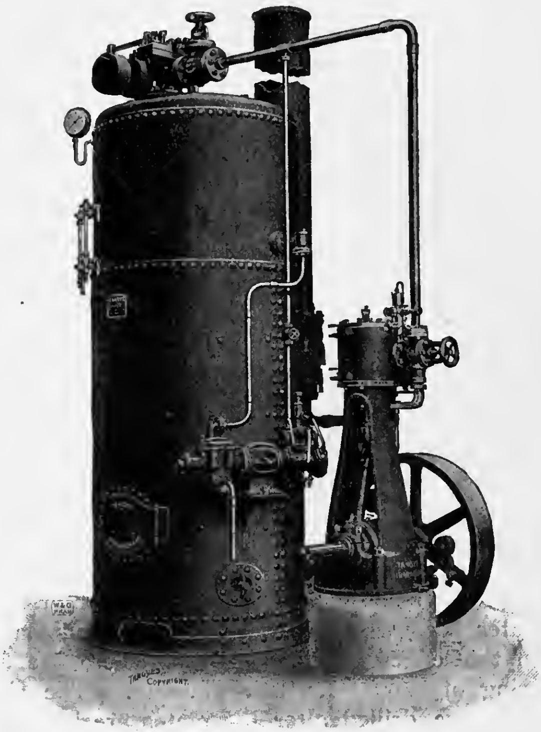


Fig. 35—Complete with Engine.

Tangye Boiler.

valves ; gun-metal blow-off cock ; gun-metal check-feed valve ; dial pressure gauge on a siphon pipe ; two trial cocks and a water gauge with gun-metal fittings in sizes up to 10 horse-power, and two water gauges in the sizes above ; and a fusible plug.

Table of Sizes.

Nominal horse-power		8	10	12	16	20	25
Height of shell	ins.	98	108	117	126	138	147
Diameter of shell	,,	44	46	48	53	57	66
,, of fire box over fire-bars	,,	36	39	40	45	49	57
Heating surface	sq. ft.	113	141	168	224	280	350
Grate area	,,	7	8.2	8.75	11	13	17.7
Fire-door opening—width	ins.	15½	15½	15½	16	16	16
,, ,, depth	,,	12½	12½	12½	13	13	13
Diameter of chimney	,,	11	12½	14	16	18	20
Length of chimney	feet	10	10	10	15	15	15
Number of tubes		48	57	64	81	89	108
Diameter of tubes	ins.	2½	2½	2½	2¾	2¾	3
Safety valves—diameter, each	,,	2	2	2	2½	3	3½
Stop valve—diameter, each	,,	1¾	2	2½	3	3½	4

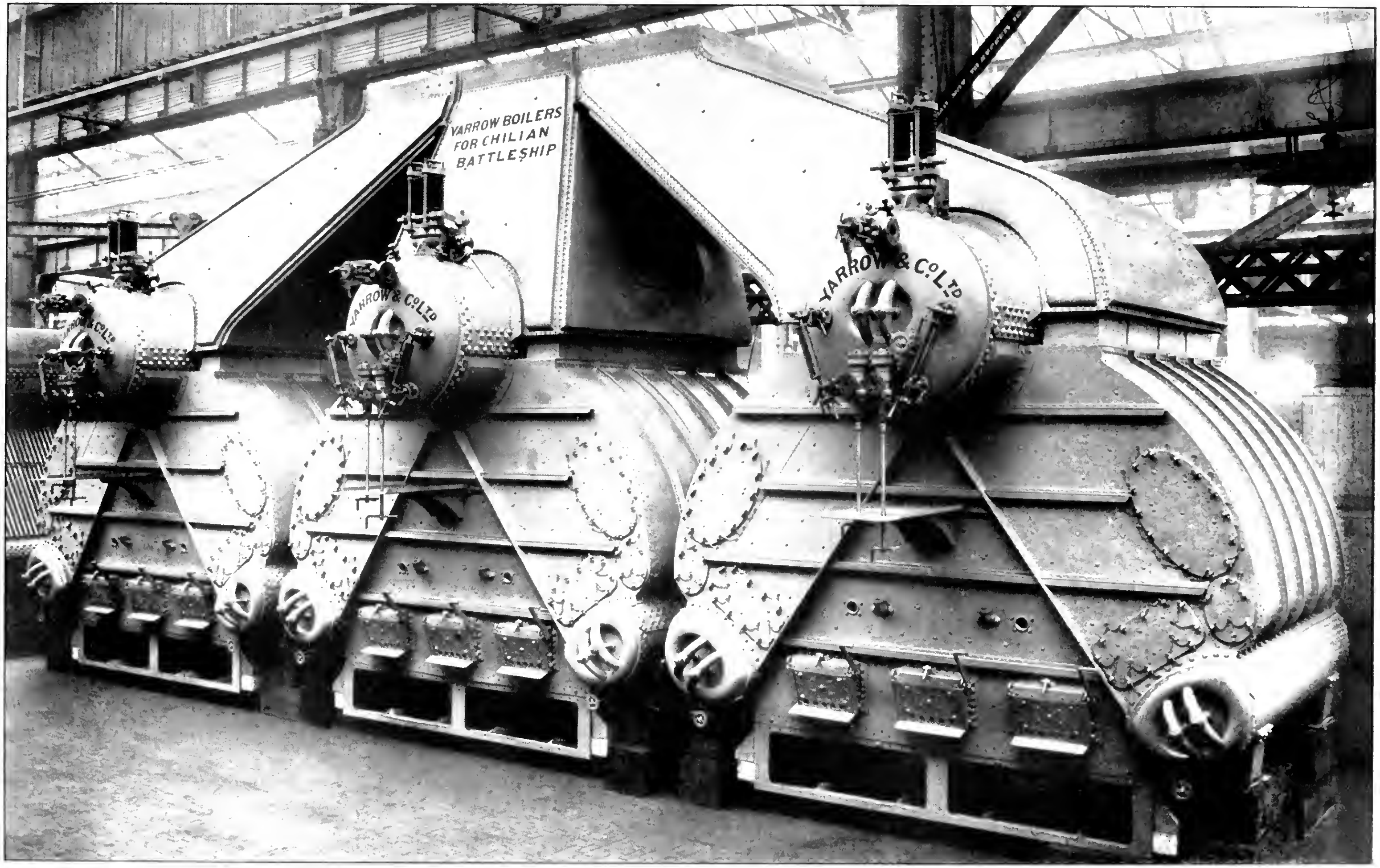


Plate I.—Water Tubular Marine Boilers placed as on Vessel.

THE COLONIAL BOILER

This boiler (Figs. 36 and 37) is made in two series, one for steam pressures not exceeding 80 lbs. per square inch, which is tested to 140 lbs.; and the other for 100 lbs. per square inch, which is tested to 175 lbs. The testing is done in each case by hydraulic pressure before leaving the works, and a certificate of test is supplied.

In each boiler the barrel and tube plates are of best "fire-box" quality mild steel; the longitudinal seams of the barrel are double riveted, and the edges of the plates planed. The tube plates are flanged by special machinery and stayed by wrought-iron

FIG. 36.

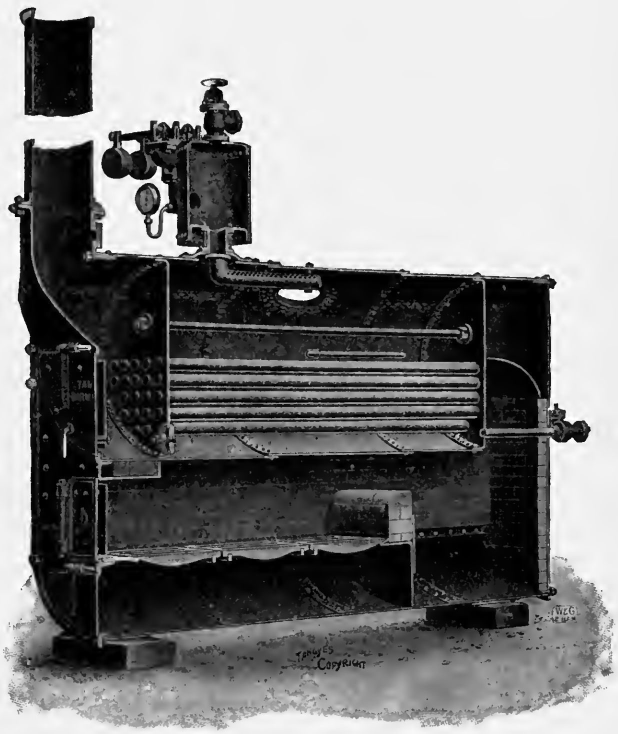


FIG. 37.

Tangye Colonial Boiler.

bar stays, with nuts and washers at each end. The rivets are of best mild steel, and are closed by hydraulic machinery in all the accessible parts. The tubes are of wrought iron, lap-welded, and swelled at the smoke-box end. The casing is of steel, protected by fire-brick linings.

TABLE OF SIZES FOR BOTH SERIES.

Nominal horse-power	4	6	8	10	12	14	16	18	20	25
Overall length of casing . . . ins.	84	96	108	120	132	141	150	156	160	168
Length of barrel . . . . . ,,	66	76	85	89	98	102	107	111	114	120
Diameter of barrel . . . . . ,,	24	27	30	33	36	39	45	45	48	51
Number of tubes	16	18	20	26	25	30	34	36	40	48
Diameter of tubes . . . . . ins.	2½	2½	2¾	2¾	3	3	3	3	3	3
Heating surface . . . . sq. ft.	67	90	121	161	193	231	269	294	334	423
Grate area . . . . ,,	5.25	7.6	9.5	12.37	15	17.87	18.4	19.8	22	25
Fire-door opening—width and depth . ins.	16×10	18×10	20×10	22×10	23×12	24×12	24×13	24×13	24×18	24×18
Length of chimney . . . . . feet	7	7	7	7	10	10	10	15	15	20
Diameter of chimney . . . . . ins.	8½	9½	11	12½	13	14	16	16	18	20
Length and diameter of dome . . ,,	19×12	19×12	22×17	24×18	24×18	24×18	24×18	24×18	24×20	33×24
Stop valve—diameter of dome . . ,,	1¼	1½	2	2	2½	2½	3	3	3½	4

The furnace is under the shell, the flame passing along under the bottom of the barrel and returning through the tubes to the chimney, the heat being well absorbed before reaching the chimney. The furnace front is in two parts, the upper portion having cast with it a base for the chimney, and being fitted with a hinged door affording access to the tubes for cleaning. The fire-door opening is of large size to admit logs, and has double doors.

Another type of boiler is shown in Fig. 38.

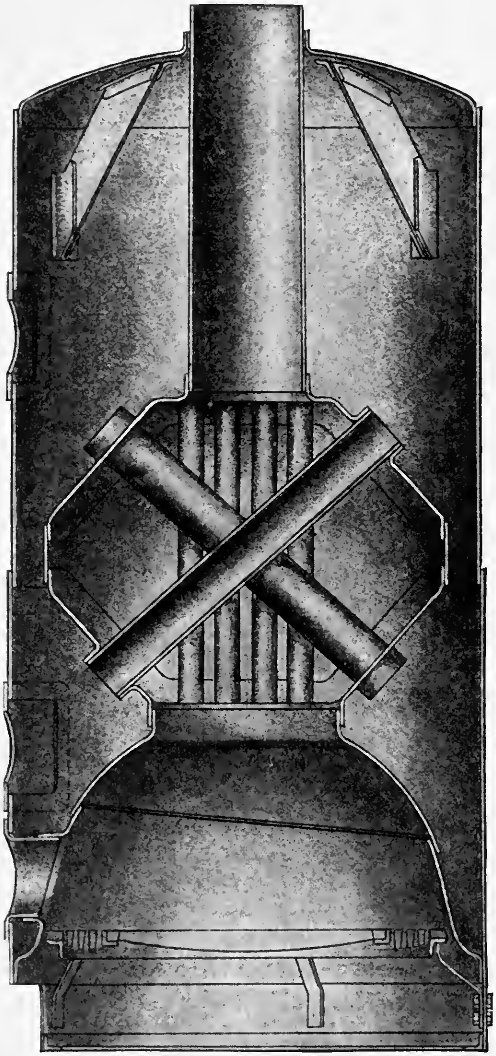


Fig. 38.—Clarke Chapman Boiler.

CLARKE CHAPMAN'S VERTICAL BOILER,

having vertical and diagonal tubes, fitted with all necessary man, fire, and mudhole doors, fire-bar supporting ring and brackets for same; the usual working pressure being 90 lbs. per square inch to Lloyds Survey.

The general construction of the boiler is as shown on the illustration, and the design specially lends itself to economy and excellence in manufacture, every part of the flanging being done by hydraulic power, and the riveting by hydraulic riveter.

The special advantages are—high efficiency, 9.3 lbs. of water at 212° having been evaporated per pound of ordinary unscreened Northumberland steam coal used, consequent economy of fuel, without any of the usual drawbacks of complicated form, etc.

Exceptional facilities for thorough cleaning and examination of every part.

It is as cheap to buy as an ordinary well-made cross-tube boiler of equal power, and occupies considerably less space, for a more powerful boiler could be accommodated in the same space as a cross-tube boiler.

In case any of the vertical or diagonal tubes require renewing, they can be replaced without disturbing the boiler, the manhole covering plates being arranged for this. The uptake is also arranged for easy withdrawal and replacement without cutting away the upper neck ring.

The same makers show the two types of cross-tube vertical tubular boilers (Figs. 39 and 40). Fig. 40 has a wet back, and Fig. 39 a dry back, with a brick lining. Two of the gusset stays are to be seen fixing the flat top to the boiler shell.

WATER-TUBE BOILERS

It is not necessary here to go over the early history of this type of boiler. Naturally, boilers of shell types were first used because of their construction not requiring refinement in tools or workmanship. The tubular boiler is essentially a machine made boiler, and if it is to be a successful boiler accurate and powerful tools are necessary in

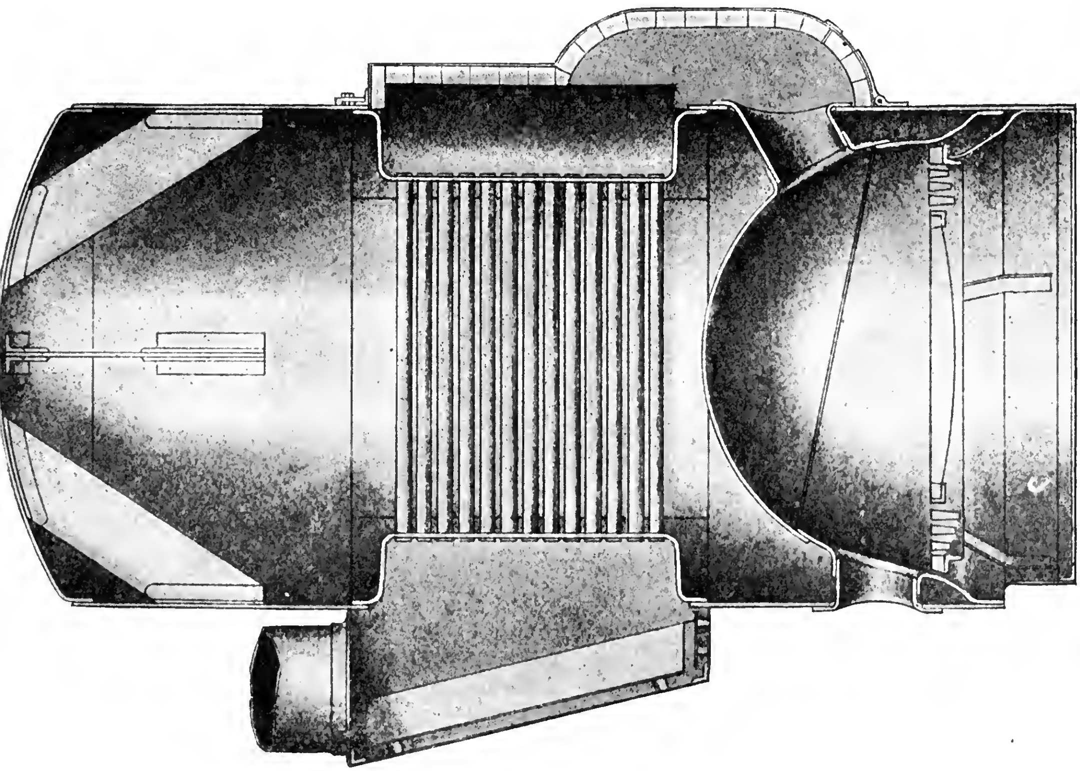


FIG. 39.—Clarke Chapman Boiler.

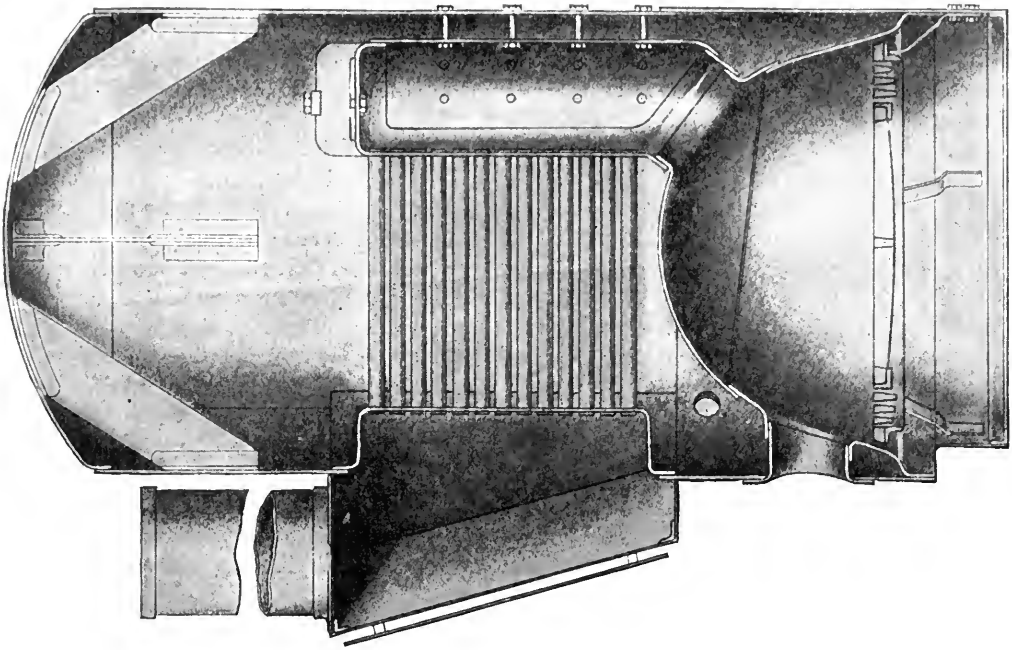


FIG. 40.—Clarke Chapman Boiler.

its production. The Babcock & Wilcox boiler has attained a position which it fully deserves. It has been gradually evolved by many years of practical experience, and by men of high scientific ability as engineers, and an extended notice of it is very instructive.

After careful construction and working of about sixteen different types of water-tube boilers it was finally considered as a problem, and solved from the data obtained in these numerous practical tests, and clearly demonstrated that the best construction and efficiency required adherence to the following elements (Figs. 41 and 42):—

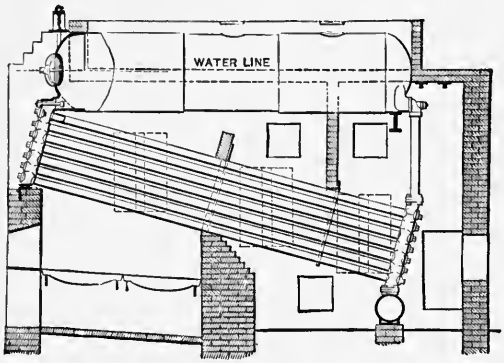


FIG. 41.—Early Boiler.

1. Sinuous headers for each vertical row of tubes. 2. A separate and independent connection with the drum, both front and rear, for each such vertical row of tubes. 3. All joints between the parts of the boiler proper to be made without bolts or screw-threads. 4. No surfaces to be used which require to be stayed. 5. The boiler supported independently of the brickwork, so as to be free to expand and contract as it was heated and cooled. 6. The drums not less than 30 inches in diameter, except for small boilers. 7. Every part accessible for cleaning and repair.

Having settled upon these points, Fig. 42 was designed having all these features, together with other improvements in the details of construction. Short pieces of boiler tube were used as connections between the sections and drum, and mud drum, their ends being expanded into adjacent parts with a Dudgeon expander. This boiler was also suspended entirely independent of the brickwork by means of columns and girders, and the mutually deteriorating strains where one was supported by the other were avoided.

Hundreds of thousands of horse-power of this style were built, giving excellent satisfaction. This type is known as the "C.I.F." (cast-iron front) style, a fancy cast-iron front being generally used therewith.

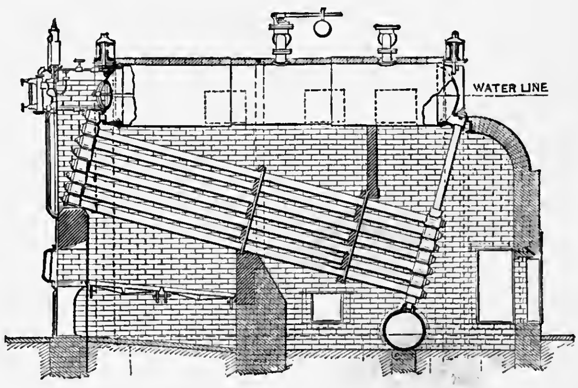


FIG. 42.—Early Babcock & Wilcox Boiler.

Fig. 43. This is known as the "W.I.F." style, the front usually supplied with it being largely made of wrought iron. In this boiler, flanged and "bumped" drum-heads of wrought steel are used; the drum is longer, and the sections are connected to cross boxes riveted to the bottom of drum.

Fig. 44 illustrates how the Babcock & Wilcox patent superheater is fitted, and it will be noticed that its application does not increase the height of the boiler or the space occupied.

The last step in the development of the water-tube boiler, beyond which it seems almost impossible for science and skill to go, consists in making all parts of the boiler of wrought steel, including the sinuous headers, the cross-boxes, and the nozzles on the drum. This was demanded to comply with the laws of some of the continental nations, and Babcock & Wilcox Ltd. have at the present time a plant turning out forgings as a regular business, which have been pronounced by the *Engineer* to be "a perfect triumph of the forgers' art."

In addition to this type, however, further modifications and designs of boilers have been brought out to meet special requirements.

Fig. 45 shows what is called the Cross type, which is made with a short drum lying horizontally. This is for export to localities to which access is difficult.

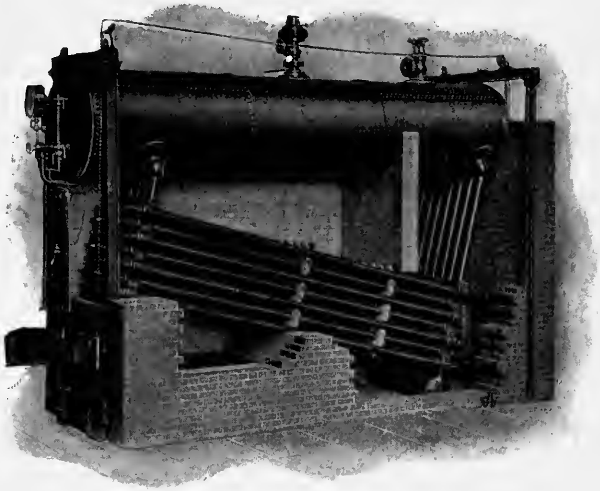


Fig. 43.—W.I.F. Boiler.

Fig. 46 is the same design of boiler, but made with an iron casing to comply with the requirements of distant places where not only is transport difficult, but no building material for brickwork is available. In the latest development of the Babcock & Wilcox marine boiler smaller tubes are used, so as to mass a large amount of heating surface in a small space, and minimise the weight. This type is installed not only in a large number of vessels, but also in many installations on land. An iron casing, with non-conducting material, is provided to take the place of the brickwork setting.

CONSTITUTION OF BABCOCK & WILCOX BOILERS

This boiler is composed of wrought-steel tubes, placed in an inclined position, and connected with each other, and with a horizontal steam and water drum, by vertical passages at each end, while a mud drum is connected to the rear and lowest point in the boiler.

The wrought mild steel end connections are in one piece (Figs. 47 and 48) for each vertical row of tubes, and are of such form that the tubes are "staggered" (or so placed that each row comes over the spaces in the previous row). The holes are accurately sized, and the tubes fixed therein by an expander. The sections thus formed are connected with the steam and water drum, and with the mud drum also, by short tubes expanded into bored holes, doing away with all bolts, and leaving a clear passageway between the several parts. The openings for cleaning opposite the end of each tube are closed by hand-hole plates, the joints of which are made in the most thorough manner, by milling the surfaces to accurate metallic contact, and are held in place by wrought-steel forged clamps and bolts (Fig. 50).

The steam and water drums are made of the best selected mild steel, and are double riveted in the longitudinal seams. They can be made for any desired working pressure, but are always tested hydraulically to at least 50 per cent. above working steam pressure.

In erecting this boiler it is suspended entirely independent of the brickwork from wrought-iron girders resting on iron columns. This avoids any straining of the boiler from unequal expansion between it and its enclosing walls, and permits the brickwork to be repaired or removed, if necessary, without in any way disturbing the boiler. All the fixtures are extra heavy and of neat designs (Fig. 44).

The fire is made under the front and higher end of the tubes, and the products of combustion pass up between the tubes into a combustion chamber under the steam and water drum; from thence they pass down between the tubes, then once more up through the spaces between the tubes, and off to the chimney. The water inside the tubes, as it is heated, tends to rise towards the higher end, and as it is converted into steam—the mingled column of steam and water being of less specific gravity than

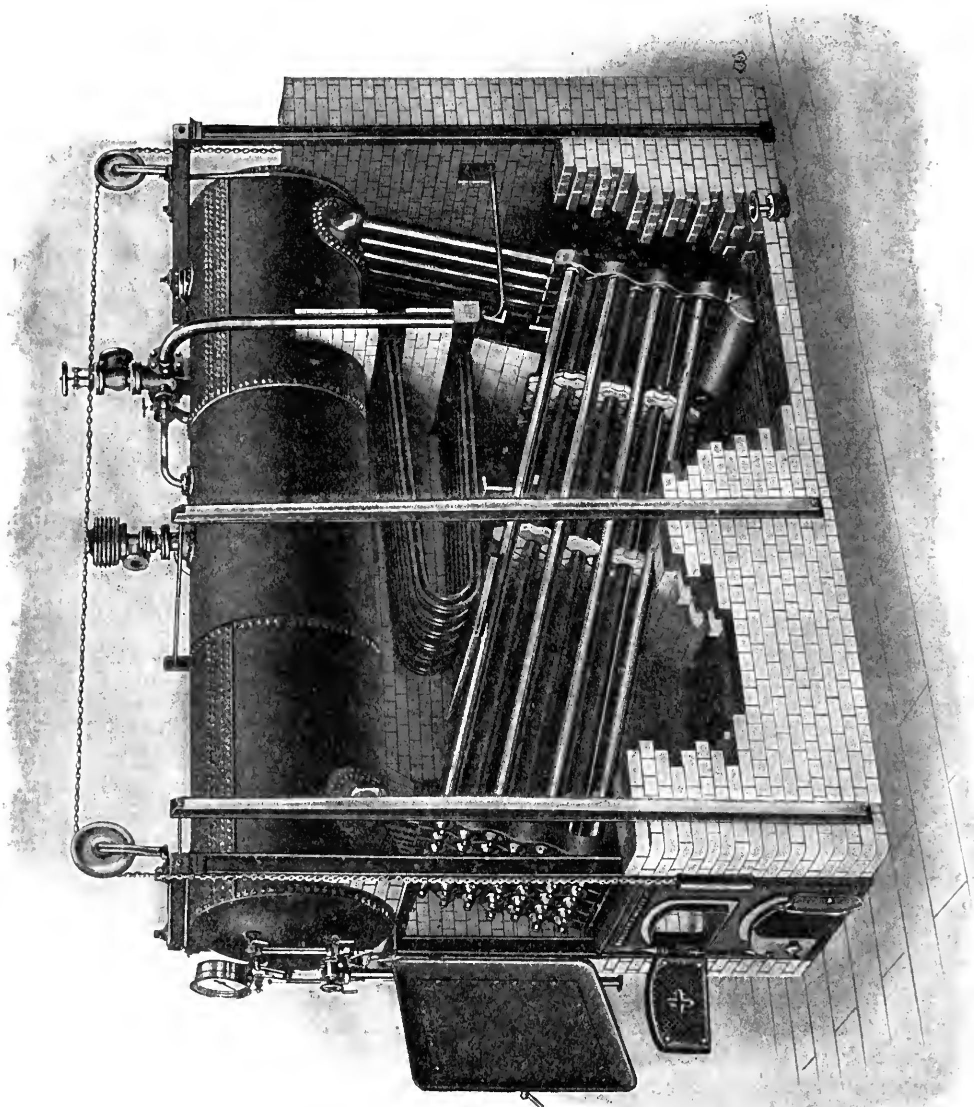


Fig. 44.—Babcock & Wilcox Boiler.

the solid water at the back end of the boiler—rises through the vertical passages into the drum above the tubes, where the steam separates from the water, and the latter flows back to the rear and down again through the tubes in a continuous circulation. As the passages are all large and free, this circulation is very rapid, sweeping away the steam as fast as formed, and supplying its place with water; absorbing the heat of the fire to the best advantage; causing a thorough commingling of the water throughout the boiler, and a consequent equal temperature, and preventing, to a great degree, the formation of deposits or incrustations upon the heating surfaces, sweeping them away and depositing them in the mud drum, whence they are blown out.

The steam is taken out at the top of the steam drum near the back end of the boiler after it has thoroughly separated from the water.

The following are the prominent advantages which this boiler presents over those of the ordinary construction.

1. *Thin Heating Surface in Furnace.*—The thick plates necessarily used in ordinary boilers in the furnace, or immediately exposed to the fire, not only hinder the transmission of heat to the water, but admit of overheating, and even burning the side next the fire, with consequent strains, resulting in loss of strength, cracks, and tendency to rupture. This is admittedly the direct cause of many explosions. Water tubes, however, admit of thin envelopes for the water next the fire, with such ready

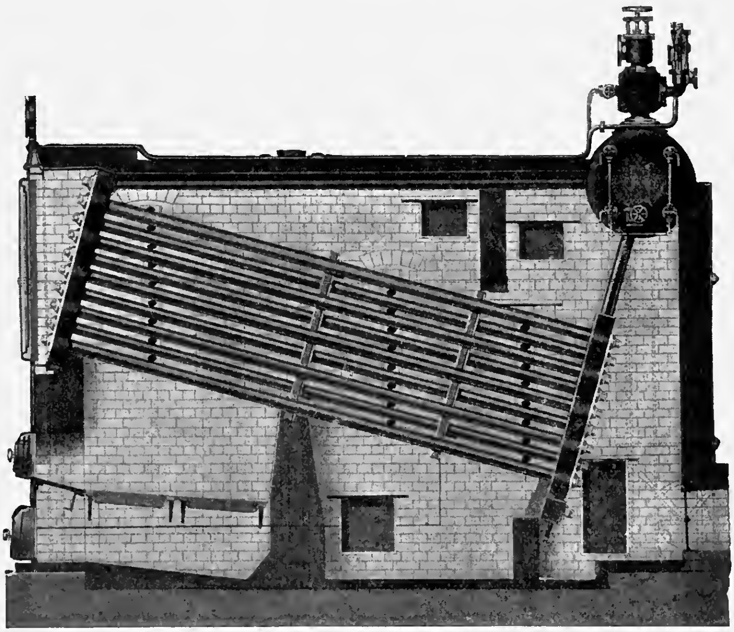


FIG. 45.—Early Babcock & Wilcox Boiler.

transmission of heat that even the fiercest fire cannot overheat or injure the surface as long as it is covered with water upon the other side.

2. *Joints removed from the Fire.*—Riveted joints, with their consequent double thickness of metal in parts exposed to the fire, give rise to serious difficulties. Being the weakest parts of the structure, they concentrate upon themselves all strains of unequal expansion, giving rise to frequent leaks, and not rarely to actual rupture. The joints between tubes and tube sheets also give much trouble when exposed to the direct fire, as in locomotive and tubular boilers. This difficulty is overcome by the ioints being removed from impingement of the fire.

3. *Complete Combustion.*—The perfection of combustion depends upon a thorough mixture of the gases evolved from the burning of fuel with a proper quantity of atmospheric air ; but this perfect mixture rarely occurs in ordinary furnaces. A large percentage of the combustible gases often escapes into the chimney in the form of carbonic oxide, or half-burnt carbon. Numerous attempts have been made to cure smoke, by admitting air to the furnace ; but though this may allow so much air to mingle with the smoke as to render it invisible, and at the same time ignite some of

the lighter gases, it in reality does little to promote combustion, and the cooling effect of the air more than over-balances all the advantages resulting from the burning gas. The analysis of gases from various furnaces shows almost uniformly an excess of free oxygen, proving that sufficient air is admitted to the furnace, and that a more thorough and perfect *mixing* is needed. Every particle of gas evolved from the fuel should have its equivalent of oxygen, and must find it while hot enough to combine, in order to be effective. In this boiler the currents of gases after leaving the furnace are broken up and thoroughly mingled by passing between the staggered tubes, and have an opportunity to complete their combustion in the triangular chamber between the tubes and drum (Fig. 51).

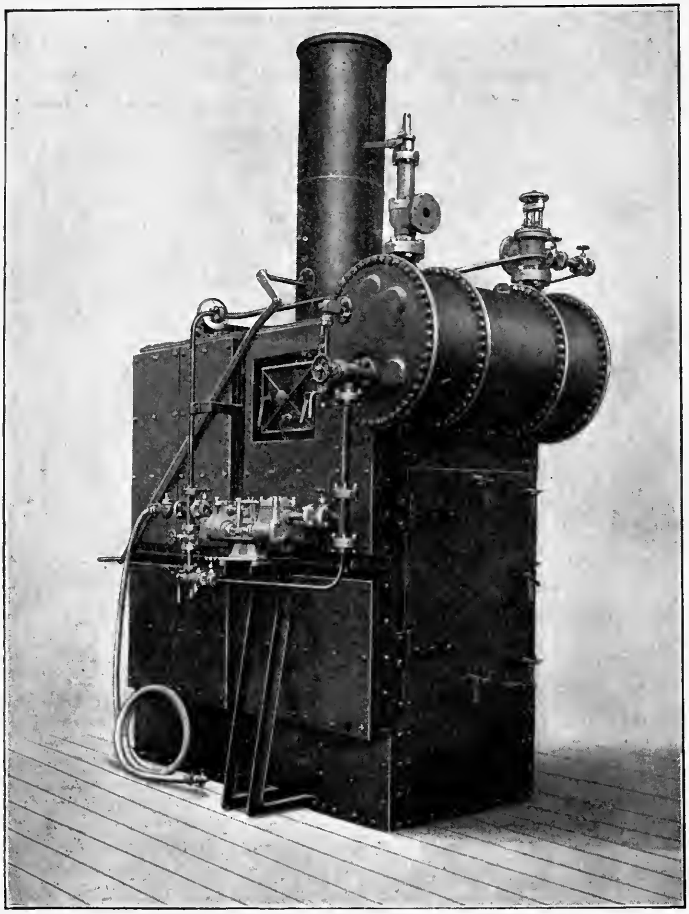


FIG. 46.—Boiler for Export. Cross Type.

That this does really take place is proved by an analysis by Dr. Behr of the escaping gases from a stack of these boilers at Mattheissen & Weicher's sugar refinery. He made many separate analysis at different times, and in no case was there more than a trace of carbonic oxide, even when there was less than 1 per cent. of uncombined oxygen.

4. *Thorough Absorption of the Heat.*—There are important advantages gained in this respect in consequence of the course of the gases being more nearly at right angles to the heating surface, impinging thereon instead of gliding by in parallel lines as in fire-tube boilers. The currents passing three times across and between the staggered tubes are brought intimately in contact with all parts of the heating surface, rendering it much more efficient than the same area in ordinary tubular boilers.

The experiments of Dr. Alban and of the U.S Navy have proved that a given surface arranged in that manner is 30 per cent. more efficacious than when in the form of fire-tubes, as usually employed.

5. *Efficient Circulation of Water.*—As all the water in the boiler tends to circulate in one direction, there are no interfering currents, the steam is carried quickly to the surface, all parts of the boiler are kept at a nearly equal temperature, preventing unequal strains, and by the rapid sweeping current the tendency to deposit sediment on the heating surface is materially lessened.

6. *Quick Steaming.*—The water being divided into many small streams in thin

envelopes passing through the hottest part of the furnace, steam may be rapidly raised in starting, and sudden demands upon the boiler may be met by a quickly increased efficiency.

7. *Dryness of Steam.*—The large disengaging surface of the water in the drum, together with the fact that the steam is delivered at one end and taken out at the other, secures a thorough separation of the steam from the water, even when the boiler is forced to its utmost.

8. *Steadiness of Water Level.*—The large area of surface at the water line and the ample passages for circulation secure a steadiness of water level not surpassed by any boiler.

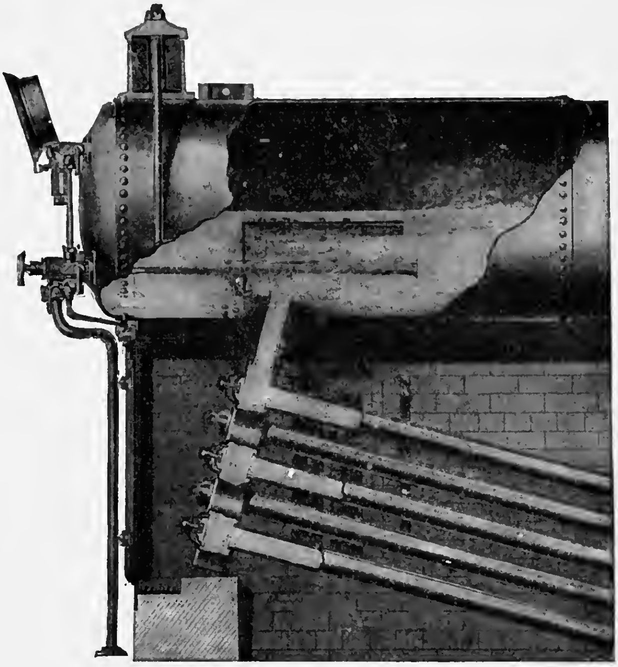


Fig. 47.—Section.

9. *Freedom of Expansion.*—The arrangement of the parts forming a flexible structure allows any member to expand without straining any other, the expanded connections being also amply elastic to meet all necessities of this kind. This is of great importance, because the weakening effect of strains from unequal expansion, between rigidly connected parts, is a prolific cause of explosions in ordinary boilers. The rapid circulation of the water, however, in this boiler, by keeping all parts at the same temperature, prevents to a large extent unequal expansion.

10. *Safety from Explosions.*—The freedom from unequal expansion avoids the most frequent cause of explosions, while the division of the water into small masses prevents serious destructive effects in case of accidental rupture. The comparatively small diameter of the parts secures, even with thinness of surface, great excess of strength over any pressure which it is desirable to use. So powerful is the circulation of the water, that no part will be uncovered to the fire until the quantity of water in the boiler is so far reduced that, if overheating should occur, no explosion could result which, in the ordinary sense of the term, would be largely destructive to property.

Fig. 48.—End Piece.

11. *Capacity.*—This is a point of the greatest importance, and upon it depends, in a large measure, the satisfactory performance of any boiler. Unless sufficient steam and water capacity is provided there will not be regularity of action; the steam pressure will suddenly rise and as suddenly fall, and the water level will be subject to frequent and rapid changes.

The value of large steam room is generally much overrated, but if it be too small the steam in passing off will sweep the water with it in the form of spray. Too much water space makes slow steaming and waste of fuel in starting. Too much steam space adds to the radiating surface, and increases the losses from that cause. The proportions of this boiler have been adopted after numerous experiments with boilers of varying capacity; and experience has established that this boiler can be driven to the utmost, carrying a steady water level and steam pressure, and always furnishing dry steam.

12. *Accessibility for Cleaning.*—This is of the greatest importance, and is secured to the fullest extent. Handholes, with metal-to-metal joints, opposite each end of each

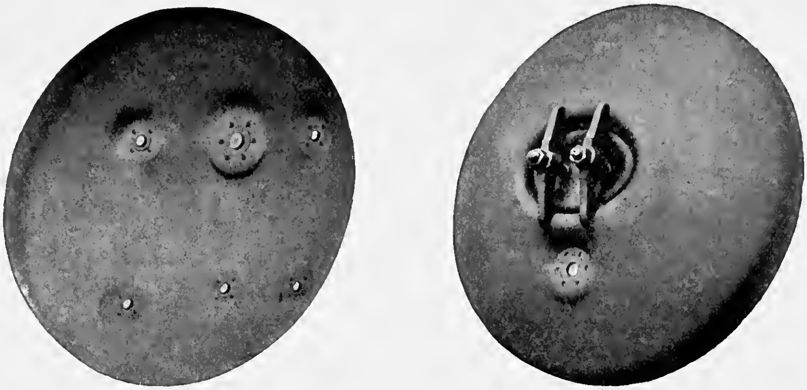


FIG. 49.—Drum Ends.

tube, permit access thereto for cleaning, and a manhole in the steam and water drum, and handholes in mud drum, are provided for the same purpose. All portions of both the exterior and the interior surface are fully accessible for cleaning. The occasional use of steam through a blowing pipe attached to a hose, operated through doors in the side walls, will keep the tubes free from soot, and in condition to absorb the heat to the best advantage.

The ordinary fire tube, or flue, receiving the dust from the fire on the interior, is

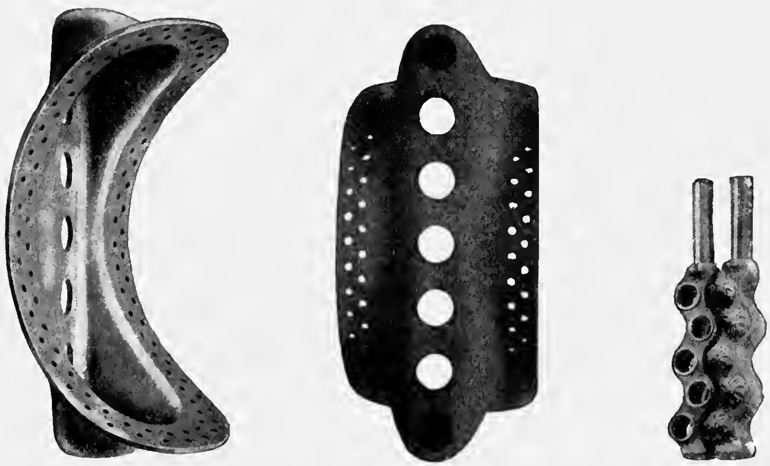


FIG. 50.—Vertical Connectors.

quickly covered from one-third to one-half its surface, and in time is completely filled. The water tube, however, will retain but a limited quantity on its upper side, after which it becomes in a measure self-cleaning.

The Portable Type.—This is entirely self-contained in a wrought-steel casing lined with fire-brick blocks, thus requiring no brickwork setting and no independent chimney. It is constructed on pretty much the same lines as the "Cross" type in other respects (Fig. 52).

The iron casing is so constructed that loss by radiation, and consequent waste of fuel, is minimised. The boiler is erected complete with its iron casing before despatch, and

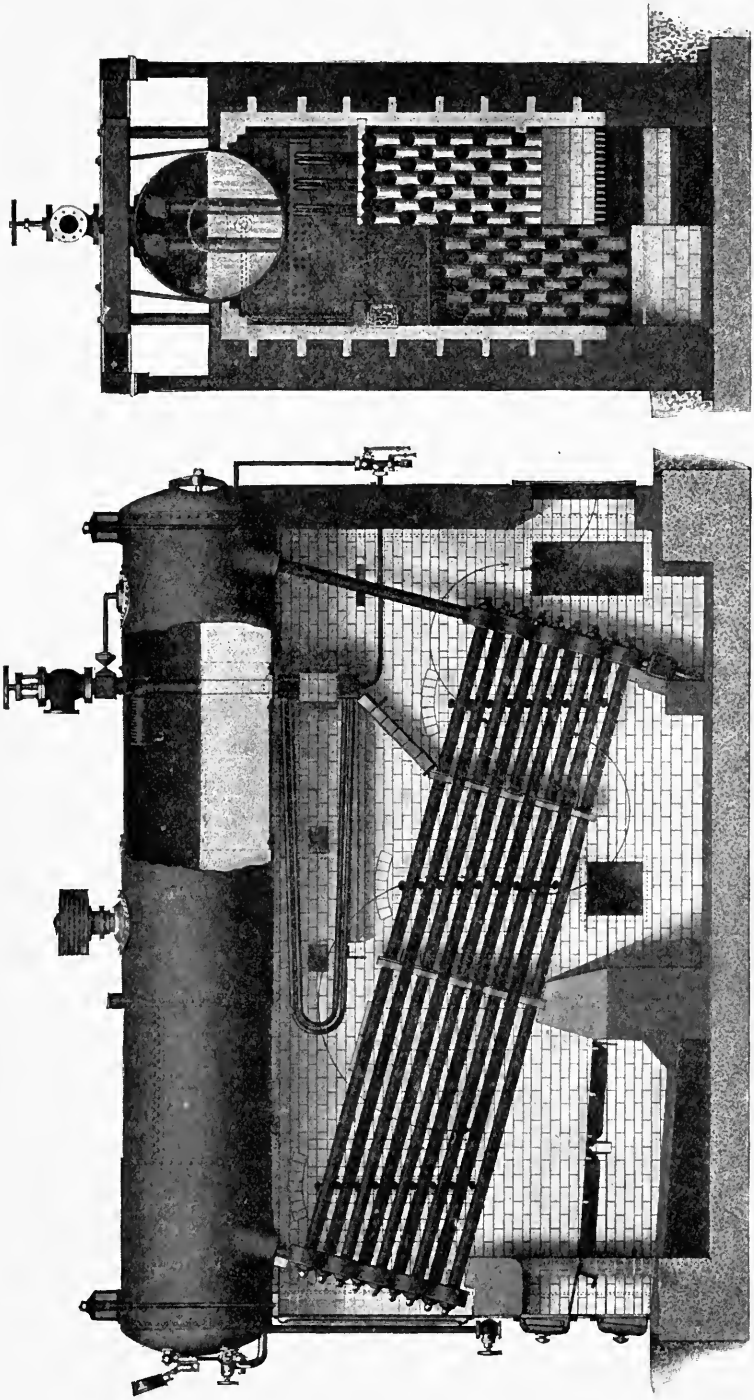


Fig. 51.—End and Side Section.

an index is provided, with numbers corresponding to those on the erection drawings and the shipping list, so that it can be fitted up with great ease by any mechanic. On this account it is in requisition for up-country work where it is difficult to obtain expert assistance for erection and management. This boiler is frequently made in such small sections that no piece exceeds 250 lbs. in weight, thus enabling the boiler to be carried through mountainous districts.

It should be added that all the types of Babcock & Wilcox boilers which have been described are in use with furnaces suitable for burning either bituminous or anthracite coal, liquid or wood fuel—either in logs, shavings, or sawdust,—straw, coffee husk, rice husk, and bagasse ; in fact, practically any fuel can be used. Apropos of this we may

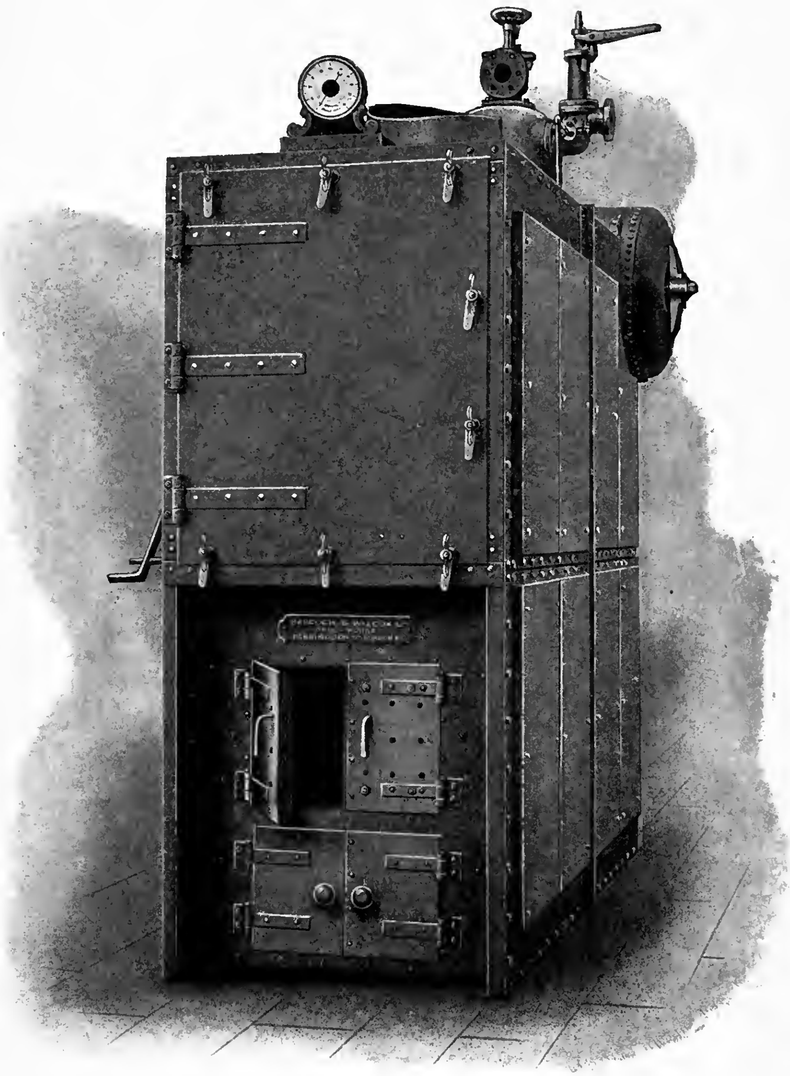


Fig. 52.—Portable Boiler.

recall attention to the fact previously noticed in our pages, that the land type has been largely adopted for steam generation where refuse destructors have been employed.

Most of the mechanical stokers upon the market can be readily adapted to the Babcock & Wilcox boilers. The Company, however, themselves make a "chain grate stoker" (Figs. 53 and 54), which differs materially from most other arrangements, and is specially suited to their boilers. One of the principal advantages of this apparatus is that it can be withdrawn as a whole from the furnace for the purpose of examination.

When at work the coal falls from a hopper on a travelling endless chain-grate, the

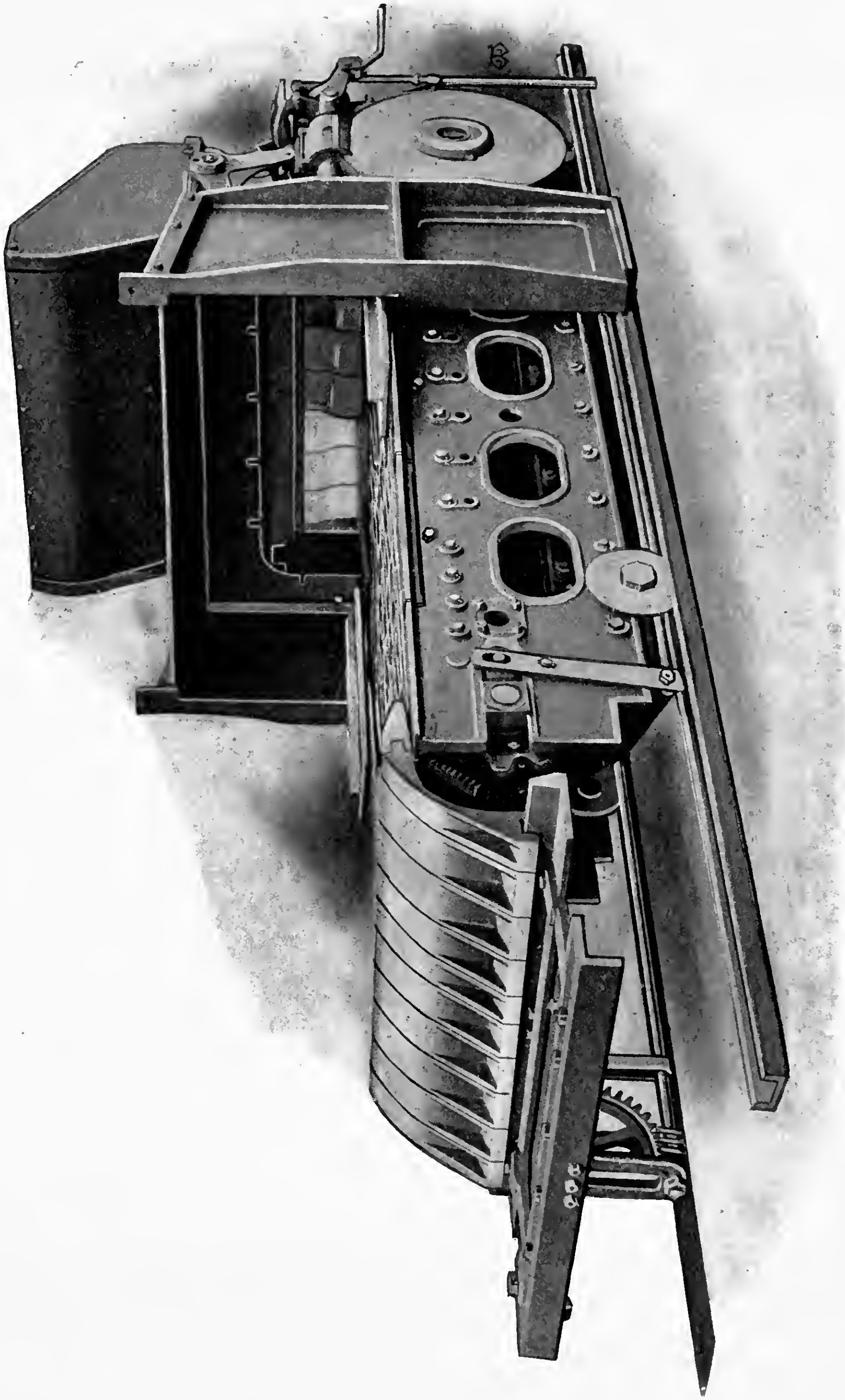


Fig. 53.—Chain-Grate.

depth of the fire being regulated by the height of the fire door. The feed of the coal is so slow that the quantity of gas evolved from the fresh fuel coming under the front end of the arch has time to complete its combustion by the radiated heat from the further end of the arch before coming into contact with the boiler surface ; thus the fuel is coked, and is gradually consumed as it travels the length of the grate, falling over the dumping grate at the back end into the clinker pit, the dumping plate of which is opened at such intervals as may be required from the front of the boiler. The speed of travel of the grate is regulated by a ratched and pawl attachment on the driving worm,

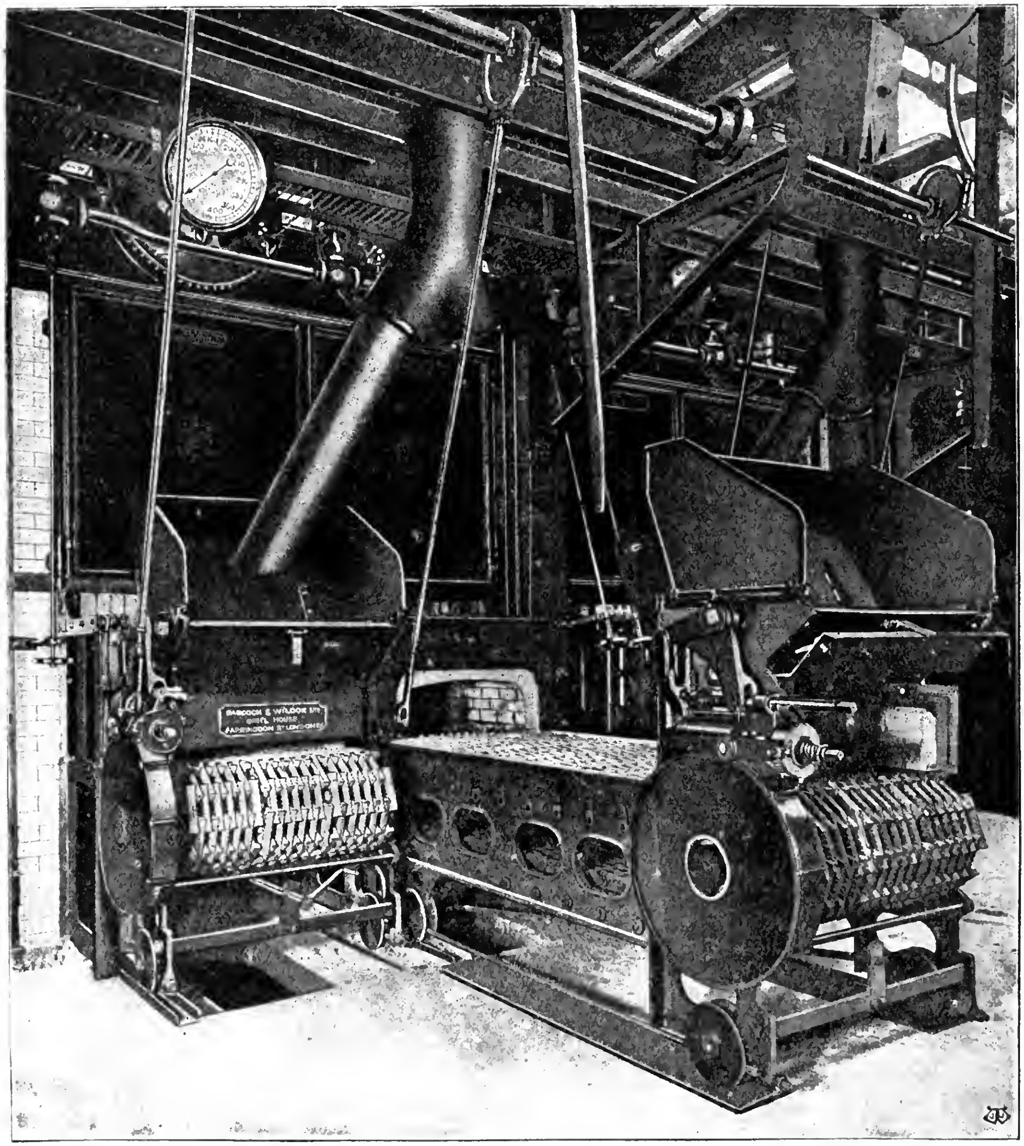


Fig. 54.—Chain-Grate and Stoker.

which latter gears into a worm wheel, on the shaft of which are drums which revolve the grate. The depth of the fire, as above mentioned, can also be regulated at will, and thus the machine can be in a moment adjusted to any kind of fuel at any rate of combustion.

The stoker can either be driven from a shaft overhead or underground, in the usual way. It can also be worked by hand by a crank placed on the end of the worm shaft, if the motive power breaks down ; or it can be worked at a stationary grate, as the fire door—which is made in halves—can be opened just the same as in fire doors of an ordinary hand-firing furnace.

The stoker is self-clinkering, and is claimed to be the only form of stoker in which the undue admission of air at the back end of the grate is prevented ; and, there being no necessity to touch the fire, the process of coking of the coal is quite undisturbed, the highest efficiency being thus obtained.

BABCOCK & WILCOX MARINE BOILER

The construction of the Babcock & Wilcox marine boiler is on the same lines, as far as the principle of water circulation, accessibility for cleaning, safety, and efficiency are concerned, as the Babcock & Wilcox land boiler.

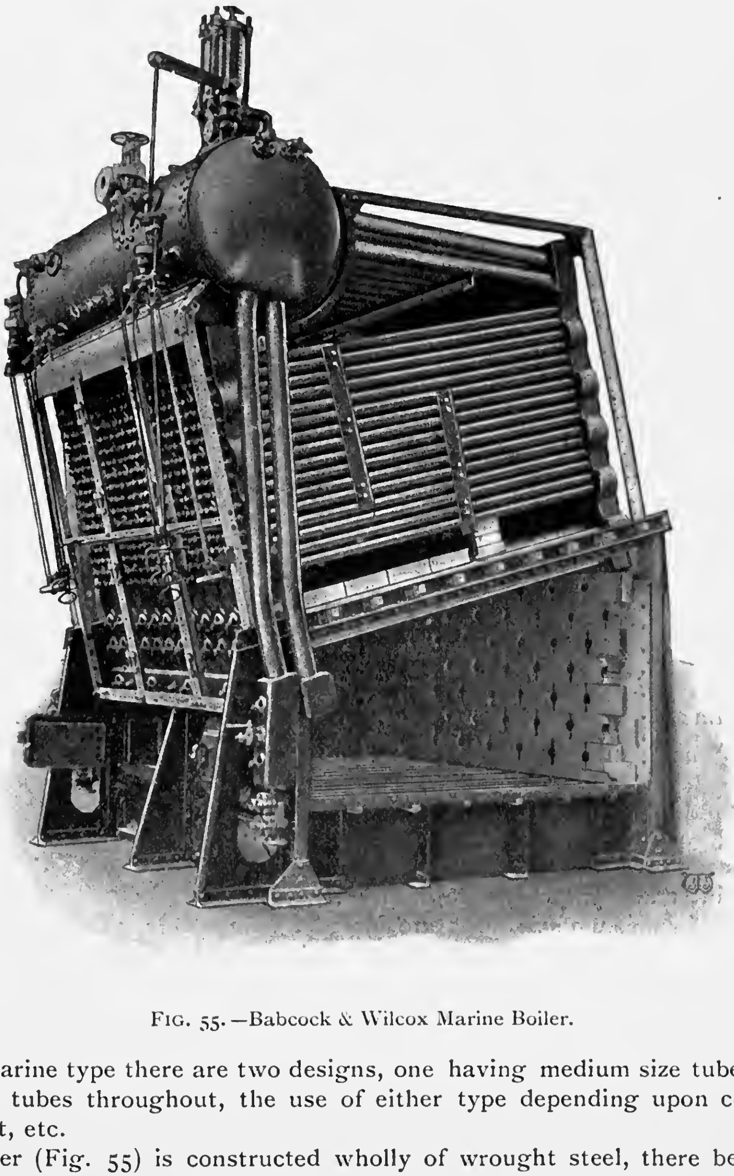


FIG. 55.—Babcock & Wilcox Marine Boiler.

In the marine type there are two designs, one having medium size tubes, the other having large tubes throughout, the use of either type depending upon conditions of space, weight, etc.

The boiler (Fig. 55) is constructed wholly of wrought steel, there being no cast metal of any description exposed to pressure. It consists in the main of an arrangement of inclined tubes forming the bulk of the heating surface, sinuous boxes or headers to which the tubes are attached, a horizontal steam and water drum, a mud drum, and a furnace of large capacity immediately beneath the inclined tubes, the relative positions of which are shown in Fig. 55.

The inclined tubes are divided into vertical sections, and, to ensure a continuous circulation in one direction, are placed on an inclination of 15 degrees from the horizontal. The tubes are so arranged as to break up and ensure efficient contact with the products of combustion.

By distributing the surface into sectional elements all danger from unequal expansion due to raising steam quickly, or sudden cooling, is at once overcome. Each section is made up of a series of straight tubes expanded at their ends into sinuous steel boxes known as "headers." The tubes are thus staggered.

Extending across the front of the boiler, and connected to the upper ends of the front headers by short tubes, is a horizontal steam and water drum of ample dimensions. As the upper ends of the rear headers are also connected to this drum by horizontal tubes, each section is provided with an inlet and outlet for steam and water.

Placed across the bottom of the front headers, and connected thereto by short tubes or nipples, is a forged steel box of square section. This box, being situated in the lowest corner of the bank of tubes, forms a blow-off connection or sediment box through which the boiler can be completely drained.

The circulation of water is as follows:—

Heat being applied to the inclined tubes and vapour formed, the mixture of water and steam rises to the high end and flows through the uptake headers and horizontal return tubes to the steam and water drum, the path of both water and steam being short and direct; the water evaporated in the tubes, and that carried along by the current induced by the steam bubbles, being replaced by water flowing directly from the bottom of the drum downwards through the front headers and into the tubes, part of this water to be in turn evaporated.

Upon entering the drum, the steam and circulating water are directed against baffle plates, which cause the water to be thrown downwards while the steam separates and passes round the ends of the baffle plates to the steam space, from which it is taken by a perforated dry pipe to the stop valve.

There is thus a continuous circulation of water in one direction, not hindered by any counter current, and this continuous circulation gives the boiler an equal temperature in all its parts, so that undue strains from unequal temperatures are avoided.

The steam and water drum is also fitted with wash plates to prevent undue movement of the water when the ship is rolling.

The tubes are of seamless steel. Opposite the end of each tube is an opening or handhole in the header, through which the tube can be examined, cleaned, or renewed, each opening being closed by a forged steel door and stud, the door being drawn up to its seat by means of a forged steel cap and nut, and in the case of the $3\frac{1}{4}$ and 4-inch tubes the joint made on the inside of the header by an asbestos wire woven gasket. The openings for medium size tubes are closed by plugs with coned joints drawn up to their seats by faced cap-nuts, thus making metal-to-metal joints.

Should a tube be found defective, from whatever cause, it may be renewed or temporarily plugged, as both ends are accessible. All necessary repairs can be made by the ship's staff.

The placing of the steam and water drum horizontally, with its centre near the water line of the boiler, provides a great body of water where it is most needed.

The location of the drum at the front of the boiler renders all valves and fittings accessible, and tends to shorten steam pipe connections.

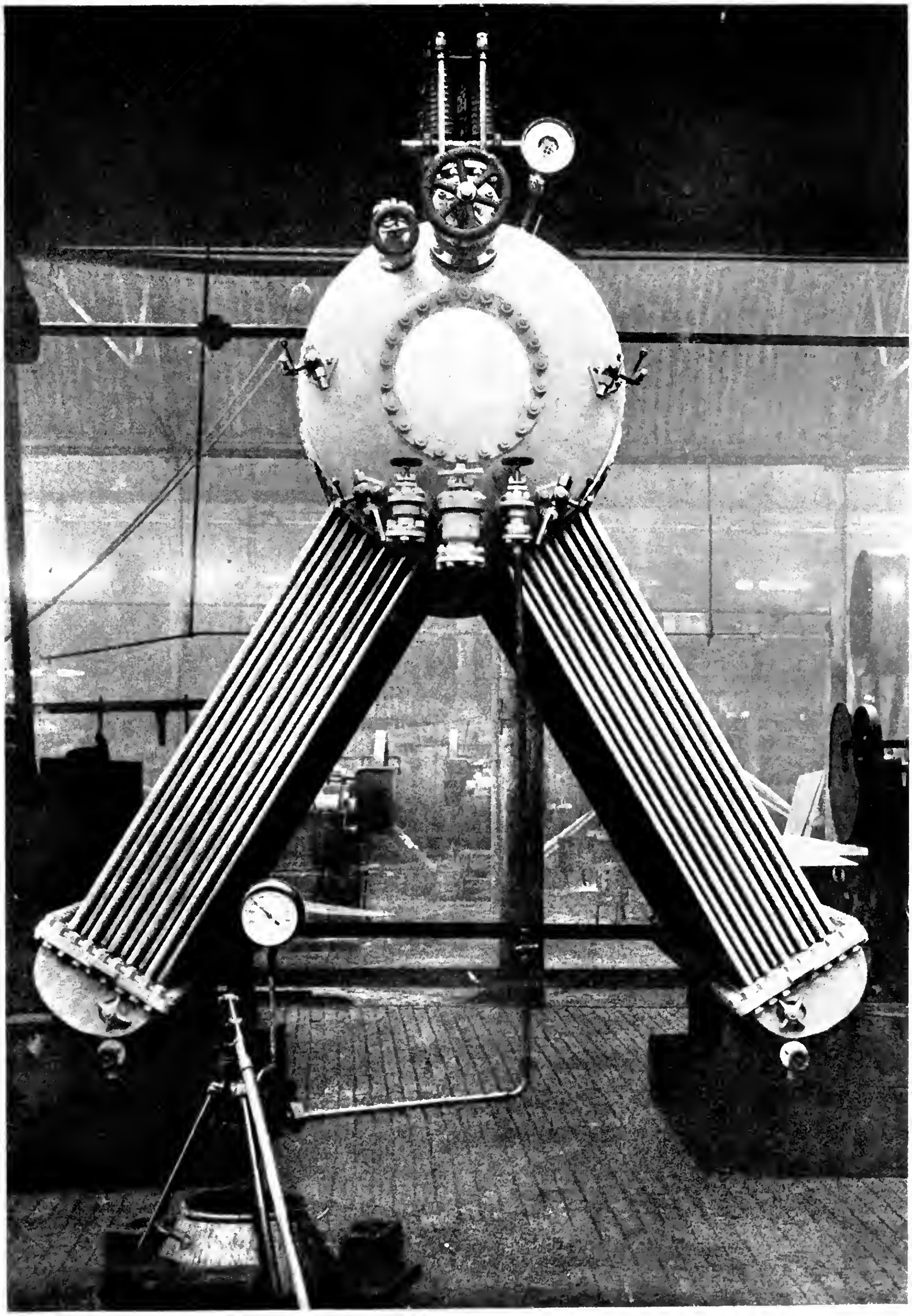


Plate II.—Straight Tube Marine Boiler.

The furnace is either built of ordinary fire-bricks carefully fitted together, or of light fire tiles, which by a special arrangement are bolted to the side plates.

The whole is encased in a special arrangement of plating fitted with non-conducting material, which is so effective in preventing the radiation of the heat that the outside of the casing is quite cool.

H.M.S. *SHELDRAKE*—TESTS AND SEA TRIALS

The *Sheldrake* is a torpedo gunboat of the *Salamander* class, with twin-screw triple-expansion engines of 3500 horse-power collectively. Each engine has cylinders 22, 23, and 49 inches in diameter, with a stroke of 21 inches.

There are two boiler compartments—divided by a water-tight bulkhead; two

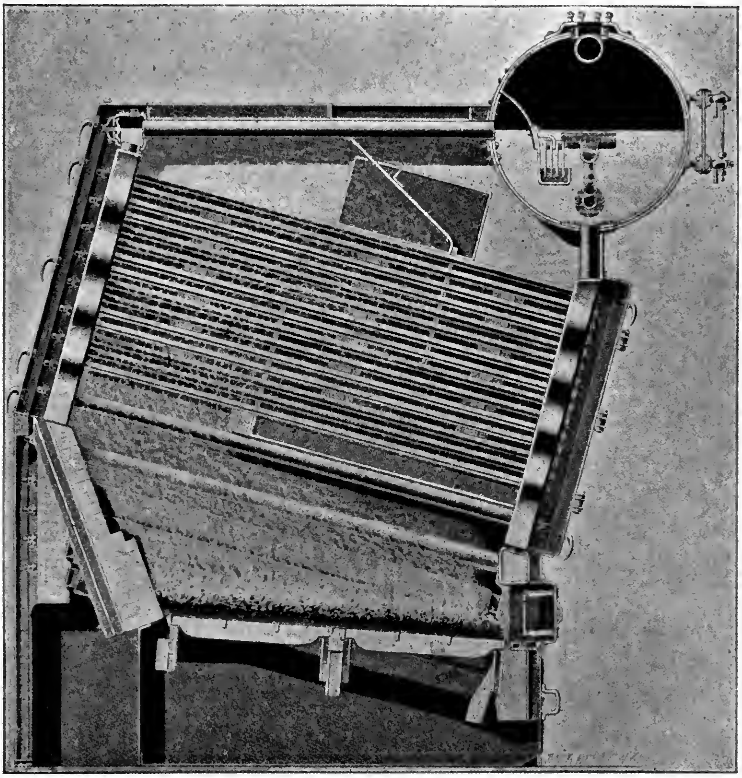


FIG. 56.—Marine Boiler. Section of Furnaces.

boilers in the forward compartment and two in the after compartment. Each pair of boilers is placed back to back, each boiler having its own stokehold. The boilers are fired fore and aft.

The total heating surface in each boiler is 2356 square feet, and the grate surface 63 square feet.

The boilers are composed of 19 sections of tubes, including side sections. The tubes throughout are of solid drawn steel, galvanized on the outside by the electro-deposition process in accordance with the usual Admiralty requirements. The tubes connecting the headers and cross boxes together are $1\frac{13}{16}$ inches in diameter—those between the headers are 7 feet 6 inches long, and those in the cross boxes 7 feet $4\frac{3}{4}$ inches. The uptake headers are connected to the steam and water drum by 4-inch tubes; 4-inch down-comer tubes are taken from each end of the steam and water drum, and connected to a wrought-iron mud box, this box being provided with blow-off and drain valves.

The stokeholds are arranged so that the air supply may be increased by means of fans, though the upcast from the stokehold remain open, and for this, four 6-foot double inlet fans were supplied, driven by engines 6½ by 5 inches, and capable of running up to 600 revolutions per minute.

There are two uptakes and two funnels,—one common to two boilers,—the inside diameter of each funnel being 5 feet, and the height above the grate bars 45 feet.

The new boilers were made under a rigorous survey by the Admiralty inspectors; and, in accordance with the terms of the contract, one of the four boilers was erected at the constructors' works, and there subjected to tests by the Admiralty authorities, to determine its capacity and efficiency.

The guarantee to the Admiralty was that one of these boilers, steamed on shore with natural draught, would evaporate 11,000 to 12,000 lbs. of water per hour, with Welsh coal; and with the feed-water at hot-well temperature, 110° Fahr. With forced draught, not exceeding 3 inches of water, it was guaranteed to evaporate 18,000 to 19,000 lbs. of water per hour from 110° Fahr. for two hours continuously.

On the test boiler the ordinary draught was that due to a funnel fixed on the top of the boiler, 3 feet 6 inches diameter, and 45 feet high above the fire-bars, corresponding to what the natural draught would be in one of these boilers in ordinary conditions of working on board ship. The assisted draught was obtained by a steam jet placed in the funnel, the steam being taken from a ¾-inch pipe, with the outlet reduced to about ½ an inch in diameter.

No baffles were used to deflect the flame, or to reduce the area between the tubes.

In the table of tests, those having the Admiralty number were carried out by the Admiralty authorities; the others were made by permission of the Admiralty for the builders' observations.

Permission was obtained from the Admiralty to place a feed heater in the uptake of the tested boiler for experimental purposes, but no heater is placed in the uptakes on board the *Sheldrake*. It will be seen from the table of tests that this heater was removed after the fifth test.

In the first five trials it will be observed that the efficiency of 74.3 per cent. (E), with an evaporation at the rate of 4.87 lbs. per square foot of heating surface, only falls to 72 per cent. (A), with an evaporation of 8.3 lbs. per square foot of heating surface; and noting the intermediate trials (B, C, and D), it shows that the efficiency, when evaporating up to 7 lbs. of water per square foot, of heating surface is practically constant, and only about 7 lbs. does the efficiency begin to fall. This proves the great elasticity in the working of the Babcock & Wilcox boiler—a result that could not possibly be obtained with the ordinary shell boiler; in other words, the amount of steam formed can vary between considerable limits without any fall in efficiency.

Test G and D—the one with an evaporation of 5.18 and the other 5.13 lbs. per square foot of heating surface—give efficiencies of 81 per cent. and 74.8 per cent., the higher efficiency of the former being due to the smaller air space between the bars.

With this boiler the highest efficiency with natural draught was obtained burning about 22 lbs. of coal per square foot of grate surface, and ⅛ of an inch air space between the bars.

Basin Trials.—The basin trials of this vessel took place at Devonport on the 14th, 15th, 16th, and 17th of November 1898.

The vessel was moored to the wharf in the usual manner in such trials, and the engines were allowed to run at such power as would take away all the steam formed by two of the boilers at a fixed rate of working. Two boilers only—alternately those in the forward and aft compartments—were taken for each trial, so as to admit of more accurate observations.

TABLE OF TESTS OF *SHELDRAKE* BOILER.

Trials	A	B	C	D	E	G	H	I
Admiralty number	I.	II.	...	...	III.	IV.	V.	VI.
Date, 1897	May 14	19	22	24	25	28	June 8	8
Heating surface of boiler—square feet	2356	2356	2356	2356	2356	2356	2356	2356
,, ,, heater—square feet	...	175	175	175	175	...	...	...
Grate surface—square feet	63	63	63	63	63	54	54	54
Fire bars used—A for Admiralty pattern; C for corrugated pattern	A	A	A	A	C	C	A	A
Air space between fire-bars—inches	½ full	½	½	½	⅛	⅛	½ scant	½ scant
Kind of fuel used	Nixon's Nav'n		Powell Duffryn's remaining 6 tests					
Duration of trial—hours	3	2	2	3	3	5	2	3
Kind of draught—N for natural; I for induced	I	N	N	N	N	N	N	N
Amount of blast in inches of water in ash pit	0.25	0.2	...	0.1	0.1	0.2	0.1	0.3-0.4
Average observed gauge pressure—lbs. per square inch	185	190	200	200	200	200	200	200
Average observed temperature of water fed to heater—Fahrenheit	...	70	70	70	70	...	...	...
Average observed temperature of water fed to boiler—Fahrenheit	70	117.5	114	111	115	70	70	70
Pounds of coal fired per hour	2564	2000	1650	1320	1260	1216	1290	2280
,, refuse per hour	487	260	91	67	75	64	194	251
,, combustible per hour	2077	1740	1559	1253	1185	1152	1096	2029
,, coal consumed per square foot of grate per hour	40.7	31.74	26.19	20.9	20	22.5	24	42.2
Pounds of water evaporated per hour under actual conditions. Feed at 70° F.	19,577	16,650	15,000	12,200	11,483	12,210	11,100	18,216
Equivalent weight of water evaporated per hour with feed at 110°	20,250	17,222	15,516	12,619	11,878	12,630	11,481	18,842
Pounds of water evaporated per square foot of heating surface	8.3	7.06	6.36	5.13	4.87	5.18	4.7	7.7
Pounds of water evaporated per square foot of grate surface	310	264	238	193.5	182	226	205.5	337
Pounds of water evaporated per sq. ft. of heating surface from and at 212° per hour	9.96	8.48	7.65	6.17	5.85	6.23	5.65	9.26
Pounds of water evaporated per sq. ft. of grate surface from and at 212° per hour	372	316	286	232	219	271	248	404
Pounds of water evaporated per pound of coal per hour (water 70°, steam pressure 200 pounds, actual observed conditions)	7.63	8.32	9.09	9.24	9.11	10.04	8.6	7.99
Pounds of water evaporated per pound of coal per hour; from and at 212°	9.15	9.96	10.91	11.09	10.94	12.05	10.32	9.59
Pounds of water evaporated per pound of combustible per hour (water 70°, steam pressure 200 pounds, actual conditions)	9.4	9.56	9.6	9.77	9.69	10.6	10.1	8.97
Pounds of water evaporated per pound of combustible per hour; from and at 212°	11.28	11.47	11.52	11.72	11.6	12.72	12.12	10.7
Mean temperature of gases in funnel—F.	650°	...	...	...	...	550°	600°	200°
Mean temperature of gases above the heater—Fahrenheit	...	600°	600°	550°	550°	...	...	...
Mean temperature in uptake below the heater—Fahrenheit	...	650°	650°	650°	650°	...	...	...
Efficiency "A"—per cent.	61.5	67	73.2	74.5	73.4	80.9	69.3	64.4
Efficiency "B"—per cent.	72	73.2	73.5	74.8	74.3	81.2	77.4	68.5

N.B.—Efficiency "A" is the percentage of the total heat of coal that was actually transferred to the water; that is, *without* allowing for loss by unconsumed coal dropping through the bars, or ash.

Efficiency "B" is the actual efficiency, allowing 5 per cent. for ash, and making allowance for the coal that fell through the bars unconsumed; that is to say, these figures are established to show the result that would have been obtained on the assumption that the grate bars had been so arranged that no loss of unconsumed fuel took place, but only the loss by the usual percentage of ash or residue in the fuel.

The total heat of combustion of the coal has been taken at 14,400 British thermal units per pound.

The temperatures of the gases were taken by noting the melting of pieces of metal, of a known melting-point, placed in the funnel and uptake, and not by a pyrometer.

The feed water was taken from the shore, and was carefully measured on its way to the boilers. The water from the hot well was allowed to run into the bilges.

On the 14th of November the two forward boilers were tried, burning 15 lbs. of coal per square foot of grate, and on the 15th the two after boilers were tried at the same rate of combustion. These two trials were to determine the economic efficiency under a moderate rate of working.

On the 16th of November the two forward boilers were tried, burning 25 lbs. of coal per square foot of grate, and on the 15th the two after boilers were tried at the same rate of combustion. These two trials were to determine the economic efficiency under a moderate rate of working.

On the 16th of November the two forward boilers were tried, burning 25 lbs. of coal per square foot of grate, and on the 16th the two after boilers were tried at the same rate of combustion; these latter trials were for the purpose of determining the economy at the maximum rate of working.

Each trial was of eight hours' duration, and was carried out with that scrupulous accuracy which is characteristic of Admiralty trials.

Sea-going Full Power Trials.—The first sea trial, which took place on the 28th of November, was of eight hours' duration, and with all four boilers in use. This was an economy trial—15 lbs. of coal being burnt per square foot of grate per hour.

RESULTS OF SEA TRIALS.

Date of Trial	28th November 1898.	1st December 1898.
Total grate surface in four boilers	252 square feet	252 square feet
,, heating surface in four boilers	9424 ,,	9424 ,,
AVERAGE PRESSURES.		
In boilers (gauge pressure)	152.5 pounds	151 pounds
In high-pressure casing (above atmosphere)	122 ,,	137 ,,
In intermediate-pressure casing (above atmosphere)	34 ,,	39 ,,
In low-pressure casing (above atmosphere)	15 absolute	6 ,,
Vacuum	25.8 inches	26 inches
Pressure of air supply to furnace—inches of water	0.2 inch	0.5 inch
Draught at base of chimney—inches of water	0.2 ,,	0.3 ,,
AVERAGE TEMPERATURES.		
External air	53° Fahr.	57° Fahr.
Boiler room	57° ,,	70° ,,
Escaping gases at root of funnel	550° ,,	550° ,,
Feed-water	103° ,,	110° ,,
Discharge	76° ,,	82° ,,
Steam in boilers	366° ,,	365° ,,
FUEL.		
Coal consumed per hour	3776 pounds	6462 pounds
Total dry refuse	5 per cent.	6 per cent.
Quality of coal	Powell Duffryn	Powell Duffryn
POWER, SPEED, ETC.		
Average indicated horse-power	2642	4050
,, revolutions per minute	242	280
,, speed of vessel per hour	17.9 knots	20.6 knots
Coal consumed per indicated horse-power per hour	1.429 pounds	1.57 pounds
Heat surface in square feet per indicated horse-power	3.5	2.3
Indicated horse-power per square foot of grate	10.5	16.

BABCOCK & WILCOX BOILER CHIMNEYS

Chimneys are required for two purposes—1st, to carry off obnoxious gases; 2nd, to produce a draught, and so facilitate combustion. The first requires size, the second height.

Each pound of coal burned yields from 13 to 30 lbs. of gas, the volume of which varies with the temperature.

The weight of gas to be carried off by a chimney in a given time depends upon three things—size of chimney, velocity of flow, and density of gas. But as the density decreases directly as the absolute temperature, while the velocity increases, with a given height, nearly as the square root of the temperature, it follows that there is a temperature at which the weight of gas delivered is a maximum. This is about 550° above the surrounding air. Temperature, however, makes so little difference that, at 550° above, the quantity is only 4 per cent. greater than at 300°. Therefore height and area are the only elements necessary to consider in an ordinary chimney.

The intensity of draught is, however, independent of the size, and depends upon the difference in weight of the outside and inside columns of air, which varies nearly as the product of the height into the difference of temperature. This is usually stated in an equivalent column of water, and may vary from 0 to possibly 2 inches.

After a height has been reached to produce draught of sufficient intensity to burn fine, hard coal, provided the area of the chimney is large enough, there seems no good mechanical reason for adding further to the height, whatever the size of the chimney required. Where cost is no consideration there is no objection to building as high as one pleases; but for the purely utilitarian purpose of steam making, equally good results might be attained with a shorter chimney at much less cost.

The intensity of draught required varies with the kind and condition of the fuel, and the thickness of the fires. Wood requires the least, and fine coal or slack the most. To burn anthracite slack to advantage, a draught of $1\frac{1}{4}$ inch of water is necessary, which can be attained by a well-proportioned chimney, 175 feet high.

Generally a much less height than 100 feet cannot be recommended for a boiler, as the lower grades of fuel cannot be burned as they should be with a shorter chimney.

A round chimney is better than square, and a straight flue better than a tapering, though it may be either larger or smaller at top without detriment.

The effective area of a chimney for a given power varies inversely as the square root of the height. The actual area, in practice, should be greater, because of retardation of velocity, due to friction against the walls.

To find the draught of a given chimney in inches of water:—Divide 7.6 by the absolute temperature of the external air ($\tau_a = t + 460$); divide 7.9 by the absolute temperature

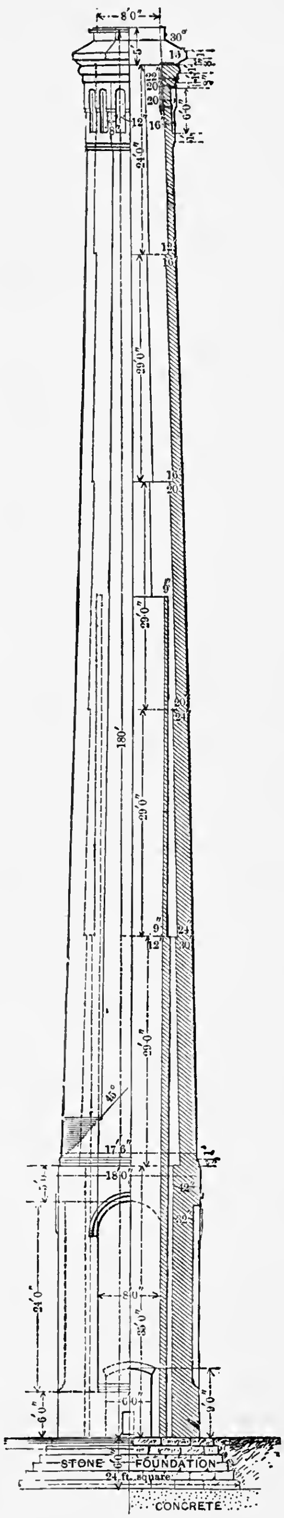


Fig. 57.—Brick Chimney.

of the gases in the chimney ($\tau_c = t' + 460$); subtract the latter from the former, and multiply the remainder by the height of the chimney in feet. This rule, expressed in a formula, would be—

$$d = h\left(\frac{7.6}{\tau_a} - \frac{7.9}{\tau_c}\right).$$

To find the height of a chimney, to give a specific draught power, expressed in inches of water:—Proceed as above, through the first two steps, then divide the given draught power by the remainder; the result is the height in feet. Or, by formula—

$$h = \frac{d}{\left(\frac{7.6}{\tau_a} - \frac{7.9}{\tau_c}\right)}.$$

To find the maximum efficient draught for any given chimney, the heated column being 600° Fahr., and the external air 62°: Multiply the height above grate in feet by .007, and the product is the draught power in inches of water. Practically nothing can be gained by carrying the temperature of the chimney more than 350° above the external air at 60°.

To determine the quantity of air, in pounds, a given chimney will deliver per hour, multiply the distance in inches, at given temperature, on the diagram, by 1000 times the effective area in square feet, and by the square root of the height in feet. This gives a maximum. Friction in flues and furnace may reduce it greatly.

The external diameter of a brick chimney at the base should be one-tenth the height, unless it be supported by some other structure. The "batter" or taper of a chimney should be from $\frac{1}{16}$ to $\frac{1}{4}$ inch to the foot on each side.

Thickness of brickwork: one brick (8 or 9 inches) for 25 feet from the top, increasing $\frac{1}{2}$ brick (4 or $4\frac{1}{2}$ inches) for each 25 feet from the top downwards.

If the inside diameter exceed 5 feet the top length should be $1\frac{1}{2}$ bricks, and if under 3 feet it may be $\frac{1}{2}$ brick for 10 feet.

HORNSBY UPRIGHT WATER-TUBE BOILER

The features claimed for this boiler are that the whole boiler can be laid open for inspection by the removal of a small number of doors, *e.g.* in the 730 horse-power size by the removal of only fourteen covers. The saving of labour in cleaning involved by this method of construction, as compared with the old-fashioned semi-horizontal type, with its enormous number of handhole doors (one to each tube), can be readily computed. It varies according to circumstances, but in most cases it amounts to hundreds of pounds per annum. The boiler can be cleaned thoroughly in four or five hours, including the time required for reducing the steam to atmospheric pressure and raising it again to working pressure. The upright position (Figs. 61 and 62) was designed to overcome the difficulties experienced with the old horizontal type, viz., the deposit of sediment in that part of the boiler which should be the most efficient (the lower rows of generating tubes), causing rapid loss of steaming power and efficiency, and making the use of the old type boiler for long periods without cleaning undesirable, unless exceptionally clean or distilled water be used. The feed water being delivered to the back, or least active part of the boiler, is relieved on its passage downwards through the tubes of the bulk of its impurities, which are deposited in the form of liquid mud in the bottom back headers. What little sediment does pass into the generating tubes will not adhere to the walls of the tubes owing to their being set in a nearly vertical position, but peels off and drops to the bottom as soon as formed. After being in constant work at full power for two years it shows less than $\frac{1}{16}$ of an inch of scale on the tubes at any point, and even this small amount only in isolated patches, which, in their turn, fall to the bottom. This magnificent result is obtained without putting a scraper through the tubes at all, and without the necessity of drawing the water off, the tubes being simply brushed down from the top, and the mud blown out through the bottom headers.

The angle of inclination of the tubes, combined with their self-cleaning properties, ensures the utilisation of a very much greater proportion of the heat applied to them, thus conducing to an economy of fuel and a thermal efficiency unattainable in the semi-horizontal or any other type of water-tube boiler. Again, owing to the freedom from deposit in the generating sections, the boiler will maintain its maximum evaporative

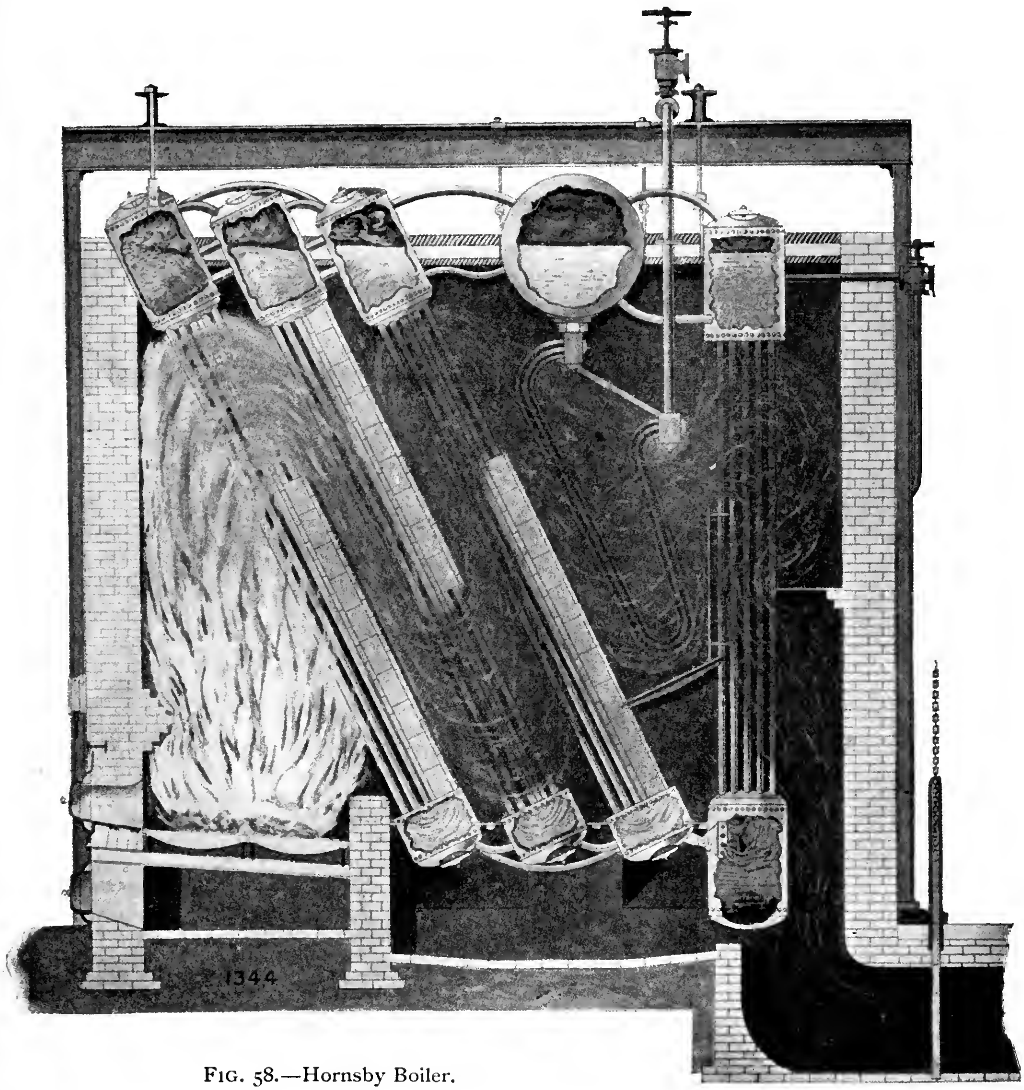


FIG. 58.—Hornsby Boiler.

power and efficiency for periods which were quite impossible with the horizontal type. The latter, as is well known, shows a very rapid falling off of power and efficiency after comparatively short periods of work, owing to the scale being deposited on what should be the most active part of the boiler, and consequently it is unsafe to rate it at more than two-thirds of its theoretical power. To balance the low evaporation per square foot of heating surface resulting from the thick deposit in the lower rows of tubes, a large excess of heating surface has to be provided, thus considerably increasing the cost.

Fig. 60 shows a nest of tubes nineteen in number fitting into two heads. In order to clean the boiler, all that is necessary is to let down the pressure of steam and at once open the top manhole. The nineteen tubes can then be easily reached and brushed (no scraper is necessary). By this means many hours are saved. All the cleaning may be completed and the boiler working again within four hours.

Fig. 58 is a complete cross section of the boiler with its setting, and illustrating the path of the hot gases through the nests of tubes. This Fig. 58 also shows—

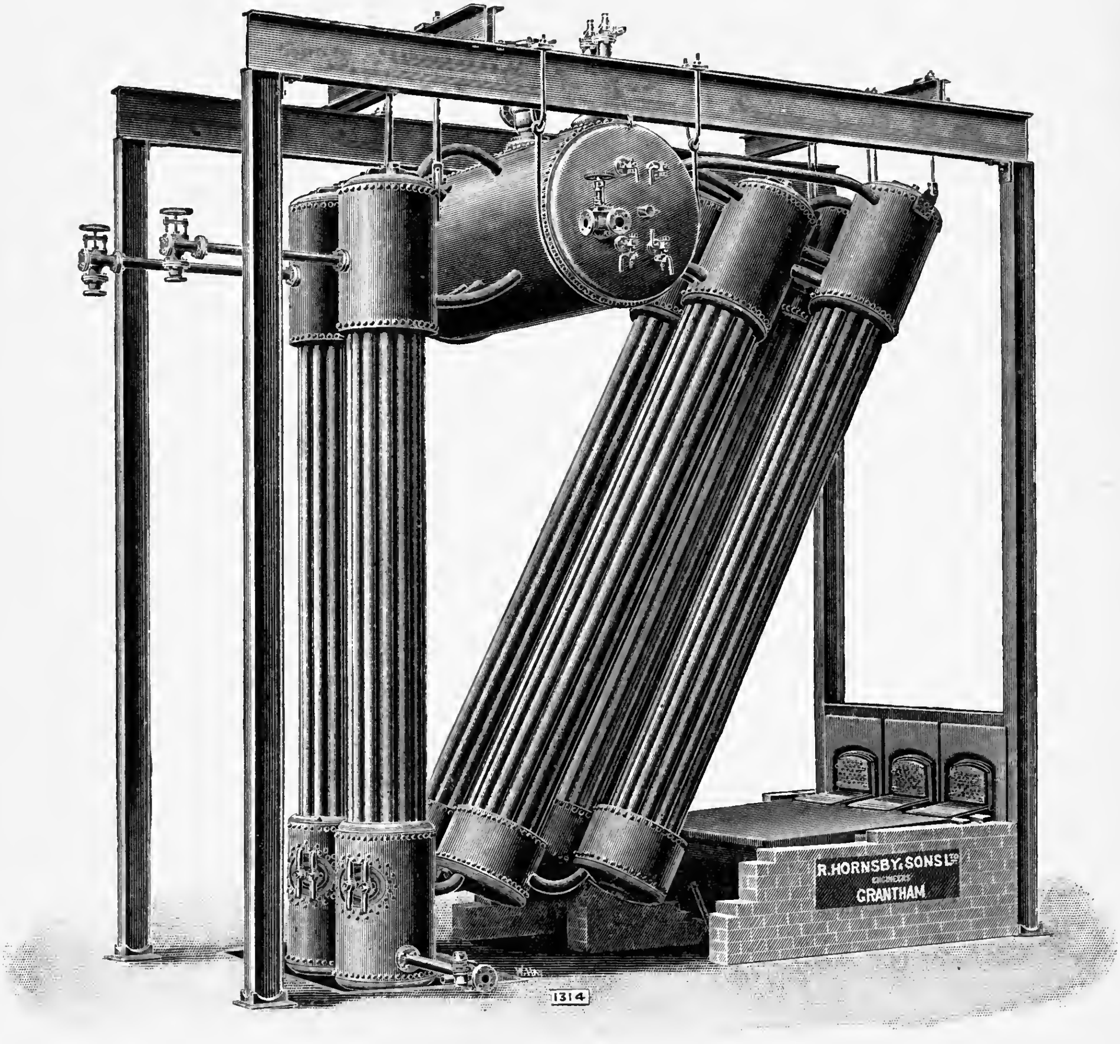


FIG. 59.—Hornsby Boiler.

1. Arrangement of three rows of steam-generating sections, steam and water drum, and one row of back economiser and feed sections.

2. Large size of combustion chamber.

3. Course of hot gases, always striking the under side of the tubes, where the greatest amount of work is done.

4. Rapid "accelerated" circulation of water in front steam-generating tubes, and large surface in headers for discharge of steam.

5. Slow and quiet general system of circulation regulated by rate of evaporation —perfectly free and automatic.

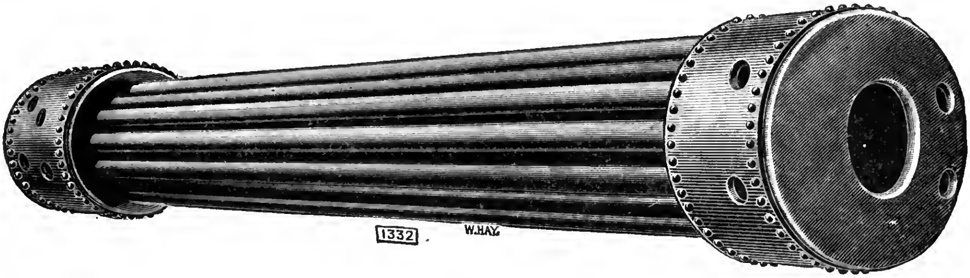


Fig. 60.—Nest of Tubes.

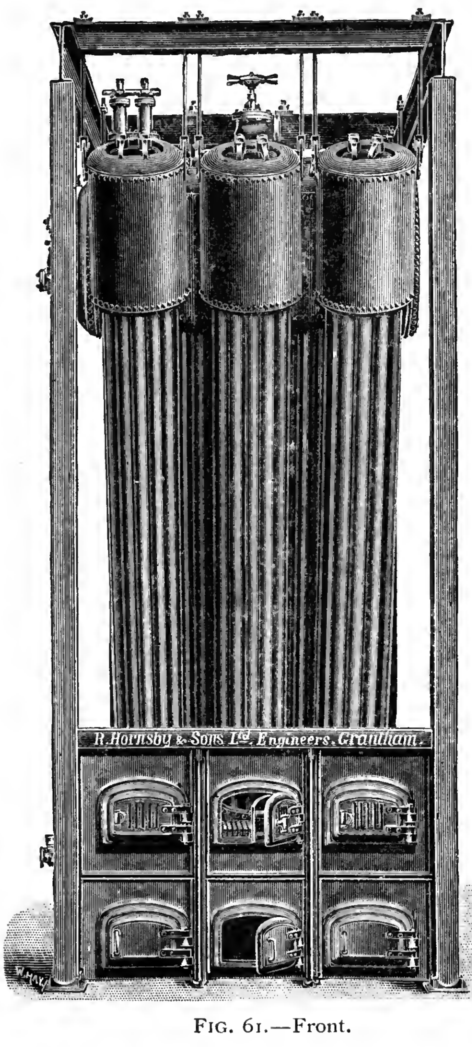


Fig. 61.—Front.

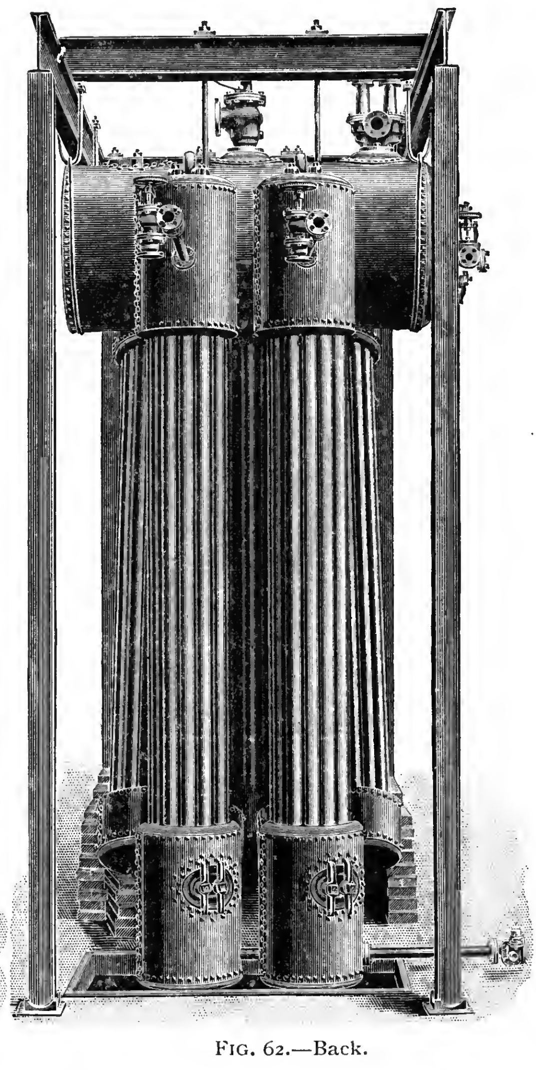


Fig. 62.—Back.

6. Separation of mud in back economiser sections.

Fig. 59 is an illustration of this boiler for Standard type 390 horse-power for electric lighting and other purposes, as supplied to the Finchley, Grantham, Pietermaritzburg, Durban, and other electricity stations.

Fig. 59 shows the boiler erected and ready for the bricklayers to build in; and Figs. 61 and 62 show an elevation of the front and back end respectively, showing how the sections are staggered, and how easily the top headers may

Fig. 63.—Superheater.

be opened for cleaning without emptying the boiler or waiting for the brickwork to cool.

The back view shows vertical feed and economiser sections, and feed and blowdown arrangements.

In Fig. 63 we have a view of the superheater formed of V-shaped tubes suspended in the space between the risers and downcomers. This firm also make a separately fired superheater.

TESTS OF HORNSBY BOILER

Result of Test of No. 2 boiler at the Finchley Urban District Council's Electricity Works on 4th July 1904:—

HORNSBY UPRIGHT WATER-TUBE BOILER.—TIME, 12.14 P.M. TO 8.45 P.M.
WEATHER, FINE. BAROMETER, 29.9.

1.	Heating surface	1692 square feet.
2.	Grate surface (7 feet 0 inches by 5 feet 0 inches)	40.25 ,,
3.	Ratio of heating surface to grate surface	42.03 ,,
4.	Kind of fuel used	Nixon's Navigation.
5.	Duration of test	8 hours.
6.	Average observed gauge pressure	160 lbs.
7.	,, temperature of feed water	91.73° Fahr.
8.	Pounds of coal fired	6,000 lbs.
9.	,, refuse	455 ,,
10.	,, combustible	5,545 ,,
11.	Coal consumed per hour	750 ,,
11.	,, square foot of grate per hour	18.63 ,,
13.	Water evaporated (total)	57,500 ,,
14.	,, per hour	7,185.5 ,,
15.	,, square foot of heating surface per hour	4.24 ,,
16.	Water evaporated per pound of coal,—actual conditions, feed water 91.73° Fahr., steam pressure 160 lbs.	9.583 ,,
17.	Water evaporated per pound of coal, assuming feed water 212° Fahr., and under atmospheric pressure	11.257 ,,
18.	Water evaporated per pound of combustible, actual conditions as 16	10.37 ,,
19.	Water evaporated per pound of combustible, from and at 212° Fahr	12.18 ,,
20.	Quality of steam saturated and slightly moist, percentage of moisture	1.2 ,,
21.	Calorific value of coal	14,800 B.T.U's.
22.	Boiler percentage efficiency	73.4.
23.	Percentage of refuse	7.6.
24.	Draught in inches of water at damper	.42.
25.	,, at chimney side of damper	.7.
26.	Analysis of gases, average of 8 samples:—	
	Carbon Dioxide (CO_2) . . 12.19 per cent.	
	Oxygen (O_2) . . . 8.44 ,,	
	Nitrogen (N_2) . . . 79.37 ,,	
26A.	Weight of flue gases per pound of coal	17.28 lbs.
27.	Temperature of flue gases	600° Fahr.
28.	,, of boiler house.	69° ,,
29.	Rise in temperature	531° ,,
30.	Heat absorbed by evaporation	10,734 B.T.U's.
31.	Heat lost by flue gases	2,141.5 ,,
32.	,, radiation, etc., and ashes	1,891 ,,
33.	Heat given by moisture in steam	33.5 ,,

(Signed) EDWARD CALVERT.

PARTICULARS OF TRIALS BY PROFESSOR ROBINSON

Date of trial	November 27, 1902.
Duration of trial	6 hours.
Heating surface (effective)	3923 square feet.
Grate area	48.56 ,,
Class of firing	Hand.
Temperature of flue gases	450° Fahr.
,, of feed water to boiler	50° ,,
Steam pressure (by gauge)	153 lbs.
Water evaporated per hour (average)	10,200 ,,
Quality of fuel	Unscreened Welsh.
Per cent. of ash and clinker to total coal	7.
Fuel burnt per square feet of grate per hour	22.3 lbs.
Draught in inches of water at boiler damper	$\frac{1}{2}$ inch to $\frac{9}{16}$ inch.
Water evaporated per pound of fuel from feed temperature of 50° Fahr.	9.4 lbs.
Water evaporated per pound of combustible from feed temperature of 50° Fahr.	10.1 ,,
Water evaporated per pound of fuel from and at 212° Fahr.	11.28 ,,
Water evaporated per pound of combustible from and at 212° Fahr.	12.12 ,,

Results of Ordinary Daily Working

Date of trial	October 24, 1902.
Duration of trial	6 hours.
Heating surface (effective)	3923 square feet.
Grate area	48.56 ,,
Class of firing	Hand.
Temperature of flue gases	510° Fahr.
,, of feed water to boiler	177° ,,
Steam pressure (by gauge)	153 lbs.
Water evaporated per hour (average)	9380 ,,
Quality of fuel	Watnall Hard.
Per cent. of ash and clinker to total coal	7.1.
Fuel burnt per square feet of grate per hour	21.9 lbs.
Draught in inches of water at boiler damper	$\frac{1}{2}$ inch.
Calorific value of fuel by bomb. calorimeter	12560.
Water evaporated per pound of fuel from feed temperature	8.81 lbs.
Water evaporated per pound of combustible from feed temperature	9.48 ,,
Water evaporated per pound of fuel from and at 212° Fahr.	9.61 ,,
Water evaporated per pound of combustible from and at 212° Fahr.	10.33 ,,

CLARKE CHAPMAN'S WATER-TUBE BOILER

This boiler is also of the straight vertical tube type in a large combustion chamber. The three Figures (Figs. 64, 65, and 66) show a longitudinal section, a sectional plan, and a cross section.

A few of the special points and advantages claimed in the above type of boiler, all of which are essential to ensure the successful working of any water-tube boiler, are here given.

1. All tubes perfectly straight and nearly vertical. No bent tubes of any description. No joints exposed to heat of furnace gases. All parts of boiler free to expand. All tubes same length. An obstructed view through each tube for inspection.

2. Each tube being nearly vertical and perfectly straight, and entering the steam drum direct without intervention of any headers, ensure a perfect steam release, and

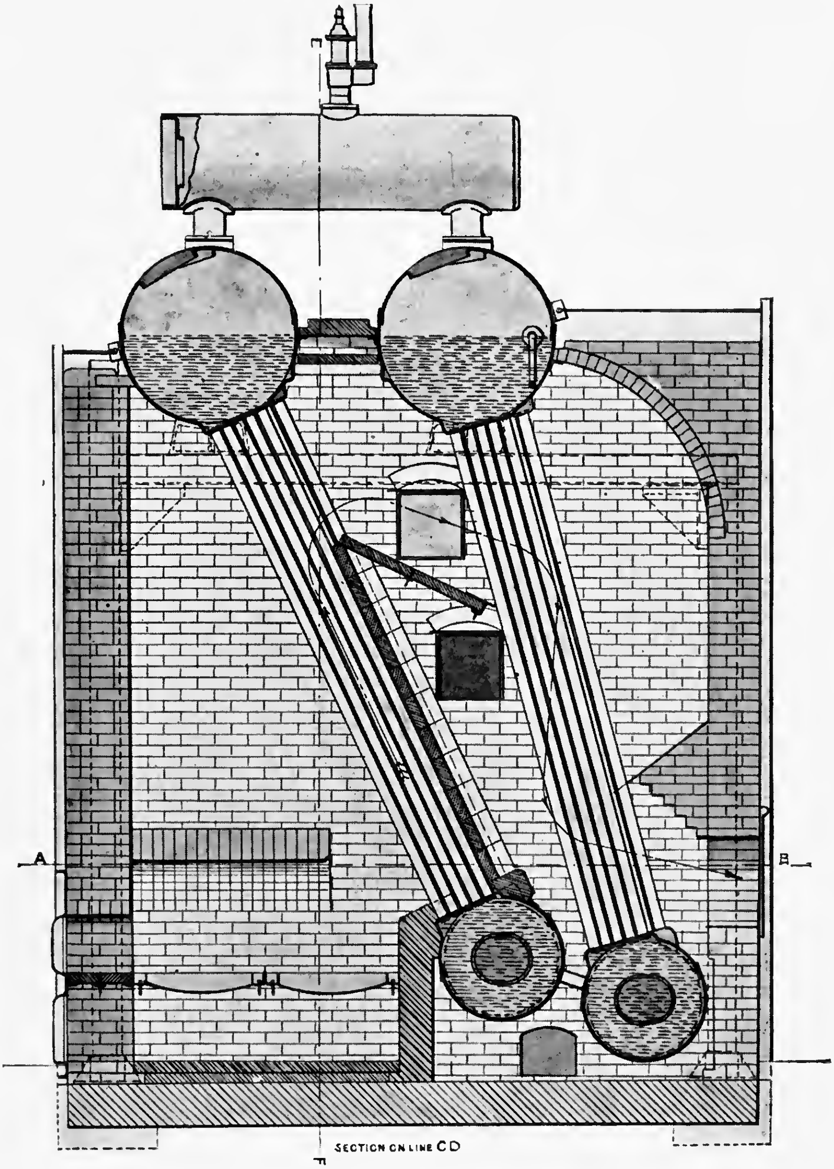


FIG. 64.—Clarke Chapman Boiler.

so adds to the efficiency of the boiler, as there are no sharp turns to retard flow of the steam globules to the steam space.

3. Free access to all parts, whether for examination, cleaning, or repairs.

4. The tubes being nearly vertical and perfectly straight, deposits are not retained in the tubes, but are collected in the large mud drums, thus overheating and destruction of tubes is reduced to the minimum. This is a distinct advantage over boiler with hori-

zontal tubes, which invariably burn through in the bottom rows, through the great tendency for deposits to collect in any tubes lying horizontally. The same danger exists with vertical tubes if they are not straight, as any bend must collect deposit.

5. Simple construction and design is such that the boiler may be worked and understood by any ordinary fireman.

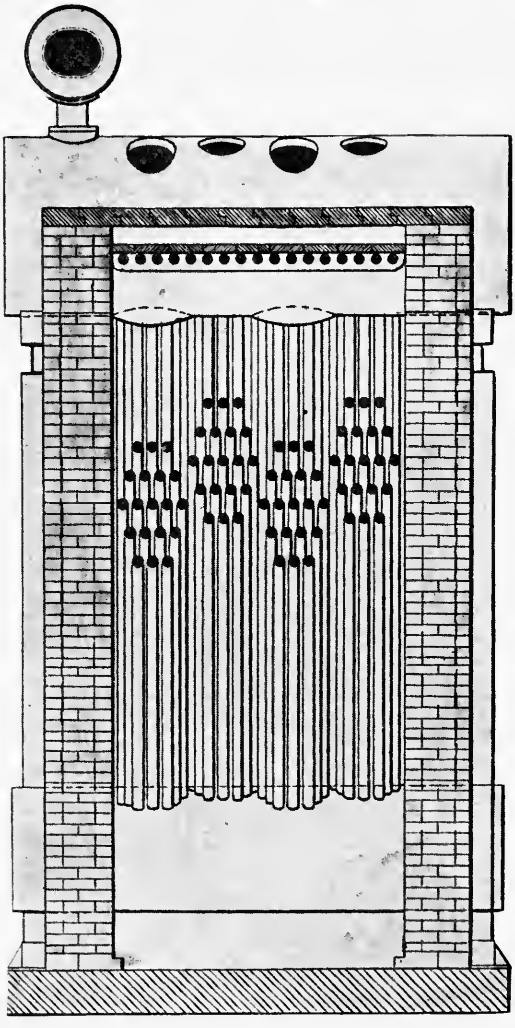


Fig. 65.—Cross Section.

6. So arranged that the whole of the heat is utilised in the most economical way, and combustion of gases completed before leaving the heating surface.

7. The design offers great facility for cleaning, as by breaking one manhole joint on each steam and water-drum the whole of the tubes can be thoroughly examined internally, and by breaking any one manhole joint in steam drum, nineteen tubes are accessible for any purpose.

8. The only tools required for this boiler are the ordinary tools with which every mechanic or fireman is fully acquainted.

PARTICULARS OF TESTS

Date	Jan. 18, 1905.	Jan. 23, 1905.
Duration of test	6 hours.	6 hours.
Heating surface—square feet	1440.	1440.
Grate area—square feet	39.	39.
Temperature of feed water	119° Fahr.	127° Fahr.
Total water evaporated	47,704 lbs.	52,866 lbs.
Pounds of coal per square feet grate per hour	18.18.	21.0.
Pounds of water per 1 lb. of coal	11.2.	10.72.
Pounds of water per 1 lb. of coal from and at 212°	12.5.	12.2.
Pounds of water per square feet of heating surface per hour	5.5.	6.12.
Pounds of water per square feet of heating from and at 212°	6.27.	7.
Total coal burnt	4256 lbs.	4928 lbs.
Nature of coal	West Wylam.	West Wylam.
Temperature of funnel gases (average)	580°.	585°.
Draught in funnel base	½ inch.	½ inch.
Average steam pressure	125 lbs.	135 lbs.
Class of firing	Hand.	Hand.

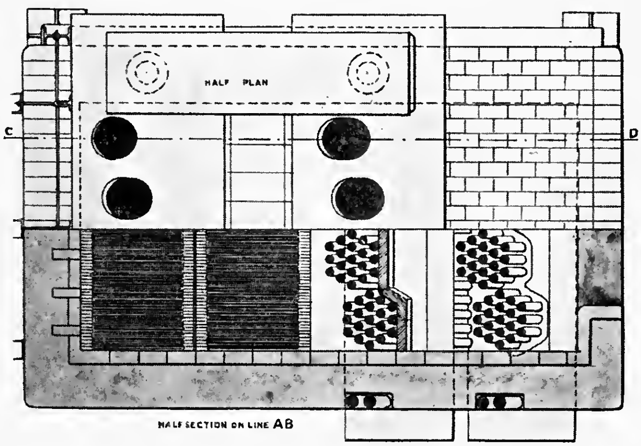


FIG. 66.—Plan Section.

THE STIRLING WATER-TUBE BOILER

This boiler has bent tubes, and is made in the various types as shown.

3-*Drum or U. Type* (Fig. 67).—This has been designed for small powers, and for the utilising of waste heat from reheating furnaces, etc., and consists of two steam drums varying in size from 3 feet to 3 feet 6 inches in diameter, connected by two banks of tubes to one mud drum.

4-*Drum or B. Type* (Figs. 68 and 69).—This is the universal type of Stirling boiler as made in the United States, and is considered there to be the best and most efficient design. As will be seen from the accompanying illustration, it consists of three steam drums and one mud drum connected by three banks of tubes.

This is also the type of boiler that has been adopted for marine work. As in the land type, the marine boiler is made in various sections to suit various conditions of service. It has been designed for all classes of ships, from very light-draught vessels and yachts where minimum weight of boiler is necessary, to large ocean-going steamers, battleships, etc., and embodies all the features of the land type boiler set forth above. The brick-setting of the land boiler is replaced in the marine by a specially designed ironclad casing, lined with firebrick in the combustion chamber, and elsewhere with suitable non-conducting material.

5-*Drum or W. Type* (Figs. 70 and 71).—This is the type of boiler that has been supplied in this country for land purposes. It consists, as the illustrations show, of three steam drums and two mud drums connected by four banks of tubes.

Though there is a difference in detail between this boiler and the 4-drum type, it will be seen that the principle is the same. The circulation is very similar in both cases, as, owing to the ample provision of cross water tubes between the two mud drums, the second and third banks of tubes and the two mud drums act in the same manner as the middle bank of tubes and single mud-drum in the 4-drum type; except that in the 5-drum type the back mud drum is farther removed from the main circulation, and therefore more favourable for the deposition of mud and scale. Also, the longer travel of the gases gives a lower temperature of the waste gases, and therefore tends to increased efficiency.

This type of boiler is suitable where very large units are desired.

In all the types the boiler consists of two or more steam drums, and one or more mud drums connected by almost vertical banks of tubes. The drums vary in size from 3 feet diameter in the smaller to 4 feet in diameter in the larger sizes. They are made of Siemens-Martin open hearth steel boiler plates, the circumferential seams being single, and the longitudinal seams double riveted. The end plates are dished to avoid the necessity of staying.

The tubes are solid drawn weldless steel, and for the land type are $3\frac{1}{4}$ inches outside diameter. In the marine type the tubes vary from $2\frac{1}{2}$ inches to 2 inches outside diameter, according to size of boiler and space to be occupied.

The tubes, which are all bent to the same radius, are curved sufficient to enable them to enter the tube plates radially, and to allow flexibility without straining. The joint between tube and tube plate is made by expanding with an ordinary roller expander.

The tubes are arranged in parallel rows in the tube plate, and are pitched along the length of the drum in alternatively wide and narrow spacing, and in such a manner that any one tube can be cut out and replaced without disturbing any other tube or tubes. This method of spacing the tubes enables any one entering the boiler, for cleaning or inspection purposes, to lay their hand on every individual tube—an important point that will appeal to all boiler inspectors.

With regard to the cleaning of the interior of the tubes, if the deposit is soft this can be readily removed by chain scrapers provided for the purpose; when hard scale is formed the quickest and most satisfactory method of removing same is to use a turbine tube cleaner.

The boiler as made for land purposes is generally provided with a brick setting, though occasionally an ironclad casing is adopted. The boiler is supported entirely free of the brickwork setting, the steam drums resting on horizontal girders carried on vertical columns. These girders and columns being outside the brickwork, this is not affected by any expansion and contraction of the steel framing, and it can be built, or removed and rebuilt, without disturbing the boiler or its connections. The mud drums are suspended by the tubes from the steam drums; and as the tubes are curved, and the mud drums kept well clear of the brickwork all round, this makes ample provision for any expansion and contraction that can possibly take place.

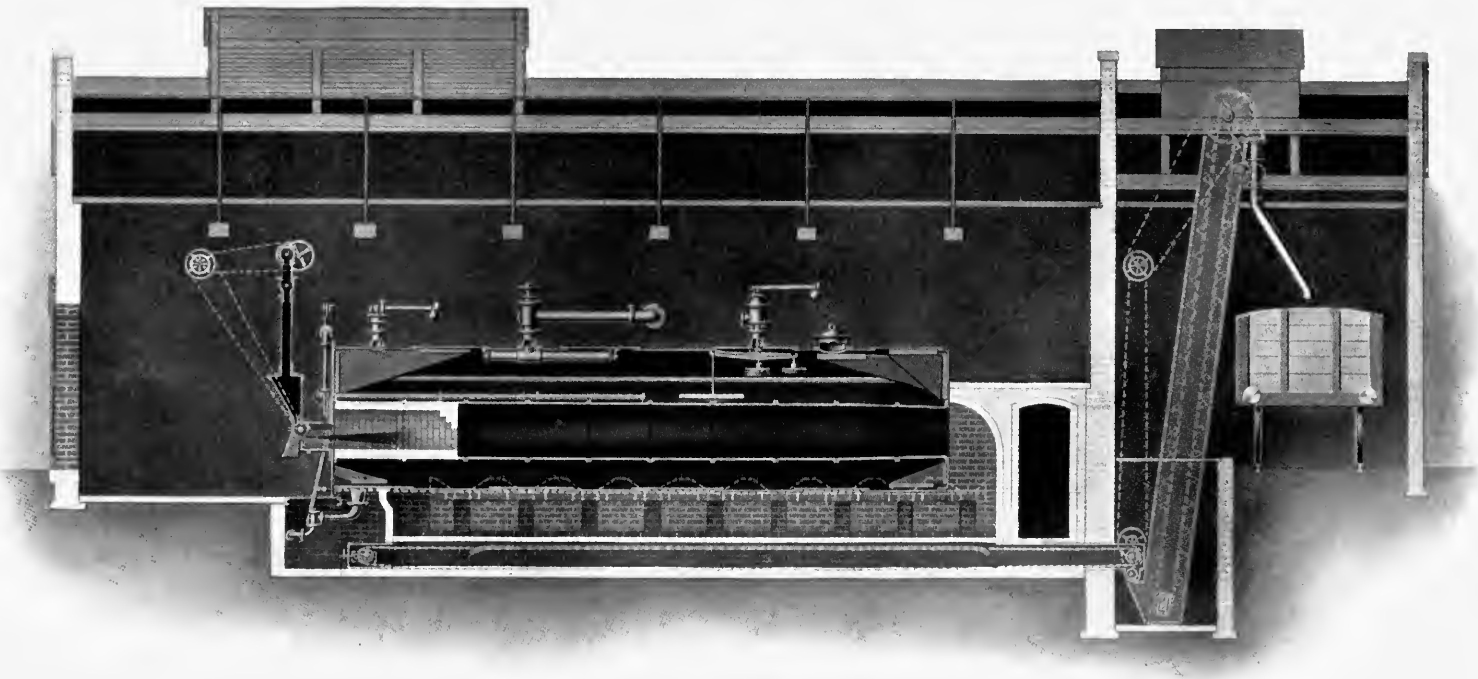


Plate III.—Sectional View of Coal Dust Fired Boiler.

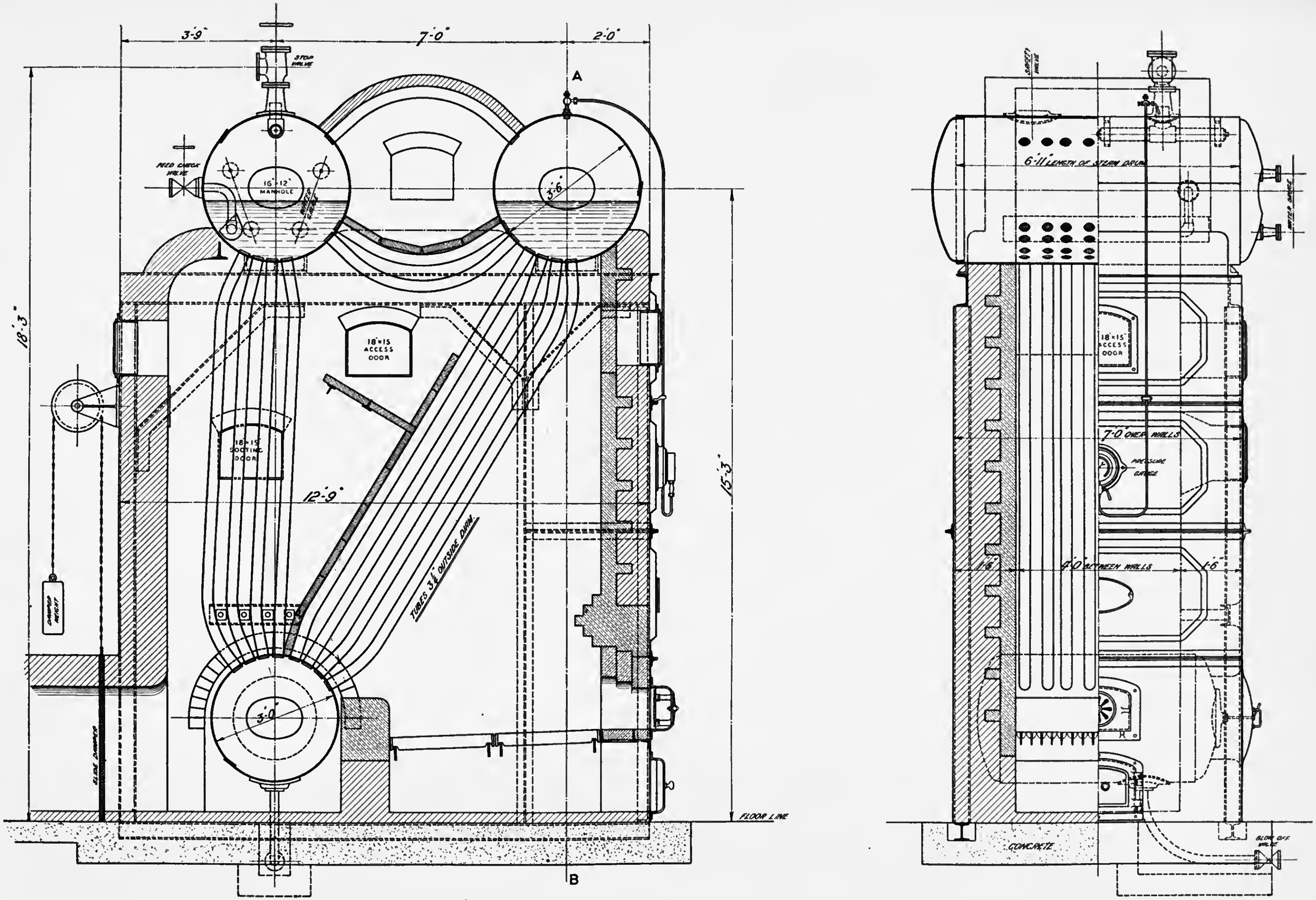


Fig. 67.—Three-Drum Stirling Water-Tube Boiler.

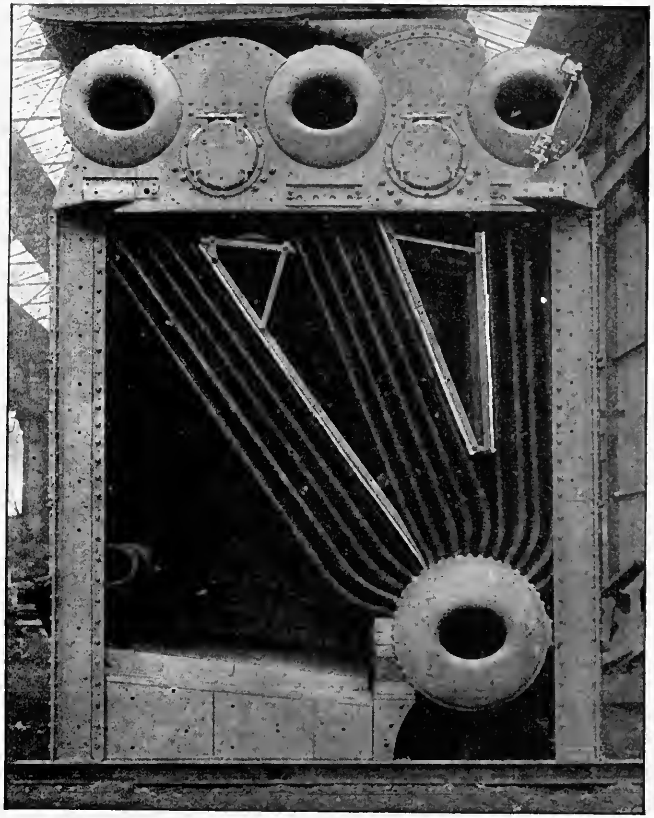


Fig. 68.—Four-Drum Stirling Boiler.

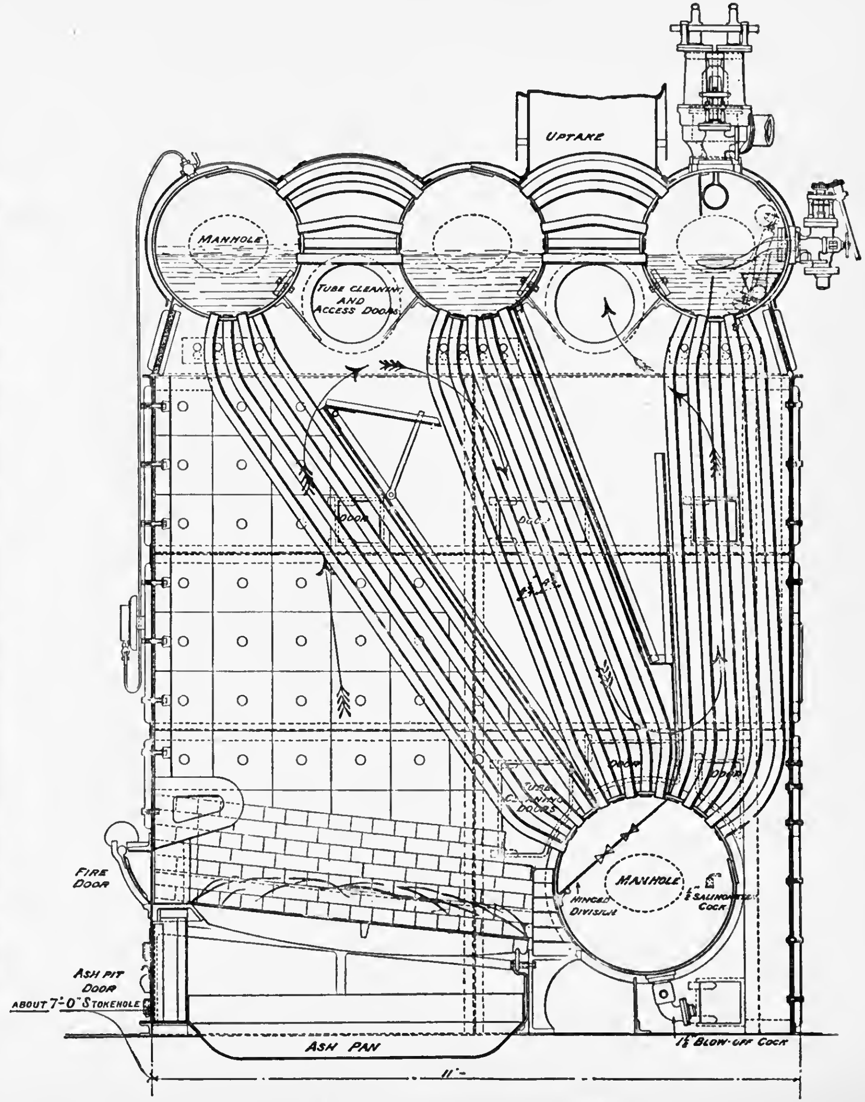


Fig. 69.—Four-Drum Stirling Boiler.

Access, for cleaning and inspection purposes, to the inside of the drums and the interior of the tubes, is gained by removing the manhole door from each drum, and these are the only joints that require to be broken and re-made when the boiler is opened up for inspection. Suitable access and sooting doors are provided in the setting for inspection and the cleaning of soot from the outside of the tubes.

By means of fire-brick baffle tiles laid on dry against the last row of tubes in each bank, suitable spaces being left at the top or bottom, as the case may be, the hot gases are made to pass up or down each successive bank of tubes, and, owing to the long travel through the water tubes, the maximum amount of heat is extracted.

The feed check valve and internal feed pipe and trough are fitted to the back steam drum, the coolest part of the boiler. The feed slowly circulates down the last bank of tubes into the mud drum, and its temperature is gradually raised to the steaming-point by the escaping gases, and, as a consequence, most of the deposit is found in the back section of the boiler. The mud drum acts as a settling chamber, the circulation in that

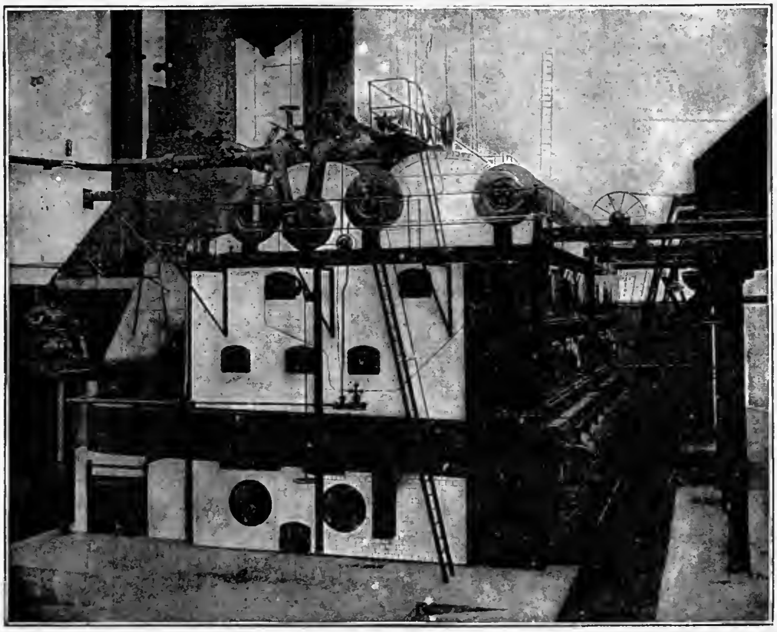


Fig. 70.—Stirling Boiler Setting.

part of the boiler being comparatively slight. As a result of this the water is purified to a great extent before it gets into the main and rapid circulation of the boiler, which is up the front bank of tubes, across from the front to the middle steam drum, and down the second bank of tubes ; consequently, the heating surface immediately over the fierce heat of the furnace tends to keep clean and free from scale. Another advantage of the position of the feed in the Stirling boiler is that the cool feed passing down the last bank of tubes comes in contact with the gases immediately before they pass out of the boiler setting. By this arrangement a low flue temperature is obtained, and consequently a high efficiency is secured. Each tube has a full area outlet for the steam as generated, and no obstruction is offered to the passage of the steam and water to the surface.

The vertical position of the tubes, and the forward position of the front steam drum, provide for a large combustion chamber ; and as this is lined with fire-brick round three sides, a high initial temperature is obtainable, with the result that low-class fuels can be used successfully with the Stirling boiler.

It will be seen from the illustrations of the various types of boilers that the con-

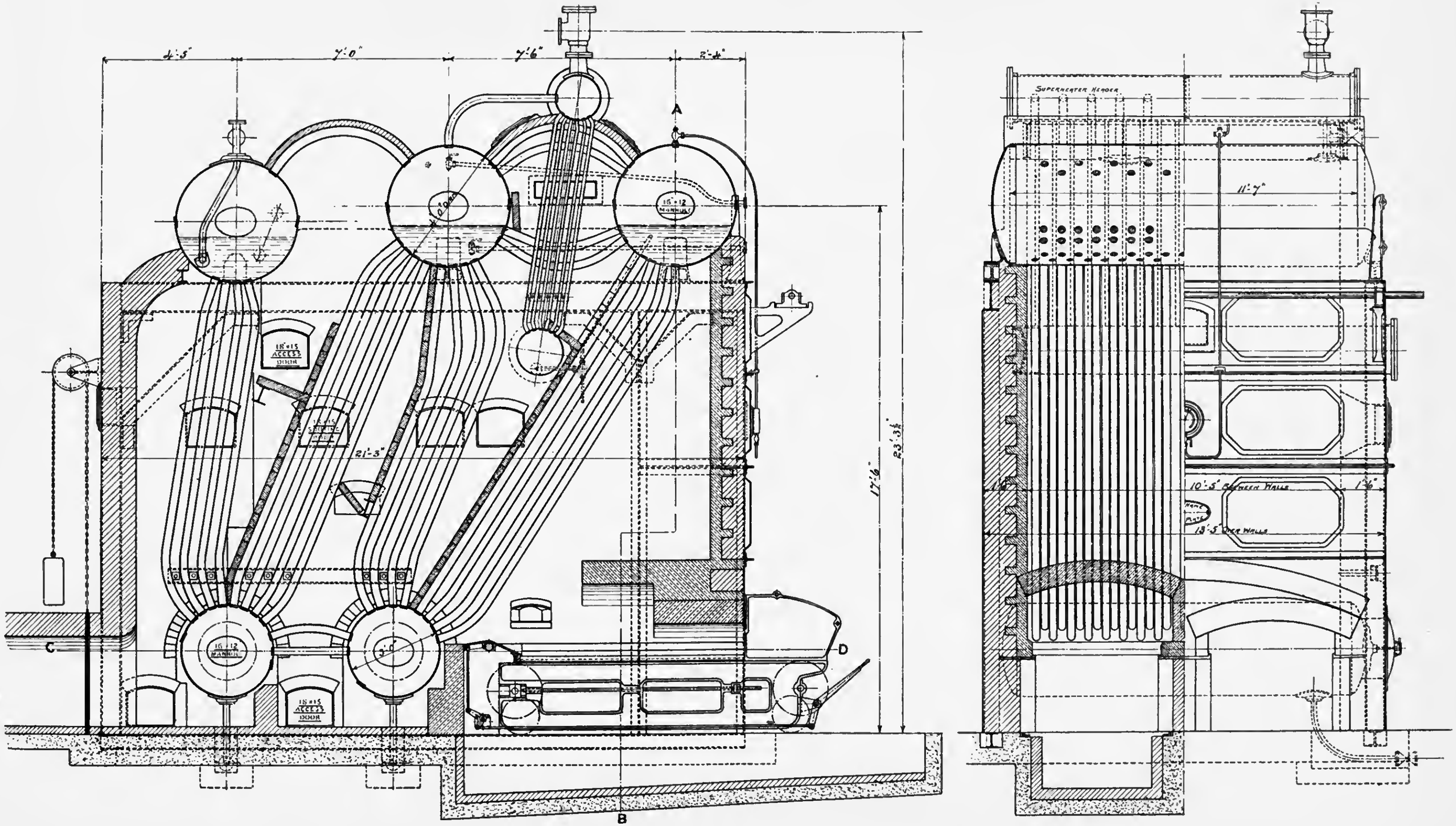


FIG. 71.—Five-Drum Stirling Boiler. Sectional Views.

struction allows of a great adjustment of grate area to heating surface, so that the grate area can readily be adapted to the kind of fuel to be used.

Each type of boiler is made to a particular standard "section," and each size of boiler in that "section" is of the same height and length, and varies only in the width. As the drums are placed transversely, it will be seen that as the boiler increases in size the water and steam spaces increase in the same ratio.

TEST ON W. TYPE STIRLING BOILER AT SOUTH EALING ELECTRIC POWER STATION,—HAND FIRED, WITH SUPERHEATER

Date of test	January 28, 1904.
Duration of test	3½ hours.
Heating surface—in square feet	6500.
Grate area—in square feet	109.
Ratio of heating surface to grate area	59.6 to 1.
Boiler pressure (average)	124.45 lbs.
Kind of fuel	North Country nuts (common).
Calorific value of coal	13,586 B.T.U.
Total coal fired	9618 lbs.
Per cent. of ash in coal	8.08 per cent.
Average weight of coal fired per hour	2748 lbs.
,, ,, per hour per square feet of grate	35.2 ,,
Total water evaporated	90,800 ,,
Average water evaporated per hour	25,943 ,,
,, ,, per hour per square feet of heating surface	4 ,,
,, ,, per pound of coal	9.44 ,,
Average weight of water evaporated per pound of combustible	10.30 ,,
Equivalent evaporation per hour per pound of coal from and at 212° Fahr. without superheater	10.29 ,,
Equivalent evaporation per hour per pound of coal from and at 212° Fahr. with superheater	10.57 ,,
Equivalent evaporation per hour per pound of coal from and at 212° Fahr. per square feet of heating surface	4.48 ,,
Temperature of feed water (average)	166.6° Fahr.
Temperature at chimney base	549.1° ,,
Average temperature of steam at superheater outlet	411.7° ,,
Amount of superheat	58.8° ,,
Average CO_2	12.72 per cent.
Efficiency	75.2 ,,
Factor of evaporation	Saturated, 1.09—Superheater, 1.13.

DETAILS OF STIRLING MARINE BOILER

Shown in Fig. 72 complete, and detailed in Figs. 73 and 74.

The effect of the ship rolling is carefully guarded against inside the top drums by the plate divisions fitted with Atlantic lips at top, which minimise the surge of water (Fig. 74). Holes at the bottom of these division plates allow the water spaces to be common to each other.

It will be noted in the sketch that the main frame which supports the boiler is well anchored to stiff parts of shipwork by rolling chocks, which are arranged with ample provision for expansion.

The bottom drum, which is suspended from the three upper drums, is also carefully provided against the rolling action, although also free to take up expansion.

Fig. 73 is a section of the tube plate, and shows the tube expanded and bell-mouthed, so that each tube becomes a stay tube, ensuring perfect steam tightness at joints. Careful tests of the force required to draw a tube from the plate shows a very large factor of safety.

The drum end is dished, no stays being fitted, and the manhole door of stamped steel type, with internal pressure, keeps joint in place even if dog bolts gave out when tightening up under steam pressure.

The division plate in the bottom drum, as shown, separates the back from front part of drum, and so prevents deposit, precipitated and brought down the back tubes, from being carried across the drum to the tubes local to the fire; at the same time communication to facilitate circulation is provided by the holes in division plate.

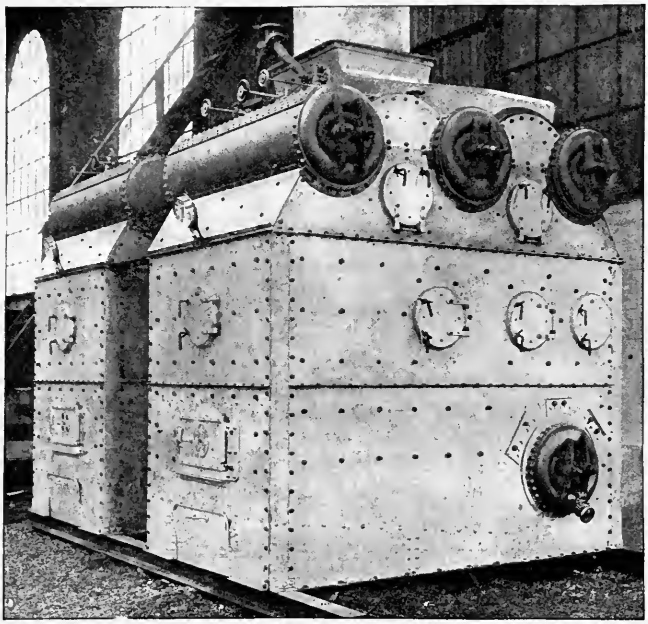


FIG. 72.—Stirling Boiler. Marine Type.

The speed of water through these holes is greater than that in the drum. There are a few drain holes at bottom of plate for draining drum. The blow-off valve blows out loose scale deposited in drum.

Figs. 75 and 76 show part elevations of the boiler, illustrating the course of the steam and water circulation.

The steam outlet is arranged as above to ensure the production of dry steam, even under the most adverse conditions. The steam released in the front and middle drums passes through cross tubes into the back drum, on which the steam outlet is placed. By the above arrangement the steam is drawn through the back quiescent drum, where, it will be specially noted, the flow of water is in a downright and opposite direction from that of the steam. The steam is consequently quite dry, and priming cannot possibly occur. Additional heat is transmitted to this dry steam as it passes through the top rows of cross tubes to the steam outlet.

THE YARROW MARINE TUBULAR BOILER

Messrs. Yarrow carried out some very instructive experiments demonstrating the effects of applying heat to water tubes, showing how heat applied to a tube in which water descends increases the rapidity of circulation. The following is a description of the demonstrations. The first was made with an apparatus which we illustrate in Figs. 77, 78, and 79. It will be seen to consist of two parallel vertical glass tubes, joined at their lower extremities by a copper bend, and at their top ends leading into a drum which is common to both. Movable Bunsen burners are placed as shown, so that three can be made to heat each tube. Above the drum is mounted an indicating apparatus, which consists of a rocking arm pivoted in its centre, and having two light rods, one at each end, which meet, the arms and rods thus forming a triangle, the apex of which acts as a pointer. Attached to one end of the arm is a light cord, which

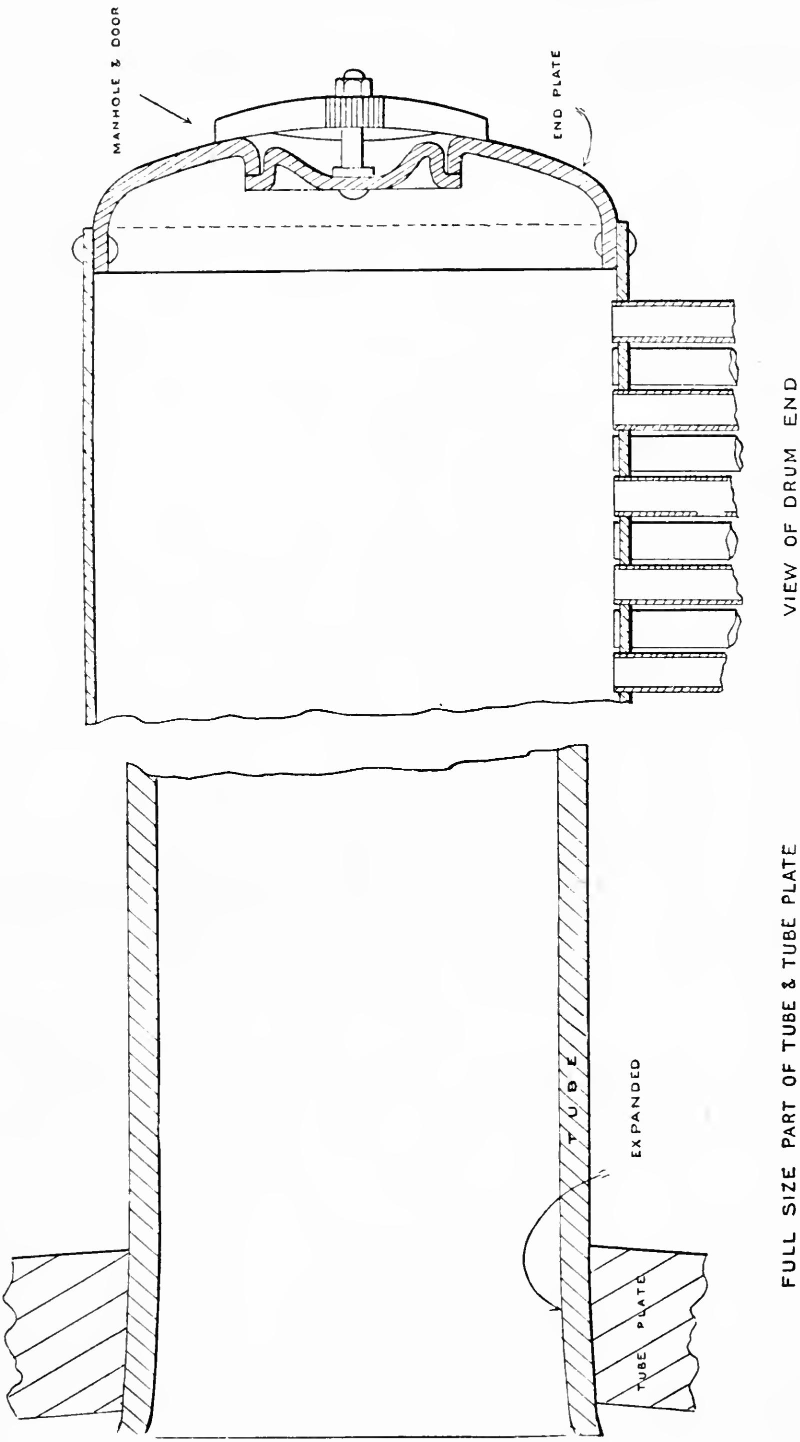


FIG. 73.—Tube Plate.

descends into the tube acting as a down-comer. At the end of the cord is a small elongated bob, having grooves turned on its exterior.

There is a graduated sector, by means of which the movement of the pointer is determined. The use of this recording apparatus is to indicate the comparative rapidity of flow of water, or water and steam, in the pipes. When there is no current, that is,

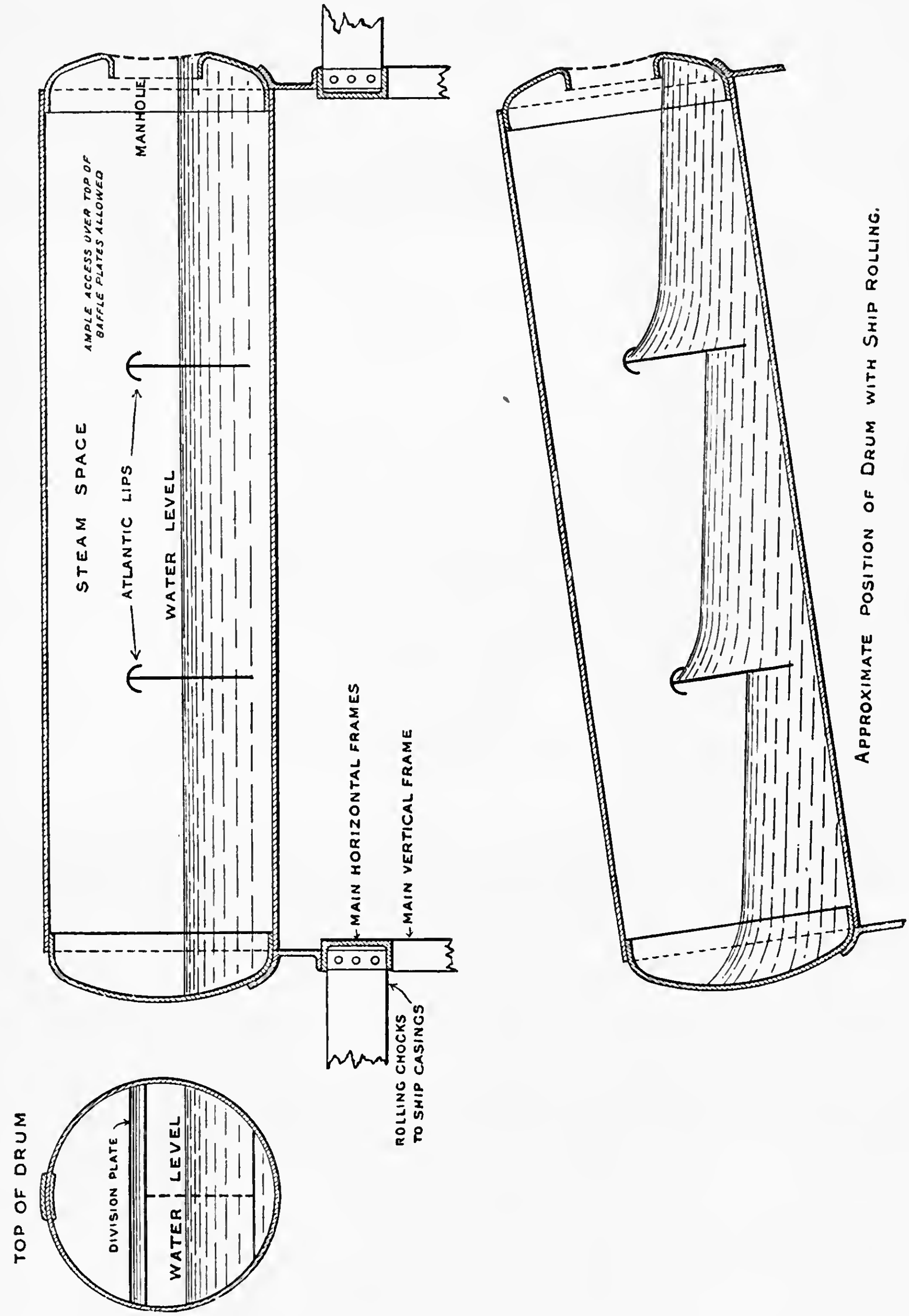


Fig. 74.—Details of Marine Boiler.

when all is cold, the pointer is in the position shown in Fig. 77, but on a current being set up, the grooved bob in attempting to flow with the current pulls on the end of the arm, and causes the pointer to move along the scale. It will be understood that the measurements taken are relative and not quantitative; that is to say, the absolute rapidity of flow is not ascertained in feet per minute, but the device may be taken as trustworthy in giving comparative results so far as the present experiments are concerned. Of course, with this apparatus the working is at atmospheric pressure. The following numbers are taken from the records of an experiment. In Fig. 77, with all cold, the pointer is at −45. One lamp was then lit and applied to the up-tube, but the current set up was too intermittent to enable a useful reading to be taken. On another lamp being applied the pointer moved to a position indicated by −12 on the scale; that is to say, the bob was pulled down, and a circulation was set up represented by this position. A third lamp having been lit, the pointer moved to −5, as shown in Fig. 78. This was the maximum current with heat applied only to the up-tube. One of the lamps acting on the down-tube was then lit, when the pointer almost immediately travelled farther along the scale to +10; another lamp on the down-tube brought it to +15; and finally, when a third lamp was added, so that all six lamps were burning, the pointer reached its maximum position of +20, as shown in Fig. 79. These experiments clearly proved that the addition of heat to the down-tube increased the circulation in this apparatus. By trials, Messrs. Yarrow had satisfied themselves that, within certain limits, the rapidity of the circulation depended mainly upon the total amount of heat applied, irrespectively of the manner in which it was divided between the descending and ascending columns.

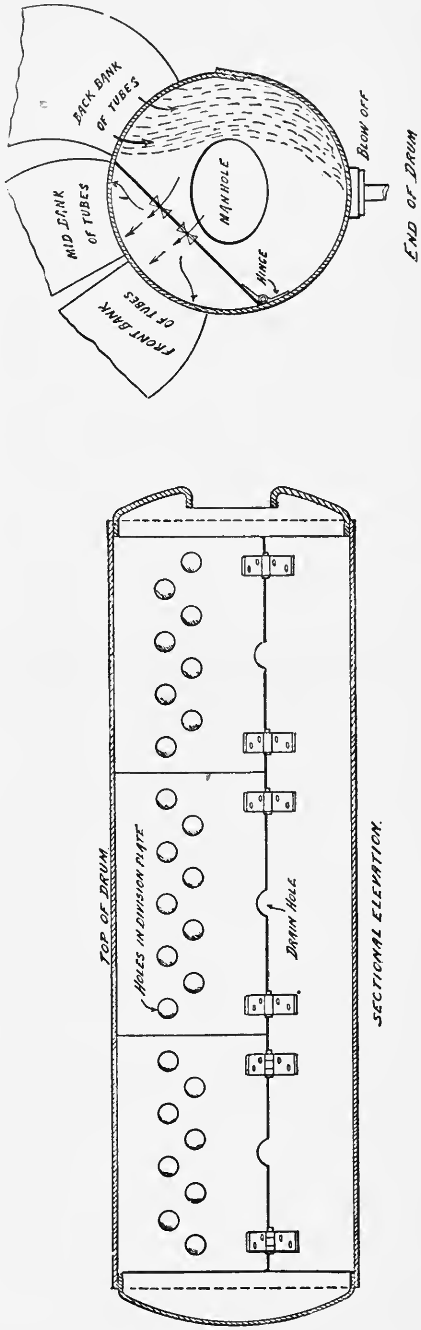


FIG. 75.—Details of Stirling Boiler.

The next apparatus used is shown in Fig. 80. It is, as will be seen, similar in most respects to the former model, but the mechanism for indicating the speed of current, which was suggested by Mr. Maxim, is designed to give absolute measurements. There is placed in the down-tube a screw of known pitch, which is suspended by a spindle at the upper end; above the receiver drum is a worm which actuates a worm-wheel in turn attached to a counter. In this way the speed of current can be estimated. When the apparatus was put in operation the increased speed of current due to heating the down-comer was very clearly shown. The following figures have been supplied by Mr. Yarrow as the results of experiments: "When two lamps were acting on the up-tube the speed recorded by the propeller was found to be 28 feet per minute. When three lamps were acting on the up-tube the speed was 36 feet per minute. When three lamps were acting on the up-tube and one on the down-tube the speed was found to be 42 feet per minute.

When three lamps were acting on the up-tube and two on the down-tube the speed was 49 feet per minute. When three lamps were acting on the up-tube and three on the down-tube the speed was 55 feet per minute." In these figures no allowance is

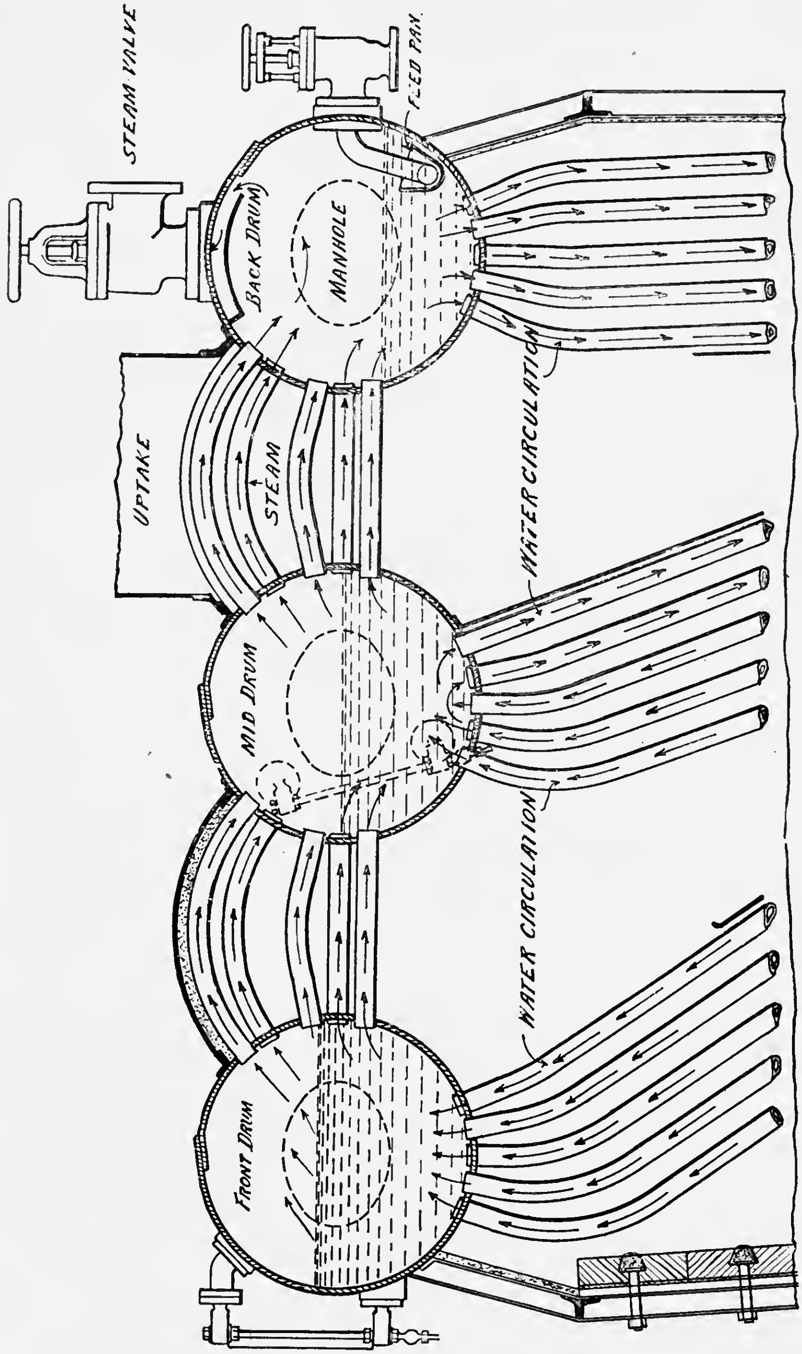


Fig. 76.—Circulation of Fluids.

made for the slip of the screw or for resistance to the flow caused by the presence of the propeller.

The next experiment is of especial interest to those who arrange the elements in a water-tube boiler with generating pipes at a small angle from the horizontal. The apparatus used is so clearly shown in Fig. 81 that little explanation is necessary. We have the six Bunsen burners, the two glass tubes, and the drum or receiver, the

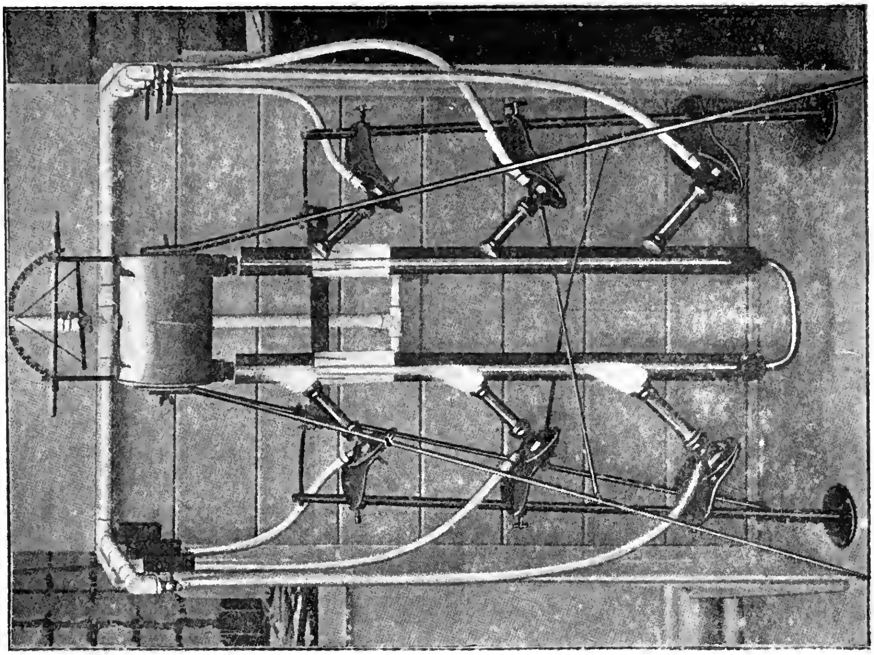


FIG. 78.—Yarrow's Experiments.

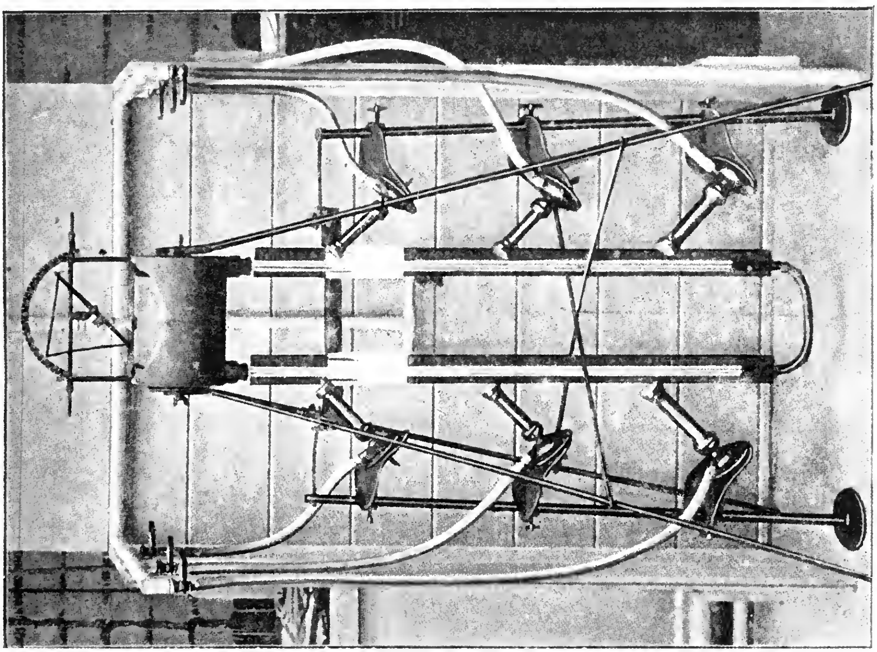


FIG. 77.—Yarrow's Experiments

only difference being that the U formed by the tubes is bent sideways just below the receiver, and the vertical extension is thus reduced. The Bunsen burners were not of the same size, those on the up-tube being larger. Circulation was started by lighting the three large burners, and the three smaller burners acting on the down-tube were then ignited. The effect was an increase of circulation in accordance with former

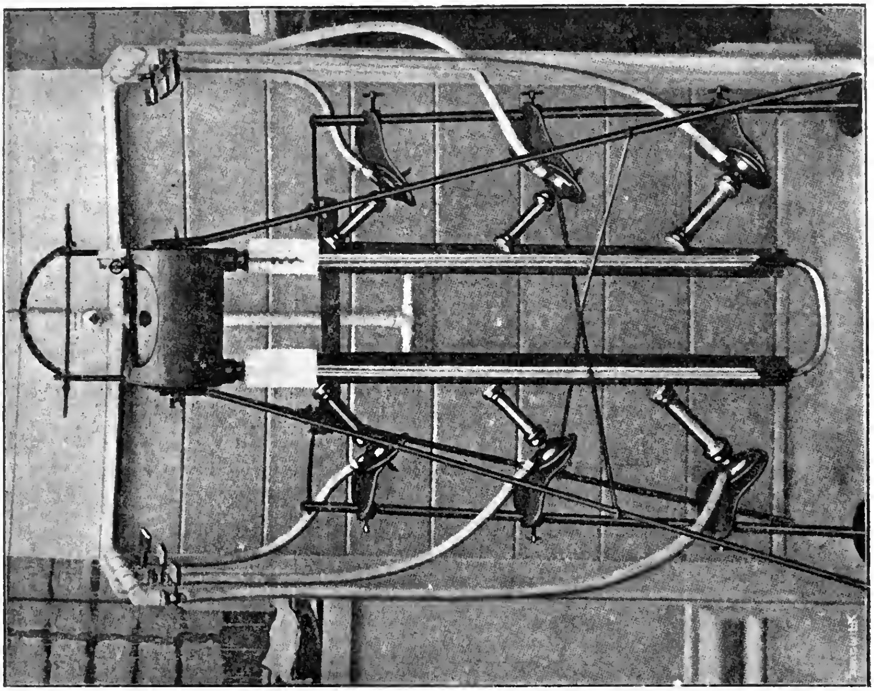


Fig. 80.—Yarrow's Experiments.

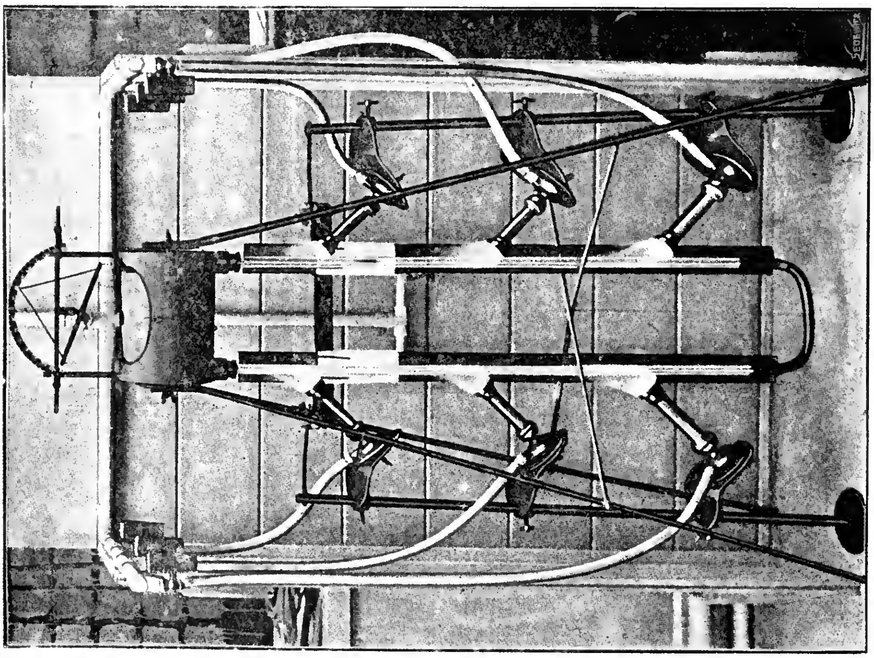


Fig. 79.—Yarrow's Experiments.

experience. It would be extremely interesting if comparative results could be obtained. With all burners in action the steam bubbles travelled with great rapidity, quite

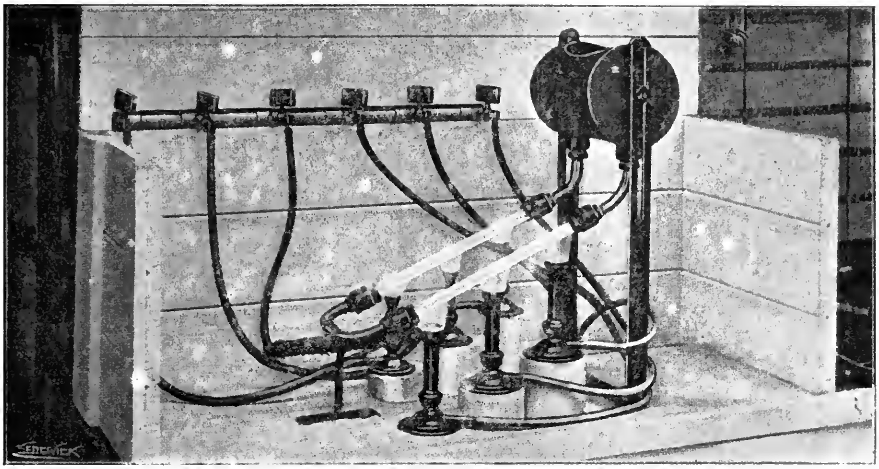


FIG. 81.—Yarrow's Experiments.

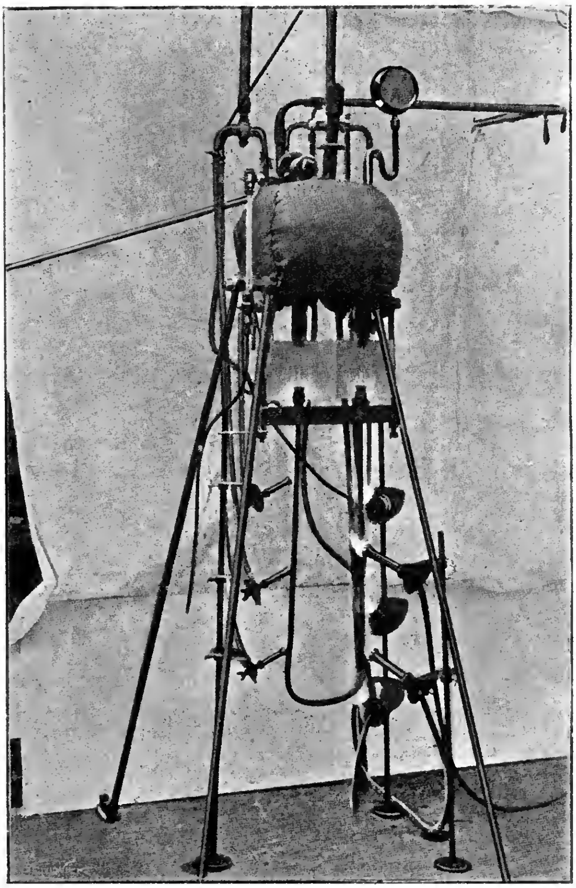


FIG. 82.—Yarrow's Experiments.

sufficient for good practical results, supposing the tubes had been acting as steam generators in a boiler, but the limit of the amount of heat supplied by the burners must be remembered in this connection.

All the experiments recorded were made at atmospheric pressure, but we now come to one conducted under different conditions, and certainly the most striking of all. Fig. 82 shows the apparatus used. It will be seen to resemble the former models

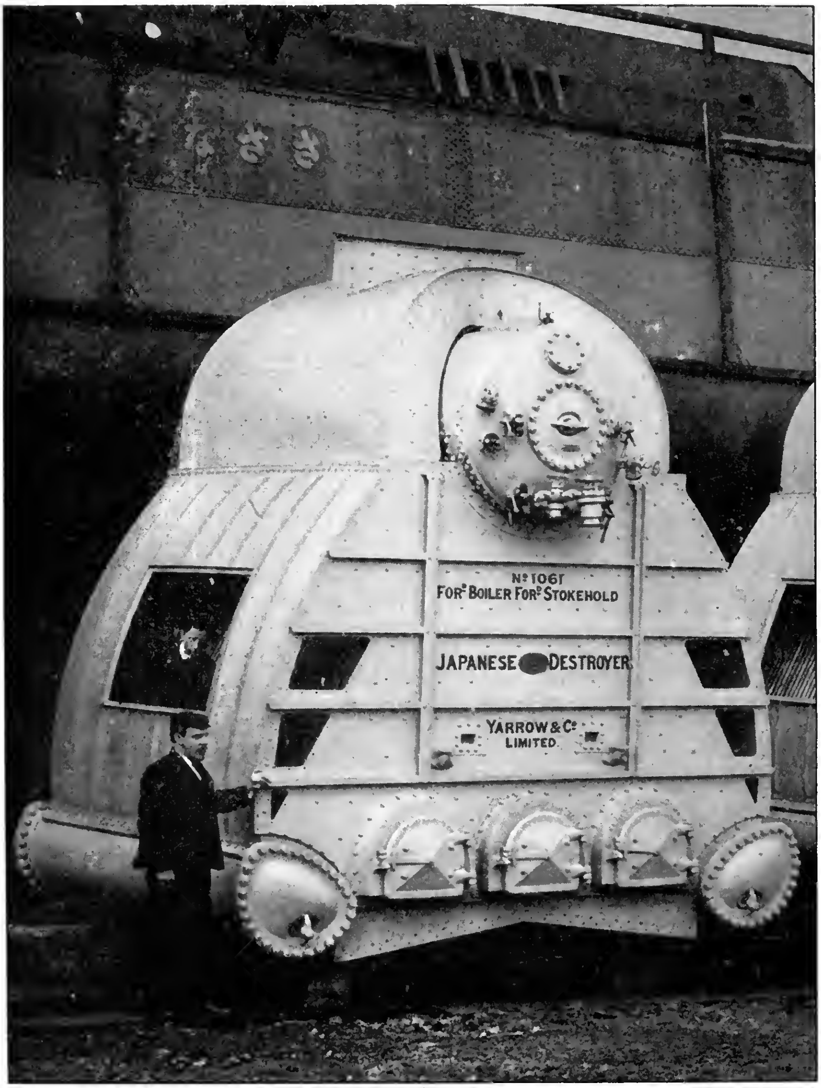


Fig. 83.—Yarrow Marine Boiler.

in general features, but in place of having an open receptacle at the top, it had a closed drum or steam chest; the two tubes, however, were connected at the bottom, and had likewise glass lengths inserted, by means of which the circulation could be observed. As a possible source of danger existed through the breaking of the glass tubes at the high pressure reached during the experiment, a screen of thick plate-glass was provided. By means of three small burners circulation was set up, and when this was fully established the five larger burners clustered round the other leg of the U

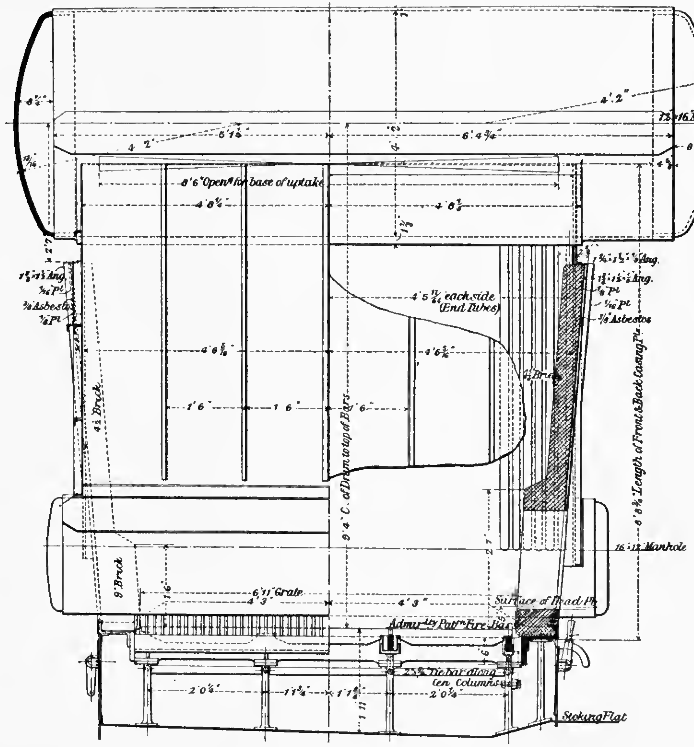


Fig. 84.

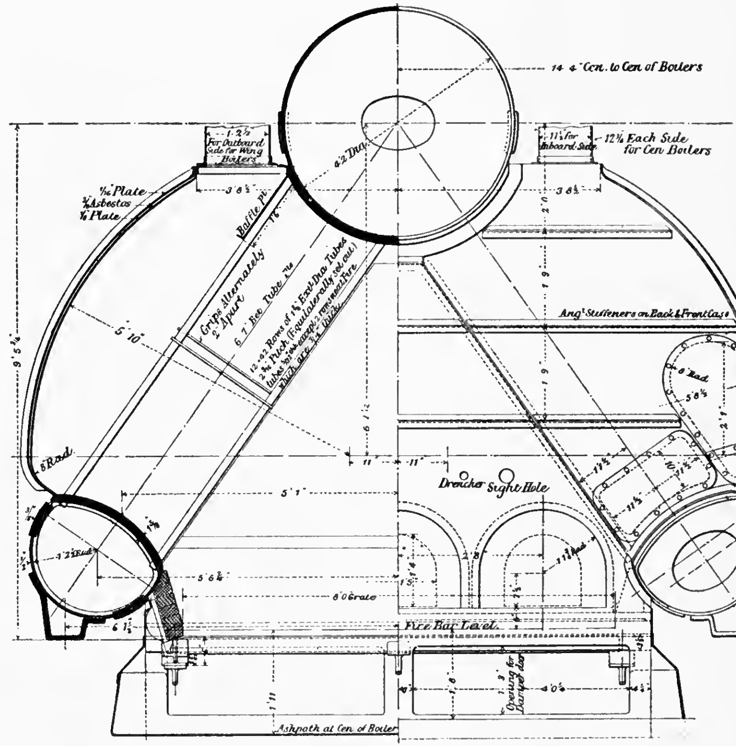


Fig. 85.

Sectional Views Yarrow Marine Boiler.

were lit one by one. The rapidity of circulation was thus greatly increased, and was maintained in the same direction, the tube which was so much more highly heated remaining the down-comer. Steam then rose until a pressure of 150 lbs. was registered on the gauge. The three small lamps applied to the outcast pipe were then gradually extinguished, but the current of steam and water was still maintained in the same direction, although the whole of the heat applied was received through the down-comer pipe.

Plate III. shows a group of three Yarrow boilers in the boiler-room of a battleship, and Fig. 83 shows a single boiler opened for inspection.

The line drawings (Figs. 84 and 85) show the construction and dimensions of a Yarrow battleship boiler.

Each boiler is capable of developing about 1200 horse-power. The weight of each boiler complete with water is $34\frac{1}{2}$ tons, and without water about 29 tons. The boilers were made for a steam pressure of 280 lbs. There are 1008 tubes in each boiler, $1\frac{3}{4}$ inch outside diameter and $\frac{5}{32}$ inch thick, except the two rows nearest the fire, which are $\frac{3}{16}$ inch thick. The average length of the tubes is 6 feet $9\frac{1}{4}$ inches, and each tube is expanded into the tube-plates, and bell-mouthed at both ends. One row of distance-pieces is fitted to each nest of tubes to maintain a uniform distance apart between them, as shown in Fig. 85. Each boiler has a heating surface of 3127 square feet.

And the following table shows the results of tests on this boiler :—

EVAPORATIVE TRIAL OF ONE BOILER (YARROW TYPE) FOR CHILIAN BATTLESHIP: HEATING SURFACE, 3127 SQUARE FEET; GRATE AREA, 53 SQUARE FEET.

Number of Hour.	Time at end of Hour.	Coal during Hour.	Coal per Square Foot of Grate Area per Hour.	Total Coal.	Water during Hour.	Water evaporated per Pound of Coal per Hour from and at 212° Fahr.	Total Water.	Total Water evaporated per Pound of Coal from and at 212° Fahr.	Air Pressure. Inches of Water.	REMARKS.
		Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.		
1	8 a.m.	2240	42.30	2,240	14,350	7.88	14,350	7.88	.26	Steam blowing off at 230 lbs. above atmos. Mean temperature of feed, 47° Fahr.
2	9 ,,	1456	27.45	3,696	12,600	10.65	26,950	8.98	.17	
3	10 ,,	1624	30.6	5,320	13,000	9.84	39,950	9.23	.23	
4	11 ,,	1568	29.6	6,888	14,750	11.58	54,700	9.77	.26	
5	Noon	1680	31.7	8,568	15,700	11.50	70,400	10.10	.32	
6	1 p.m.	1792	33.8	10,360	14,900	10.22	85,300	10.12	.33	
7	2 ,,	1400	26.4	11,760	12,150	10.69	97,450	10.20	.30	
8	3 ,,	1960	37.0	13,720	10,800	6.78	108,250	9.70	.34	
9	4 ,,	1344	25.4	15,064	9,600	8.79	117,850	9.61	.33	
10	5 ,,	1176	22.2	16,240	9,400	9.83	127,250	9.63	.35	
11	6 ,,	1232	23.2	17,472	10,550	10.52	137,800	9.70	.58	
12	7 ,,	1568	29.6	19,040	12,150	9.54	149,950	9.70	.84	
13	8 ,,	1568	29.6	20,608	12,350	9.68	162,300	9.68	.85	
14	9 ,,	1176	22.2	21,784	12,150	12.71	174,450	9 85	.96	
15	10 ,,	896	16.9	22,680	10,400	14.26	184,850	10.03	.95	
16	11 ,,	1848	34.9	24,528	10,000	6.65	194,850	9.78	.24	Cleaned fire.
17	Midnight	1624	30.6	26,152	14,450	10.93	209,300	9 85	.37	
18	1 a.m.	1568	29.6	27,720	12,550	9.85	221,850	9.85	.32	
19	2 ,,	1568	29.6	29,288	11,700	9.18	233,550	9.81	.33	
20	3 ,,	1624	30.6	30,912	14,500	10.98	248,050	9 87	.77	
21	4 ,,	1680	31.7	32,592	14,600	10.69	262,650	9.92	.98	
22	5 ,,	1512	28.5	34,104	13,900	11.31	276,550	9.97	1.10	
23	6 ,,	1848	34.9	35,952	13,800	9.19	290,350	9.94	1 23	
24	7 ,,	1904	35.9	37,856	16,200	10.46	206,550	9 96	1.07	

Average evaporation from and at 212° Fahr. during 24 hours = 9.96 lbs.

Figs. 86 and Plate III. show two views of the complete boilers without casing or furnace, and fully explains its construction.

One feature in the boiler arrangement is that the air passes to the fire through openings fitted with light non-return valves, which are attached to a diaphragm plate fixed to the front of the boiler. Immediately there is pressure in the stokeholds the air passes through these valves round the entire casing of the boiler, and then underneath the bars to the furnace. By this means the coal bunkers, which generally surround the boiler, are kept comparatively cool; and, what is a much greater advantage, the hinged doors, from their position, are not likely to be distorted, while if these hinged doors are placed in front below the bars, as previously done, they are very apt to get out of shape by the heat they are subjected to, and also by the accumulation of cinders preventing the doors from closing properly.

The advantage of straight tubes is self-evident, as they can be readily cleaned out and examined internally. It is a cheap form of construction, and the number of spare tubes required to be carried, as they are all straight, is much less than if they are curved

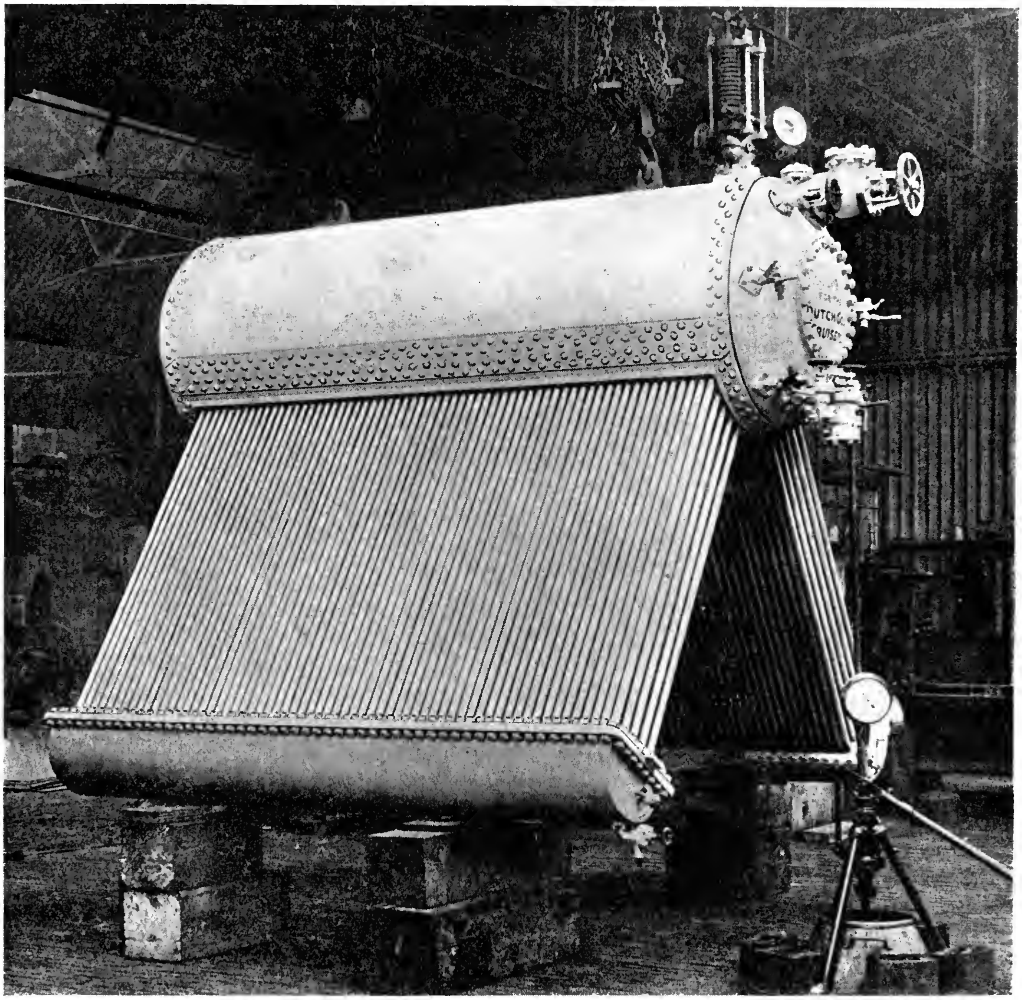


FIG. 86.—Yarrow Boiler Tubes.

to various forms. Boilers having straight tubes have now been in actual service for many years without any disadvantage being found through their adoption. The fact is, the tubes are for all practical purposes, at the same temperature as the water, and are consequently of the same temperature as one another, therefore the difference through expansion—if there be any—is of such a trifling character as not to be beyond the limits of the elasticity of the material. This was clearly confirmed by Professor Watkinson's paper on water-tube boilers delivered at the Institution of Naval Architects.

THORNYCROFT'S TUBULAR MARINE BOILERS

The great difficulty about the introduction of a new type of boiler is that, although it may give excellent results for the first year or so, it may develop defects later on, the

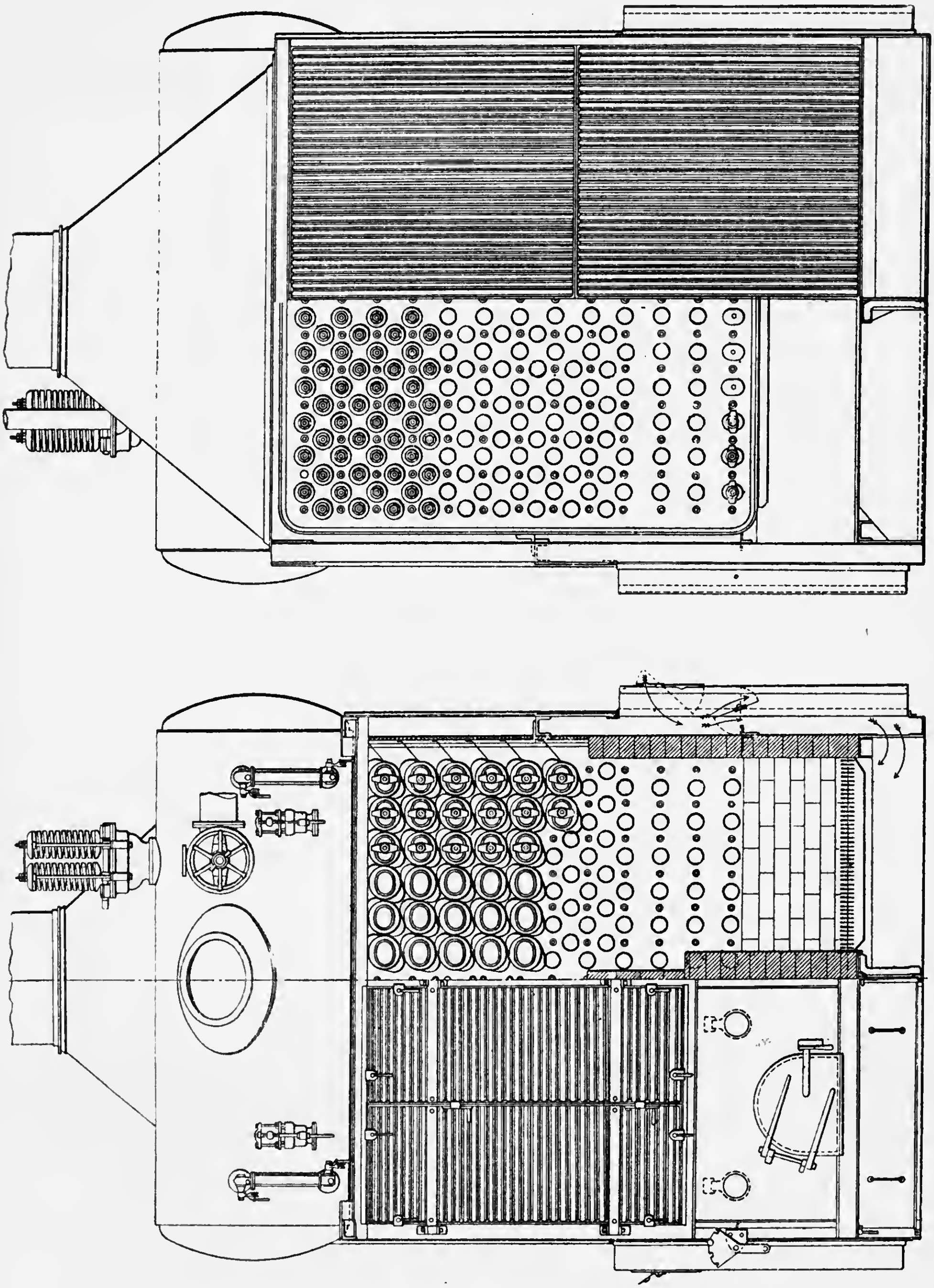


Fig. 87.—Thornycroft's Boiler. Sectional View.

tubes becoming encrusted, and hence distorted, and giving rise to leaky joints, or the tubes may be found to corrode.

The "Thornycroft-Marshall" boiler has now passed beyond this stage, as Messrs.

Thornycroft have had a non-sectional boiler and Messrs. Hawthorn & Leslie a sectional boiler in daily use in their works for about three years.

The boiler in Messrs. Thornycroft's yard has been working with a mixture of town water and water from the Thames, the latter containing so much mud in suspension that it deposits two feet of mud in the settling tanks per month, in addition to a large amount

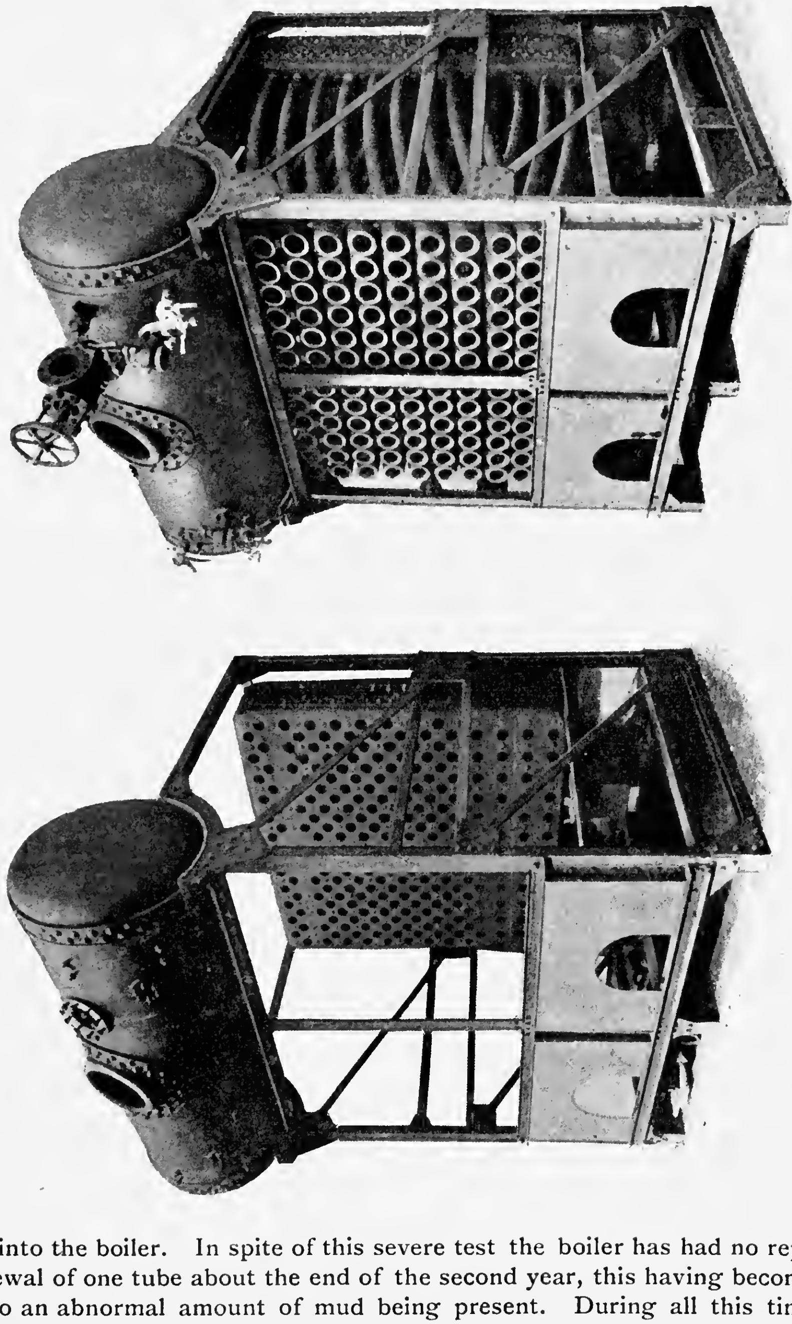


Fig. 88.—Thornycroft-Marshall Boiler.

carried into the boiler. In spite of this severe test the boiler has had no repairs beyond the renewal of one tube about the end of the second year, this having become encrusted owing to an abnormal amount of mud being present. During all this time there has been no sign of a leaky joint.

To describe first the non-sectional type. It will be seen from Figs. 87 and 88 that it consists essentially of (1) a large horizontal steam drum or separate barrel, (2) a vertical water box, and (3) the generating tubes.

The generating tubes are connected in pairs to a junction box at one end, and at

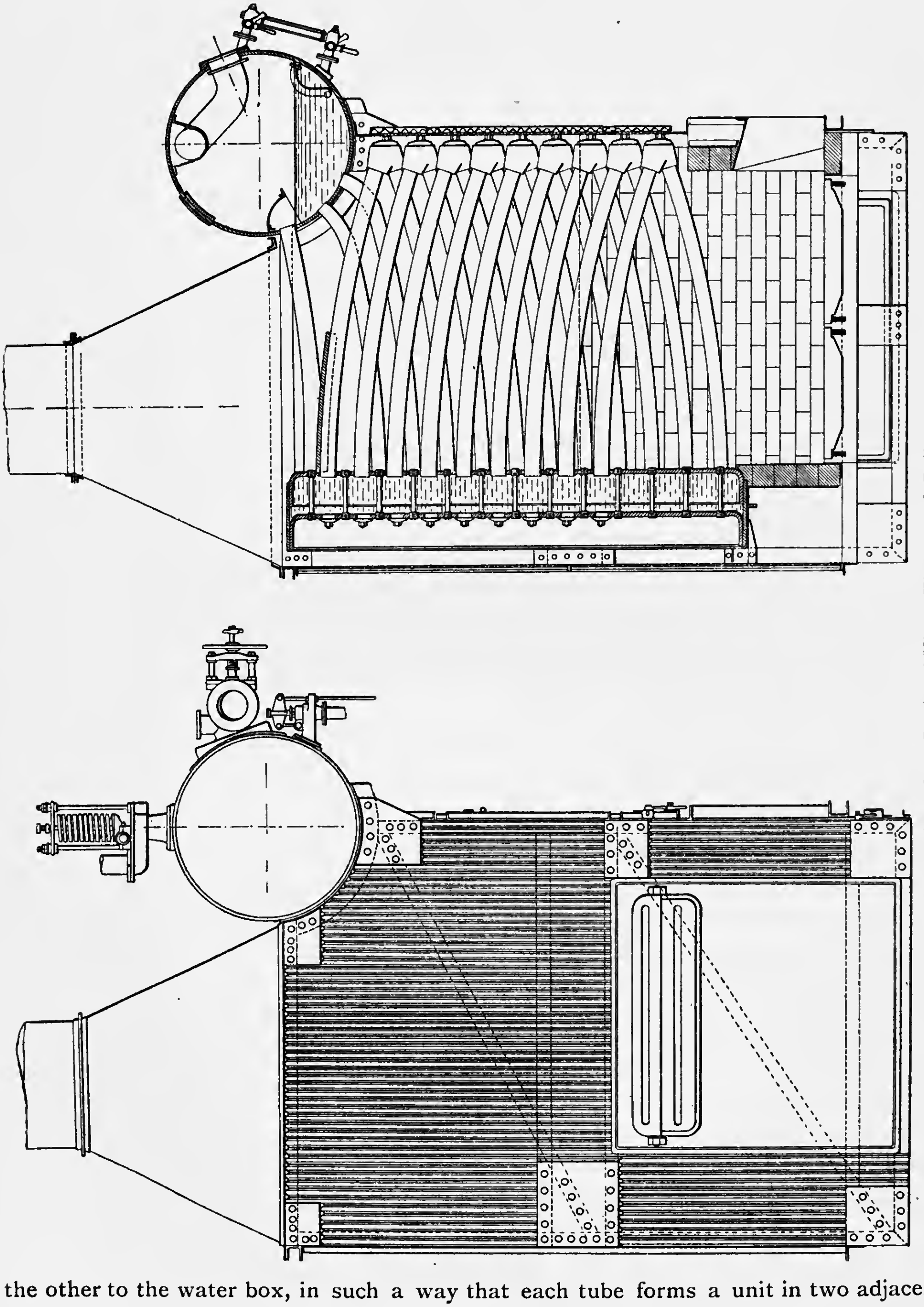


Fig. 89.—Sectional Views Thornycroft Boiler.

the other to the water box, in such a way that each tube forms a unit in two adjacent vertical rows or columns. As is clear from the Figures, alternate columns enter the water box low down, and the intervening ones as high up as possible, so that the tubes have a considerable upward slope, first from the water box to the junction box and then back from the junction to the water box. A pair of tubes and their junction box may be compared to the breast-bone of a fowl held against a wall in a nearly vertical plane, with the upper end being just on one side of a vertical line and the lower part on the opposite.

From the upper part of the water box three rows of tubes lead to the separator barrel. The whole is enclosed in a steel casing as in Fig. 89, or may be in brickwork for land purposes.

The boiler is filled with water to about one-third the diameter of the separator barrel. The water circulates in an upward direction along the lower tube of any pair to the junction box, and then on through the upper tube to the water box, with the accumulating steam bubbles, where the steam rises to the top of the box, and thence to the separator barrel, carrying a certain amount of water with it, which is prevented from splashing the steam pipe by a baffle plate (see Fig. 90). The particulars of the boiler are given in the following table:—

Floor space occupied—Length	8 feet 0 inches.
,, ,, Width	9 ,, 9 ,,
Height from floor plates or ashpan	12 ,, 8 ,,
Tube surface	1200 square feet.
Grate area	32.5 ,,
Surface ratio $\frac{\text{Tube surface}}{\text{Grate area}}$	37.
Maximum working pressure	220 lbs.
Weight of boiler complete, with casing, furnaces, fittings, brickwork, and mountings	$14\frac{1}{4}$ tons.
Weight as per above per square foot of heating surface	26.6 lbs.
Weight of contained water at working level and temperature	3 tons.
Weight of water as above per foot of heating surface	5.6 lbs.
Total weight, boiler with water	$17\frac{1}{4}$ tons.
Weight as above per foot of heating surface	32.2 lbs.
Number of tubes	252.
External diameter of tubes	$3\frac{1}{4}$ inches.
Thickness of metal in tubes	7 L.S.G. = 0.176 ,,
Material of tubes	Solid-drawn steel.
Radius to which tubes are bent	15 feet $8\frac{1}{2}$ inches.
Floor space covered by boiler	78 square feet.
Total evaporation with natural draught from and at 212° Fahr.	6800 lbs. per hour.
Indicated horse-power at 19 lbs. per indicated horse-power for all purposes	357.
Total evaporation with assisted draught from and at 212° Fahr.	8730 lbs. per hour.
Indicated horse-power at 19 lbs. per indicated horse-power	460.

The feed water is controlled by the well known "Thornycroft" feed regulator, which requires an excess pressure in the feed pipes of only about 40 lbs. per square inch, instead of 200 or 300 required by some systems—an advantage which requires no comment.

It enters the separator barrel, then passes down through the lowest row of tubes connected thereto, and so it will be seen that the water is always above the highest part of every tube, which is considered a great advantage by many engineers.

It will be seen that the circulation is very simple, and that there is ample rise per foot run of tube, which allows of plenty of head for producing the circulation.

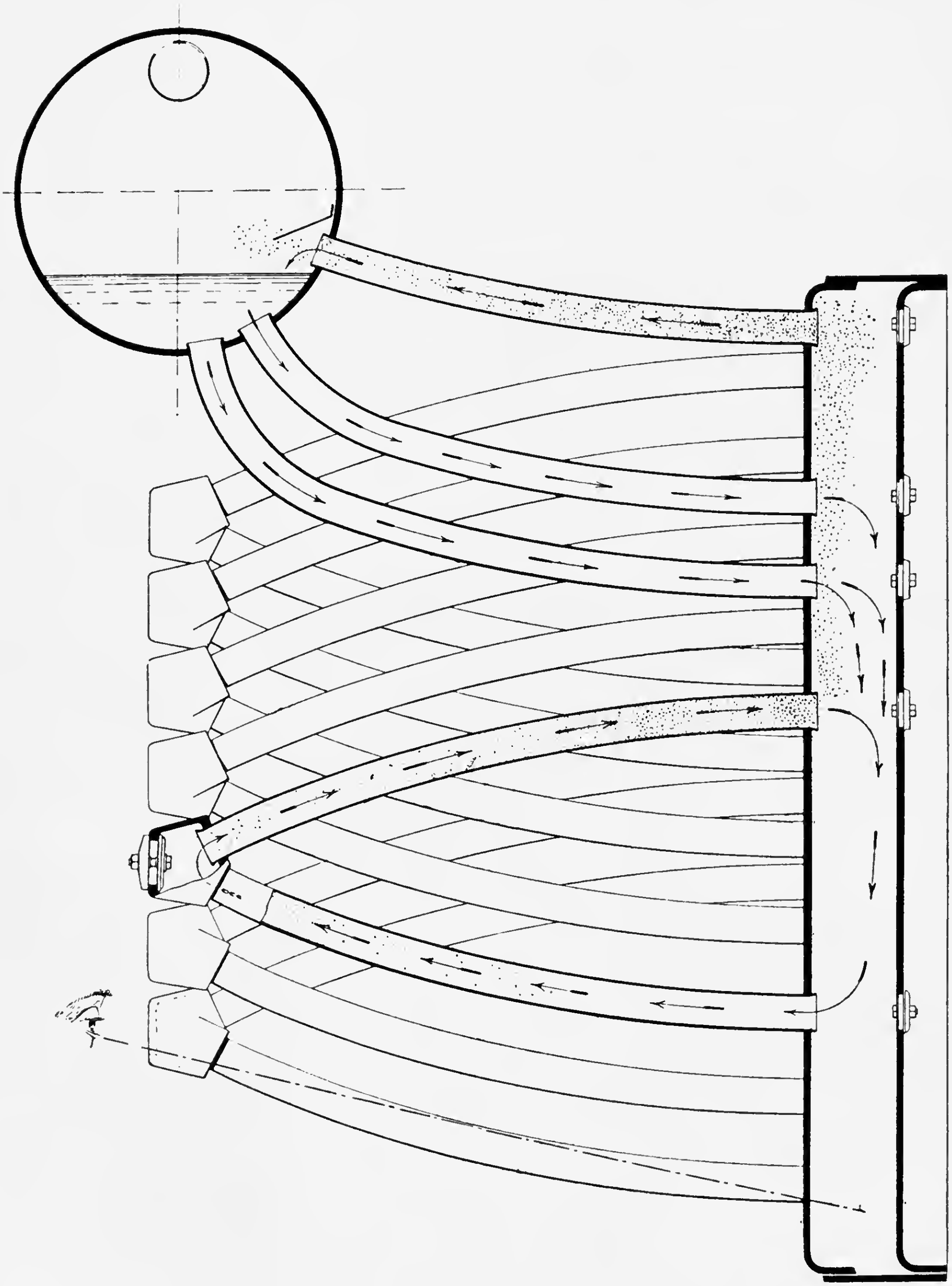


FIG. 90.—Circulation in Thornycroft Boiler.

In the non-sectional type, as usually made, the generating tubes are about $3\frac{1}{4}$ inches external diameter, and slightly curved to a radius of about 16 feet. This curvature is the same for all the generating tubes (except the small number leading to the separator barrel), so that the supply and stowage of spares (if any are considered necessary) is quite as simple as if the tubes were straight.

Since there are doors at either end, and the curvature is so slight, it is possible to inspect the inside of every tube throughout the length from one end or the other. It is thus evident that while possessing the advantages of slightly bent tubes, it is virtually a straight tube boiler.

The junction boxes are not restrained in any way, and this, in conjunction with the slight curve in the tubes, allows of free expansion under greatly varying temperatures without the distortion which nearly always occurs with tubes which are originally straight or restrained at both ends. Another great advantage of a slight bend in the tubes is that it enables them to enter both the tube plate and the junction boxes at right angles, which allows of tubes with considerable inclination being expanded with a roller expander, thus making a simple and thoroughly reliable joint, instead of necessitating a screwed joint, which is often both costly and leaky. In this connection it is worthy of note that slightly bent tubes are now fitted in a well-known type of water-tube boiler originally famous for its straight tubes.

The junction boxes are so constructed that the two tubes entering each can be expanded and inspected through one door, an arrangement which at once reduces the number of sight doors by 25 per cent. This facilitates the work of inspection.

On reference to Figs. 89 it is apparent that any tube can be readily extracted and replaced. Indeed, if a tube became damaged in any way, the quickest method of getting the boiler to work again is to plug the tube and its fellow in the same junction box, precisely as would be done in the case of a fire-tube marine boiler. If so plugged, only two tubes would be put out of action instead of a large number, as would happen under similar circumstances with a boiler having a number of tubes in series.

The separator barrel is of very simple construction, with plain dished ends, and the tubes connected therewith are simply expanded into the plate.

The water box is also exceedingly simple. The flat surfaces are much smaller than those dealt with every day in marine boilers, and it is not more difficult to make. It is found that there is no distortion, and the stays are bored hollow, so as to give immediate warning should one be fractured. The sight doors in the water box are very neat and readily removed, the joint being made with a copper band, which seldom requires renewal.

The whole boiler is surrounded with a casing, which can be readily removed, so that all parts can be easily examined, and the disposition of the tubes renders them very easily accessible for cleaning, both inside and out, the outsides of the tubes being readily accessible for sweeping, both from the front and from the sides of the boiler. The sweeping is done with a steam brush consisting of a tube with closed ends and holes all round.

The wide spaces between the lower tubes add considerably to the effective height of the fire box, rendering the combustion very complete and efficient. The gases pass upwards among the tubes, and, owing to the latter crossing each other at frequent intervals (as seen from the sides) and being almost in contact, the gases are made to take a zigzag course, and so are induced to give up as much of their heat as possible, a fact which is amply proved by the cool uptakes, even when the boiler is forced far beyond the output usually required in modern boilers for large vessels or land purposes.

The arrangement of air ducts outside the fire box has the double advantage of keeping the stokehold cool, and assisting the efficiency by warming the air as it passes under the fire-grate.

The steam produced is very dry, and as the steam space is ample, no reducing valve is required, and the engines work at the same pressure as the boiler.

A series of evaporative trials were carried out a short time ago under the auspices of the boiler committee. They were not intended to be laboratory experiments to find the absolute maximum economy under laboratory conditions, but to show what the boiler would do under working conditions, with the ordinary coal used in the works. As will be seen from the following table, the results are highly satisfactory:—

"THORNYCROFT-MARSHALL" BOILER, NON-SECTIONAL TYPE.

OFFICIAL TRIALS, EACH OF EIGHT HOURS' DURATION.

Trial numbers	1.	2.	3.	4.	5.	6.	7.	8.
Coal	Hand-picked Welsh and the ashes made	Hand-picked Welsh and the ashes made	Hand-picked Welsh	Hand-picked Welsh and the ashes made	Welsh dust screened through $\frac{1}{2}$-inch mesh and the ashes made	Hand-picked Welsh and the ashes made	$\frac{2}{3}$ Welsh $\frac{1}{3}$ Hartley and the ashes made	Commercial bunker Welsh unpicked and the ashes made
Mean steam pressure—lbs.	180	181½	185	185	185	204	208	211
Total area for egress of steam—square inch	0.7496	0.9458	1.0297	0.4993	0.6284	0.6136	0.7040	0.6834
Vacuum at base of funnel—inch of water	0.15	0.25	0.28	0.20	0.21	0.20	0.20	0.18
Under grate — inch of water	0.05	0.12	0.14	0.00	0.05	0.11	0.09	0.06
Total coal burned—lbs.	585	780	975	390	585	585	684	652½
Burned per hour per square foot of grate—lbs.	18	24	30	12	18	18	21	20
Temperature of gases in uptake—degrees Fahr.	Not taken	Not taken	685	386	450	514	544	557
Steam valve for blast	Shut	Open	Open	Shut	Open	Shut	Shut	Shut
Duty of 1 square foot of heating surface per hour. Coal burned—lbs.	.4875	.6500	.8125	.3250	.4875	.4875	.5700	.5437
Water evaporated per hour from and at 212° Fahr.—lbs. per square feet heating surface	5.202	6.618	7.278	3.564	4.485	4.836	5.647	5.610
Equivalent evaporation from and at 212° per pound of coal—lbs.	10.671	10.183	8.958	10.966	9.200	9.919	9.907	10.318

The above trials were carried out under the supervision of Admiralty officers.

To ascertain the amount of smoke produced, a trial (No. 7) was made with a mixture of Welsh and North Country coal. This was found to be very small under most trying circumstances, and the uptakes and casings were found to be exceedingly cool throughout the trials.

To meet the requirements of engineers who prefer straight tubes, and who are prepared to sacrifice the undoubted advantages of slightly curved tubes to their preference for absolutely straight ones, Messrs. Thornycroft have designed the boiler shown in Fig. 91; the tubes in this case are about 2 inches external diameter, and are grouped. This is a very efficient type of boiler, and admits of a large heating surface being disposed in a small space.

The sectional type of boiler possesses most of the general advantages of the non-sectional type, and where any of these are lacking it has compensating advantages of its own.

Having described the non-sectional type, the other will be easy to comprehend.

To the under side of a separator barrel like that described above a number of vertical headers are connected with intervening spaces. These are the upper headers of the elements, one of which is shown in Fig. 93. The lower headers are connected to a square cross pipe, which is supplied with water from two downtake pipes, one on either side of the boiler.

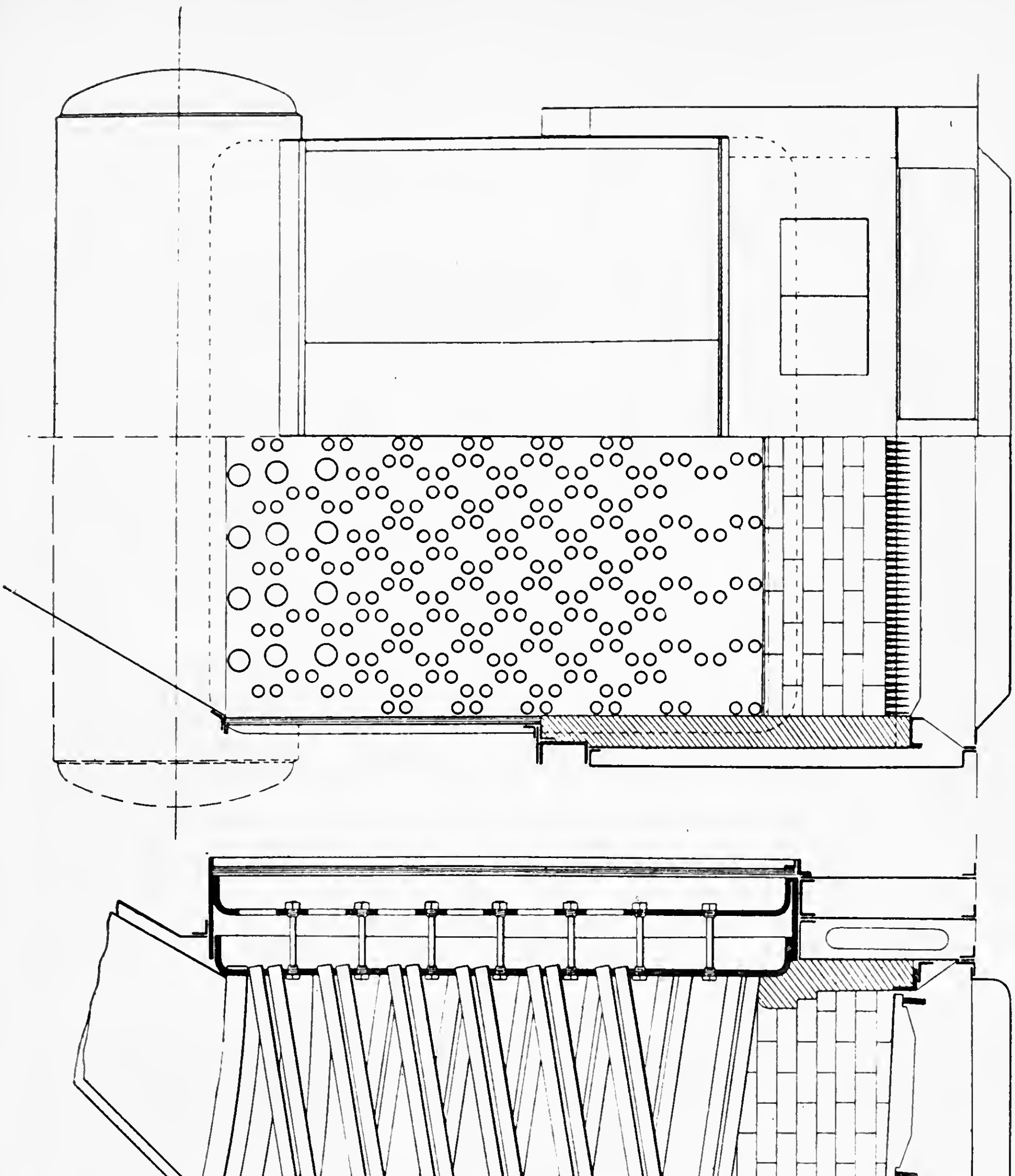


FIG. 91.—Straight-Tube Boiler.

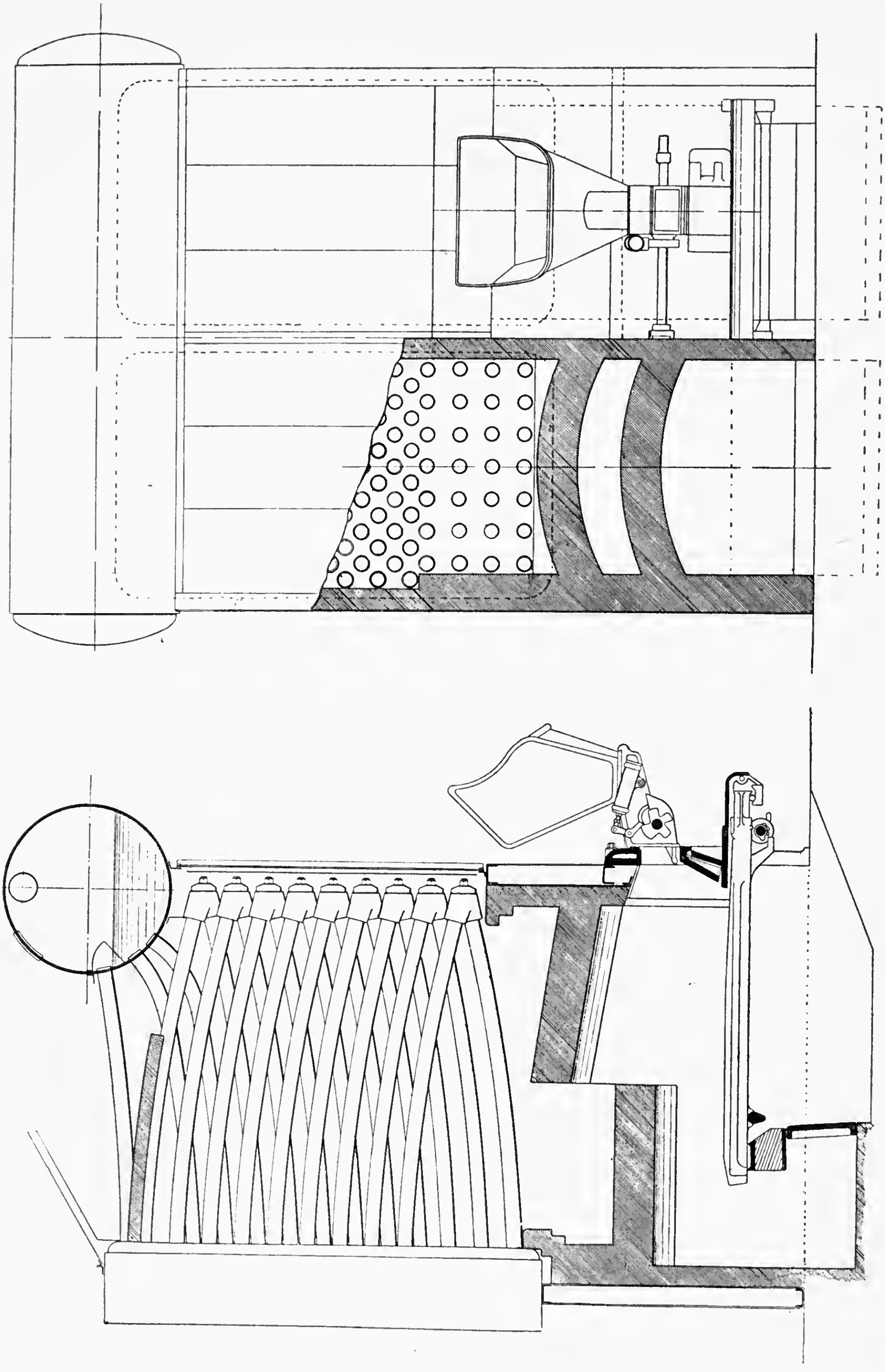


FIG. 92.—Land Boiler and Stoker.

The generating tubes are connected with junction boxes at the opposite end in pairs; and sight-holes are provided at either end.

The alternate elements are "handed," so that two upper headers and two lower headers come together. This gives a series of spaces, those at the bottom being utilised as small auxiliary combustion chambers, while those at the top may be used to insert feed heaters or economisers.

The element shown in Fig. 93 has absolutely straight tubes, so that the sectional type, like the non-sectional, will meet the requirements of those who prefer straight tubes; but as usually made, the tubes have a slight curve at one end, to enable them to enter the headers normally, and to obviate any tendency to distortion when hard forced. This curve in no way interferes with inspecting the tubes from end to end.

The boiler is filled with water to the middle of the separator barrel, and the feed enters it through the feed heaters, which are distributed all along its length. Then the water passes along the down tubes to the cross pipe, and thence to the lower headers,

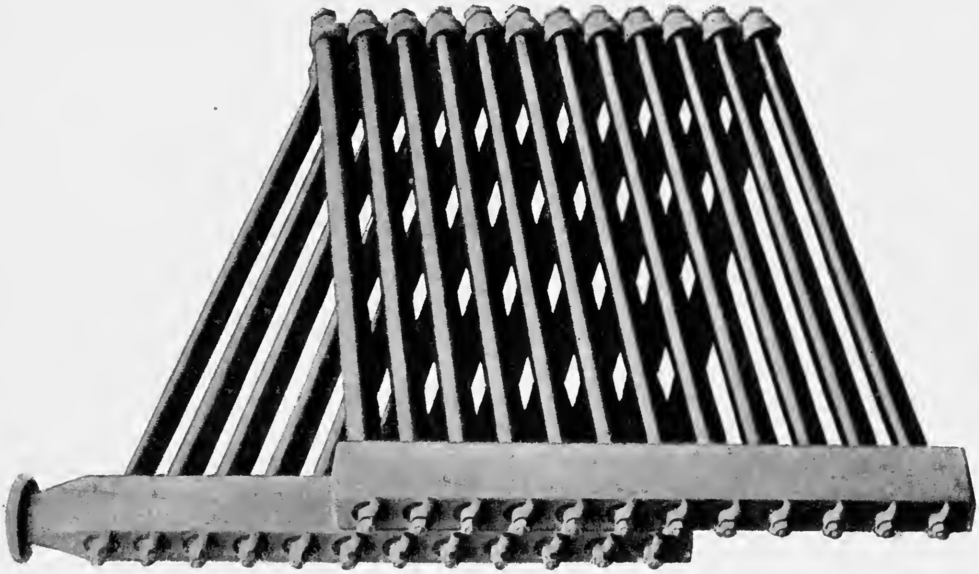


FIG. 93.—Section of Boiler Tubes.

then through the generating tubes, which are, as the electricians say, "in parallel," into the junction boxes, and thence to the upper headers, and so to the separator barrel, where baffles are provided and the steam is drawn off. The circulation is therefore not, as in the non-sectional type, part local and part general, but is wholly general.

The sectional type does not admit of quite so much heating surface being provided in a given space, but, on the other hand, it can be reduced to smaller component parts, and is more easily erected without disturbing decks than the non-sectional type.

A pair of tubes can be plugged just as in the case of the non-sectional type, but it is preferable to remove a whole element rather than to cut out a single pair of tubes for replacements.

The "Thornycroft-Marshall" boiler is eminently suitable for a land boiler, and, as previously mentioned, it can be either enclosed in a casing or in brickwork.

Fig. 92 shows a large land boiler, fitted with mechanical stokers.

LAUNCH TYPE OF THORNYCROFT BOILER

In its original form this boiler has two parallel barrels one over the other, the upper being the steam and the lower the water drum. They are connected together by some eight or nine large downtake tubes, bent for purposes of construction, and generally of about 4 inches diameter ; and also by two groups of curved generating

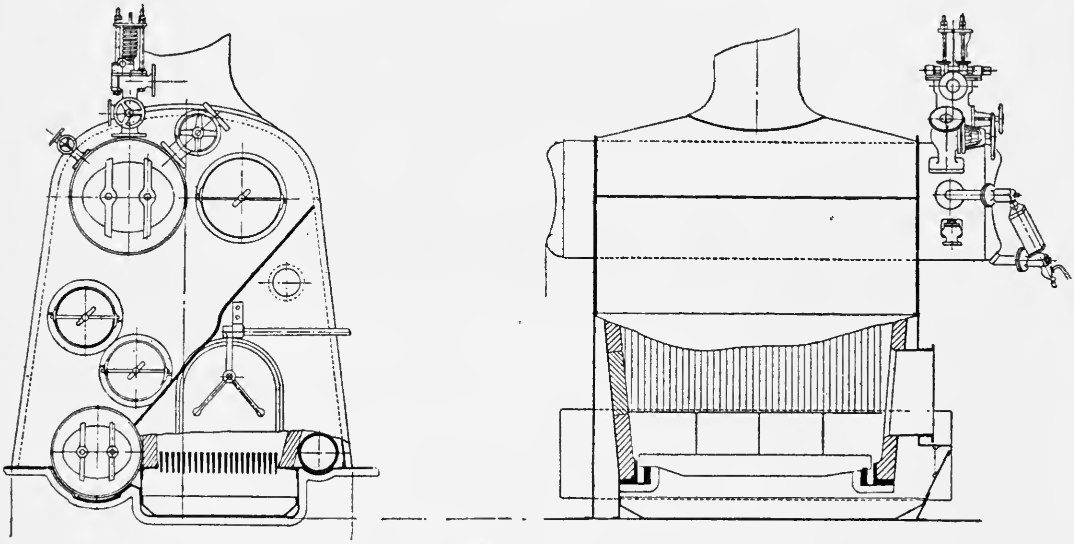


FIG. 94.—Launch Boiler.

tubes, each bounded by a pair of water-tube walls. On either side of the lower barrel is a fire-grate.

The two fire boxes are each bounded, on one side by one of the two groups of tubes, and on the other by a water-tube wall formed as described above, the ends being

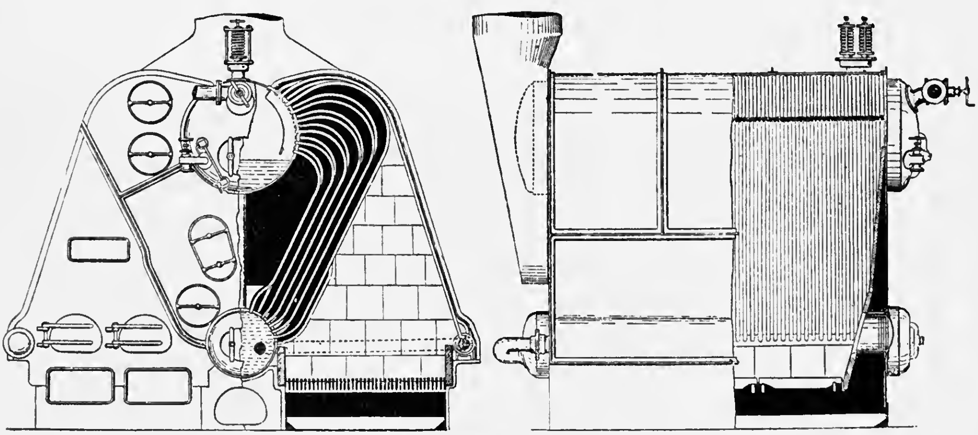


FIG. 95.—Marine Boiler.

closed by bricks and plates. These wall tubes are supplied with water by a pipe connected with the lower barrel, and bent round on the outer sides of the grates.

The gases pass through the fire-box walls into the groups of tubes by the apertures near the lower barrel and up among the tubes in a diagonal direction, emerging through the central walls into the heart-shaped central space under the upper barrel. They then proceed along to the back of the boiler into the smoke box and up the chimney.

A third design, brought out soon after the "Daring" boiler, was the "Launch" type (Fig. 94). This is best described by saying that it consists of half a "Daring" boiler, except that in its original form the tubes forming the outer wall of the fire box are bent into the lower large tube to form a fire grating.

In the case of the "Daring" boiler the demand for larger boilers has led to multiplying the number of tubes in the wing barrels themselves, until in many recent designs there are as many tubes in the wing barrel groups as in the central groups, and they form flues with water-tube walls in the same way as those in the centre.

The wing barrels have also become large enough to admit a man for expanding tubes, which simplifies construction and renders inspection easier.

In some modern designs also the cross connecting tube is done away with, the wing barrels are connected to the steam drum direct, and the gases have been taken off the top of the boiler.

THE MORRIN CLIMAX TUBULAR BOILER

The boiler consists of a vertical cylinder and loop-like tubes, extending the entire height of the generator, which comprise the principal heating surface, as shown in Figs. 96 and 97.

The main cylinder (shell) A is constructed similar to any cylindrical boiler shell, and

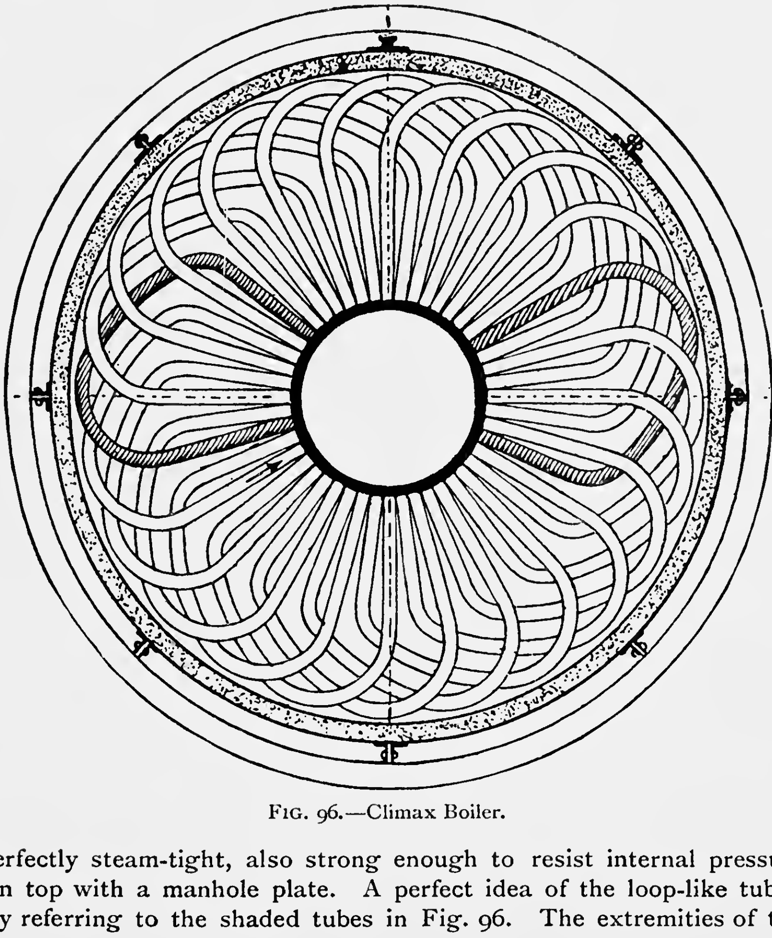


FIG. 96.—Climax Boiler.

is made perfectly steam-tight, also strong enough to resist internal pressure, and is provided on top with a manhole plate. A perfect idea of the loop-like tubes may be obtained by referring to the shaded tubes in Fig. 96. The extremities of these tubes extend and are expanded into the cylinder A, forming a steam-tight connection. Their ends are in higher planes to each other, as will be seen by referring to the lower shaded tube in Fig. 96. The heads are pressed to a radius equal to the diameter of the shell, and require no braces. The tubes are $1\frac{1}{2}$ to 3 inches in diameter, and 280 to 1000 in number, according to the size of the boiler; and their aggregate length varies with the size of the boilers from 1000 to 12,000 feet, or equal to about two and a quarter miles in the largest size.

These tubes are bent as shown in Fig. 96, and re-enter the cylinder about 18 inches higher than their initial entrance.

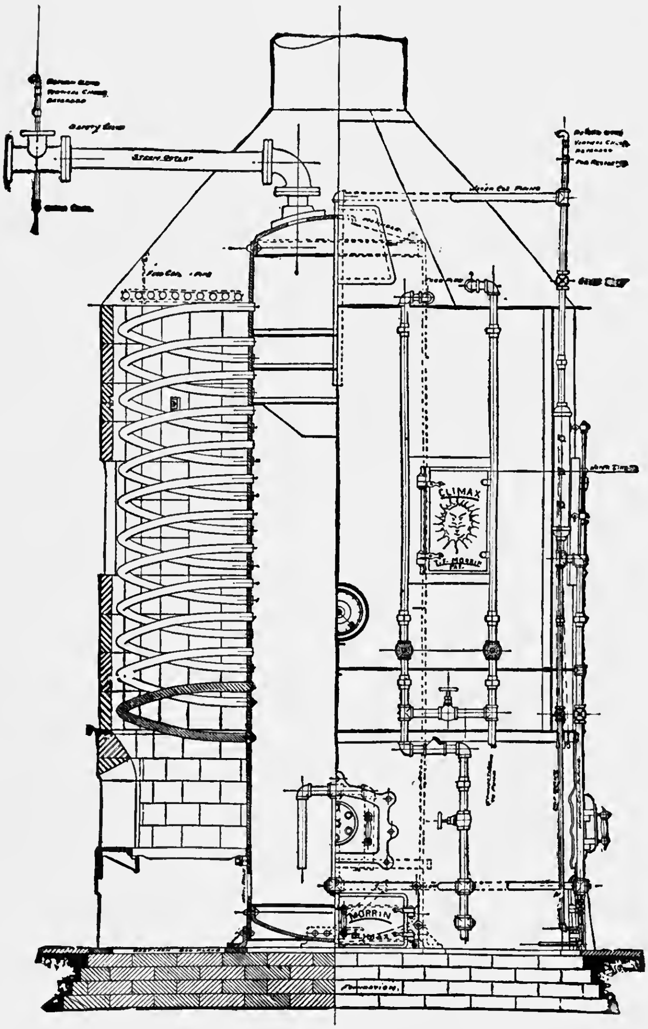


Fig. 97.—Climax Boiler.

The central drum below the fire level affords a settling space for sediment. Access to this drum is obtained by a full-sized manhole. It is simple in construction, presents a plain surface without braces, and can be readily cleaned.

In the main cylinder, a short distance above the water level, a deflector plate is inserted, which tends to throw back any water that may be carried by the steam, and a series of diaphragms divide the upper portion of the cylinder, forming a series of superheating chambers, through which the steam is successively compelled to circulate by the connecting loop-like tubes, thus becoming thoroughly dried and superheated. The steam thus generated passes into a reservoir, which is provided for above the top row of tubes. This is made perfectly clear to the reader by referring to Fig. 98. As the boiler increases in size, so also do the water and steam spaces in the same ratio.

Above the central shell, resting on the row of tubes, is a coil 100 to 300 feet in length, according to the size of the boiler, of $1\frac{1}{2}$ to 3-inch pipe. This coil is welded and without screw joints. The feed water flows through this coil or economiser before entering the boiler, and thus absorbs considerable heat from the waste gases; it then passes to the main cylinder, thence into the curved tubes, in which a rapid circulation is maintained by reason of their upward course and the intense heat by which they are surrounded.

The fire box surrounds the large vertical cylinder, and is annular in form. It is enclosed in a casing of iron, which is bolted together in sections, and lined with a patent fire-brick. It may be said of this brick that, wherever used, it has met with the greatest appreciation and praise from the parties having charge of the boiler plant. The height of fire chamber adds largely to perfect combustion. Ordinarily three or four fire doors are provided, according to the size of the boiler.

The construction of the cylindrical shell into which the tubes are inserted is the same as that of any boiler shell, with the exception that it is welded longitudinally instead of riveted, allowing of a uniform spacing of the holes for the tubes. The tubes are bent to a template and expanded into the shell in the usual manner. The heating surface is efficient, and evaporates with a rate of combustion of 12.5 lbs. of coal per square foot of grate per hour, 6 lbs. of water per square foot of heating surface per hour, requiring less than 5 square feet of heating surface per horse-power, on a basis of 30 lbs. of water per horse-power per hour. The ratio of grate to heating surface is very effective, consequently steam is rapidly formed and a high economy of fuel obtained.

Since the largest diameter exposed to bursting pressure is the small, vertical cylindrical shell, these generators can be of large power and still be entirely safe under any pressure desired. The factor of safety in this boiler is very high.

One of these boilers has been under steam day and night for eleven years, and shows no sign of failure anywhere; a tube which was cut out for examination during the season of 1894 was in as good condition as when first put in. A tube recently removed from the same boiler thoroughly substantiates the foregoing claim.

The bent tubes and the main shell are filled with water, and the heat circulates amongst the tubes, around the outer shell and thence to the flue. No other possible arrangement of the same amount of material could give as much heating surface in so small a space. The heat is almost entirely absorbed before it reaches the chimney, and the loss from radiation is very slight. The water and steam heating surfaces are in proper proportion to each other, thus making it possible to generate dry steam in a very short time.

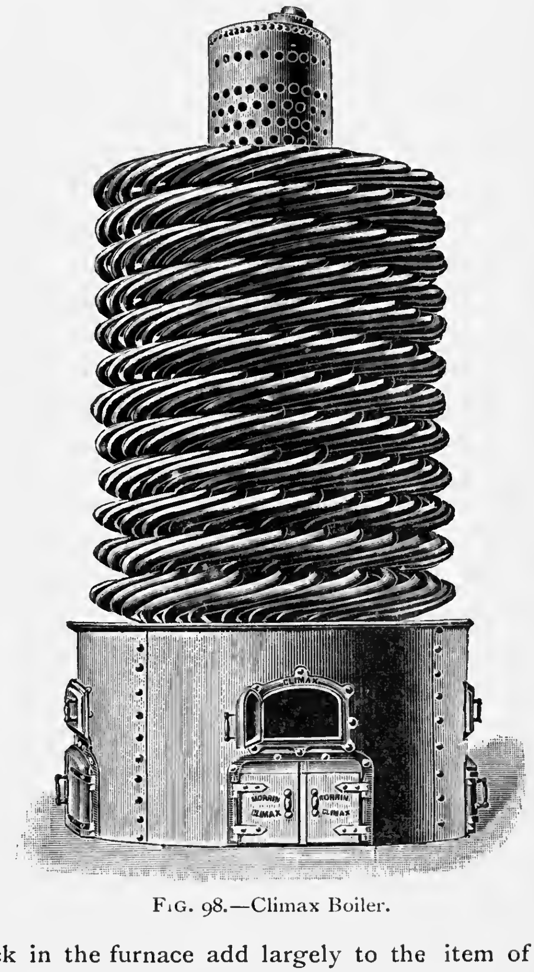


Fig. 98.—Climax Boiler.

The patent smoke-preventing fire-brick in the furnace add largely to the item of economy by promptly igniting the gases of combustion.

In erecting this boiler the central or main shell is stood upon the cast-iron foundation plate, which is set upon the masonry. The foot castings attached to the main shell are then secured to the foundation plate by means of tap bolts. After this operation the work of placing the tubes in the shell is commenced. After all the tubes have been properly expanded the whole is subjected to a hydrostatic test of 300 lbs. to the square inch.

Should it be necessary to remove one or more tubes from the boiler after the test has been made, on account of a pin hole or sand spot, the water is run out of the boiler and a new tube inserted, which is done in a very few minutes. The tubes are again tested to see that those inserted have been properly expanded. This operation completed, the work of placing the casings, which have been lined with the porous fire-brick during the period of placing and testing the tubes, are then placed in position and securely bolted. The canopy or bonnet is next placed, and thus the work of completion goes on until every part is in its proper position.

The time consumed in the erection of any one of these boilers averages about three weeks, so that a person ordering a boiler can have steam on his plant within six weeks from date of placing the order. The same cannot be said of every type of boiler now on the market.

The "Climax" is very easily handled, all parts being sectional. The heaviest of the sections does not weigh over 500 lbs., while the main shell varies in weight from 2 to 8 tons according to the size of the boiler.

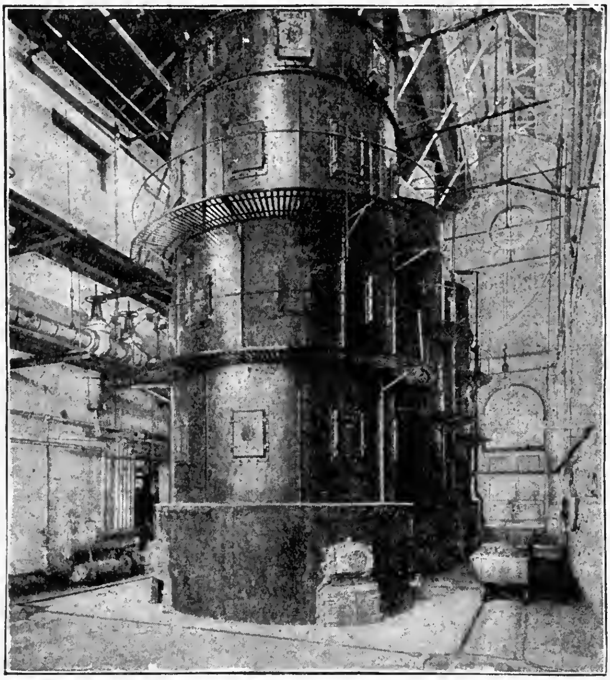


FIG. 99.—Climax Boiler.

The tubes are packed in bundles of six to eight, the casings and furnace sections crated. All fittings, bolts, and minor parts are boxed, so that they can be conveniently and easily handled.

The following is an account of a trial of the boiler by Messrs. Dean & Main of New York:—

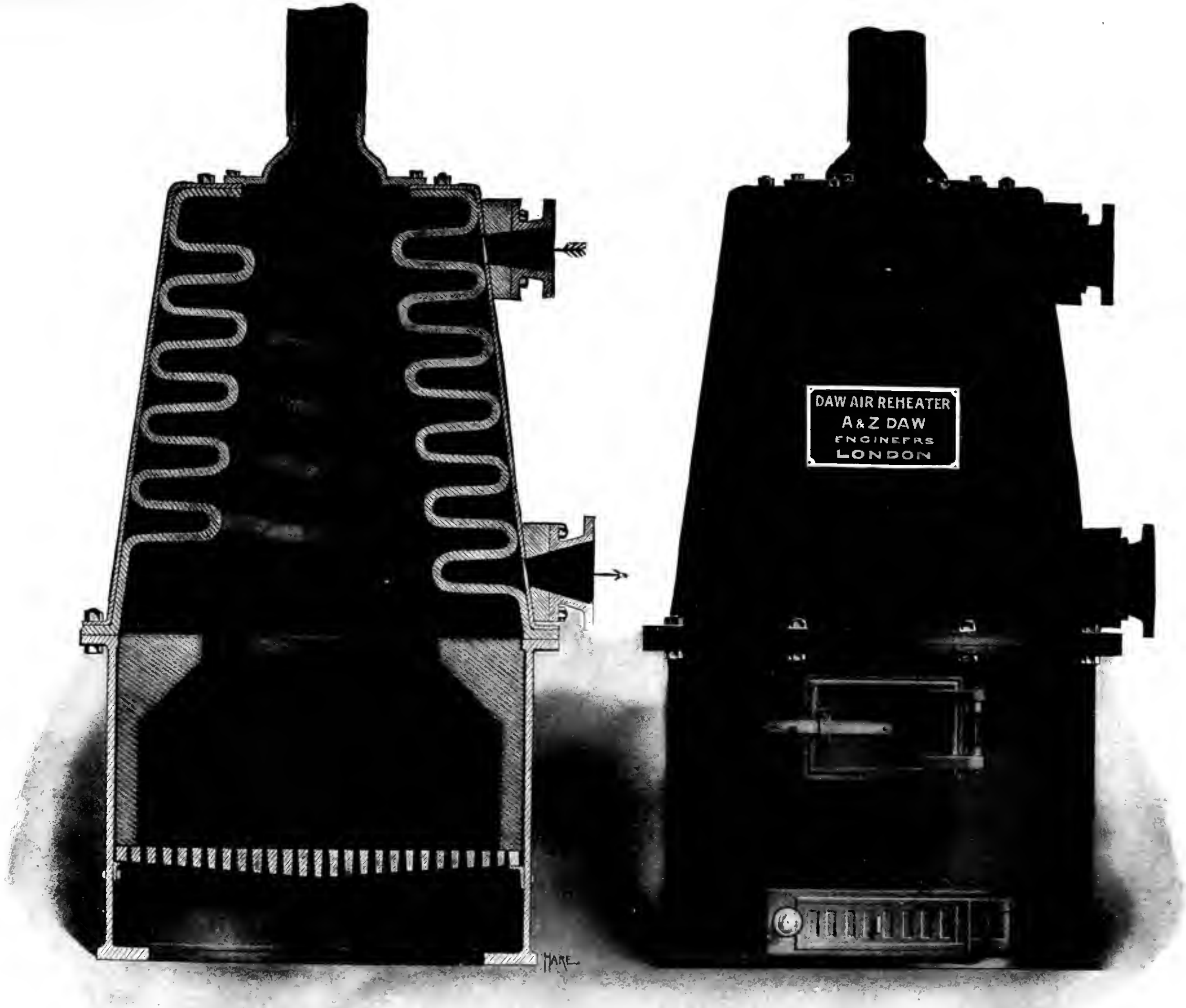
The boiler was fired by an automatic Wilkinson stoker, which worked well until 11.30 p.m., February 1, when it broke down in such a way as to render hand-firing necessary on one quarter of the grate. Before the break-down was discovered a considerable area of the grate became bare in consequence of the stoker not feeding, and after hand-firing began an excess of air was unavoidably admitted during the process of poking the fire. The boiler was therefore handicapped to some extent during the last ten and one-fourth hours of the trial, not only from the causes noted, but from the impossibility of uniform firing.

As the trial was made for the purpose of determining the boiler's evaporative performance, no measurement was made of the amount of steam consumed by the stoker. This had been done sufficiently before.

Before the test was made the boiler was cleaned, and the fire had been lighted some ten hours before the trial began.

The water and coal were accurately weighed on sensitive and correct scales, which were proved by standard weights.

In order to determine the quality of the steam, a Green's thermometer was inserted in the steam pipe near the boiler, in a deep well, and a Peabody throttling calorimeter was connected close by. The quality of the steam was found to vary from a condition of being superheated to that of moisture, as shown in the table. Superheated steam existed during sixteen and one-quarter hours, and moisture during seven and three-quarter hours, and corrections for these conditions were


DAW AIR REHEATER
A & Z DAW
ENGINEERS
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made in the usual manner, assuming only that water was fed to the boiler at a uniform rate.

Occasionally the stoker would drop a large quantity of incandescent coke. While the coal probably would not have given over 6 per cent. of refuse on a hand-fired grate, in this case it was practically 11 per cent. This would not affect the evaporation per pound of combustible except as it involved the loss of heat in the hot coke, but if the refuse had been only 6 per cent., which an inspection of the coal used showed probable with hand-firing, the evaporation per pound of dry coal from and at 212° would have been 11.63 lbs.

The coal used was George's Creek, Cumberland. All lumps were picked out and given to other boilers, while the Climax used the fine coal of the pocket. A sample for analysis was taken, but unfortunately by a misunderstanding was thrown away, so that we do not know its calorific value. It has been assumed in the table of results that these calorific values were 14,500 and 15,425 British thermal units per pound of coal and combustible respectively, and these cannot be far from the truth.

Two samples of coal were dried for about eight hours each on a brick flue during the trial, and yielded an average moisture of 4.12 per cent.

TRIAL OF 1000 HORSE-POWER "CLIMAX" BOILER, WITH WILKINSON STOKER. — AT MILL OF MERRIMACK MANUFACTURING CO., LOWELL, MASS. (*February* 1–2, 1897).

Kind of fuel	Fine George's Creek.
Kind of trial	Running start and stop.
Duration of trial	24 hours.
Grate surface	113.6 square feet.
Total heating surface	10,000 ,,
Ratio of total heating surface to grate surface	88.
Average steam pressure in boiler, by gauge, per square inch	81 lbs.
Average atmospheric pressure per square inch	14.84 ,,
Average absolute steam pressure in boiler per square inch	95.84 ,,
Force of draught in column of water between damper and boiler	0.21 inch.
Average temperature of external air	36°.
,, ,, fire-room	93°.
,, ,, feed water before entering boiler	37.3°.
,, ,, escaping gases after leaving boiler	407°.
,, ,, steam	339.1°.
Moist coal consumed	76,687 lbs.
Moisture in coal	4.12 per cent.
Dry coal consumed	73,528 lbs.
Total dry refuse	8069 ,,
,, ,,	10.97 per cent.
Total combustible	65,459 lbs.
Dry coal consumed per hour	3064 ,,
Combustible consumed per hour	2727 ,,
Percentage of moisture in steam for $7\frac{3}{4}$ hours	3.84 per cent.
Number of degrees superheated, average for $16\frac{1}{4}$ hours	22°.
Number of heat units in 1 lb. dry coal, by analysis, assumed	14,500 B.T.U.

Number of heat units in 1 lb. combustible, by analysis, assumed	15,425 B.T.U.
Specific heat of superheated steam at constant pressure	0.48.
Heat units absorbed by boiler per pound of steam generated	1175.6 B.T.U.
Total heat units absorbed by boiler	774,880,282 ,,
Heat units imparted to boiler per pound of dry coal	10,538 ,,
,, ,, ,, of combustible	11,838 ,,
Efficiency of boiler, based upon dry coal, approximately	72.7 per cent.
,, ,, combustible, approximately	76.7 ,,
Factor of evaporation for boiler	1.22.
Total water pumped into boiler	663,124 lbs.
Water actually evaporated, corrected for quality of steam	659,136 ,,
Equivalent water from and at 212° Fahr., boiler only	804,146 ,,
,, ,, ,, per hour, boiler only	33,506 ,,
Water actually evaporated per pound of dry coal	8.96 ,,
Equivalent per pound dry coal from and at 212° Fahr., excluding economiser	10.94 ,,
Water actually evaporated per pound of combustible	10.07 ,,
Equivalent per pound combustible from and at 212° Fahr., exclusive economiser	12.29 ,,
Horse-power on basis of 34½ lbs. water from and at 212° Fahr., per hour by boiler	971 horse-power
Number of square feet of heating surface per horse-power	10.3 square feet.
Horse-power per square feet of grate surface	8.53 horse-power.
,, builders' rating at square feet per horse-power	1000 ,,
Per cent. developed above or below rating	2.9 per cent.
Dry coal actually burned per square foot of grate surface per hour	27 lbs.
Water evaporated per square foot of heating surface per hour from and at 212° Fahr.	3.35 ,,
Water evaporated per square foot of grate surface per hour from and at 212° Fahr.	295 ,,

THE MUMFORD MARINE BOILER FOR LAUNCHES

This boiler is shown in Fig. 100 as fitted into the vessel. It is a tubular boiler in which the outside shell can be drawn up. It is lagged and protected by heat non-conducting lining. The surface condenser is simply a thin copper tube along the keel of the boat. For small launches these sets have been largely used.

COAL-DUST FIRING FOR BOILERS

This system has been brought to considerable perfection, and is worthy of close attention by colliery owners and engineers; and also by those interested in prevention of smoke from steam boilers.

In some degree the nuisance of intensely black smoke issuing from a factory or works chimney has been prevented or abated, but not without loss of efficiency. To obtain both desiderata has cost innumerable experiments and great expense, but their combination is absolute in the Schwartzkopff system of coal-dust firing. The idea of utilising coal dust as the best means of securing perfect combustion is not of recent date, but it may safely be said that the principle was not accurately and economically employed until the Schwartzkopff system was discovered.

Briefly stated, the system is this. Slack, which may be of the poorest quality, is pulverised to about the consistency of flour, then carried along a conveyor or iron pipe and sprayed into the furnace by a revolving steel "brush." No bars or grating is needed in the furnace. A piece of common cotton "waste," soaked in petroleum, ignited and put into the furnace, is sufficient to start the fire. Within a few minutes after the brush has been started the furnace becomes a white heat. A peep into a

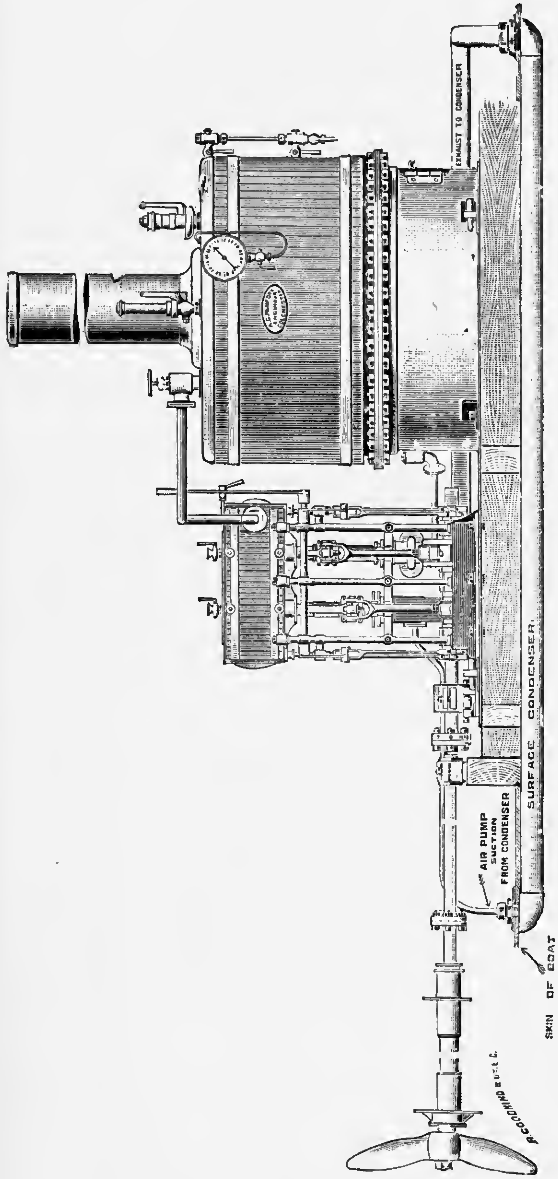


FIG. 100.—Small Boat Marine Outfit.

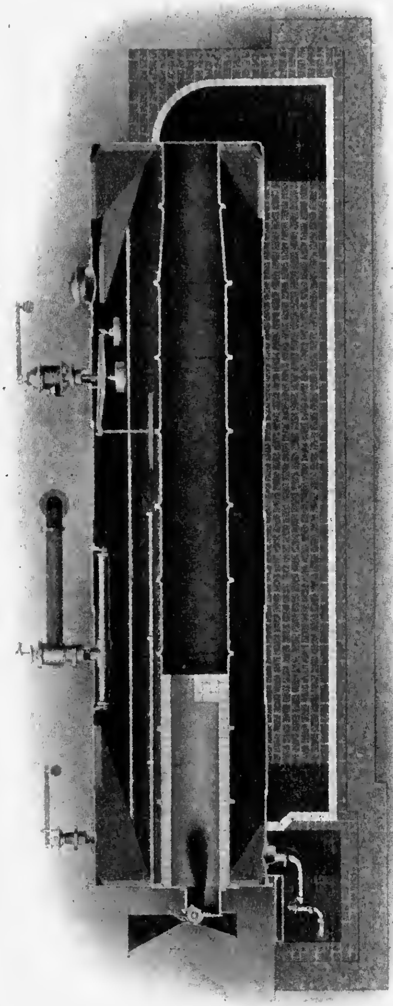


FIG. 101.—Coal-Dust Fired Boiler.

furnace fed on the Schwartzkopff system affords a truly marvellous sight. There is a greater intensity of heat by many degrees than is possible with hand-firing, yet no coal or ashes are present. Only a small quantity of white dust, which falls in a molten state to the bottom of the furnace, is to be seen. Numerous tests have proved that with the very worst slack on the market the Schwartzkopff system shows better results in firing than by hand-stoking. This is the especial merit of the system. The smokelessness is an important though subsidiary advantage which enhances the merit of the system. By it the problem of perfect combustion is solved. Hand-stoking is, of course, absolutely abolished. One man can with ease look after a battery of a dozen furnaces.

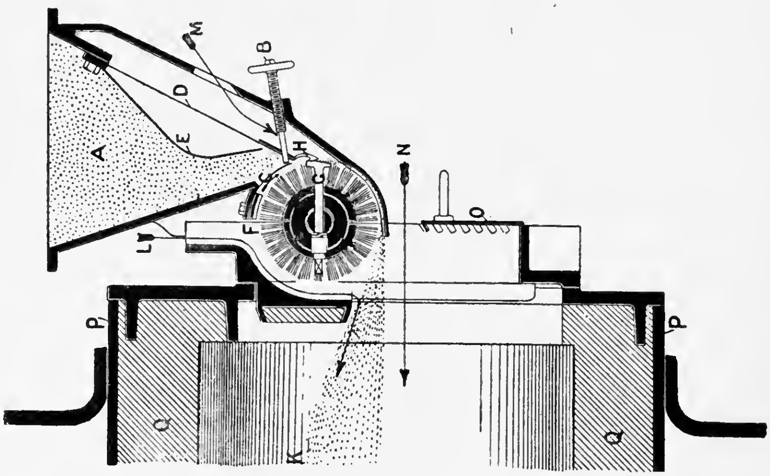


Fig. 103.—Transverse Section.

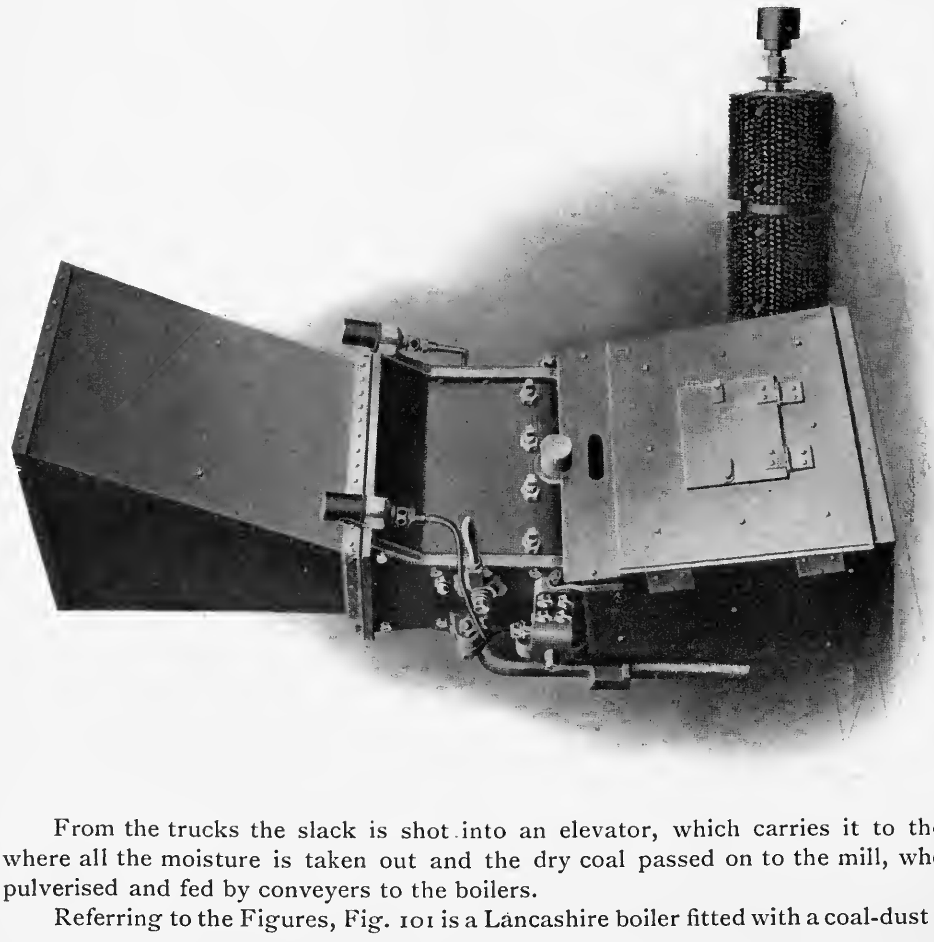


Fig. 102.—Coal-Dust Stoker.

From the trucks the slack is shot into an elevator, which carries it to the drier, where all the moisture is taken out and the dry coal passed on to the mill, where it is pulverised and fed by conveyers to the boilers.

Referring to the Figures, Fig. 101 is a Lancashire boiler fitted with a coal-dust burner.

The refractory brick-lined furnace is clearly seen. No radiant heat reaches the boiler plates from the furnace. In Fig. 102 we have an external view of the coal-dust burner as ready for fitting in front of a boiler furnace door. In Fig. 103 the coal-dust burner is shown in section.

The shoot A receives the pulverised coal. It is closed on the bottom by the bent steel plate C (adjustable by the screw B) from the loose flap D. A fixed plate E relieves the flap D from the pressure of the powdered coal. F is a brush, the bristles consisting of steel wires. It carries in the middle the hammer G, which strikes at every revolution of the brush against the nose H of the steel flap D, and moves the same slightly back from the plate C. As this latter is kept by the screw B in its position, a slot-like opening is made with each revolution of the brush, through which the powdered coal falls upon the brush. The coal is caught by steel wire bristles and driven into the combustion chamber K. As soon as the hammer G has passed the nose H the flap D, owing to its elasticity, strikes back against the plate C. In this manner the coal dust is kept agitated in the shoot, and consequently an absolutely regular feeding down takes place.

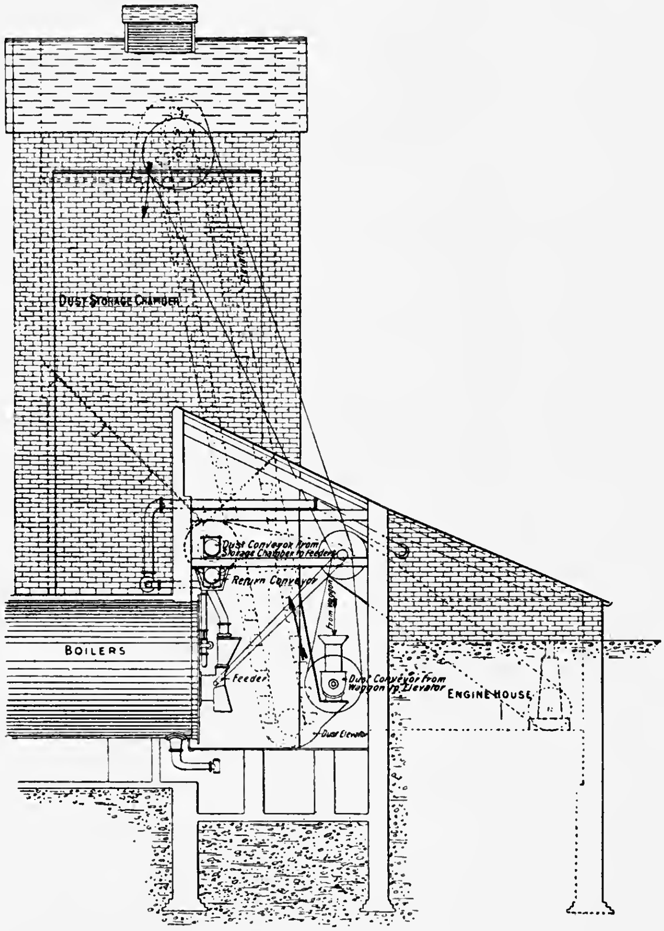


Fig. 104.—Coal-Dust Firing.

The combustion chamber K is formed in the simplest manner; for example, in a flue boiler by lining the flue with fire-bricks for a length of 5 to 9 feet, and providing a fire bridge at the end of this lining. The brick walls Q attain in a very short time the temperature necessary for constant ignition of coal dust. The first ignition of the coal dust is effected without any difficulty by a small wood fire, or by burning a little old waste soaked in petroleum. A boiler standing all night has the fire properly started in five minutes. The necessary amount of air is introduced to the furnace in the directions indicated by the arrows L, M, and N, and it is quite sufficient to regulate the admission by the sliding plate O. The amount of coal dust is regulated during the firing by the screw B. The farther the screw is pushed back, the wider becomes the distance between C and D.

During firing, only the regulation of the plate O and the screw B is necessary, and the only work for the firemen is the removal every ten hours of the ash dust, which, as already explained, lies in a molten state at the bottom of the combustion chamber; but this operation does not affect the working of the furnace. One man can attend a battery of twelve boilers, or even more. For driving the firing apparatus mechanical power is necessary equal to only one-tenth of a horse-power.

Fig. 105 shows the dust firer fitted to the front of a water-tube boiler, and Figs. 104

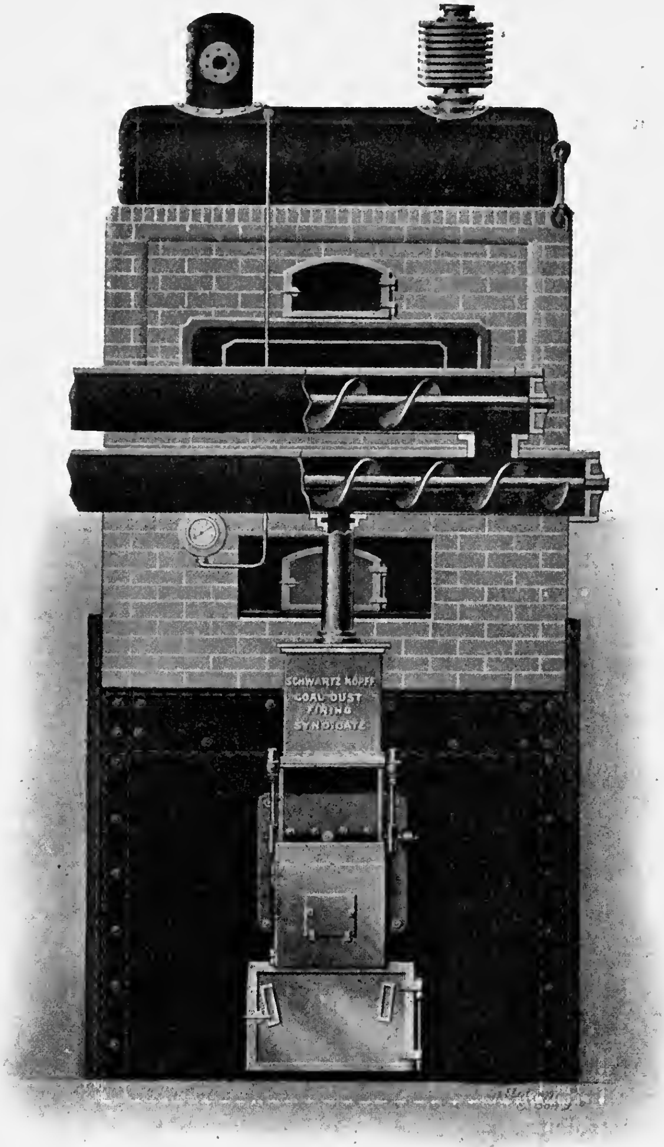


Fig. 105.—Coal-Dust Boiler.

and 106 are a side and end view of a battery of five boilers, showing how the whole of the fuel and dust is handled entirely by mechanical means.

LIQUID FUEL FOR BOILER

The large supplies of cheap natural oils and oils the by-products of distillation of coal and wood, and gas works refuse, has induced the attention of engineers to the use of them in boilers for steam raising.

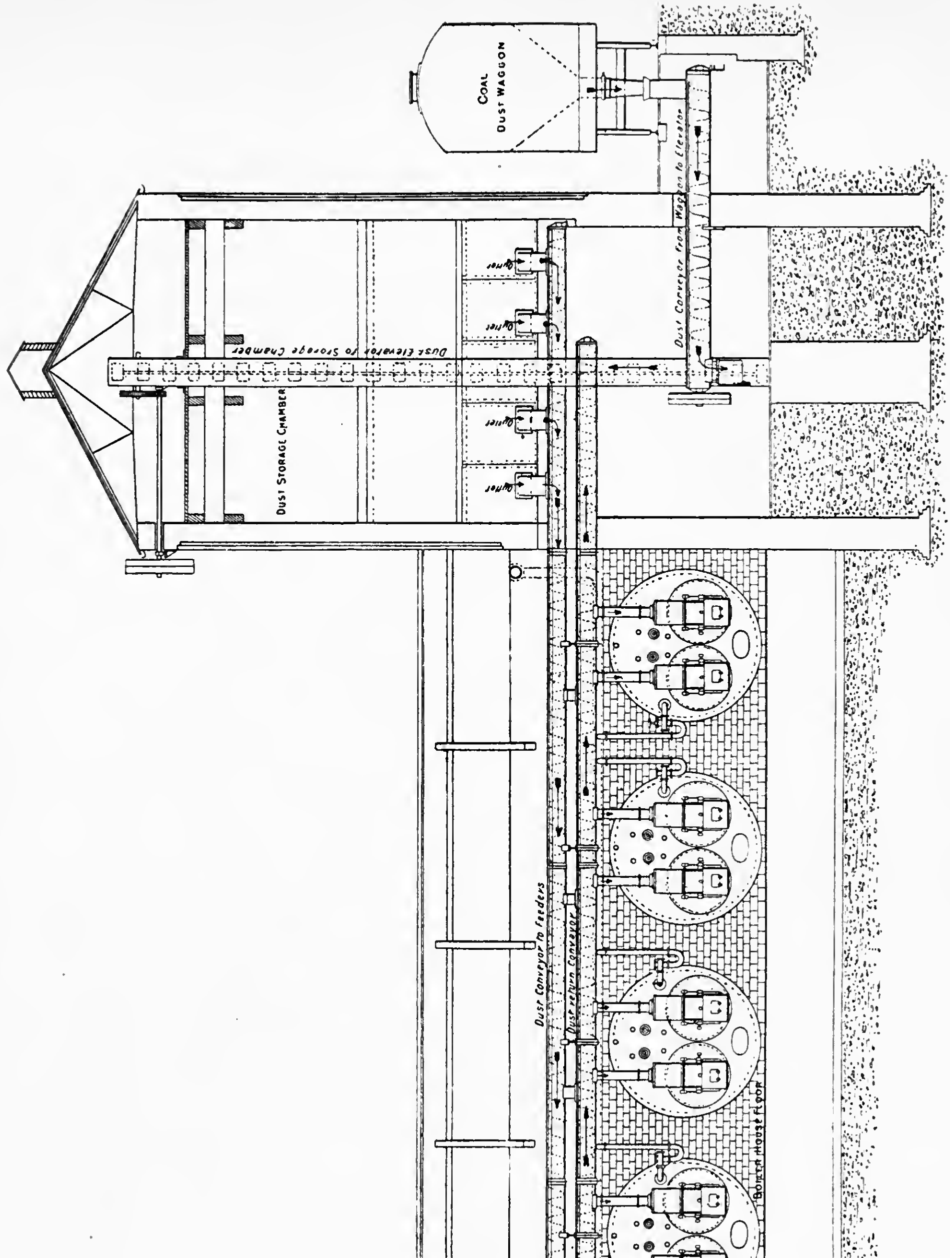


FIG. 106.—Handling Coal-Dust Fuel.

There are three methods for utilising oils as fuel; in all of them the oil must be thoroughly atomised, sprayed, or broken up into fine particles.

The simplest method is to spray the oil into the furnace by a centrifugal nozzle, shown on page 66 of Volume IV. of this work, Fig. 97. The oil in this case is kept under pressure, or falls under a head from a tank overhead.

The second method is to employ a steam jet acting somewhat as an injector to break up the oil. The first method is suitable for thin oils which flow freely; the second for viscous oils or tar. The third method employs compressed air, either cold or heated, and may be best carried out in a nozzle, the invention of Messrs. Priestman Brothers for spraying oil in their engine by compressed air. This spray-maker is of considerable interest; the air pressure is from 5 to 20 lbs. per square inch, and the oil is carried in a vessel overhead or above the level of the oil nozzle. The air is passed through an opposing nozzle to that of the oil, so that they meet in opposition. The oil, being the heavier fluid, carries through the air jet, but in passing is broken up into a cloud of fine particles. The nozzle is shown in section in Fig. 107; it may also be used with steam instead of air. In either case the oil and air or steam must be at the same pressure. The quantity of oil must also be regulated. If too much is used the flame becomes smoky, if too little the flame is readily extinguished.

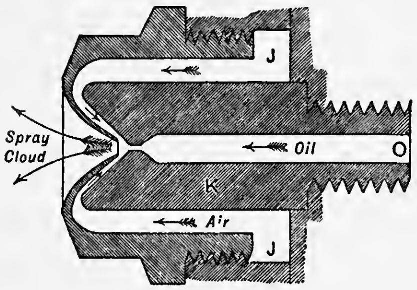


FIG. 107.—Priestman Nozzle.

An American engineer, Mr. George G: Bennett, has made some experiments in which he asserts that the steam alone in an oil jet without any air supply will consume oil. This opinion, based on experiment, is somewhat difficult to accept. The oil consists of hydrogen and carbon; the steam consists of hydrogen and oxygen, and the oxygen of the steam is only just sufficient to satisfy the demands of the hydrogen in the steam.

Steam subjected to intense heat of a flame may be dissociated into its two elements, the oxygen when then free may combine with the carbon of the oil, although it cannot at that high temperature associate with the hydrogen; there would therefore be free hydrogen produced, unless some action occurs whereby this freed hydrogen recombines with the oxygen and carbon again. Such an action is unknown to occur, so that we must assume that some air enters into the combination to supply further oxygen.

Mr. Bennett's own explanation is here given:—

"We know that dry steam under pressure is a true gas, and a good supporter of combustion, and when decomposed by some suitable arrangement the gases burn with intense heat, but some form of carbon must be used to effect the decomposition. We also know from experience that this decomposition actually occurs when burning oil with the aid of steam. Let us illustrate this point. In 1 lb. of steam there is 0.889 lb. of oxygen and 0.111 lb. of hydrogen. The amount of steam required to effect the complete combustion of 1 lb. of oil is as follows:—To burn 1 lb. of carbon requires 2.67 lbs. of oxygen. As the average crude petroleum contains about 85 per cent. carbon and about 12 per cent. hydrogen, the amount of oxygen required to effect the complete combustion will equal $2.67 \times 0.85 = 2.269$ lbs. of oxygen, and the weight of steam required to furnish this weight of oxygen will be $2.269 \div 0.889 = 2.55$ lbs. of steam or water.

Steam is composed of 0.111 per cent. hydrogen and 0.889 per cent. oxygen. One pound of hydrogen requires $0.889 \div 0.111 = 8$ lbs. of oxygen for its combustion, which is contained in $8 \div 0.111 = 72$ lbs. of steam or water. But as we have only 12 per cent. hydrogen in the average crude oil, it will require only 12 per cent. of 8 lbs. of oxygen—that is, it requires 8 lbs. of oxygen for the complete combustion of 1 lb. of hydrogen, and consequently $8 \times 0.12 = 0.96$ lb. of steam to furnish the required oxygen for the combustion of the hydrogen; so that the total amount of steam required for the combustion of 1 lb. of crude petroleum is $2.269 + 0.96 = 3.229$ lbs. As more or less atmospheric air will find its way into the furnace, 3 lbs. of steam would be ample in my estimation.

It has been demonstrated that 1 lb. of oil will evaporate at least 15 lbs. of water. So that the percentage of steam used to atomise and force the oil into the furnace is very small in proportion to the steam generated; probably 2 per cent. would be very high. Not only this, but we are always sure of complete combustion and of no waste of fuel. The flame may be intensified by merely operating a valve controlling the supply, either the steam or the oil. In the other case, when air alone is used for the combustion of the oil, we have the cost of installing air pumps, auxiliary air superheaters, which require extra fuel to operate; and not only this, but the amount of air required is extraordinary. This is just where the trouble occurs—namely, in not being able to distribute the air where it is required most, and the production of black smoke is the result. Those who have experimented with air will readily agree on this point.

With the use of steam there can be no uncertainty, for complete combustion can be maintained at all times. There is no such thing as a smoky furnace, no trouble with the tubes or flues stopping up with soot, no air to regulate; the burner can be made automatic, and as long as the steam and oil supply is maintained at the correct standard no further attention is necessary. Some of the advantages of liquid fuel are:—Its concentrated form, economy of handling, increased evaporative efficiency, cleanliness, abatement of the smoke nuisance, reduction in depreciation account, reduction in repair account, reduction in sundries account, and efficiency in emergency."

The efficiency of oil over that of our best coal, pound for pound, is from 30 to 40 per cent. In regard to cleanliness it has no competitor; no dust or dirt from the handling of ashes or coal. There is also a large saving in paint, brooms, tube cleaners, and waste. The great cost of installing smoke consumers in cities where the smoke nuisance is experienced may be ignored, because there will be no necessity for complying with the law. Smoky chimneys will be a thing of the past. When burning oil a smoky chimney is good evidence of imperfect combustion.

The time required to convert a furnace from coal to oil burning, and *vice versa*, is very short, not over two hours at best. The methods I have always used in changing a furnace from coal to oil burning are, to clean all the ashes and clinkers off the grate (it is not necessary to remove the grates), then cover the grate with a layer of fire-brick, over the fire-brick spread a layer of ashes or sand (common clay will do if nothing better can be found), 2 or 3 inches in depth, which will be sufficient. To change back to coal requires only a few minutes.

In regard to oil burners, there is really no secret in making a good burner. Nearly all the oil burners in the market at the present time give good results when properly installed and handled. In my experiments with oil burners I found that the simplest form of burner gave the best results, provided proper care was used in its construction. A burner that is very complicated, so that it requires an experienced person to operate it, will generally give more or less trouble, and will be found unsatisfactory. The burner must be so constructed that it will atomise the oil before it enters the furnace. If this is not accomplished there is liable to be more or less waste of oil and a smoky furnace.

One great objection urged against the use of oil as fuel is due to its inflammable and explosive qualities. This no doubt arises from lack of knowledge as to its nature, because those who have had experience with crude oil know differently. The fact of the matter is, crude oil is very hard to ignite. Even a red-hot bar of iron has no effect. This proves that the oil is not as dangerous as many consider it to be. If you wish to put out an oil fire, do not attempt to extinguish it with water, for water has a tendency to intensify the flame: it must be smothered out by earth or sand.

The all-steam sprayer has not been met with as yet in practice.

KÖRTING'S LIQUID FUEL APPARATUS

This firm employs two methods of spraying the oil, using either centrifugal sprayers or steam-jet sprayers: the first for marine purposes and for all stationary plants of large size, where the highest economy, combined with reliability and minimum attention, is required; and the second for small plant, in which the cost of installation has to be kept low, or where the liquid fuel employed is of a thick nature, such as tar.

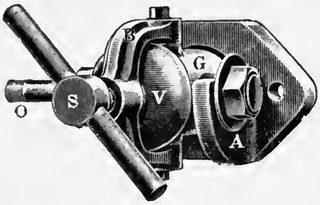


FIG. 108.—Centrifugal Spraying Nozzle.

The application of the centrifugal sprayer obviates the defects of the steam-jet system, whilst securing several important advantages. In spraying petroleum, raw naphtha, mazut, astatki, etc., by means of steam jets, a certain portion of the heating value of the fuel is lost, as the steam has to be raised to the furnace temperature, and, being used for spraying, is lost to the boiler.

In the case of marine boilers this loss is specially disadvantageous, as the steam used for spraying represents a loss of water, which has to be replaced. This loss is often 100 per cent., or even more than the weight of oil sprayed.

This disadvantage is obviated by this centrifugal sprayer, which consists of a centrifugal spray nozzle, through which the oil is forced by means of a pump, and is thus injected into the furnace in an atomised condition, without the assistance of a steam jet.

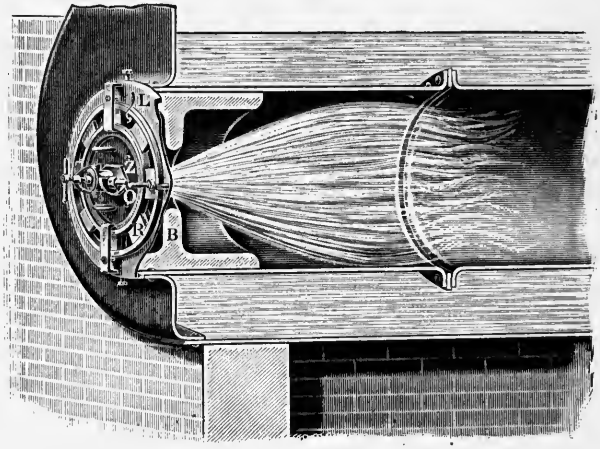


FIG. 109.—Oil Firing Centrifugal Spray.

The fluid particles issue from the mouth of the sprayer in the form of a cone, and so give a wide, round flame, and no intense local flames are formed.

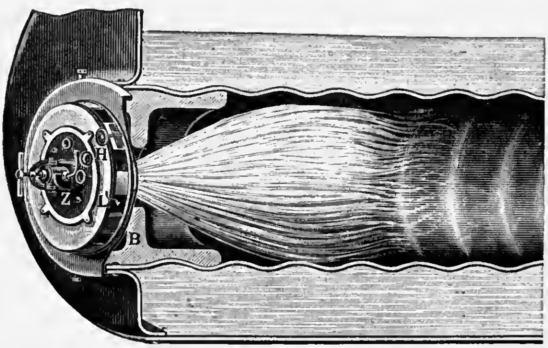


FIG. 110.—Oil Firing.

The oil runs from the supply tank to the pump, by which it is put under a pressure of 30 to 75 lbs., according to the evaporation required, and is then raised to the centrifugal sprayers, fitted immediately in front of the furnace, as per Figs. 108 and 109. On the way the oil is heated, by means of tubular heaters, to a temperature of 220° to 260° Fahr., and in this condition it is sprayed into the furnace without the least noise.

With scarcely any attention worth mentioning, the liquid fuel is drawn from the storage tanks and pumped into the furnace. With the air admission correctly adjusted, which is easily secured by a movable slide, combustion is complete and smokeless.

Cylindrical air admission slides, similar to that shown in Fig. 110, take up more room than the plain circular slide in Fig. 109, but afford better protection to the stoker from the radiating heat.

The pump should be of the direct-acting type, and to guard against breakdown a reserve pump should be provided. This precaution should always be taken with large plants and with marine work.

The pumps, with accessories, heaters, filters, reducing valve, air vessel, etc., are shown in Fig. 111.

In the oil pipe leading to the apparatus a small tubular heater, which is supplied with live steam, is fitted, for the purpose of increasing the fluidity of the oil, in case the latter, by low temperature, has become viscous.

Two filters, to be used alternately, are provided, and the pressure pipe from the pumps is also fitted with two strainers, and a strainer is fixed in the sprayer casing. Finally, the sprayer can be immediately exchanged for another, which ensures the plant from interruption through obstructions.

The steam used in the pump, as well as that employed in the heaters, is recovered as condense water, and returned to the boiler for re-use.

A steam pressure reducing valve maintains the pressure at a constant value, and minimises the attendance, while an overflow and safety valve prevent the oil pressure from rising, thus obviating useless consumption of fuel.

In the case of marine type boilers the full section of the furnace is used, the grate being unnecessary, and there is therefore a gain in heating surface. The heating and the resulting expansion is equable, and all the water surrounding the tubes is correspondingly heated. The short fireclay lining in the furnace serves as some protection against the intense temperature of the oil flame, and enables the boiler to be readily set to work again after a short interruption, as no after heating up is necessary, the oil igniting on the incandescent fireclay.

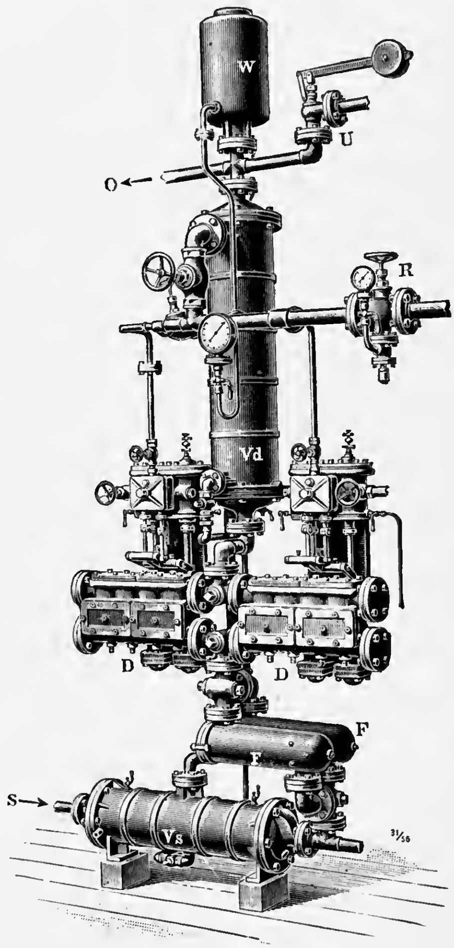


FIG. 111.—Oil Pumps.

The warming up of large cylindrical boilers offers no difficulty whatever. The method of firing adopted is shown in Fig. 112. A scoop or tray containing oil is mounted on the firebrick, and the oil is ignited, the temperature of the furnace rising slowly but continuously in a time varying up to 24 hours.

The Hamburg-American line have had four of their cargo steamers equipped with this system of oil firing. Two of these steamers, the *C. Ferd. Laeisz* and the *Segovia*, having boilers of about 750 square feet heating surface in twelve furnaces, work with natural draught and consume about 32 tons of oil per 24 hours, as compared with 45 tons of good German coal; while the other steamers, the *Sithonia* and *Silvia*, of about 7000 square feet heating surface and nine furnaces, with the air heated on the Howden system, use only about 27 tons of oil in 24 hours, as compared with 42 tons of coal.

The *Almissa*, a passenger and cargo steamer of the Austrian Lloyd, is fitted with oil-firing plant. This vessel, which is about 2500 tons burden, has engines of 900 horse-power, and two boilers, each having 1400 square feet heating surface and two furnaces. The *Almissa* undertakes regular journeys from Trieste to Dalmatia, and formerly used on the journey 43 tons of Cardiff or 74.7 tons of Dalmatian coal, whilst now 23.5 tons of oil are found sufficient.

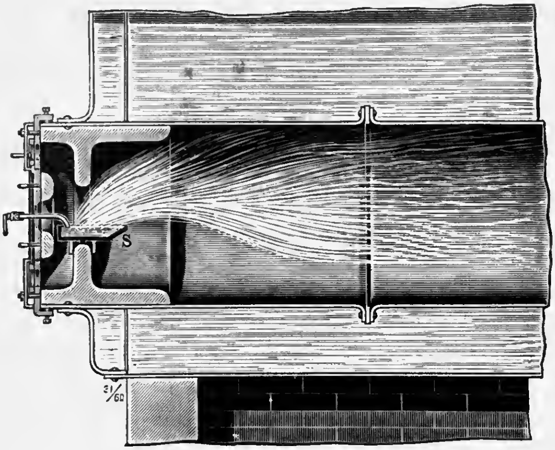


FIG. 112.—Lighting up.

In Russia alone over 3500 centrifugal sprayers are in use.

STEAM-JET SPRAYERS

Steam-jet sprayers are adopted, as previously mentioned, for small plant, and in cases where the fuel is heavy and viscous, as, for instance, tar. These apparatus are also used if combined oil and coal firing is required.

The division of the fuel into fine drops is effected either by a jet of steam or a mixed jet of air and steam. The pure steam jet should be employed for spraying heavy fuels, on account of its high velocity and of the heat contained, but for light fluids a mixed jet can be used. In apparatus

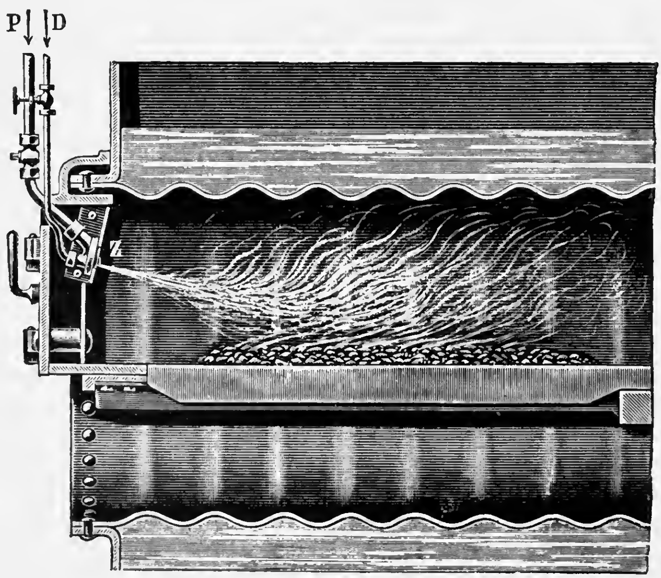


FIG. 113.—Steam-Jet Sprayer.

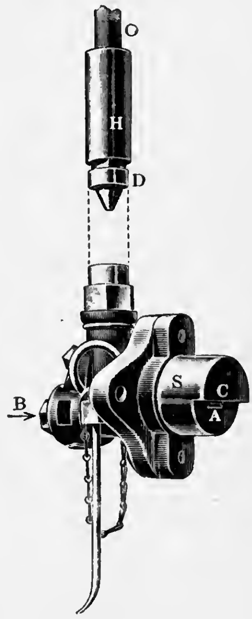


FIG. 114.—Sprayer.

of the latter kind the steam jet sucks in air, which, mixing with the steam, passes through a small air compressor in the lower part of the sprayer and is put under pressure, thus forming a suitable means of spraying the fuel. The Figure (Fig. 114) shows steam-jet sprayer with air compressor.

The arrangement of the steam-jet sprayer with Lancashire or marine boilers, in case the full section of the furnace is at disposal, is exactly the same as the centrifugal sprayer. The liquid fuel flows from a tank standing at some height, in which the oil is suitably heated, and to which it is raised by a pump. The fire is regulated by the stop valves provided with each sprayer. The equipment of the pump with filters in the suction, and strainers in the pressure pipes, and with air vessel and gauge and steam pressure reducing valve, is the same as with the centrifugal sprayer.

If compressed air is available it can be used without further arrangement for working the sprayers.

The erection and working of oil firing plant, employing steam or air for spraying, differs only in the following points from the centrifugal spraying plant.

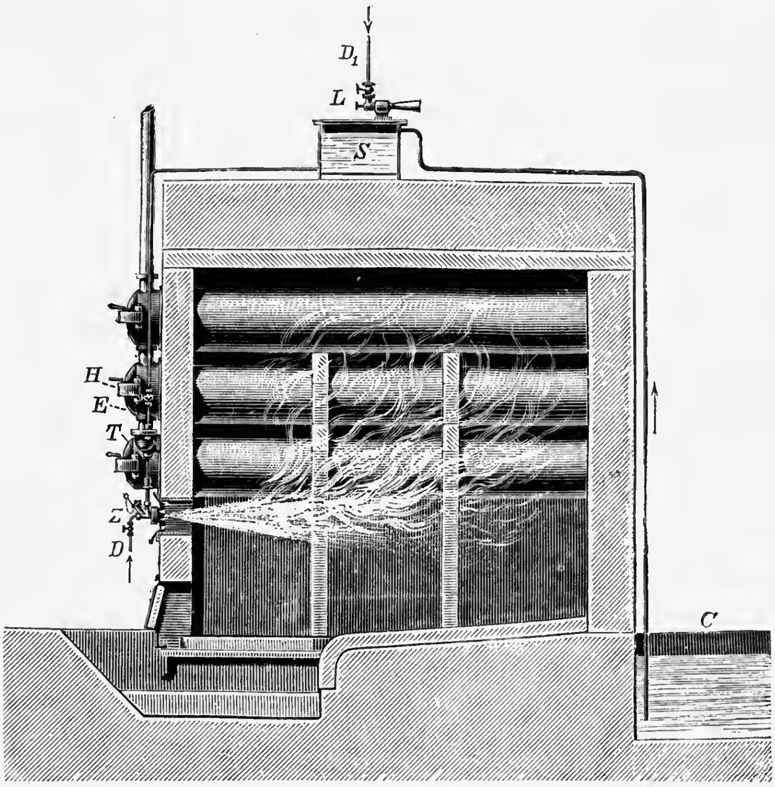


FIG. 115.—Steam-Jet for Tar Fuel.

The pump does not force the oil direct to the sprayer, but raises it to an intermediate tank placed above. In this tank the oil is heated to a temperature of 140° to 160° Fahr. by means of a coil, and then flows to the burners with a slight fall. Regulation of the quantity of oil sprayed is effected through adjustment of the cocks belonging to each sprayer, and an overflow valve is not therefore required.

The special heaters and the strainers for preventing stoppage are not, in this case, necessary.

Working.—Coarse impurities, such as sand, shavings, fibrous matter, etc., must be removed from the oil.

Warming up is effected by means of oil contained in a pan, as per Fig. 112. For this purpose a cast-iron pan is mounted on the fire-brick, and the oil pipe, after the sprayer has been removed from its casing on the front plate, is fitted with a small piece of pipe, as shown in Fig. 112. With suitable arrangements for air admission the oil will burn in the pan with a clear flame, and with hardly any smoke worth mentioning.

The regulation of the oil is effected by valves on each sprayer, until about 22 to 33 lbs. of oil per pan are burnt per hour.

As soon as the boiler pressure has risen to a sufficient extent the pans may be removed and the sprayer put in place. The heaters should then be started, care being taken to expel any air in them, and the sprayers being shut off, the oil should be circulated until the thermometer indicates about 212° Fahr. The pressure of the oil above 30 lbs., which is the normal working pressure, rises with the speed of the pump. The temperature should then be raised to 248° Fahr., and the cocks on the sprayers opened one after another and the fires lighted. The working pressure can be reduced by adjustment of the pump and overflow valve, if the work on the boiler is diminished, the opposite being done if the boiler is to be forced.

The air slides on the front plate of the furnace should be fully open at starting, and as soon as the fireclay lining is at red heat the air admission should be adjusted till smokeless combustion results.

The spraying of liquid fuel at the temperature given above, and from a pressure of 15 lbs. upwards, should be fine and equable. If a stoppage should occur, this will be most probably due to dirt, and the filters, strainers, and sprayers should be overhauled, cleaned, and replaced.

In many agricultural districts in Germany, alcohol is recovered as a by-product in such quantities that no market is available for it, but it finds a ready application as fuel.

The centrifugal sprayers are specially suitable for oils containing more or less water, no further water being added in the burning process, as in the case of steam-jet sprayers.

The use of alcohol, the calorific value of which is considerably below that of mineral oils, is with this method much more satisfactory.

The arrangement for firing with alcohol is generally of the same character as the oil-burning plant, but the provision for heating and the precautions against interruption through stoppages are somewhat simpler.

BOILER TUBES AND FLUES

The formation of deposits and scales on boiler tubes is shown in Fig. 116. On the left-hand side is a fire tube in which soot and ashes collect on the lower inside when the tube is horizontal or nearly so; while scale forms on the upper outside. The middle Figure is a section of a water tube, also horizontal. Here the scale is inside and ashes outside. In a vertical tube as shown on the right hand the scale and soot are equally distributed over the surfaces, and more regular working is attained. In most boilers the tubes are now nearly vertical, and rapid circulation is maintained to avoid deposits forming.

FIG. 116.—Boiler Scale.

At one time boiler-makers believed firmly in large tapered cross-tubes fixed in the flues of Lancashire and other common types of boilers. They were thought to be effective in promoting circulation, and in presenting increased heating surfaces. It has, however, been generally recognised that tubes in a boiler to be effective must be small and numerous. Hence the tubular boiler's popularity for quick steaming.

Corrugated flues are now more often adopted. They, with the same thickness of metal, have about three times the strength, and expose a very large heating surface. The ordinary style of this tube is shown at top of Fig. 117, and the spirally corrugated flue at bottom of Fig. 117. The first is now almost universally used in marine cylindrical boilers for the fire flues.

The latter is used for Lancashire boilers, and has plain bands at intervals for receiving cross tubes if desired.

BOILER FITTINGS

These are numerous, and we have only referred to the more important types. For water level gauges, Messrs. Hopkinson's are very good examples.

The breakage of a water gauge glass in high-pressure steam boilers is fraught with danger; any appliance which prevents the serious consequences arising from this cause is one of the most important and desirable safety fittings that can be attached to a steam boiler.

Although the danger exists in every description of steam boiler, it is most apparent in the stokeholds of steamships, on the footplates of locomotives and tram engines, where the attendants necessarily work in confined places, and from which it is difficult for them to escape.

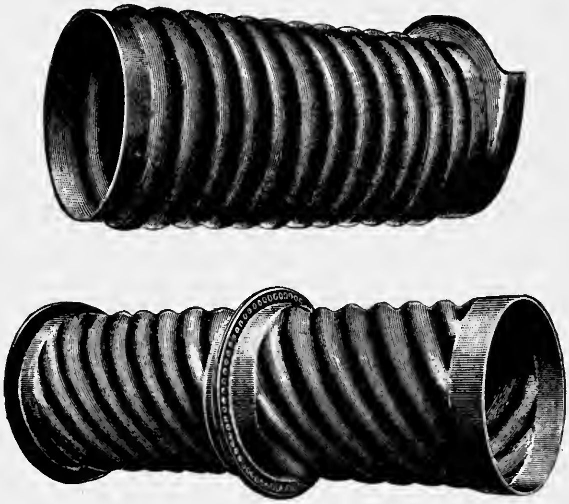


Fig. 117.—Corrugated Boiler Flues.

Many accidents of a serious, and some of a fatal character, have occurred from this cause. The escaping steam and water when a gauge glass bursts often occasions cases of scalding and injury even to the attendants of land boilers, but to those in charge of boilers on steamships, locomotives, and steam trams it is much more serious, as they are practically imprisoned in a confined place, and consequently suddenly become enveloped in the escaping contents from the gauge, and, being unable to approach it to shut off the cocks, are therefore scalded or otherwise injured, and liable to lose their lives, thus creating the additional risks of overrunning the signals and of runaway engines, thereby endangering the lives of helpless passengers who may be in the railway carriages and tram cars.

Every boiler attendant knows that to close the cocks of a water gauge and shut off the escaping steam and water when the gauge glass bursts is a difficult and dangerous task, and any apparatus that will successfully relieve him from this danger and responsibility is of such vast importance that it can scarcely be overestimated.

To avoid this form of accident it is the duty of boiler owners to avail themselves of proper means, and by adopting Hopkinson's absolute water gauge a complete and certain preventive is provided.

There have been many forms of automatic valves and other devices fitted to water gauges to shut off and lessen the escape of steam and water when the glass breaks. Such arrangements have proved inefficient in practice, and often a source of danger.

HOPKINSON'S SAFETY WATER GAUGE,

Shown in side and front views in Fig. 118, has for its object the automatic shutting off the communication with the boiler. When the gauge glass bursts the pressure in the lower arm forces the safety column ball A to its seat as shown in dotted lines, and shuts off escape of water ; simultaneously, the pressure in the supplemental tube J, together with the escaping steam in the top arm, forces the ball valve B to its seat (as shown in dotted lines) and shuts off the escaping steam.

The escape of both steam and water is thus automatically and effectually stopped, the gauge can be approached, and the cocks closed with absolute safety.

After the cocks D and E in the steam and water arms are closed, and the try cock F opened, both arms, together with the supplemental or back tube J, are thoroughly

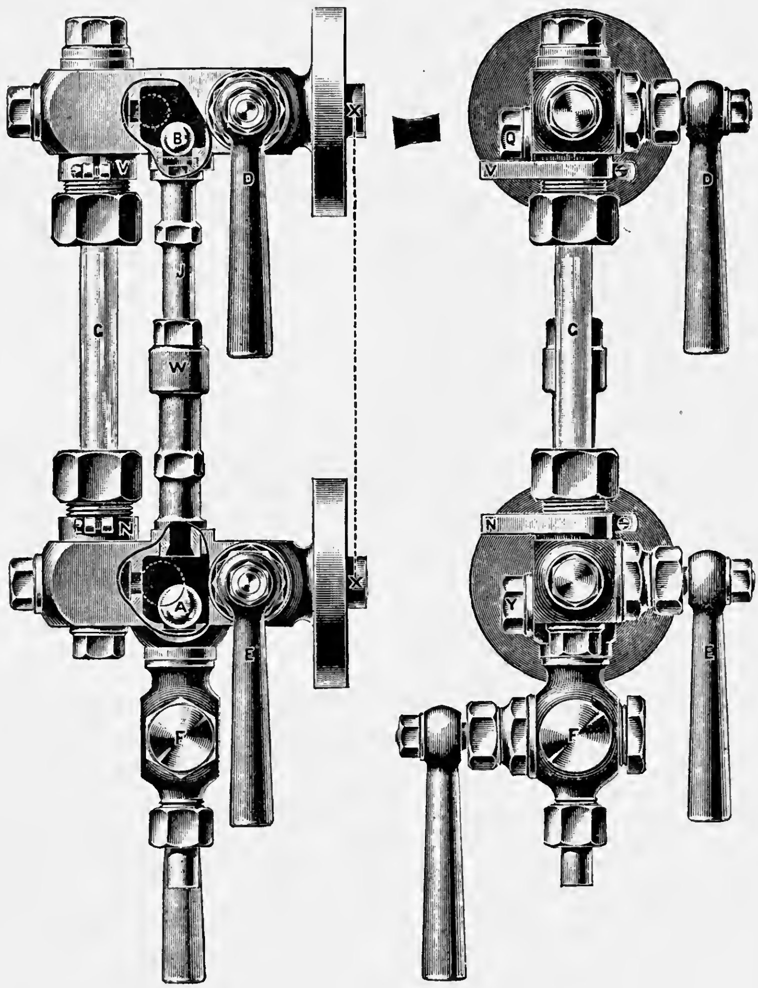


Fig. 118.—Water-Level Gauges.

emptied and drained. The balls A and B then fall from their seats by gravity into their normal position, as shown in the illustration. A new glass can then be inserted, and the gauge is automatically put in proper condition ready for the cocks being opened, and the gauge set to work again.

The automatic ball valves A and B in the top and bottom arms are always in equilibrium of pressure when the glass is intact, therefore can only be forced to their seats when the glass actually bursts, and under no other circumstance. They are accessible for examination and cleaning whilst the boiler is under pressure by merely closing the cocks D and E in the steam and water arms respectively, and opening the try cock F and removing the screws Q and Y at the side of the gauge, so that it will be seen the automatic ball valves A and B can be removed and inserted, and the thoroughfares cleaned whilst the boiler is working and without taking the gauge to pieces.

The following points are claimed on the score of safety.

After the gauge has been blown through or put out of work, to insert a new glass, or for any other purpose, on being re-started suppose the cock E in the water arm is first opened, the cock D in the steam arm being closed, the action of the gauge under these circumstances is such that the automatic safety column ball A will not be forced

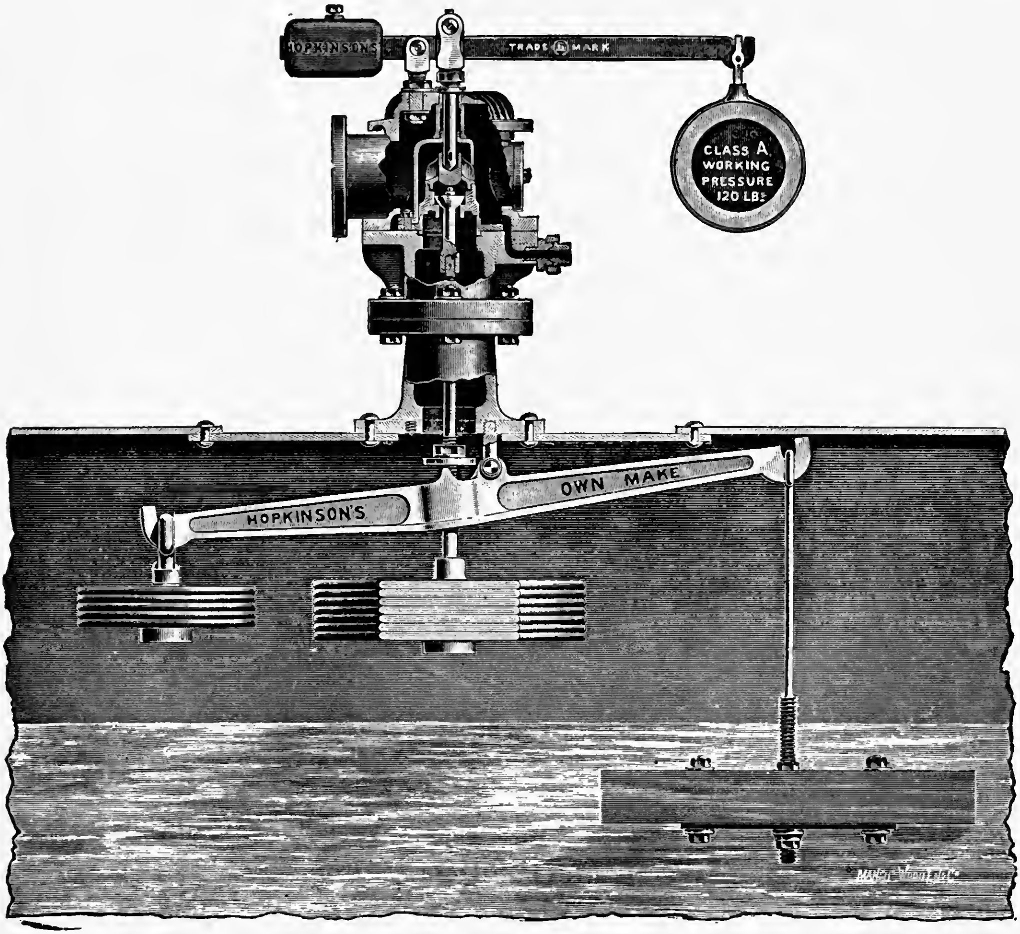


Fig. 119.—High and Low Safety Valve.

to its seat, and close the thoroughfare betwixt the boiler and the gauge glass, but the full pressure of the boiler enters the gauge glass the same as if the gauge was without automatic valves.

If the cock D in the steam arm is opened, and the cock E in the water arm closed, when the try cock F is opened the steam arm can be blown through the thoroughfares with full boiler pressure equal to the full area of the orifice, and without blowing the automatic valve B to its seat, precisely as if there was no automatic valve in the top arm.

Again, if the gauge has been put out of work to insert a new glass, or the cocks closed for any other purpose, suppose the cock D in the top or steam arm is opened first, the cock E in the water arm being closed, the action of the gauge under these circumstances is such that the automatic valve B will not be forced to its seat, but the full steam pressure in the boiler will enter the glass, as if automatic valves were not fitted.

Another important fitting is the safety valve, which blows off when steam is above pressure and when water falls below a safe level; it will also blow off when water is too high. Fig. 119 pretty well explains itself. On a lever inside the boiler are two floats.

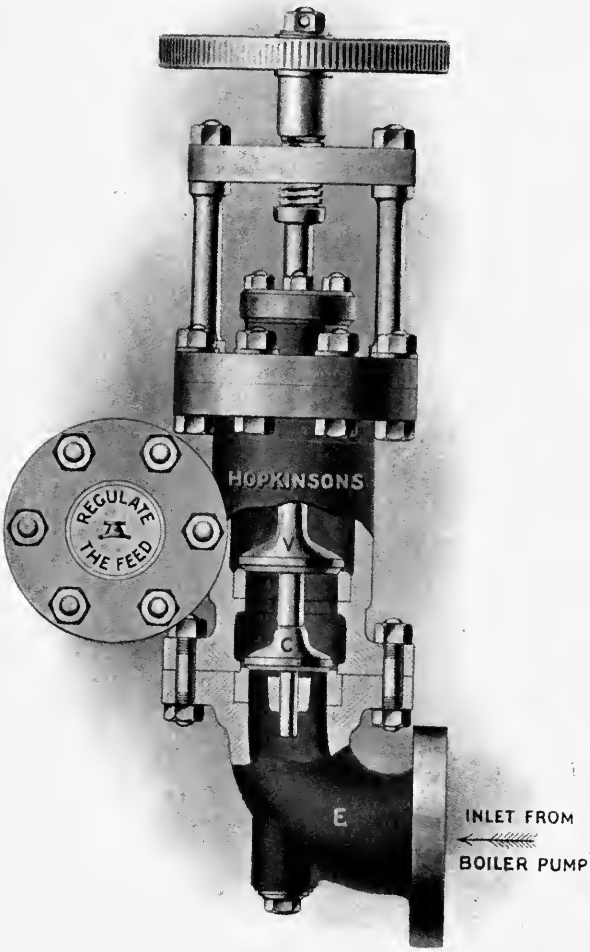


FIG. 120.—Feed Valve.

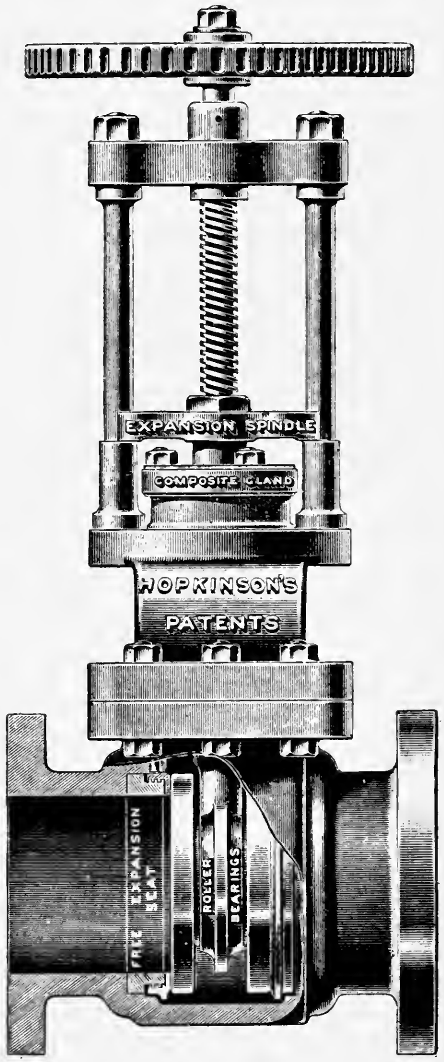


FIG. 121.—Parallel Slide Valve.

This lever acts, as will be seen, upon a central valve rod which is weighted by the middle weight to close the smaller internal central valve. When water falls the large float descends, and by its weight lifts the rod and valve and blows off steam. Again, when the water rises as far as the small float and the middle weight the valve is again opened to blow off. The external lever and weight are raised when the steam pressure becomes too high.

The accessible check feed valve is another satisfactory invention (Fig. 120).

Ordinary feed valves are liable to become leaky from many causes, and this has often proved a great annoyance and trouble, and a source of danger, not to mention loss of time and money.

It is very desirable that the engineer should be able to examine the check valve, and if necessary repair the same whilst the boiler is under steam.

This feed valve provides this important advantage in the simplest manner

Should the valve become leaky or inoperative from dirt or any other cause, the engineer is afforded access to the same whilst the boiler is working by merely closing the valve V and removing the elbow E, which contains both the valve C and the valve seat. No other parts of the valve need be disturbed.

The type of valve illustrated is designed for use on the ordinary type of Lancashire or Cornish boiler, but there are many modifications specially arranged to suit water tube, marine, dry back boilers, and other types of steam generators.

The screwed portion of the spindle is outside the valve, and therefore not subject to fluid pressure or the action of the water. The valve is fitted with a "Composite" gland, and the spindle acts as an indicator to show the lift of the valve.

PARALLEL SLIDE STOP VALVE

These are fitted with composite glands, a speciality of Messrs. Hopkinson. This gland is shown in Fig. 122.

The usual mode of constructing a stuffing box or gland is to form an annulus or circular cavity betwixt the gun-metal valve spindle and the lid of the valve. This cavity is usually filled with fibrous packing in a cord-like form, made from hemp or asbestos, and it is compressed by great mechanical force into this annulus by means of stud bolts and gland until it is so hard that it assumes a solid mass or brick-like form ; and to render it impervious to the action of fluid within the valve body, the compressive power required is enormous, setting up unnecessary strains and stresses of an undesirable character.

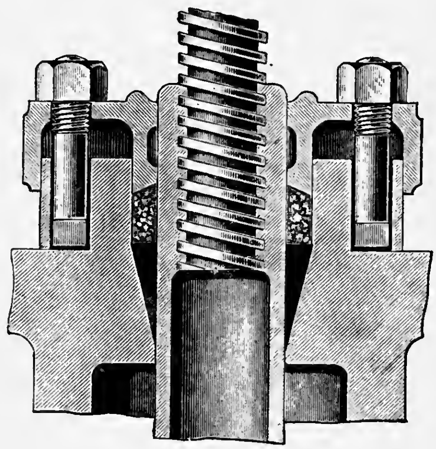


Fig. 122.—Gland Packing.

If the packing is hemp it burns away by the heat of the steam, if asbestos it is affected by the water ; in either case it deteriorates, and becomes less in quantity. Therefore constant attention is required to keep the gland tightly screwed up, and under the best of conditions. This is a very unmechanical contrivance for accomplishing the objects.

Hopkinson's composite gland obviates the before-mentioned difficulties, and is found in practical work to be perfect for its purpose.

The portion of the lid forming the stuffing-box is cylindrically bored out to a conically formed bottom, and we insert therein a bush made of specially prepared flexible material, coned on its outside surface or periphery to the same taper as the conical portion or seat in the bottom of the lid, and the valve spindle passes through a hole therein (Fig. 122).

This bush is made of a patent packing material which resists the action of the water, and is unaffected by high-pressure steam. It is sufficiently pliable as to accurately fit both its conical seat and the valve spindle and make a fluid-tight joint.

In the cylindrical portion of the stuffing-box is inserted a preparation of asbestos and plumbago above the bush, which is compressed by means of our improved gland, thereby forcing the bush against its seat and also around the spindle.

The packing material exerts a gentle and flexible pressure on the conical bush, sufficient to prevent the escape of water or steam on its conical bearing, and between the bush and the spindle, so that the said packing material is only in a small degree subjected to the action of the fluid, and it further assists in preventing leakage, if any, that may pass betwixt the bush and the spindle.

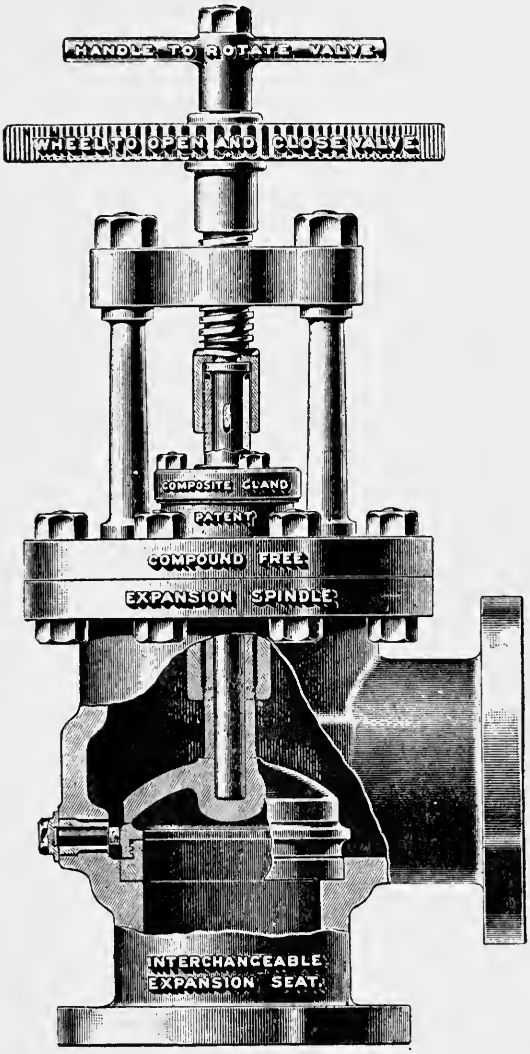


Fig. 123.—Screw-Down Stop Valve.

Another feature is the outside screw. The outside screw removes the thread on the spindle and nut from the action of the fluid, and reduces wear and tear to a minimum; these parts (liable to wear) can always be observed. The trunk spindle rises with the valve discs, and indicates the opening and closing of the valve and its position.

The interchangeable expansion seat prevents the seat from warping or getting out of shape, and becoming loose in the valve body. The valve seat can be removed, repaired, replaced, or renewed without dismounting the valve body. The seat rings are made in duplicate, and interchangeable.

The compensating valve spindle provides for the differential expansion betwixt the iron valve body and the gun-metal valve spindle. The spindle cannot jam or wedge fast in the body by unequal expansion as heretofore; destructive strains and dangerous conditions arising from screwing down ordinary valves do not exist.

The composite gland ensures fluid tightness round the spindle, and dispenses with the annoyance of a leaky gland and the trouble of rebacking the same. The patent roller bearings on which the valve discs are carried reduce the point of contact with the eye in the spindle to the lowest possible limit. The discs are pressed to their seats by means of a spring which is carried on pivot points, so that the friction is reduced to a minimum and the valves are free to revolve on their axis when being opened and closed. Fig. 123 shows the arrangement for a screw down mushroom valve, which with the foregoing will explain itself.

CHAPTER III

THE TRANSMISSION AND DISTRIBUTION OF POWER FROM PRIME MOVERS

This subject is one which is quite a modern subject, and has developed immensely during the past twenty years. The advantages of carrying power from a waterfall or from large power generators working on cheap fuel are now obvious to engineers of all classes. Electricity offers paramount advantages for power transmission to a distance in most cases. Electrical engineers, however, claim far too much for it. They are apt to forget other means for transmitting power, which means have paramount advantages over electricity in a good many cases.

It has yet to be shown that electricity produced by heat engines and transmitted electricity to moving railway trams is in all cases a better system than carrying a prime mover on the train. At present the electric systems of trams and short railways are threatened with competition by internal combustion engines on the vehicles themselves Hence we have the motor bus and motor locomotive type, both of which have been already referred to.

The transmission of power to a distance in bulk for distribution among consumers is scientifically an easy problem. Its success, from an engineering point of view, is beyond a doubt. The engines, dynamos, conductors, insulators, and other apparatus required have reached a commonplace level of practical efficiency, and the loss in transmission is small. Commercially, the problem presents some difficulties. The first point, the cost of fuel for the prime movers. If that fuel is not a good deal cheaper than the fuel within reach of the proposed consumers, then there is not much chance of the electric supply of power from a distance successfully competing against a local supply.

But it is held that generators of large size, working always about full load, can produce electric power cheaper than smaller units. That is true if the small units are very small. Anyone requiring a daily supply of over 250 horse-power can produce that power electrically himself, at a lower cost than a distant generator using the same fuel.

A still more important feature is that power can be equally well and efficiently transmitted in bulk to a distance by either electricity, compressed air, or gas. But it is to be observed that when the electricity, compressed air, or gas is delivered to a consumer he has before him the same question in each case, and that is whether to receive the power on two or more large motors, electric, air or gas, as the case may be, or whether to divide up the motors into numerous small units and to thereby save the use of the wastefully running shafting belts and gear wheels required to distribute the power from one large motor.

Suppose the case of a cotton mill, using, say, 250 horse-power, in which about 150 horse-power is consumed in the distribution shafts, pulleys, wheels, etc., one large motor substituted for the steam engine would effect no reduction in the power lost in distribution. To reduce this loss many small motors would be required, say, ten motors of 20 horse-power, probably reducing the loss by 50 horse-power. It is here that electricity shows to advantage; for small electric motors, having no reciprocating parts and only simple bearing to lubricate, can be hung up or fixed down anywhere, and require no more attention than to oil the bearings. If they are made as they should, and can be, their maintenance is no more than that of shafting.

But in the other case, where one or two large motors are used, and the power distributed mechanically, gas is in the best position. The gas engine has reached a high degree of perfection; the production of gas for power purposes has also reached high economy. Power gas can be produced from cheap fuel, and delivered to power consumers at a distance cheaply and with little loss.

Compressed air is limited in application, but still has a very large field of usefulness peculiarly its own.

Steam cannot be used economically at any distance. For land power purposes its popularity is falling. The steam engine is essentially a prime mover, competing against the internal combustion engine. But the internal combustion engine has many advantages, not the least being that its fuel can be economically transmitted in conduits to a distance.

Rope transmission has been applied to a short distance transmission under some circumstances successfully. And water transmission of power is also very successful where other systems fail.

It is the business of the modern engineer to discriminate between the methods at his disposal, and to avoid the common notion that because a thing is done by electricity it is necessarily better done than by any other means. Many instances are to be seen, in cases of electrical distribution of power, where motors are used without any possible advantages over a common belt and pulley. It will also be observed, in most of the large manufacturing shops making electric motors, that the power distribution within them is mostly carried out by mechanical means, belts and pulleys. To carry out power distribution effectively requires small motors, and many of them, of much higher efficiencies than many of those to be found in the market.

Again, it is to be remembered that, meanwhile, the distribution of power by mechanical means has received an impetus towards improvements by reason of the electric motor competition, and is not now so wasteful as it was.

The conclusion is that if a large number of small motors are not used, and the mechanical distribution of the power mostly retained, then small saving in the large distribution losses can be obtained by electricity or any other power distributor; and that if one or two large motors are to be used, then the only question is whether a prime mover on the spot can supply the power cheaper than it can be delivered from a distance. The local generator will have the advantages if the power is over 250 horse-power, and the fuel costs the same on the spot that it does at the distance.

Another point is that the distant supply may be more costly than the local supply, due to the first using steam power and the second cheap power gas. In this respect the electric power supply in bulk schemes are somewhat handicapped for the future, most of them using steam power, while the power users are becoming acquainted with the more modern internal combustion engine power, which makes a better use of the fuel.

DISTRIBUTION BY BELTS, ROPES, AND WHEEL GEARING

Belts and ropes have an important position in this subject, and can never be entirely superseded. When scientifically applied they are successful and economical. Belts, however, not so long ago were very often badly used, and their proper dimensions ill understood. Ropes have also a large field of usefulness. Wheel gearing never has been and never can be a satisfactory member in distributing power, and is to be avoided whenever possible. Wheel gearing for transmitting or modifying motion is in its right place, but when put to transmitting any amount of power it has never been entirely satisfactory. It has much friction, soon wears loose, and suffers from vibration and backlash. It is tolerated on motor cars, because the engine is not reversible, and the engine speed is not controllable easily.

BELTS

Are now so well known and fully treated in special works that short notice only is here necessary, and that of main belts and special belts.

A belt transmits power from pulley to pulley by a difference of tension, and through friction between the belt surface and the pulley. The breaking strain of a new belt is about 4000 lbs. per square inch. But the ordinary working strains for leather belts of usual thickness are as follow:—

Ordinary single belts, 50 lbs.
Light double belts, 70 lbs.
Heavy double belts, 90 lbs.

Link belts,	$\frac{3}{8}$	inch thick,	42	lbs.
,,	$\frac{1}{2}$	,,	48	,,
,,	$\frac{5}{8}$	,,	57	,,
,,	$\frac{3}{4}$	,,	66	,,
,,	$\frac{7}{8}$	,,	78	,,
,,	1	,,	90	,,

On ordinary pulleys for everyday work the belt speeds do not exceed 2000 feet per minute, but higher speeds up to 3000 feet are becoming more common, using lighter belting and wooden pulleys.

The tension on a belt calculated per horse-power is, of course, less the higher the belt speed. At 3000 feet the stress or tension is—

$$\frac{33{,}000}{3000} = 11 \text{ lbs.}$$

Tullis gives in the following tables the horse-power to be transmitted by belts:—

SINGLE LEATHER BELTING

1 in.	width of single belt	on pulley	6 in.	diameter at	6400 ft.	Belt speed per	minute, 1 h.p.
1	,,	,,	12	,,	3200	,,	,,
1	,,	,,	18	,,	2400	,,	,,
1	,,	,,	24	,,	1600	,,	,,
1	,,	,,	30	,,	1240	,,	,,
1	,,	,,	36	,,	1066	,,	,,
1	,,	,,	42	,,	950	,,	,,
1	,,	,,	48	,,	800	,,	,,
1	,,	,,	60	,,	680	,,	,,
1	,,	,,	72	,,	533	,,	,,
1	,,	,,	84	,,	457	,,	,,
1	,,	,,	96	,,	400	,,	,,
1	,,	,,	108	,,	355	,,	,,
1	,,	,,	120	,,	250	,,	,,

DOUBLE LEATHER BELTING

1	in. width of belt	on pulley	18	in. diameter at	1333	ft. Belt speed per minute,	1 h.p.
1	,,	,,	24	,,	1000	,,	,,
1	,,	,,	30	,,	875	,,	,,
1	,,	,,	36	,,	730	,,	,,
1	,,	,,	42	,,	625	,,	,,
1	,,	,,	48	,,	500	,,	,,
1	,,	,,	60	,,	400	,,	,,
1	,,	,,	72	,,	335	,,	,,
1	,,	,,	84	,,	286	,,	,,
1	,,	,,	96	,,	250	,,	,,
1	,,	,,	108	,,	222	,,	,,
1	,,	,,	120	,,	200	,,	,,

A belt will do 30 per cent. more work without slip than proposed in this table, provided it be kept in proper condition, but at the same time it must be kept somewhat tighter. By keeping the same belt working under high tension it will drive over twice

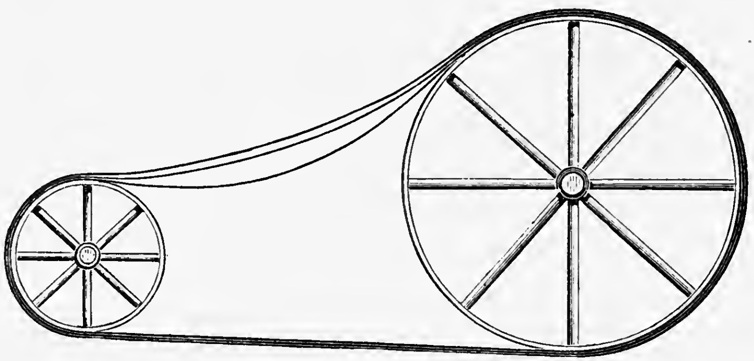


FIG. 124.—Compound Belts.

the power given; but, of course, this can only be done at the expense of the life of the belt, extra lubrication, grinding of bushes, wear of shafting, and consumption of coal.

Compound driving is a simple and most trustworthy means of transmitting power without loss from slip. By adopting compound belts much space is saved that would otherwise be required. The cost of a narrow pulley is, of course, much less than the price of a wide pulley. Two 20-inch belts, working compound, will transmit more power than one 40-inch belt will do working from a wide pulley. In the case of the narrower belts, the cushion of air between the pulley and the belt is much easier got rid of from pressure than it is possible in the case of the wider belt; while, at the same time, these belts check the influence of centrifugal force upon each other. The outside belt is the more powerful belt of the two, because it travels at a higher speed and covers a larger diameter than the belt next the pulley.

Compounding of belts means laying one or more belts on top of the other. It is by far better to employ two, three, or four thin supple belts together in two, three, or four layers, and not sewn together or riveted, than to use a heavy rigidly made belt of double or treble thickness made up by sewing or riveting. That this obvious fact escaped detection so long among engineers is a striking instance of conservatism.

The method is shown in Fig. 124 by three belts.

The following is given as an example of

COMPOUNDING AT LARGE IRON WORKS NEAR STOCKTON

This is a drive where two compound 12-inch thin orange-tan belts became masters of a very severe drive. The engine pulley is 9 feet diameter, driving to a large dynamo, the pulley of which is only 1 foot diameter. Many kinds of belt had been tried, but the best of them went to pieces in a short time. 100 horse-power is the power wanted, and the belt speed is very high. Centrifugal force prevented these other belts from keeping a hold of the small pulley. Only two-thirds of the power could be got. The light, rough, orange-tan belts took charge of the power at once. They have been working night and day for over three years, giving out all the power of the engine. The reason of this is—centrifugal force has little effect upon compound belts, seeing they are independent and travel at different speeds. If the under belt feels inclined to lift from the pulley, the motion is checked at once by the outer belt travelling faster, holding the under belt to the work all the time. The owners of this plant say the compound belt was put to work on 13th December 1894, and has worked continuously ever since, and given entire satisfaction. It is the only belt tried that has successfully prevented slip on the 12-inch pulley.

This simple plan saved the expense of a proposed extensive alteration.

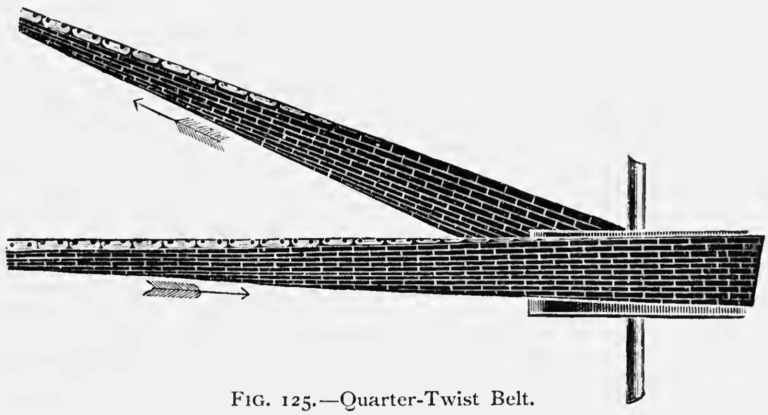


Fig. 125.—Quarter-Twist Belt.

At a Walsall foundry two single orange-tan belts—one 10 inches and the other 8 inches wide by 29 feet long—have been transmitting 50 horse-power since 1891, with only one adjustment. This a very severe drive. The driving pulley is 5 feet diameter and the driven pulley 2 feet diameter, while the speed of engine is 80 revolutions. These belts have never given an hour's trouble, although carrying a heavy load. The form of the pulleys in this case assists the belts very much. The driver had a convexity of $\frac{3}{32}$ inch, while the small pulley is nearly flat. A double belt caused no end of trouble; before compounding single belts were adopted.

In every application of the theory of compound belt driving the result has been most satisfactory, and very highly appreciated.

They work well as shifting belts; such as driving iron-planers and plate-bending rolls, meeting the thrust of the shifting gear much better than in the case of one belt.

Quarter-Twist Driving

Fig. 125 shows this class of drive. In using ordinary flat belts for this class of drive it will be observed that a large portion of the belt assumes a slack appearance on the inside of the twist, which never comes in contact with the face of the pulley. Very often only one-half of the belt is really doing the work. This want is now met by the long-sided belt. By giving the distance between the centres and the diameter of both pulleys, a long-sided belt can be made that will curve to the twist perfectly, bringing every inch of the width of the belt in full contact with the face of the pulleys, without straining the belt more on one side than the other. These belts ought to be made of light weighing, thin, tough, pliable leather. This class of belt works splendidly whether driving vertical

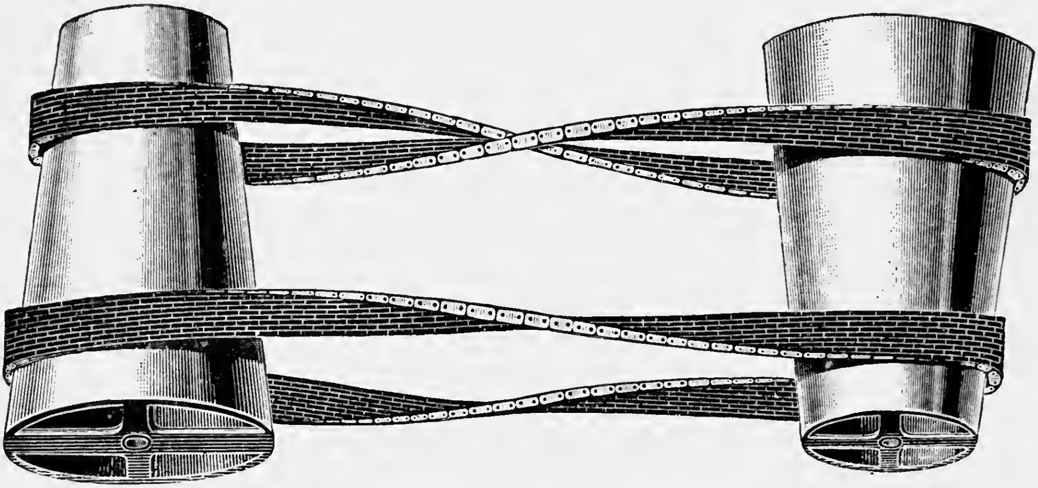


FIG. 126 —Cone Belts.

or horizontal shafts. Compounding this class of drive gives perfect results, while at the same time such belts do not require to be kept working under high tension.

Heavy belts on this class of drive have to be kept at the work under high tension, because a heavy belt will hang away from the lower vertical pulley, or slip off a horizontal one.

It is not commonly known that this quarter twist can for small powers be used on a fast and loose pulley and shifted. In few books is it clearly stated the condition under which a quarter-twist belt will work.

The tight side of the belt, that is, the side for the time being under strain, should fall

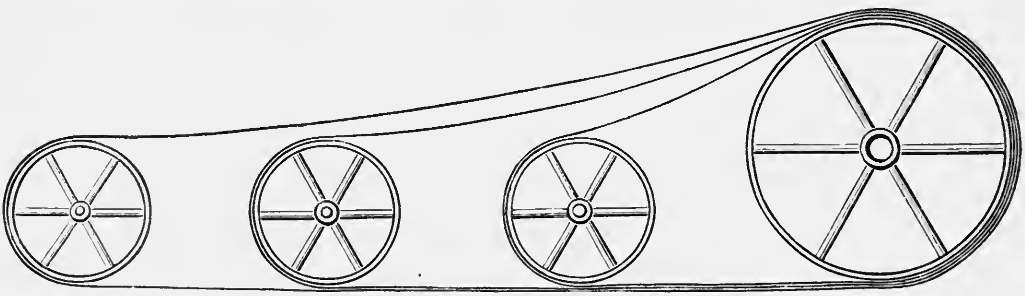


FIG. 127.—Compound Driving.

vertically and have a quarter twist as shown in Fig. 125. For this purpose the pulleys must be located at right angles, so that the belt centre leads from the centre of the face of the driving pulley to the centre of the face of the driven pulley, but the slack side runs at an angle, and if the drive is reversed it would therefore immediately run off the pulleys. Again, the tension side of the belt twist must run towards the driving pulley as shown in Fig. 125 ; the lower arrow indicates that the pulley shown is the driving pulley.

Cone speed working with belts of ordinary make is impossible, as the belt creeps up towards the base, and would break, but by thickening one side of the belt so that its outer face when on the cone becomes parallel to the axis they can be run on any part of the cones. If the belt is open it must get a full twist, so as to present the thick edge towards the apex of the code. Such a belt will work also as a crossed belt, as shown in Fig. 126. A link belt is necessary, and may be made up with one edge half-inch thick and the other two and a half inches thick, and they may be compounded with flat belts. Such a cone drive is useful in testing machinery, and might be useful in motor cars if room could be found for the long cones necessary.

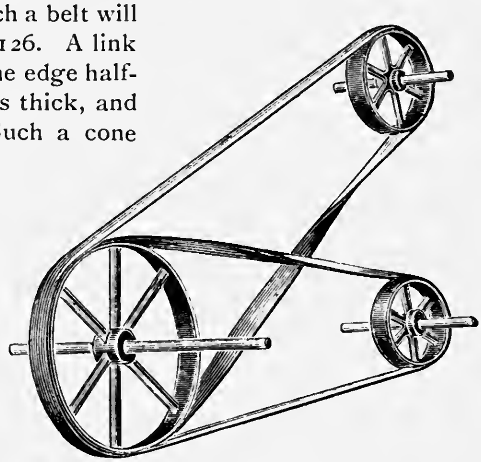


Fig. 128.—Compound Driving.

Fig. 127 shows how two or more machines may be driven from one driving wheel.

Fig. 128 shows another method by which two shafts can be driven by one belt from one driving pulley, by making a twist upon the two portions of the belt that come together. The belt is made to clear itself. The drive is then the same as if it were an ordinary cross belt.

Fig. 129. These illustrations show an easy plan of connecting shafts by belt where the wings of a factory are built to obtuse angles. The shafts will be driven parallel to each building.

Belts should always be run, wherever possible, with the tension side underneath, so that the sag of the slack side increases the pulley contacts.

In regard to the proper length of belt pulley centres from each other, that depends on circumstances. Large pulleys may be much nearer than small ones, and in fact a

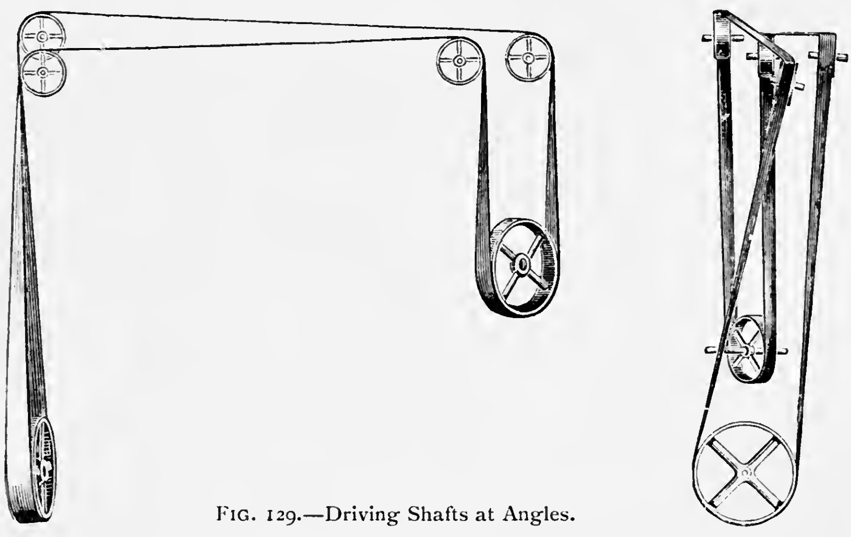


Fig. 129.—Driving Shafts at Angles.

nice means for connecting high-speed machine dynamos and pumps is to put them close up to a high-speed engine, such as a petrol engine, and drive from the petrol engine fly-wheel on to a pulley of equal size, or nearly so, by a narrow high-class belt. In this way the author has driven a centrifugal pump by petrol engine, the fly-wheel 12 inches, and pulley 12 inches, centres apart 16 inches, speed 1000 revolutions per minute, 4 horse-power being transmitted by a 3-inch belt.

ROPE DRIVING

This system is mostly in use for long spans, and for what was much used under the teledynamic system with wire ropes. There are two systems, the American single-rope system, in which the rope passes continuously round the series of pulleys, a jockey pulley sliding and hauled back by a weight keeping the ropes taut, as shown in Fig. 130. This system has not much to recommend it ; if the rope breaks the whole affair is stopped.

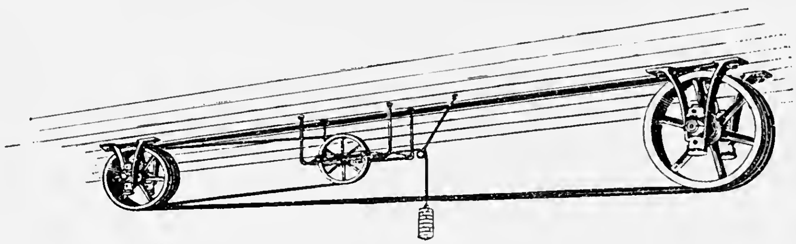


FIG. 130.—Rope Drive.

The English system consists in running a number of ropes in parallel grooves, each rope complete in itself; if one breaks it makes little difference, and need not cause a stoppage.

Mr. Edwin Kenyon, in his work on transmission of power by ropes, discusses the matter fully, and his views are given here in essence. He gives an instance of transmission which shows its flexibility. 225 horse-power is transmitted from an engine above ground through a tunnel to a distant shaft by 8.1$\frac{3}{4}$ inch ropes. The fly-wheel is 13 feet 6 inches diameter, going at 83 revolutions per minute, a jockey pulley 4 feet 4 inches diameter deflects the ropes into the mouth of the tunnel, beyond the jockey pulley the ropes are carried on two pairs of pulleys 2 feet in diameter, and fixed at unequal distances. The centres from fly-wheel to jockey pulley, thence to first and second guides, and thence to driven pulley, which is 5 feet 6 inches in diameter, are as follow respectively:—

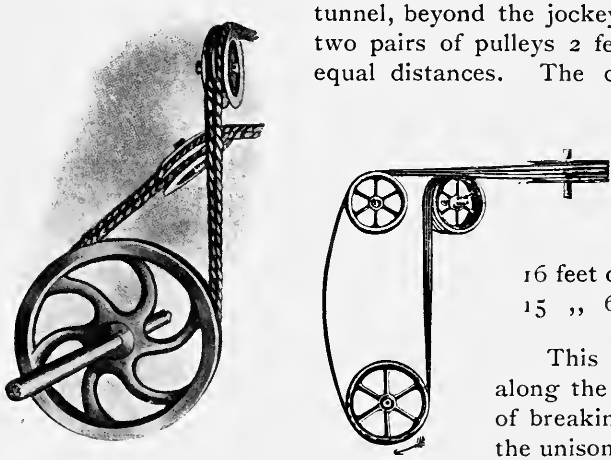


FIG. 131.—Rope Drive.

16 feet 0 inches.	29 feet 0 inches.
15 ,, 6 ,,	22 ,, 0 ,,

This unequal distribution of centres along the driving track has the advantage of breaking up the measure and destroying the unison in any oscillations which may be set up in the ropes. Strong wave-like vibrations are sometimes observable between the engine and the jockey pulley when the load is suddenly removed or when starting the engines, which, as they cannot synchronise along the entire length, quickly diminish to mere rippling disturbances.

An interesting combination of rope drives is also to be seen at a bleach work in Ireland, where the power is transmitted from a water turbine to the main shaft over the top of the driving pulley with four crossed ropes, and again round guide pulleys to a shaft fixed at right angles with two ropes.

Shafts fixed at right angles may be successfully driven by the aid of guide pulleys, as shown in Fig. 131. It will be seen that the pulling side of the rope is deflected by the guider resting at the necessary angle, while the "idle" side is directed by the pulley having the horizontal axis. The transmitting and receiving pulleys need not necessarily rest upon the same plane, nor at any particular angle; so also may the position of the guiders be altered to suit any set of circumstances, *e.g.* they may be placed either above or below the driving line.

Right-angled driving may also be accomplished by the introduction of guide pulleys running freely (in opposite directions, of course) upon a vertical shaft. Deep grooves require to be cut into the guiders, and it is necessary for the ropes to be kept moderately tight. In another drive sustaining pulleys are introduced to prevent the ropes falling away from the guiders.

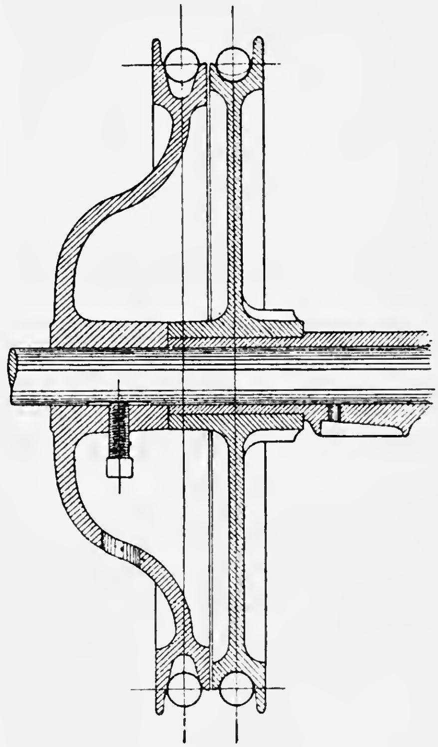


Fig. 132.—Fast and Loose Rope Pulley.

GUIDE PULLEYS GENERALLY TOO SMALL

In the majority of cases guide pulleys are made too small, and on this account the ropes are worn out much sooner than they should be.

Fast and loose rope pulleys are used in many mills, a fork guiding the rope from one to the other. From Fig. 132 it will be seen how this contrivance is fitted up. The fast pulley is keyed on to the shaft, while a sleeve is fitted for the loose one to run upon. The rim section (Fig. 133) shows the shallow intermediate groove mentioned, and also the clearance allowed between the prongs of the fork which passes the rope in and out of gear with the greatest ease. The fork usually takes the curve of the pulley, allowing just sufficient room to clear the rims in passing.

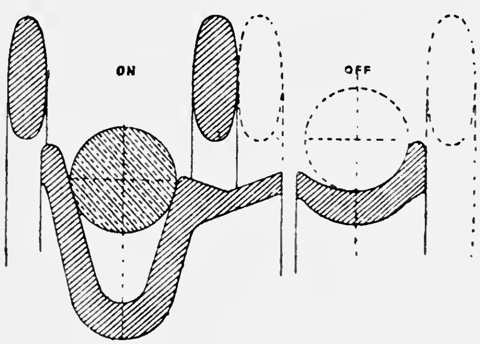


Fig. 133.—Rim Section.

Fast and loose rope pulleys are also attached to the overhead gearing of lathes, to mortar mills, to milling, and to numerous other classes of machinery.

A radius fork operates the rope, which is worked by a rod. The conditions are so varied that almost every case requires different handling.

GROOVES ON ROPE PULLEYS

One of the most important items in the whole economy of rope transmission, at least so far as mechanical arrangements are concerned, is the construction of the grooves. Many and varied are the shapes and angles which have at different periods been submitted or adopted. The difficulty of selecting a suitable rope is not by any means lessened when the manufacturer is expected to provide one that will work equally in different formed grooves, which are supposed to represent both driving and driven pulleys. The only course left open in such cases is to ascertain as near as possible the mean.

When templets of existing grooves require to be taken, the most correct, as well as the easiest method, is to obtain a plaster cast, which when trimmed off gives an exact impression. Before making the mould it is advisable to grease the grooves.

The angle at which driving grooves are constructed vary as much as from 54 degrees to 15 degrees, the latter being applied to the driving of cotton machinery with small bands, and from the results obtained it would appear that every diameter of rope has its most appropriate angle. While this need not be carried to the extent of providing a range of templets to cover all sizes, some line of demarcation between the acute and obtuse is advisable. One firm of engineers works to four different angles, beginning with 30 degrees for small ropes from $\frac{5}{8}$ of an inch to $\frac{7}{8}$ of an inch in diameter, 36 degrees from 1 inch to $1\frac{1}{4}$ inch, 40 degrees from $1\frac{3}{8}$ inch to $1\frac{5}{8}$ inch, and 45 degrees from $1\frac{3}{4}$ inch to 2 inches. The best practice is 30 degrees for all driving ropes under 1 inch in diameter,

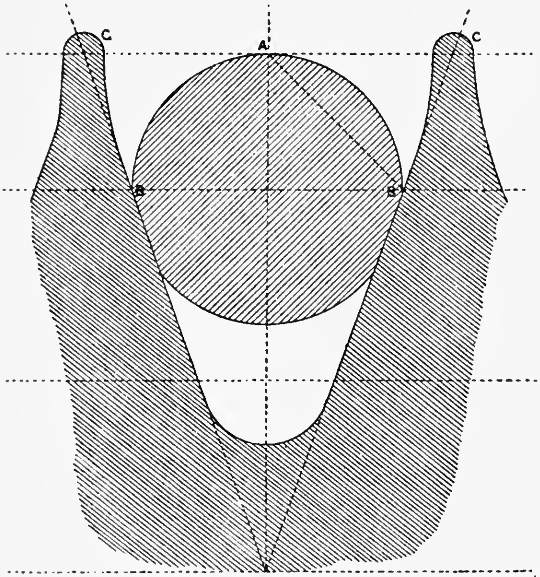


Fig. 134.

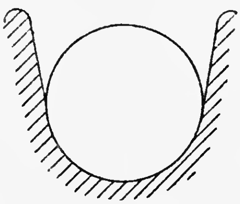


Fig. 135.

Groove Pulleys.

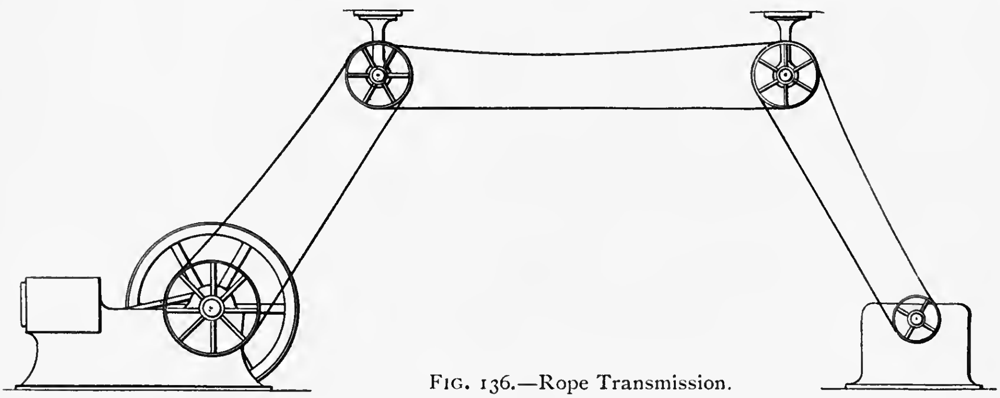


Fig. 136.—Rope Transmission.

and 40 degrees for all above that size, including the 2-inch diameter. Indeed, from experience of $1\frac{1}{2}$-inch ropes in angles of 29 degrees, acute grooves afford a check against revolving action. In setting out a groove it should always be borne in mind that a rope is at its best when it assumes the cuneiform.

METHOD OF SETTING OUT GROOVES

Therefore, instead of commencing with a circle to which the groove sides are merely tangent, the grooves are wedge-shaped to prevent the rope reaching the bottom. Credit is due to Mr. William Kenyon for discovering a method for setting out grooves accurately.

Referring to Fig. 134, it will be seen for a 40-degree groove that the first process is to draw a circle representing the diameter of the rope through which the vertical and horizontal centre lines are projected. Afterwards the chord of the arc "A B" is marked off. This becomes the standard of future measurement, and points the centre of the curve terminating the groove from the centre of the circle, and, when repeated downwards, fixes the apex of the angle, which always comes out just under 40 degrees, whatever the size of the rope may be. Extend the lines of the angle through the point "B B," cutting off segments of the circle on the way, until they intersect the upper horizontal line at "C C," which points fix the radius of the flanges from "B," and also ascertain the thickness of the metal. If the angles were carried out to the full extent, and the terminals simply rounded off, the power could be nearly doubled if required by the introduction of thicker ropes.

Grooves having no power to transmit, but which are simply used as carriers, should be so arranged that the rope will fall well into the bottom; a little more easement should, however, be allowed than is shown in Fig. 135. The pitch of carrier grooves should also correspond with that of the grooves to which they are tributary. Grooves for cross-driven ropes should be either spaced or (which is to be preferred) used alternately.

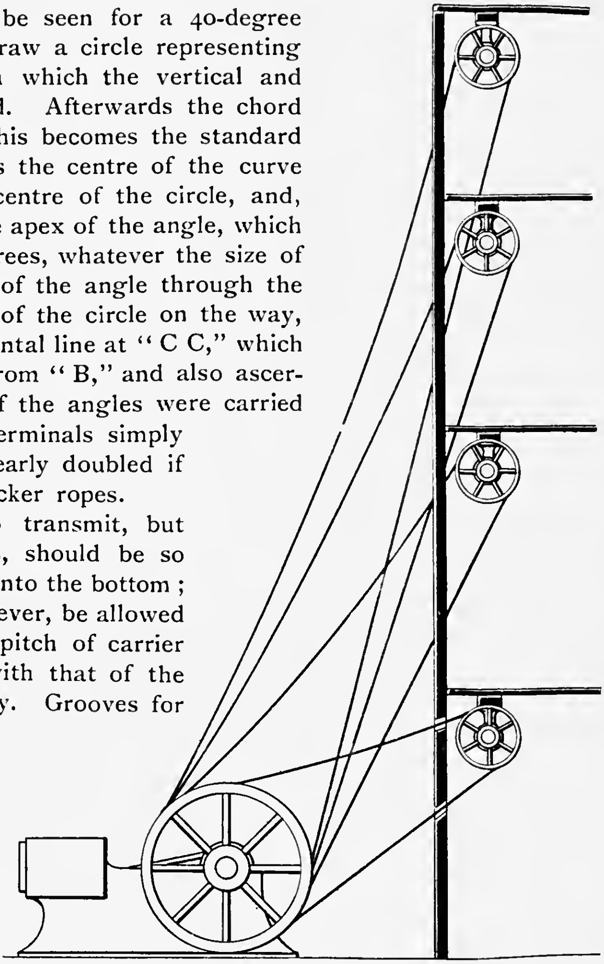


Fig. 137.—Rope Transmission.

A 3-strand cotton rope of good quality is preferred, and the following is a reliable table of powers which good 3-strand cotton ropes may be expected to transmit at 1000 feet per minute, when running over pulleys not less than thirty times the diameter of the rope employed, and in angular grooves not exceeding 46 degrees:—

1	inch diameter	rope will	transmit	3	horse-power.
$1\frac{1}{8}$	,,	,,	,,	4	,,
$1\frac{1}{4}$	,,	,,	,,	5	,,
$1\frac{3}{8}$	,,	,,	,,	6	,,
$1\frac{1}{2}$	,,	,,	,,	7·3	,,
$1\frac{5}{8}$	,,	,,	,,	8.6	,,
$1\frac{3}{4}$	,,	,,	,,	10	,,
$1\frac{7}{8}$	,,	,,	,,	11.5	,,
2	,,	,,	,,	13	,,

Those figures ignore any supposed detriment from centrifugal tension. They are based upon the many times proved hypothesis that a rope $1\frac{3}{4}$ inch in diameter will transmit 10 horse-power per 1000 feet of speed, and that this power is a constantly increasing quantity in the ratio of speed. This at once launches us into the metric system, so far as velocity is concerned (would that this system prevailed throughout, and that British prejudice did not compel circumlocutory calculation, the sole object of which appears to be that of complication). Thus, by lopping off these wonderful terminal ciphers, speed is at once reduced to power — 1000 feet 10 horse-power, 1100 feet 11 horse-power, and so on to the limit of mechanical capacity. The powers of the remaining sizes are calculated upon the relative sectional areas, the $1\frac{1}{4}$ inch diameter being fixed at over half that of the $1\frac{3}{4}$ inch. This gives a little benefit in driving force to the smaller rope.

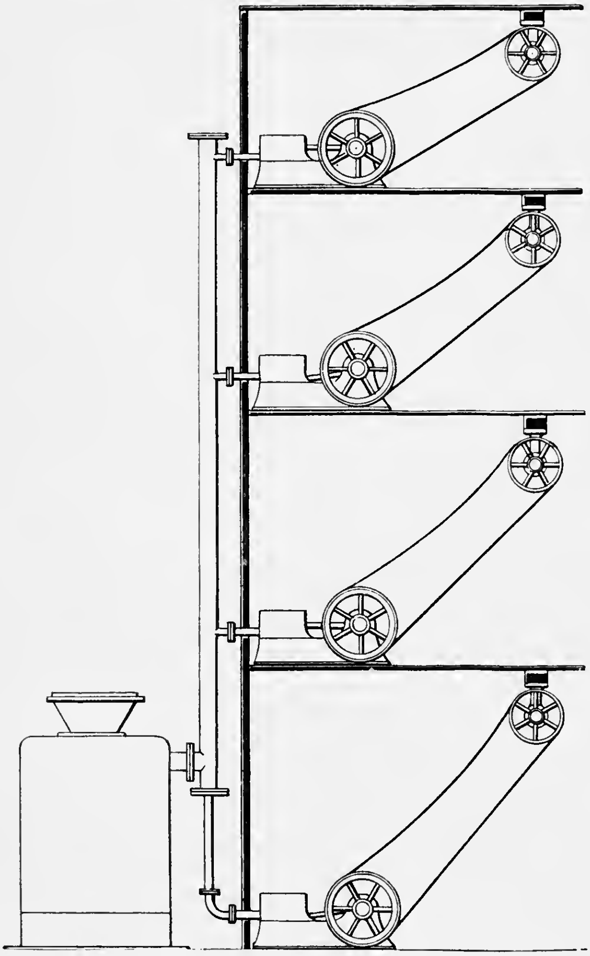


FIG. 138.—Gas Engines and Rope Transmission.

Fig. 136 shows a diagram of a system of rope transmission from a gas engine in three spans; the mid span may be long and supported at intervals by carrier pulleys.

Fig. 137 shows a rope drive to four floors from one engine, and Fig. 138 shows a gas plant working a separate engine on each floor with a main rope drive; this with a suction gas producer is a prime system of such high economy that it would be difficult to surpass.

Steel wire ropes for transmitting large powers were at one time largely used, but only in rare cases would they be so used now. They have a large field of usefulness in haulage and lifting tackle.

TRANSMISSION OF POWER BY WHEEL-GEARING

Fig. 139 shows a diagram of this class of transmission; it is to be found in textile factories. No modern engineer would think of such a system; it is very inefficient, and even when made with the greatest skill and care it creats a tremendous amount of noise and vibration. All wheel-gearing is to be avoided in transmitting power. Wheel-gearing is only to be tolerated in transmitting motion with very small powers, or slow speeds such as in clocks, watches, machine tools, etc. The motor car and motor boats at present suffer considerably from the necessity for employing wheel-gearing between the non-reversible and constant speed engines and the driving axle; the gear at first works fairly well, but in a short time it gets slack and rattles noisily, backlash sets in and vibration begins.

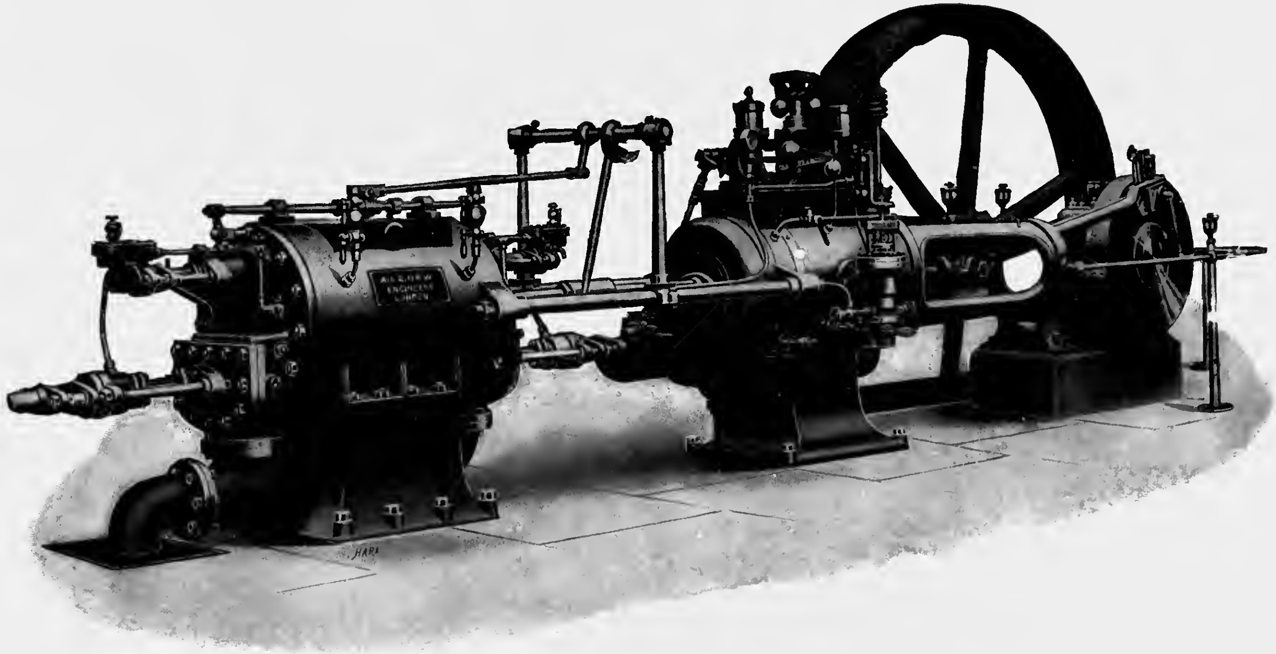


Plate V.—Tandem Air Compressor.

The old millwrights delighted in wheel gearing, and that of a very primitive style of wheels ; then mills could be heard for miles around when at work. They generally started off from the engine with an immense gear wheel ; the engines were slow speeded. Thirty or forty revolutions per minute was considered a terrific speed for an engine in an old mill, so that the first shaft was geared up by wheels.

This style of engineering is still carried on in Yorkshire. Only recently a large silk mill put in a large modern built engine to replace the old one, and actually retained all the old gear wheels. In this case the transmission of the power given by a really beautiful prime mover absorbed over 75 per cent. of the brake horse-power of the engine, which required three 28 foot by 7 feet 6 inch Lancashire boilers to keep steam to it. This sort of engineering accounts to a large extent for the decline of some industries. Some manufacturers will not get out of the old ruts. Here was a case where a modern transmission plant would have worked wonders even with the old prime mover, and still greater wonders with a modern prime mover; but no, the old plant remains and the new prime mover —a giant, crippled by slow speed, exerting all its power to effect a very small amount of useful work, and grinding away at the transmitting gear — has not effected much improvement.

Belt gearing is the best of all the mechanical means for transmitting small powers up to 20 or 30 horse-power over short distances. And, in fact, is better than electric transmission in the great majority of cases inside factories and mills.

Ropes come next to belts as mechanical transmitters ; they come in for use for spans too long for belts, and for larger powers.

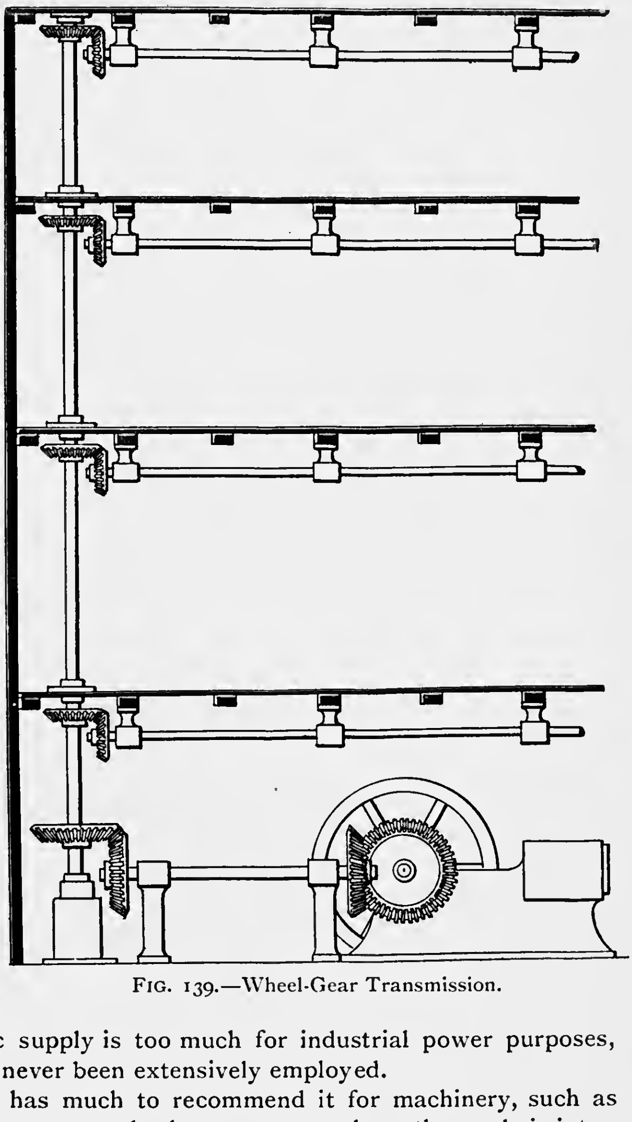


FIG. 139.—Wheel-Gear Transmission.

HYDRAULIC TRANSMISSION OF POWER

There are two systems: low pressure, such as can be worked from ordinary town supply mains ; and high pressure, supplied by special mains in which the water is kept under pressure by mechanical means.

The cost of water from public supply is too much for industrial power purposes, hence the low-pressure system has never been extensively employed.

But the high-pressure system has much to recommend it for machinery, such as cranes, hoists, lifts, capstans, dock-gates, and other purposes where the work is intermittent and for short periods.

The height to which water would require to be pumped to produce the high pressure is beyond anything available as a natural reservoir; hence Lord Armstrong invented the hydraulic accumulator, in order to store some water under pressure, and to maintain an even pressure all over the system. The pressures used being from 800 to 1000 lbs. per square inch.

The hydraulic accumulator is a simple ram working in a cylinder, and heavily weighted as shown in Fig. 141 in section, and in Fig. 140 complete.

The amount of storage is not great, but it can perform an immense amount of work in a short period of time.

Fig. 142 shows a set of steam pumps for maintaining the water supply. These are often arranged so that when the accumulator is full up the steam is automatically cut off, and when the accumulator falls the steam is automatically turned on.

Engines for working machinery have been designed for hydraulic pressure, and

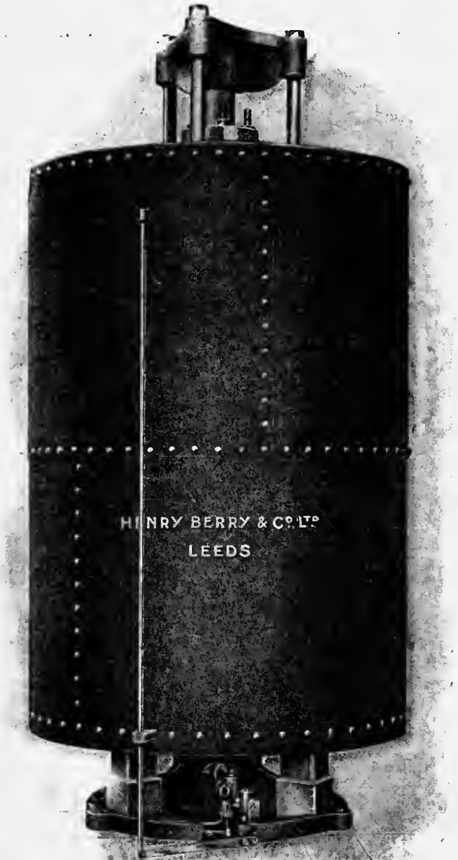


Fig. 140.

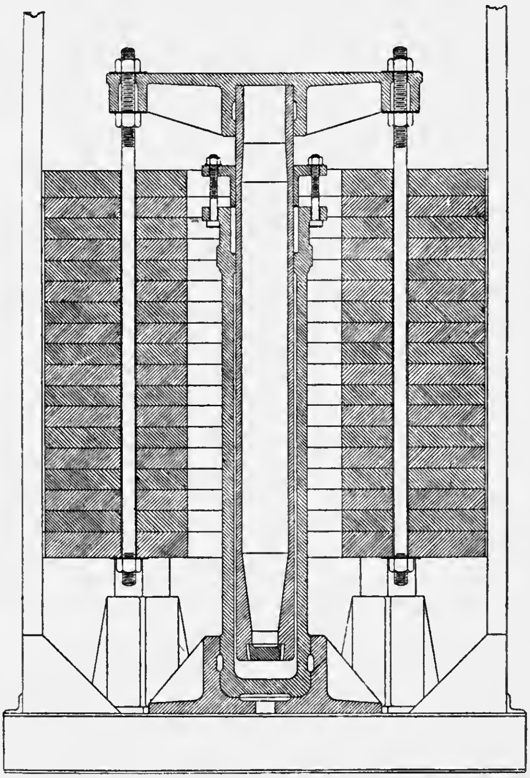


Fig. 141.

Hydraulic Ram Accumulator.

have been referred to in Volume I. Compressed air and electricity are so much superior for driving machinery continuously, that the hydraulic engine is of comparatively little importance.

The machines worked most satisfactorily by hydraulic pressure are here briefly considered. The most important is the hydraulic press.

An important improvement on the ordinary press is the differential machine, Mr. F. W. Scott's patent shown in Fig. 143.

The differential machine, illustrated in connection with a hydraulic press, has been introduced to economise the use of the high pressure water, it being a fact that in nearly all applications of the hydraulic press, although a high pressure of $1\frac{1}{2}$, 2, 3, or 4 tons is necessary to finish the operation of pressing, yet a very moderate pressure is sufficient for the greater part of the operation.

The differential machine is designed to fill this earlier portion of the operation, and consists of two cylinders one above the other,—the piston rod of the piston in the large cylinder being the ram of the smaller cylinder, the larger cylinder being filled with water with its piston at the lowest extremity.

The pressure water is let into the small cylinder by means of a valve, and the water in the larger cylinder is driven into the press, forcing the ram of press upwards for the

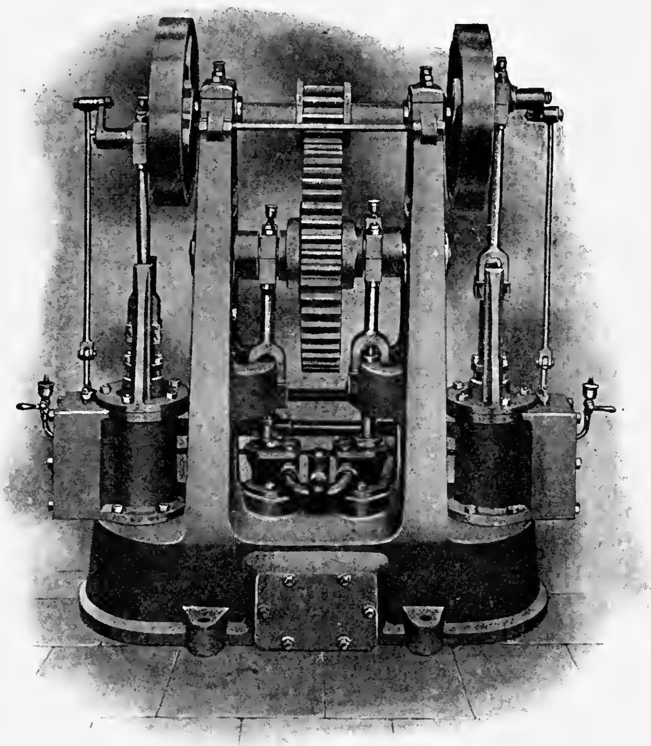


FIG. 142.—Steam Hydraulic Pumps.

larger part of its stroke. The connection between the differential machine and the press is then closed, and the high-pressure water let into the press to finish the operation.

A practical example is afforded by a press now at work. This press has a ram 12 inches diameter, and a stroke of 11 inches, and prior to the introduction of the differential machine each operation took 1246 cubic inches of 30 cwts. pressure water, and now, with the differential machine, 355 cubic inches of pressure water; which means, that if working by accumulator, four times the number of presses could be served, or if by pumps, pumps of one-fourth the capacity only would be needed, and consequently about one-fourth the power required.

In the illustration the differential machine is shown on the left and the press on the right, with the valves between. Each machine is specially constructed for the work it has to do. It is necessary to ascertain the most economical pressure for the large cylinder of the machine.

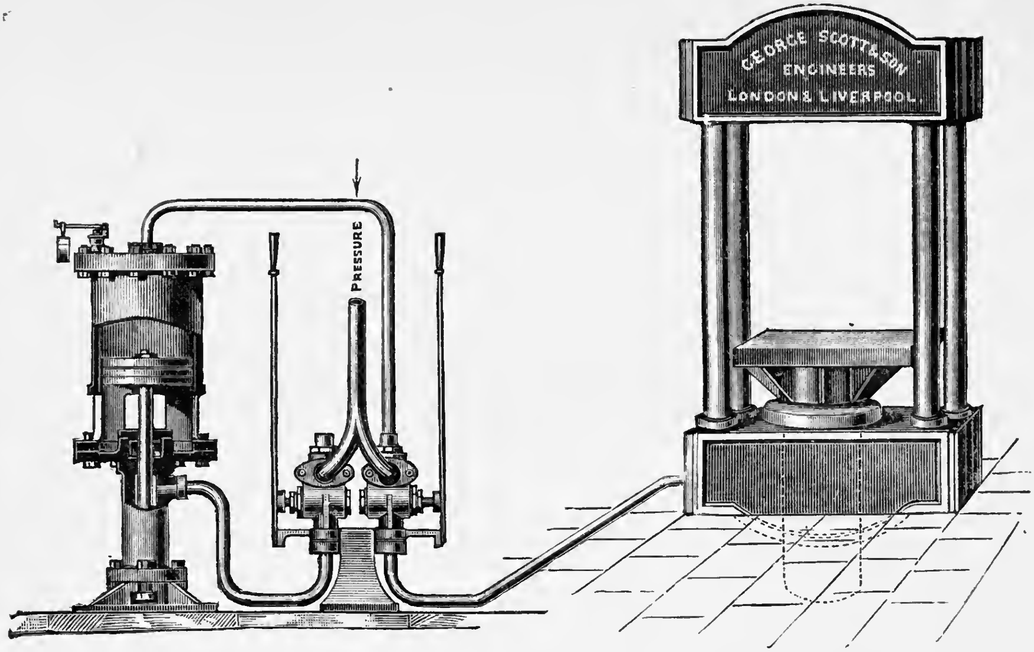


FIG. 143.—Differential Hydraulic Press.

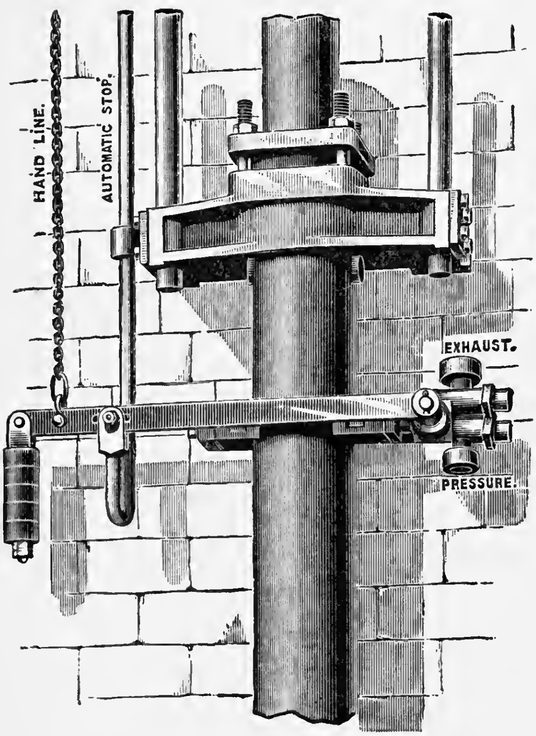


FIG. 144.—Hydraulic Crane.

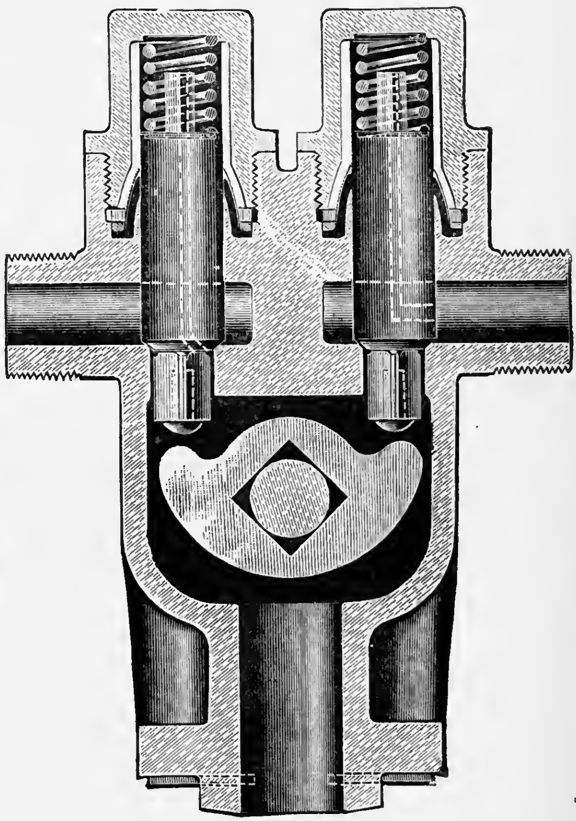


Fig. 145.—Working Valves.

Mr. Scott's working valves are shown in Fig. 145 in section. The pressure inlet is on the right hand and the exhaust on the left hand; the valves are opened by the cam operated by a lever. There is only one spindle, one stuffing box, one lever, and no weight; both valves cannot be opened at one time.

The clearance between the contact points at so short a distance from the centre of the lever gives a large travel at the end of a comparatively short lever. In order to keep the valves closed when not opened by the cam, the pressure water is turned on to the tops of both valves, leakage being entirely prevented by the leathers. Thus when

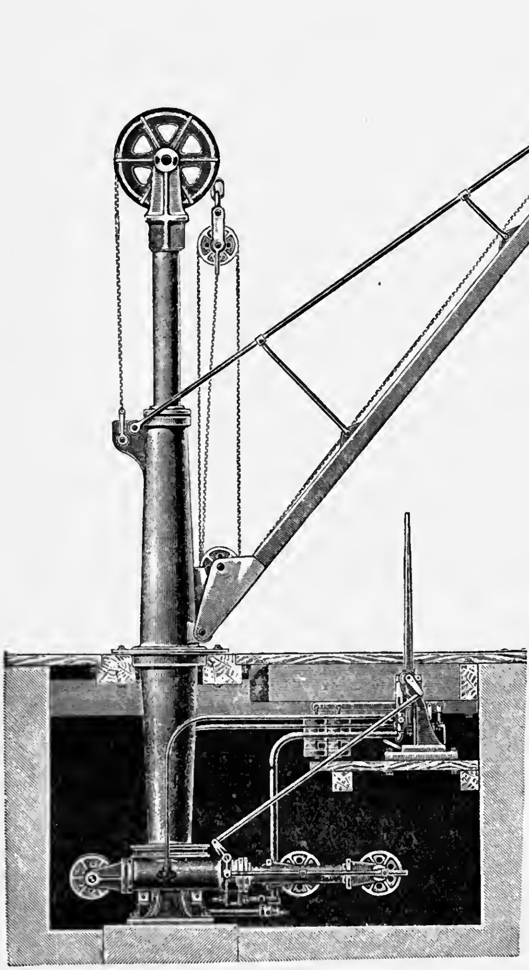


FIG. 146.—Hydraulic Crane.

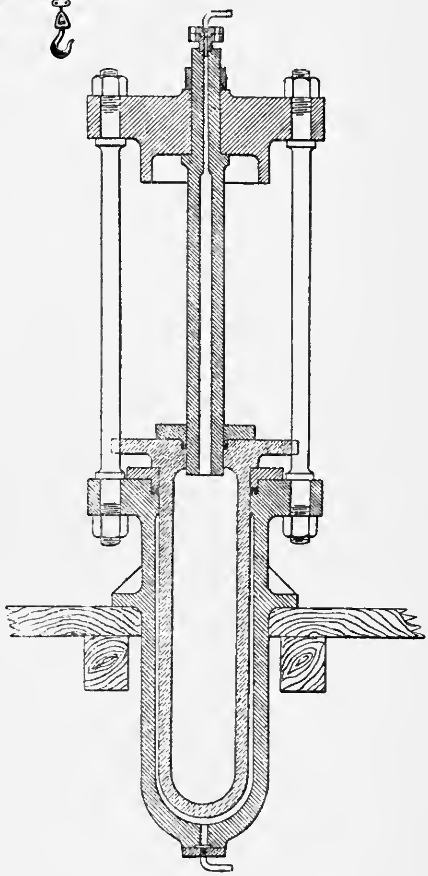


FIG. 147.—Hydraulic Intensifier.

the valves are open they are in equilibrium, and when closed have ample power behind them to keep them so, being at the same time so proportioned that they relieve any sudden heavy pressure set up by shock on the ram. The springs are only used to overcome the clasping tendencies of the leathers, and are of the lightest pattern.

Given now that grit gets under the valve seat, and the valve is attempted to be closed by moving the cam; no mass of weights is acting to crush the valve on to its seat, the valve itself is in equilibrium, the pressure up and down being equal, all but the 3 or 4 pounds pressure exerted by the small spring. This pressure, whilst amply sufficient to close the valve, is not enough to press the grit either into the seating or valve. The operator then raises the valve again, and allows the water to wash away the grit. Supposing after a lapse of time the valve requires re-grinding, nothing has to be taken down, the caps are removed, a spanner applied to the squares formed on the valves for this purpose, and in five minutes the valve is as good as new. The only wearing parts are the springs, leathers, phosphor bronze contact buttons and cams, and the valves. The leathers can hardly be said to wear, as they never come into contact with other than a perfectly polished surface. The springs cannot be unduly strained, as the lift of valve is limited, and as they are never in contact with flowing water they do not rust.

Fig. 144 shows the application of a patent working valve to an hydraulic crane. The valve is fixed direct to the cylinder, and the automatic stop rod is coupled direct to the working lever. The machine in this case is worked by the hand chain shown, and the small weight is not required for the valve, but to counterbalance the chain, and enable the operator, by lifting the weight on the one side, to allow this weight to open the valve. If, instead of working the machine by a line, the operator had grasped the lever, then this weight would not be necessary. It is not, of course, absolutely necessary to place the valve direct on the machine ; it may be fixed at any convenient point, and connected by pipes. The valve shown is called a right-handed valve, the pressure inlet being when the valve stands on the flange, by which the connection to the cylinder is made (the stuffing box being next to the observer) on the right-hand side. All B pattern valves are made so that the user can erect them either as right or left handed, by reversing the spindle and stuffing box. It should also be clearly stated whether unions or flanges are required. The flange by which the connection to the cylinder is made may be of any form desired.

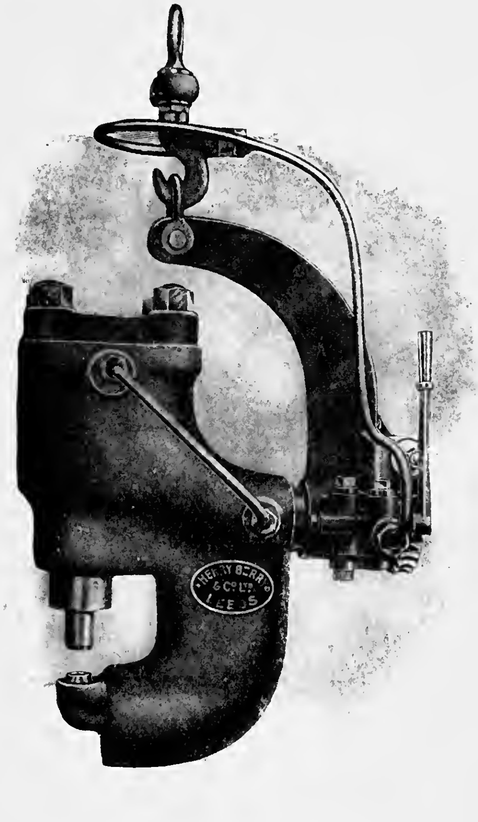


FIG. 148.—Hydraulic Riveter.

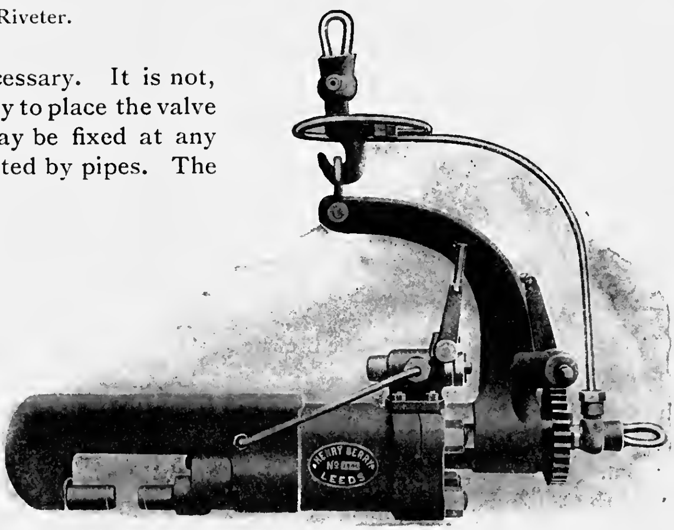


FIG. 149.—Hydraulic Riveter.

A vertical pressure intensifier is shown in Fig. 147 in section; the hollow ram moves upon the central hollow ram of small size. The pressures given are proportional inversely as the square of the diameter of the two rams.

Fig. 146 shows a complete derrick crane. The vertical ram does the lifting, while the horizontal ram in the pit shows the jib.

Hydraulic pressure is also largely used for punching and riveting in shipbuilding and boiler work. Two types of hydraulic riveters are shown in Figs. 148 and 149, portable for use while hanging from a crane.

The velocity of water in hydraulic pipe systems must be restricted to about 3 feet per second, to avoid shocks and function losses.

The amount of energy transmitted by pipes with pressure water may be found by the following rule:—

Let D be the internal diameter of the pipe in inches; p the working pressure in lbs. per square inch; H the head, in feet, due to the pressure, so that $p = 0.433$ H; v the velocity in feet per second. Then the gross work transmitted is—

$$U = \frac{\pi}{4} D^2 p v \text{ foot-lbs. per second}$$
$$= 0.34 D^2 H v \text{ foot-lbs. per second;}$$

or in horse-power—

$$\text{Horse-power} = .001428 D^2 p v$$
$$= .000618 D^2 H v.$$

At 750 lbs. pressure the power transmitted by pipes from 3 to 12-inch diameter is as under:—

Diameter of Main in Inches.	Gross Horse-Power transmitted.
3	29
6	116
9	260
12	463

Hydraulic transmission systems of great interest have been extensively laid out, where the motive powers are waterfalls, at Zurich and Geneva.

COMPRESSED AIR TRANSMISSION

The power of prime movers can be economically and effectively transmitted by compressed air. The employment of compressed air for the purpose is of ancient date, and the applications have been mostly to rough and special work where economy was hardly ever studied at all, so that the impression on the minds of most engineers was that compressed air was of necessity wasteful as a power transmitter.

A more scientific study of the subject, however, reveals the fact that it can be used with high economy, and it holds its own in engineering works universally as a transmitter of power, to riveting, chipping, drilling, caulking machinery, also in mining for rock drills, coal cutters, and pumping.

The fundamental fact that air is heated by compression and cooled by expansion accounts for a certain amount of inevitable losses if the air is stored or carried in long pipes, in which cases the air loses the heat of compression, and this heat must be restored to it before it can work economically again.

This heating by compression also reduces the weight of air compressed in the air pumps when compounded, so that the air should be cooled during compression in the pumps to get the best results.

On the general results and aspect of the question of compressed transmission we may quote Professor Unwin's *Howard Lectures*.

Compressed air transmission is a perfectly general method of distributing power for all purposes. Whether in any given case it is the most advantageous, the least wasteful of power, or the cheapest in working cost, depends on various circumstances. M. Hanarte believes that it is and will continue to be the most economical method of transmission to considerable distances. The loss in the air mains is very small. The motors worked expansively are efficient. The mains can be carried by any path, and differences of elevation between the compressing and working points do not sensibly affect the result. In hydraulic transmission the water must be collected, stored, and in some cases filtered, and having actuated a motor, means must be found for removing it. But air is everywhere available, and can be discharged anywhere without causing trouble. Compressed air has peculiar advantages in the case of underground transmissions. It has been used to replace manual labour in situations where hardly any other motive power could have been employed. In driving a tunnel at a mine, for instance, the cost was reduced to one-half, and the rate of boring was three times as fast when compressed air machinery replaced hand labour. In such cases the advantage is so great, even with uneconomical machinery, that the inducement to adopt very perfect machinery is absent. Hence much of the air compressing plant at mines has been unnecessarily inefficient and wasteful of power. In many cases air compressing plant has been driven by water power, and this also has tended to a neglect of the conditions necessary for economical working. The safety of an air main is obvious, and even a leakage or burst of the main is much less serious and attended with less damage than that of a water or steam main. Air leakage is less dangerous than electric leakage. When an air distribution is introduced in a town, power users do not require new plant and need incur no outlay for motors. The boilers, with all their attendant disadvantages of stoking, removal of ashes, cleaning, and risk of explosion, are dispensed with, and the steam engine, with little alteration, serves as an air motor. If an electric system is introduced the old motors must be removed and new motors purchased. Further, if electric motors are themselves of high efficiency, they run at a high speed, and in most cases there is considerable loss in the gearing required to adapt them to ordinary purposes.

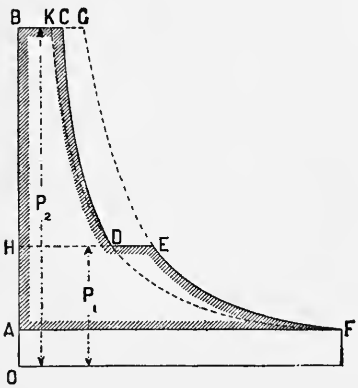


FIG. 150.—Diagram of Compound Compressor.

In regard to adaptability to various requirements, compressed air is in a very advantageous position. Electricity supplies power and light, but it cannot be used for supplying heat, except at a cost prohibitive in most applications. Gas supplies heat, power, and light. But for lighting it is open to obvious objections, and for heating and power it is expensive. Pressure water supplies power, and indirectly light, if a motor is used to drive a dynamo. But except where cheap water power is the original source of energy, it is too expensive for most purposes where motive power is required. Steam supplies heat, motive power, and indirectly light if a steam motor is used to drive a dynamo. But it is more expensive than compressed air, and involves more risk and attention. Compressed air can be supplied so cheaply that not only can it be used directly as a source of motive power, where that is the commodity required, but it can be advantageously used to drive sub-stations and private installations for generating electricity for lighting purposes or for working pumps and ventilating fans. With a water cushion between the air and the lift ram, compressed air is as convenient for working lifts as pressure water.

Properties of Air.—Let P be the pressure (absolute) in lbs. per square feet, V the volume of a pound in cubic feet, and T the absolute temperature in Fahrenheit degrees. These quantities are connected by the relation

$$PV = 53.2\ T.$$

Let $P_aV_aT_a$ be corresponding quantities for air at ordinary atmospheric temperature and pressure. It will be assumed that ordinary atmospheric air before compression is at a temperature of 60° Fahr., or 521° absolute, and at a pressure of 2116.3 lbs. per square foot. For these conditions

$$P_aV_a = 53.2 \times 521 = 27{,}710 \text{ foot-lbs.},$$

and the volume of a pound of air is

$$V_a = 13.09 \text{ cubic feet.}$$

WORK WASTED IN HEATING IN COMPRESSOR PER POUND OF AIR COMPRESSED.

$\frac{P_1}{P}$	p_1 = Pressure of Compressed Air in Lbs. per Square Inch.		Work wasted.	
	Absolute.	By Gauge.	Adiabatic Compression. $n = 1.41$	Partially cooled Compression. $n = 1.25$
2	29.4	14.7	0.077 P_aV_a	0.052 P_aV_a
4	58.8	44.1	0.322 ,,	0.209 ,,
6	88.2	73.5	0.562 ,,	0.363 ,,

In the various compressors to be described, several methods for cooling during compression will be noticed.

Compound compressors, in which the compression is carried out in several stages with cooling between the stages, have been very successful.

The effect of the intercooler is very important in reducing the heating loss. The compound diagram is shown in Fig. 150. Air is compressed from p_a to p_1 in the low-pressure cylinder. Then in passing through the intercooler it shrinks in volume from HE to HD, the point D being on the isothermal, if the cooling surface is sufficient. It is then further compressed to p_2 in the high-pressure cylinder. The work saved by intermediate cooling is the area EDCG. The adoption of these intercoolers is important, because it removes the chief objection to the adoption of high-working pressures in air transmissions.

Then the clearance between the piston and cylinder ends of the compressors also causes losses, for the air in this space expands and fills the cylinder at atmospheric pressure when the maximum pressure reaches a certain value. For instance, if the clearance is 10 per cent., the compressor will furnish no air if worked at 11 atmospheres, and only half the volume described by the piston if worked at 6 atmospheres. The importance of reducing clearance is therefore obvious. With solid pistons in dry compressors some clearance is necessary; but it may be reduced to 1 to 3 per cent. of the volume described by the piston by careful design. With water-piston compressors the clearance may be reduced to zero, though at high pressures an equivalent source of loss would arise from air absorbed by the water during the compression stroke, and given off during the return stroke. In compound compressors the effect of clearance is diminished, because for each cylinder p_1/p_a is less than in a simple compressor.

In order to show how important the cooling action during expansion in the motor cylinder is, temperature curves have been drawn in Fig. 151 for expansion from various pressures down to atmospheric pressure—that is, for what may be termed complete expansion. The full curves show the fall of temperature during adiabatic expansion. The dotted curves show the corresponding fall of temperature when some heat is supplied during expansion. If $P_1V_1T_1$ are the initial pressure, volume of a pound, and absolute temperature, and $P_2T_2V_2$ the corresponding quantities at any stage of the expansion, then

$$\frac{T_2}{T_1}=\frac{p_2V_2}{p_1V_1}=\left(\frac{p_2}{p_1}\right)^{\frac{n-1}{n}}$$

where n has the values 1.41 or 1.25, according as the expansion is adiabatic, or with heat supplied as assumed above.

The lower set of curves show the temperature fall when the air is initially at a temperature of 60° Fahr.; the upper set of curves, the temperature fall when the air is reheated before use to 200° Fahr.

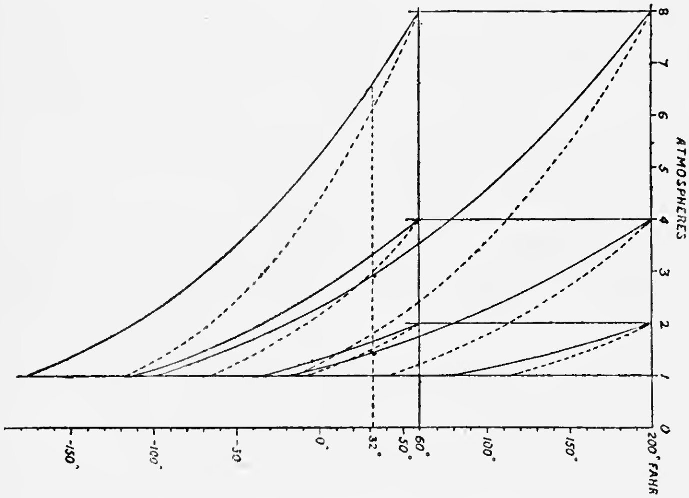


Fig. 151.—Reheating Diagram.

The curves show strikingly how limited is the possible range of expansion, with air not reheated before use, if the difficulty of a very low temperature of exhaust is to be avoided. On the other hand, they show how much the possible range of expansion is increased by moderate reheating of the air before use, when the exhaust does not fall below freezing-point. The effect of some heat supply during expansion, sufficient merely to alter the index of the expansion curve from 1.41 to 1.25, is not very great on the terminal temperature.

The heat supplied is used with great efficiency, and a larger fraction of it is converted into work than in ordinary heat engines. Further, very small, easily managed, and simple reheating apparatus can be employed. A simple coil of pipes, with a small furnace capable of heating the air current 300° Fahr., may increase the work done per pound 30 per cent. The heat is used five or six times as efficiently as heat supplied to a good steam engine.

AIR HEATERS

For the raising of the temperature of the compressed air after transmission and before use in the motors, air heaters are employed. The heaters, from their position in the cycle of operations in a compressed air power system, are generally called air reheaters.

"DAW" PATENT AIR REHEATER

In all general applications this is a practical form of reheater, is exceedingly simple, easily applied, and the fuel is used to great advantage.

As will be seen from the illustration (Plate IV.), the "Daw" reheater consists essentially of two cast-iron shells bolted together, and resting upon a fire-brick lined furnace having all the usual fittings. The inner shell is made in corrugated form, presented by a worm or sinuous passage starting from the air inlet at the top and coiling downwards to the air outlet at the bottom. The reheater is in the form of a truncated cone of increasing diameter from the top downwards, so that the sinuous passage progressively increases in diameter from the inlet to the outlet orifices to allow for the expansion of the compressed air as it travels through the heater. The sinuous passage splits up the air into a thin stream and exposes it to the greatest heating surface, rapidly and economically heating it to the desired temperature.

The reheater should be placed as close as possible to the point where the heated air is to be used, and all hot pipes should be well insulated to prevent radiation.

AIR COOLERS

The cooler the air is kept before and during compression the less will be the power required to compress it. The reason of this is that the air expands by heat, and the increase in volume causes additional resistance to the advance of the piston in the compression cylinder.

Cooling before compression.—To secure the best results, the air to be compressed should be drawn from outside the engine-room and from the most advantageous point for the coolest air, with freedom from dust and other foreign matter. Drawing the air in as cool as possible will increase the capacity of the compressor, and reduce the work of compression to the extent of a saving of 2 per cent. for every ten degrees the temperature is lowered. During winter there will frequently be from forty to sixty degrees difference in the outside and inside temperatures of the air, equivalent to a gain of 8 to 10 per cent. in efficiency obtained without any expense. Whilst the difference in summer will not be so great, it is still worth providing for.

Cooling during compression.—During compression the difficulties encountered in properly cooling the air are considerable, as there is not sufficient time during the stroke to abstract the heat by any available means. The generally accepted modern practice is to water-jacket the cylinders, and for single-stage compression is practically the only means available. Air does not part with heat readily to a metal surface, and as only a layer of the air comes in contact with the cylinder walls the heat produced by compression is very imperfectly abstracted by water-jacketing.

During the early development of the compressor water pistons were adopted, the air being displaced by a mass of water driven by an ordinary piston, and whilst the water directly absorbs part of the heat there are so many practical drawbacks to this system that it has been entirely abandoned.

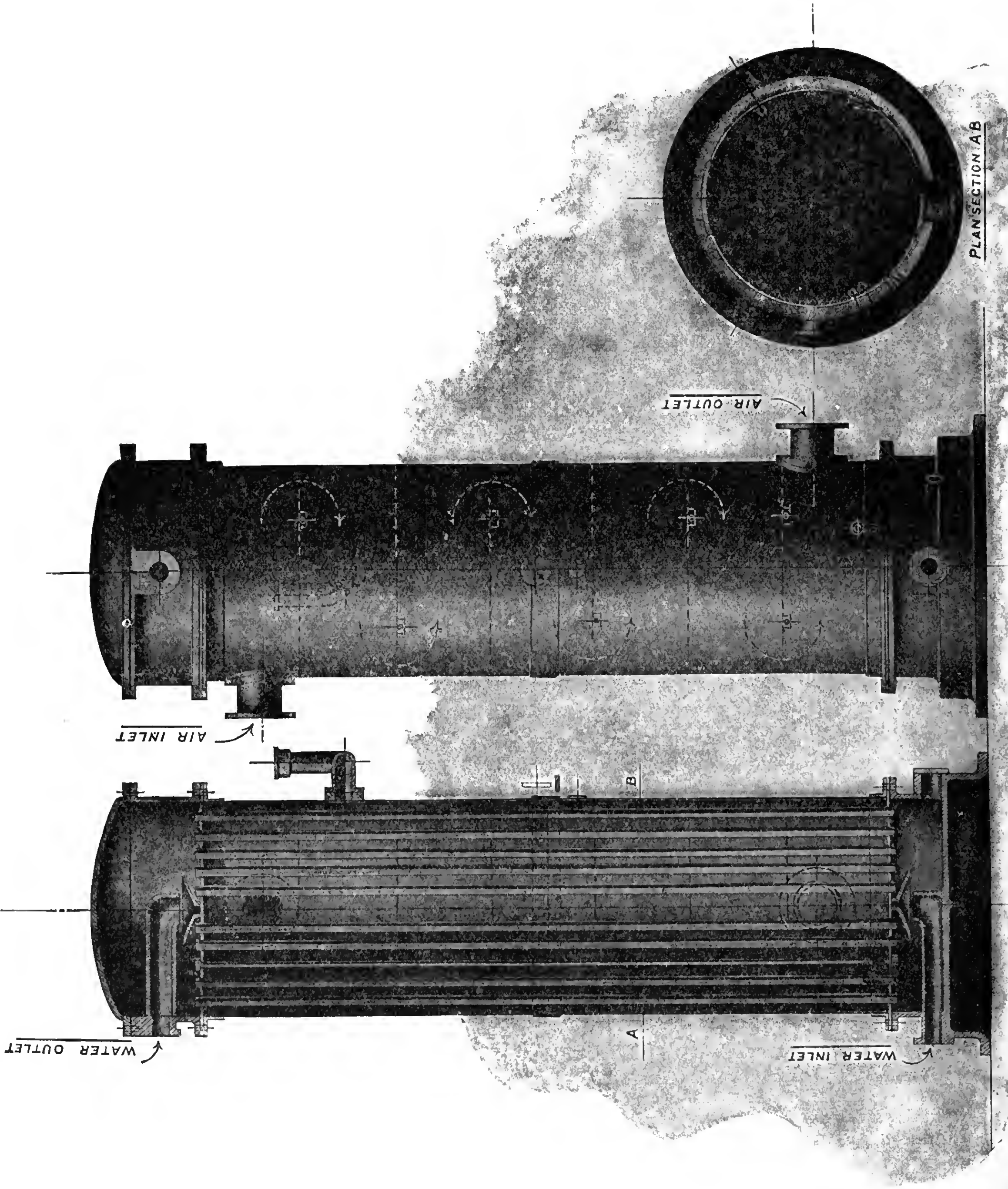
A more powerful cooling action is obtained by the injection of water in a fine spray into the cylinders, but this cooling is to a great extent deceptive, as it takes place late in the stroke and during the discharge of the air, and the work is not reduced thereby as it should be. Further, it adds an undesirable amount of moisture to the air, and makes lubrication exceedingly difficult.

The difficulty experienced in abstracting the heat in single-stage compression is practically overcome by multi-stage compression. One of the advantages of stage compression is that more time is taken to compress a unit volume of air, which while being compressed is brought into contact with a larger percentage of the cylinder walls, thus increasing the useful effect of the water jacket. The larger saving is, however, effected by abstracting the heat in the air by an intercooler, thereby causing the air to shrink in volume between the stages.

To secure that all the heat is abstracted between the stages, the intercooler must be properly designed, when it should reduce the temperature of the compressed air to within 5° or 6° Fahr. of the temperature of the cooling water, which in general is somewhat below that of the atmosphere. By this means it is possible to approximate the isothermal compression.

Various forms of intercoolers are adopted by builders of air compressors, but unfortunately many manufacturers sacrifice utility to cheap construction, so that many so-called intercoolers supplied are such in name only, and not in cooling result.

For the best cooling effect the intercooler should be made as a large receiver to reduce the velocity of the air in its passage through same, and have ample cooling surface to abstract the heat from the air, and such cooling surface must be arranged



that the air be broken up as completely as possible in its passage through the intercooler, so as to bring all the air into actual contact with the cooling surface.

The "Daw" Vertical Receiver Intercooler is illustrated in Fig. 152. The air passes around the tubes and the water through them, and the baffle plates effect a thorough splitting up of the air and efficient cooling. Further, for the volume of air to be passed, the intercooler is made by us of ample size to ensure the best results.

These intercoolers are naturally expensive to build, but first cost is a small item when compared with the efficiency of the compressor, measured by the fuel and water consumed.

Cooling after compression.—When it is desired to dry the air or to reduce it to its original temperature before it enters the pipe line, aftercoolers are used, and are identical in construction to intercoolers. They serve as a drier of air, reducing the temperature of the air to the dew-point, thus abstracting largely the moisture before the air passes into the pipe line. It is impossible, however, to abstract all the moisture in the air in an aftercooler, and they must be used in conjunction with separators, when the air has

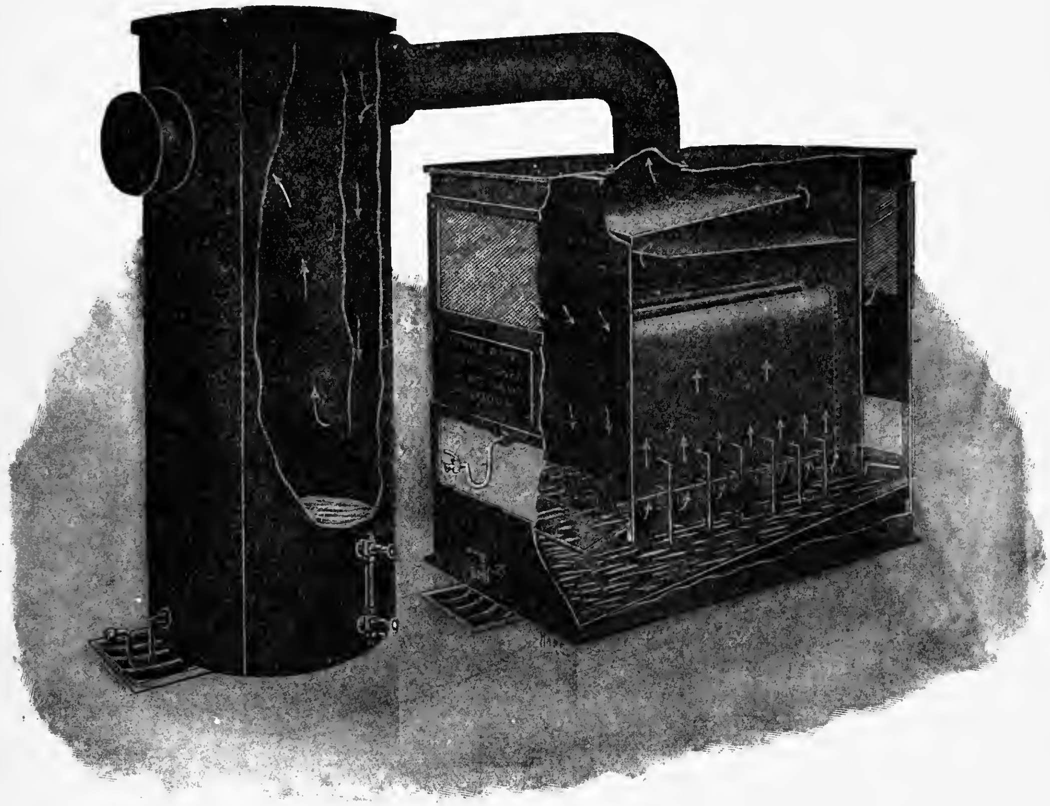


FIG. 153.—Air Washer.

to be made as free as possible of all undesirable moisture. The drying of the air is of importance when difficulties are experienced with the freezing of the exhaust. Also with pipes laid over the ground an aftercooler may prevent the accumulation of ice on the inside surface of the pipes.

THE "DAW" AIR WASHER

The thorough washing of the air either before or after compression is not easy of accomplishment, and the arrangement illustrated above is probably the most efficient washer devised for the purpose. It was supplied by us with a two-stage compressor having a free air capacity of 2560 cubic feet per minute (the cylinders being 28-inch diameter low pressure, and 18-inch diameter high pressure, by 40-inch stroke), to remove all the dust from a heavily dust-laden atmosphere.

From the illustration (Fig. 153) it will be seen the washer is extremely simple, and proved on test remarkably efficient. The inlet openings are protected by wire gauze, and arranged on opposite ends of the washer to balance any suction pressure on the surface of the water. The air passes down through the end vertical channels, and is distributed through five horizontal troughs over the surface of the water in the washer. Slots are cut in the side plates of each of the troughs, and the air in passing through these slots is split up into thin streams and thoroughly washed by the water, which normally covers the slots to a depth of 3 inches. The vertical baffle plates arranged along the troughs are to prevent swishing of the water, and the horizontally inclined baffle plates are to arrest any particles of water carried up by the air, and as a further precaution a vertical water separator is introduced between the washer and compressor. A sludge cock is fitted for periodically washing out the sludge that may accumulate.

SHOP TEST OF "DAW" PATENT CLASS E CROSS COMPOUND STEAM AND TWO-STAGE AIR COMPRESSOR.

Registered No. 112. Date, 25th November 1903.

Dimensions of Compressor—	
Low-pressure air cylinder, diameter	20½ inches.
High-pressure air cylinder, diameter	13 ,,
Low-pressure steam cylinder, diameter	24 ,,
High-pressure steam cylinder, diameter	12 ,,
Common stroke of all cylinders	30 ,,
Clearance of low-pressure air cylinder	1.12 per cent.
,, high-pressure air cylinder	.90 per cent.
Revolutions per minute during test	94
Piston speed	470 feet.
Capacity cub. feet of free air at 94 revolutions per minute	1007
Reduction in capacity due to clearance in low-pressure cylinder	29 cubic feet
Net capacity in free air per minute	1048 ,,
Temperatures—	
Shop temperature, Fahr.	65°
Temperature of cooling water, Fahr.	80°
,, water jacket, low-pressure air cylinder	88°
,, ,, high-pressure air cylinder	86°
,, air at exit from low-pressure cylinder	215°
,, air at exit from intercooler	88°
,, air at exit from high-pressure cylinder	214°
,, water passing intercooler	90°
Cooling water used—	
Quantity of water passing intercooler, gallons per hour	1490
,, ,, water jacket, low-pressure cylinder, gallons per hour	45
Quantity of water passing water jacket, high-pressure cylinder, gallons per hour	40
Pressures—	
Barometer	29.9
Initial steam pressure, lbs. per square inch	140
Intercooler gauge pressure, lbs. per square inch	21
Receiver gauge pressure, lbs. per square inch	72
Steam cylinders—Mean pressure, high-pressure cylinder	62.3
,, low-pressure cylinder	11.25

Pressures (*contd.*)—

Air cylinders—Mean pressure, high-pressure cylinder . 34.85

,, low-pressure cylinder . 15.67

Indicated horse powers—

Air cylinders—		Steam cylinders—	
Low-pressure . .	73.66	Low-pressure . .	72.48
High-pressure . .	65.89	High-pressure . .	100.35
Total . .	139.55	Total . .	172.83

Isothermal power required to compress net capacity of free air at test speed and pressure, namely, 1048 cubic feet to 72 lbs. gauge 119.47

Efficiency ratio of compression—

$$\frac{\text{Total isothermal power}}{\text{Total I.H.P. air cylinder}} \times 100\% = \frac{119.47}{139.55} \times 100\% = 85.61\%$$

Efficiency ratio between steam and air cylinders—

$$\frac{\text{Total I.H.P. air cylinder}}{\text{Total I.H.P. steam cylinder}} \times 100\% = \frac{139.55}{172.83} \times 100\% = 80.75\%$$

Efficiency of compression from atmosphere to receiver—

$$\frac{\text{Isothermal air}}{\text{I.H.P. steam}} \times 100\% = \frac{119.47}{172.83} \times 100\% = 69.13\%$$

Remarks.—During the shop test the compressor was supported on loose foundations only, and when erected in position on solid foundations the efficiency between steam and air cylinders, on the known efficiency of similar "Daw" compressors, will exceed 90 per cent., and the efficiency of compression from atmosphere to receiver will in actual work exceed 90 per cent. of 85.61 per cent., or 77.05 per cent.

The compressor ran smoothly, and both the mechanical and air governors acted promptly.

Fig. 154 shows the diagrams taken during these tests.

SERGEANT REHEATER

Figs. 155 and 156 represent the Sergeant air reheater in its simplest and most efficient form, the heater proper being made of two cast-iron shells bolted together, having no tubes of any description to burn out or leak.

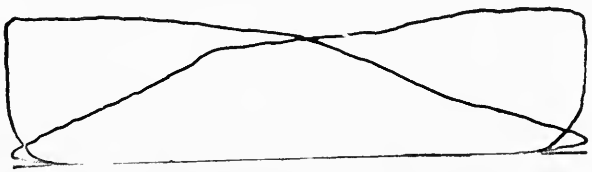
The heater is made in any size corresponding with the volume of air used.

From tests made with this heater (42 inches in diameter by 54 inches high) it has been found capable of heating 340 cubic feet of free air per minute at 40 lbs. pressure to 360° Fahr., giving a gain of 35 per cent. in the measured amount of work done by the air after passing through the heater, compared with the same volume of air when used cold.

A heater of this size will heat less air to a higher temperature, or more air to a lower temperature, than stated above; but if it should be required to heat more than 400 cubic feet of free air per minute, to get the best economy, it is advisable to use the heaters in series, allowing about 400 cubic feet of free air per minute for each heater. The heater should be placed as near as possible to the point where the air is to be used, and the outlet pipe should be as short as possible, and well covered so that the air will retain its heat.

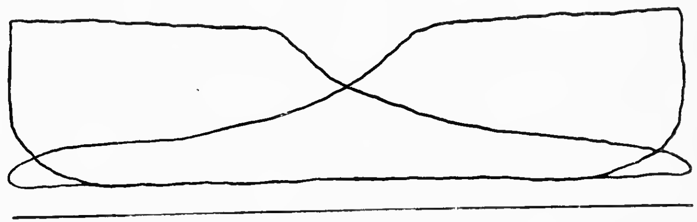
Low-Pressure Back End. Air Scale $\frac{1}{30}$.

Low-Pressure Front End. Air Scale $\frac{1}{30}$.



Low-Pressure Steam Cylinder. Scale $\frac{1}{30}$.

Air High-Pressure Front End. Scale $\frac{1}{60}$



High-Pressure Steam Cylinder. Scale $\frac{1}{120}$.

High-Pressure Back End. Air Scale $\frac{1}{60}$.

FIG. 154.

SERGEANT VERTICAL RECEIVER INTERCOOLER

This type of intercooler (Fig. 157) is used in compressors having compound air cylinders. The air discharged by the intake of low-pressure cylinder passes downward on its way to the high-pressure cylinder. A large number of small tinned brass tubes are set close together, dividing the stream of air in thin sheets ; water circulates from the lower end and discharges through the tubes. The shell is steel, and large enough for the proper filling of the high-pressure cylinder. A manhead, drain, and low-pressure pop safety valve are furnished. Contraction and expansion cannot cause leakage. The whole nest of tubes are easily removed for cleaning, and, not being common iron pipe, used by most makers, do not rust nor foul readily. This is the pattern giving ample volume for best results and cooling the air to or below its original temperature depending on the water used. It does not form an unsightly attachment to the compressor, as it may be located some distance away in the basement, in a corner, overhead or in another room. It is an expensive type to build, but to get permanently economical results in compound compression it is essential that the design throughout be the very best, combined with the largest possible area of cooling surface.

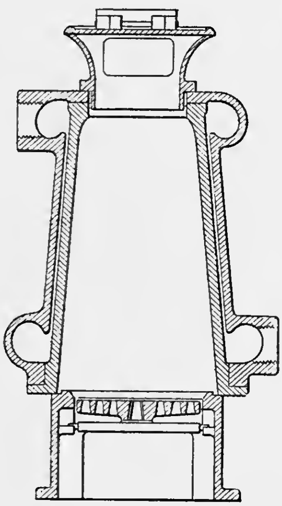


Fig. 155.—Reheater. Section.

Fig. 156.—Reheater.

As an aftercooler this arrangement offers a perfect means of aftercooling the air or gases where it is not desired that the fluid enter the pipe systems above its original temperature. Used in this way, whether with a compound or non-compound compressor, it is practically impossible for any moisture to pass into the pipe line, as moisture will be precipitated by the cool tubes and may be drawn off at intervals. Such use also prevents the flame passing to the mine or tainting the air, in case of an explosion, something which rarely occurs, but may in important cases be guarded against to advantage.

THE CONSOLIDATED PNEUMATIC TOOL COMPANY'S INTERCOOLER

The intercooler shown in section in Fig. 158 is furnished with two-stage compressors. The air passes in at opening marked air inlet, and out on opposite side of shell marked air outlet. A baffle plate is fixed in centre of shell, extending from side to side and from bottom tube sheet to within a few inches of top tube sheet. Air entering from low-pressure cylinder is thus compelled to travel between the closely spaced brass tubes up over top of baffle plate and down through an equal number of tubes to the outlet, on its way to the high-pressure cylinder. The combined base and water head is divided into three compartments by cast-iron partitions, and the upper water head into two compartments. The cooling water enters at the bottom, and is compelled to traverse the entire length of tubes four times before passing out, as indicated by arrows showing water circulation. A hand-hole in each compartment of lower water head affords easy access for cleaning, and by removing upper heads the tubes are accessible for same purpose. A drain is furnished for each water compartment, and this draining should be carefully attended to whenever there is danger of freezing. A drain is also provided for drawing out water from the air chamber. The upper water head has lugs cast on it, which fit inside the air

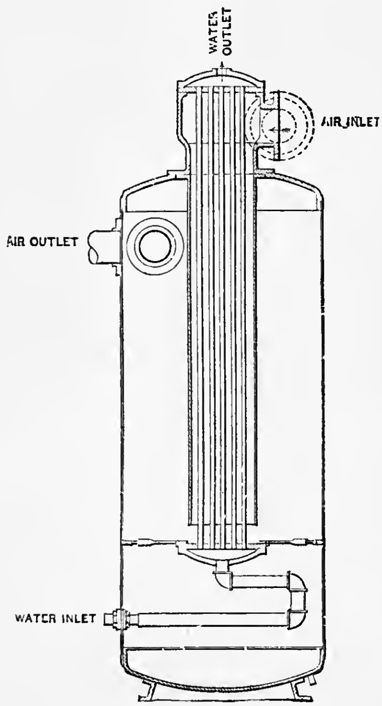


FIG. 157.—Intercooler.

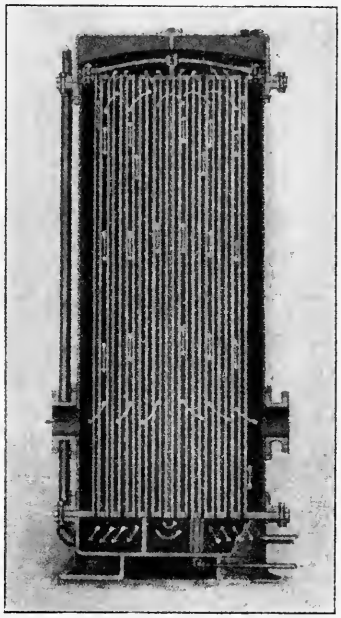


FIG. 158.—Intercooler.

head, preventing any straining on tubes through intercooler being laid on its side in shipment, at the same time leaving water head free to move up and down to accommodate expansion and contraction of tubes. These intercoolers are designed with an unusually large area of cooling surface and are proportionally efficient.

In connection with the heating of air, reference may be made to the cooling of air so far as to liquefy it or to freeze it into a solid; this is done by pressure and abstracting heat from it. Proposals have been made to use air in the liquid or solid form in a prime mover, heating it to expand into the gaseous form under great pressure. No doubt power could be obtained by this means, but at enormous expense, and so power could be obtained by heating up a boiler full of ice until it became steam, but no sane engineer would fill a boiler with ice if he could get water, and he would not use cold water if he could hot water. It throws a reflection upon modern methods of education when we come across such proposals made by men who have evidently been through the higher grade schools of the country. A university graduate proposed to use a solid air cartridge for an air gun, ignorant of the fact that a lump of solid air takes a considerable time to melt and a considerable time to boil into gas, whereas a gun explosive must instantaneously become gaseous upon ignition

AIR PUMPS

A simple air pump is shown in Fig. 159, one of Messrs. Scott's make. It is intended for driving by eccentric or belt and crank. The valves in this case are spring loaded for closing, and are fired in the cylinder covers in order to reduce the clearances.

Such a simple pump is only of use for small pressures and occasional use. For high pressures water-jacketing is necessary, also mechanically opened valves; some makers, however, adhere to the spring-closed valves. Figs. 160 and 161 are sectional views of the Ingersoll-Sergeant air compressor cylinder.

The inlet and discharge valves are ample in number, large in area and light in weight, giving only a slight resistance to the admission and expulsion of air, the importance of which will be understood when it is recollected that this must be accomplished in one-fifth of a second, when running at 150 revolutions per minute. Common compressors usually show a loss of 15 to 25 per cent. in capacity, and an additional loss to the same extent in power through the neglect of proper proportions of air valves.

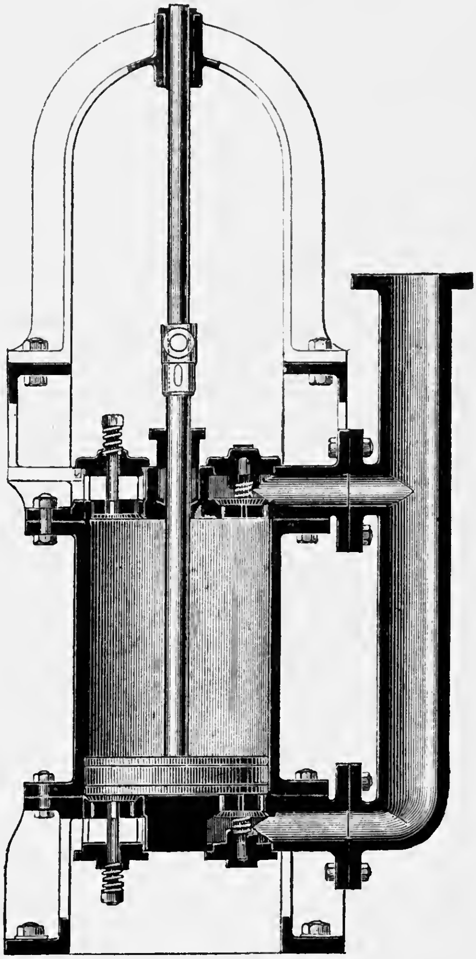


Fig. 159.—Air Pump.

The inlet valves are offset, and cannot be drawn into the cylinder should a stem break, wrecking the compressor. When the inlet valves are located in the cylinder heads, sieve-like guards are necessary. Such valves, seats, and metal guards become very hot, and the incoming air straining as hot metal in thin sheets takes up considerable heat, the consequent expansion wasting power and decreasing capacity. With this construction the inlet ports are free and direct, valves are jacketed, and the tendency is to always keep the air in contact with cold parts, thus lowering the temperature of the incoming air, which enters the cylinder freely and with little drag.

The removal of the caps gives access to the valves and seats without breaking a pipe or cylinder head joint.

Most horizontal inlet valves located in the cylinder heads cannot be properly lubricated, and, becoming gummed and clogged by the dust carried by the incoming air, move sluggishly with considerable suction resistance. They wear down out of line with their seat and, not closing promptly, there is a back puff or loss of air, already less in volume (through resistance to its entrance) than the assumed cylinder capacity. Our inlet valves run in a bath or seal of oil, which is crowded into the valve pockets by the piston and are flushed clean, springy, and free while dropping squarely on their seats, and allowing a complete filling of the cylinder with cold air at high speed. Being enclosed, they are less noisy than the usual poppet construction. The air may be drawn from any

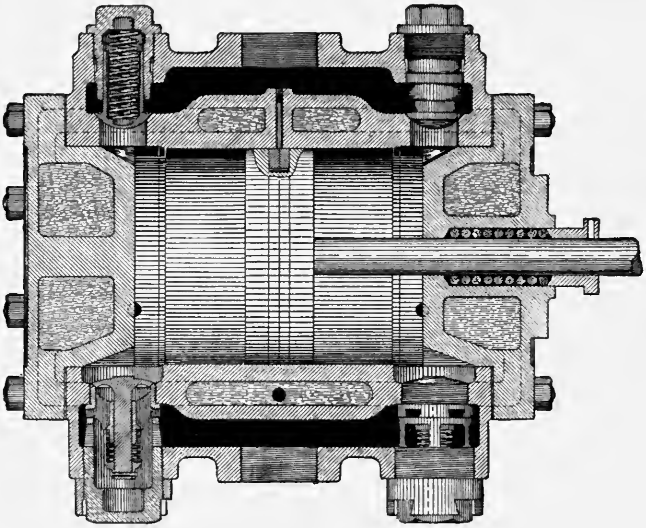


Fig. 160.—Ingersoll-Sergeant Cylinder and Valves.

source favourable for coolness, dryness, or freedom from dust through a wooden conduit laid below the floor line or elsewhere.

Valves are drop forging, steel, and indestructible; they can be replaced very quickly,

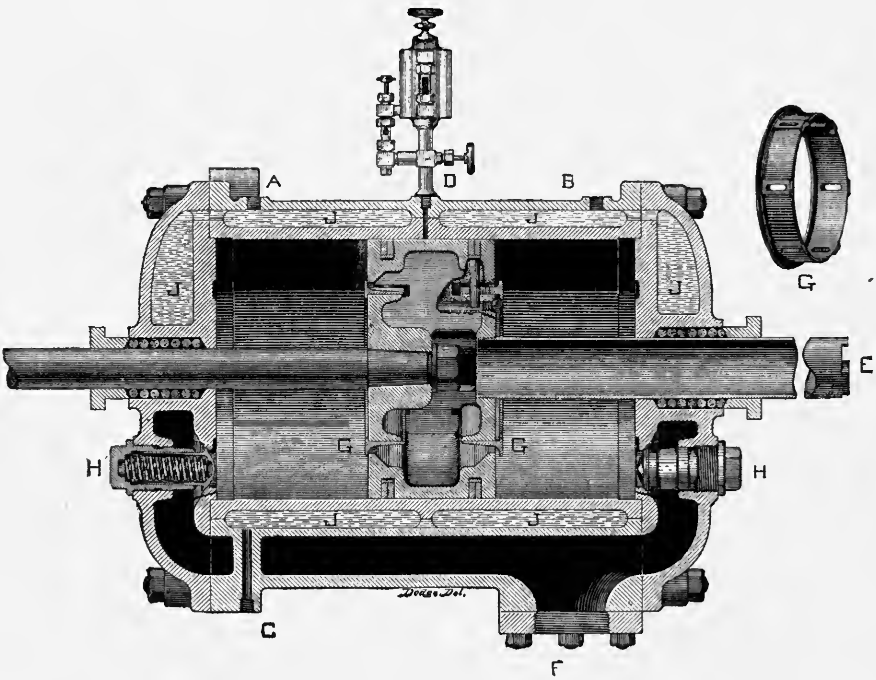


Fig. 161.—Details of Piston Air Cylinder.

and do not hammer their seats and wear leaky or crystallise as heavy bronze valves invariably do under heat and vibration. The clearance space is very small, the piston just clearing the valves and travelling close to the heads.

The air cylinders are completely water-jacketed, not only around the barrels but through the heads as well, as the removal of the valves from the heads allows us to jacket all air heads completely, and this space is much more valuable for cooling purposes than the cylinder jacket, because temperatures are highest near the end of the stroke where the highest pressures occur.

DETAILS OF PISTON AIR CYLINDER.

A. Circulating Water Inlet.
B. Circulating Water Outlet.
C. Water-Jacket Drain Pipe.
D. Oil Hole for Automatic Oil Cup.
E. Air Inlet (through piston inlet pipe).
F. Air Discharge (showing flange).
G. Piston Inlet Valves.
H. Discharge Valves.
J. Water Jacket.

The two inlet valves are located in the piston, and, with the tube, are carried back and forth with the piston. The valve on that face of the piston which is toward the

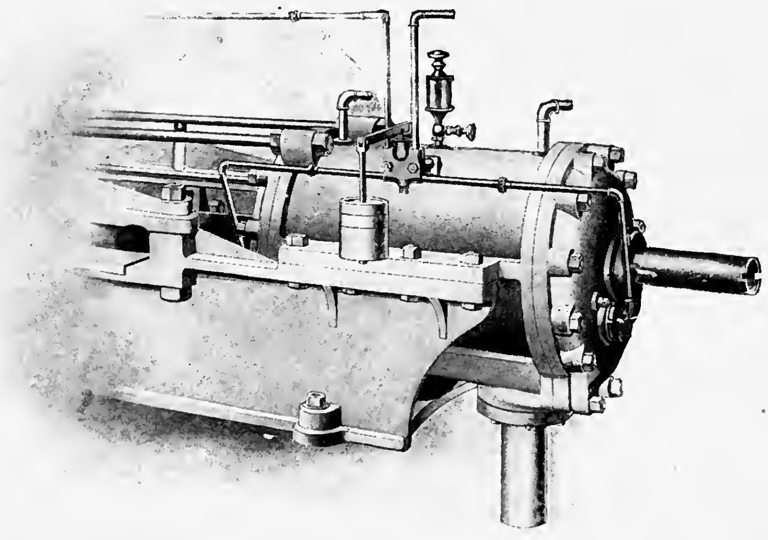


FIG. 162.—Air End of Ingersoll-Sergeant Piston Inlet Cold Air Compressor, showing Automatic Air Regulator and Unloading Device.

direction of movement is closed, while the one on the other face is open. This is exactly as it should be, in order to force out the compressed air from one end of the cylinder while taking in the free air at the other ; when the piston has reached the end of its travel there is, of course, a complete stop while the engine is passing the centre, and an immediate start in the other direction. The valve which was open immediately closes. There is no reason for its remaining open any longer, and it closes at exactly the right time, its own weight being all that is necessary to move it. The valve on the other side is left behind by the piston, and the free air is admitted to that end of the cylinder for compression on the return stroke. No springs are used, and there is none of the throttling of the incoming air and none of the clattering and hammering so noticeable with poppet valves. As there is nothing to make the valve move faster than the piston, it stays behind until the piston stops, leaving the port wide open for the admission of air. It is well known that while the fly-wheel and, of course, the crank rotate at a uniform speed, the movement of the piston is not uniform, but gradually increases in speed from the start till the crank has reached half-stroke, when it gradually slows up till the crank is on the centre, and at this moment of full stop the valve gently slides to its seat.

That these inlet valves are as positive and prompt in their movements at low as at high speeds has been shown by tests in which the movement of the valve was shown to be perfect when running in a duplex Corliss compressor as slow as 9 revolutions per minute.

The large ring air inlet valves admit of a large area of opening with but a small throw of valve, thus quickly opening a large supply port, enabling the compressor to run at high speed without a reduction in efficiency, and with safety to the moving parts. As the travel of the valve is only about one-quarter of an inch, it does not move far enough to acquire sufficient momentum to injure itself or its seat, and remains perfectly

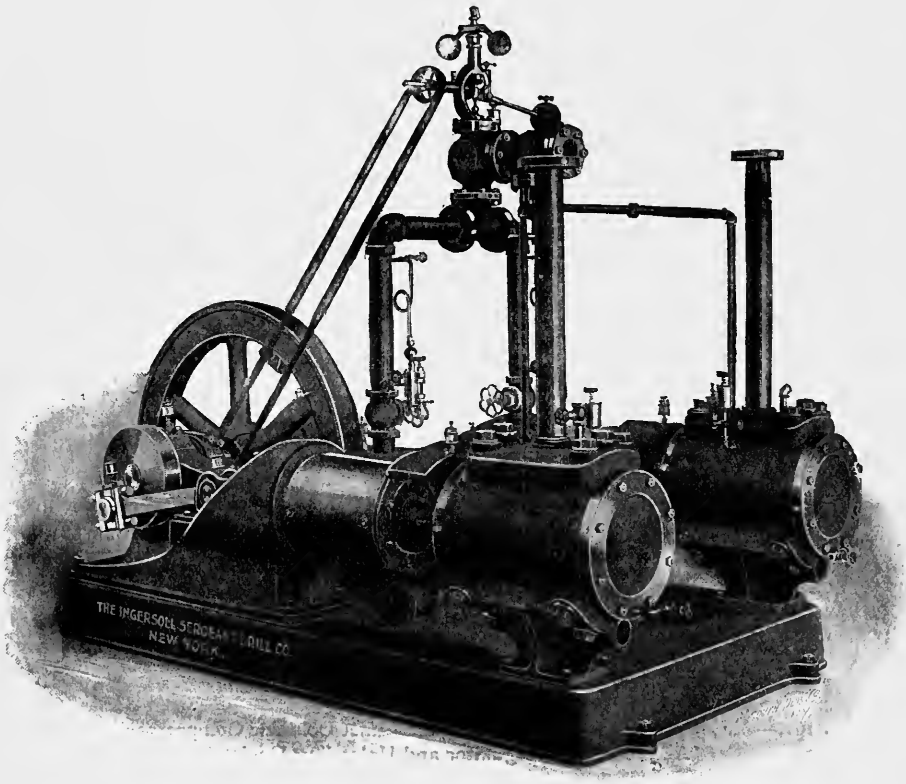


FIG. 163.—Steam-Driven Air Compressor.

tight till worn out. It is as positive in its action and as indestructible as a piston ring. Experience has shown that these valves will wear many years before requiring attention.

The clearance spaces are reduced to a minimum. An examination of the figures will show that there are no counter-sunk spaces in the heads for inlet valves. A shallow circular groove is turned in the heads, into which the projecting part of the inlet valve is received.

The admission of free air, being through the inlet tube, creates a constant and uniform flow of air in one direction only. Careful measurements of the volume of air discharged through accurate meters shows more air from the piston inlet cylinder than can be obtained from any other pattern of equal diameter. With compressors which must start the air from a state of rest at each stroke, and draw it into the cylinder against the resistance of poppet valve springs, there is a loss of 5 to 10 per cent.

This loss is not present with the piston inlet construction. Fig. 163 is a complete view of the Ingersoll-Sergeant compressor.

AIR END OF INGERSOLL-SERGEANT PISTON INLET COLD AIR COMPRESSOR, SHOWING THE AUTOMATIC AIR REGULATOR AND UNLOADING DEVICES.

The regulator of an air compressor presents difficulties in certain kinds of work which have been overcome with an improved unloading device. In mining and other similar work there are often times when all the machines are stopped, and no air is required for a few minutes or for several hours, but as the engineer has no means of knowing how soon the air will be needed it is not desirable to stop the compressor. The usual practice is to throttle the compressor down to a slow speed, the surplus air escaping through the safety valve in a most wasteful and annoying manner.

The Ingersoll-Sergeant regulator (Fig. 162) is so arranged that, when the pressure rises beyond the desired point by reason of stoppage of the machinery using the air, a passage is opened between both ends of the air cylinder, whereby the air at full pressure is admitted on both sides of the piston, holding the inlet valves tightly closed. The piston, having air pressure on both sides of it, is exactly balanced and moves in equilibrium ; the air pressure following it on both sides, back and forth, the result is a balancing of forces, and no more power is required to move the piston than would be if both air heads were entirely removed. At the same instant that this connecting passage is opened the steam supply is automatically throttled to a point which just admits sufficient steam to keep the engine turning over at slow speed, using only sufficient steam to overcome the slight friction. The compressor will run this way until the air pressure has been lowered by being drawn away, when the passage is closed, the steam automatically turned on, and, the inlet and discharge valves resuming their regular movements, the work of compression goes on in the regular way. The action of this regulator is entirely automatic. It takes full and complete charge of the machine, the only attention required from the engineer being an occasional oiling and adjustment of the wearing parts. The point at which the regulator performs is usually several pounds above the pressure to be carried. As the speed can be regulated very closely with the adjustable cut-off to meet the varying requirements, the regulator will seldom be needed, but it is there to control the machine thoroughly, under the varying demands of air consumption.

THE DAW AIR COMPRESSOR

This is a good example of a balanced valve compressor.

The inlet valve gear Fig. (164) shows the inlet valve A in an open position. It is pivotted at B, and opens inwards, its weight and the pressure within the compressing cylinder, and also the strong spring C, tending to keep it closed.

The valve is opened at the commencement of the suction stroke through the small slide valve D, which is actuated by the valve gear E, placing the rear end of small cylinder F in communication with the receiver through pipe S, so that the pressure in the latter acts upon the piston G, to overcome the action of the spring C and the weight of valve A, such pressure being maintained and the inlet valve thereby kept in its open position, after it has been opened, during the full length of the suction stroke. On the completion of the suction stroke the small slide valve D is reversed to exhaust, and the spring C, being thus relieved from the pressure acting against it, closes the valve. The small cylinders F and H act as dashpots or buffers, and ensure the valve opening and closing quietly without shock. The pressure set up on the inlet valve piston G, at the commencement of the suction stroke, is sufficient to ensure the inlet valve A opening instantly, and the removal of the pressure causes the equally ready closing of the valve by the spring C.

The discharge valve is shown in its closed position, the spring J, pressure in receiver, and weight of valve K, tending to close it. It is pivoted similar to the inlet valve, and is arranged to open outwards in its relation to the compressing cylinder, and is enclosed in a casing in open communication with the receiver, the pressure in which consequently is always exerted on the back of such valve.

The discharge valve K is also balanced through the small slide valve D, which is actuated by the valve gear, placing the front end of balancing cylinder L in communication with the receiver, so that on the pressure in the compressing cylinder becoming equal to the pressure in the receiver the latter pressure, acting upon the piston M, balances the difference in pressures on the discharge valve K, due to the valve seating, also the spring J, and the weight of valve, causing the discharge valve to open without any excess pressure being set up in the compressing cylinder. As the

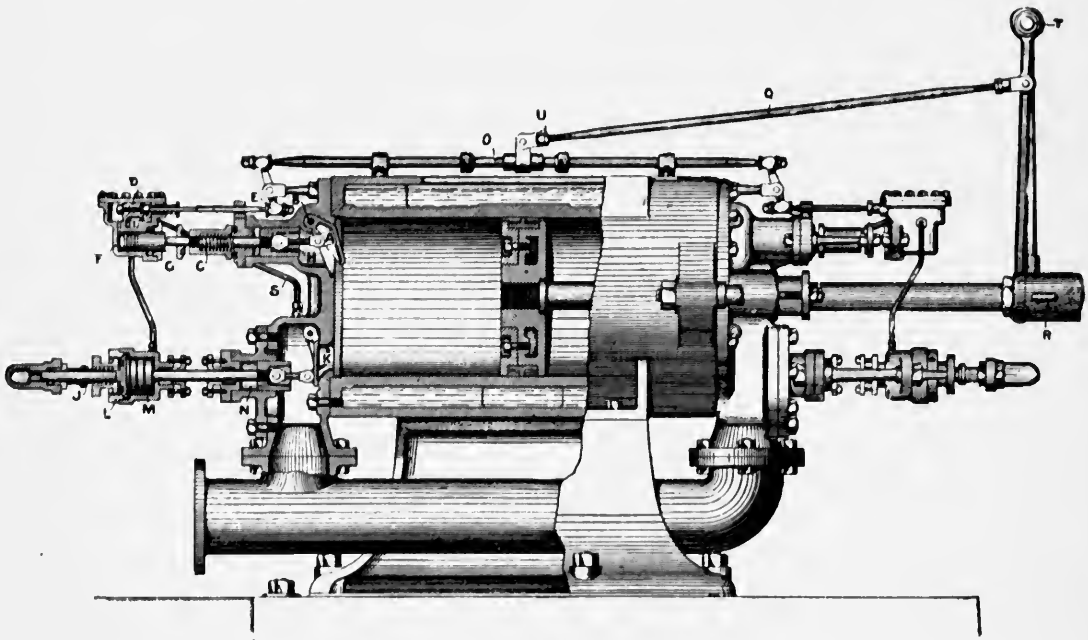


FIG. 164.—Daw Air Compressor.

discharge valve lifts off its seat a portion of the balancing pressure in cylinder L becomes an active force, opening the valve rapidly, and maintaining it full open until the compression stroke is completed. The slide valve D is then reversed by the valve gear, so that the pressure in cylinder L is exhausted, and the strong spring J, being thus relieved from the pressure acting against it, instantly closes the valve. The cylinders L and N act as dashpots or buffers, and ensure the valve opening and closing quietly without shock.

The small slide valves D controlling the small pistons, governing the opening and closing of the inlet and discharge valves, are mechanically actuated as follows :—

To the piston rod is connected a short rod R which actuates the long arm of a lever, the fulcrum T of which is placed a distance above it approximately equal to the travel of the piston. Forming part, or connected with this lever, is a connection nearer to the fulcrum to give a short travel to the rod Q. This has a sliding connection U upon the horizontal rod O, upon which are adjustable stops which actuate the small slide valves D exactly at the end of each stroke of the air compressor, the valves remaining stationary at all other times. By this positive motion it is ensured with absolute certainty that the valves D will move exactly at the time required, thus causing the admission valves to open and the discharge valves to close in the manner required to give the best results.

The use of a special gear for operating the valves greatly simplifies the compressor, as instead of a large number of small valves only one inlet and one discharge valve is required. All the valve gear is upon the outside, where it is easily accessible for adjustment and attention.

A 3-inch circular valve with $\frac{1}{4}$-inch seating exposes a surface of 7.07 square inches to the pressure in the receiver, and 4.91 square inches to the pressure in the compressing cylinder. If then air was being compressed to 80 lbs. gauge the pressure on the valve on the receiver side would be $7.07 \times 80 = 565.5$ lbs., which would have to be balanced by an equal total pressure, *i.e.* 565.5 lbs. on the cylinder side of the valve before it

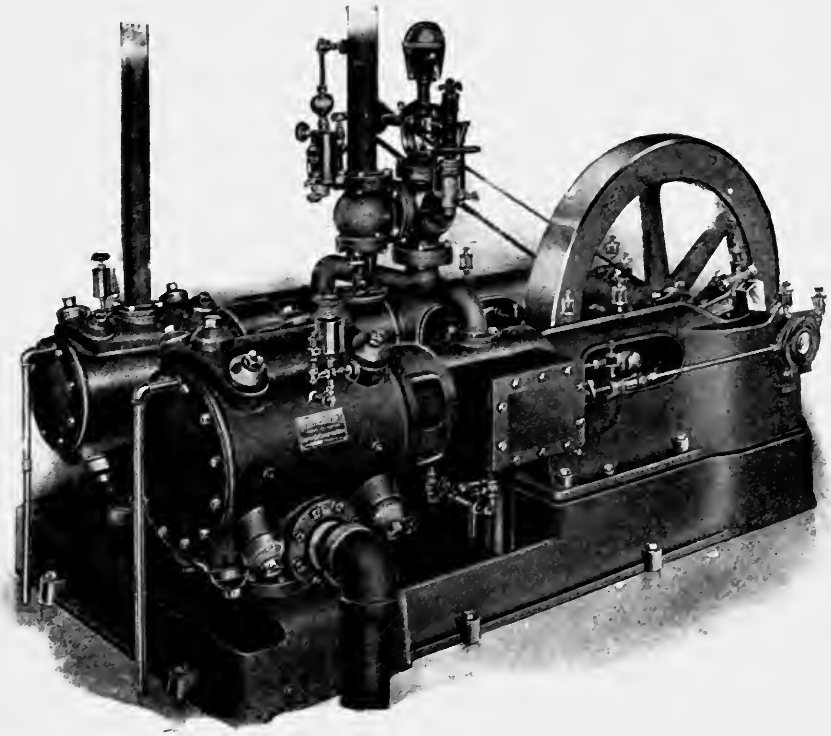


FIG. 165.—Steam-Driven Air Compressor.

could open and the compressed air be delivered into the receiver. The unbalanced valve therefore necessitates a pressure per square inch of $\frac{565.5}{4.91} = 115.2$ lbs. in the compressing cylinder, or 35.2 lbs. above the required pressure.

On the other hand, a 6-inch circular valve with $\frac{5}{16}$-inch seating exposes a surface of 28.27 square inches to the pressure in the receiver, and 22.69 square inches to the pressure in the cylinder. The total pressure on the receiver side of valve is therefore $28.27 \times 80 = 2261.6$ lbs., and would have to be balanced by a pressure per square inch of $\frac{2261.6}{22.69} = 99.7$ lbs., which is an excess pressure of 19.7 lbs.

In the latter and most favourable case, owing to the excess pressure the whole volume of air in the cylinder is heated 50° higher than with Daw balanced discharge valves. The increased work, during compression only, which this causes, according to the law of the equivalence of heat and work, is 13.4 per cent., and it is much greater for the smaller valve. Owing to some of the "excess pressure" being lost during expulsion of the air under the receiver pressure, the actual loss of efficiency is perhaps not so high as the 13.4 per cent., but nevertheless the loss is serious, and is saved by the Daw balanced valve system.

Discharge valves necessarily open and close under considerable pressure, and in addition to balancing the "excess pressure" due to the valve seating the Daw automatic balancing and controlling arrangement ensures the rapid and quiet opening and closing of the valves at the highest speeds.

In the Daw system of inlet and discharge valves the balancing and controlling are effected by the air pressure, and there is thus no rigid connection to the moving parts as in mechanically operated valves, and in consequence no danger of accident

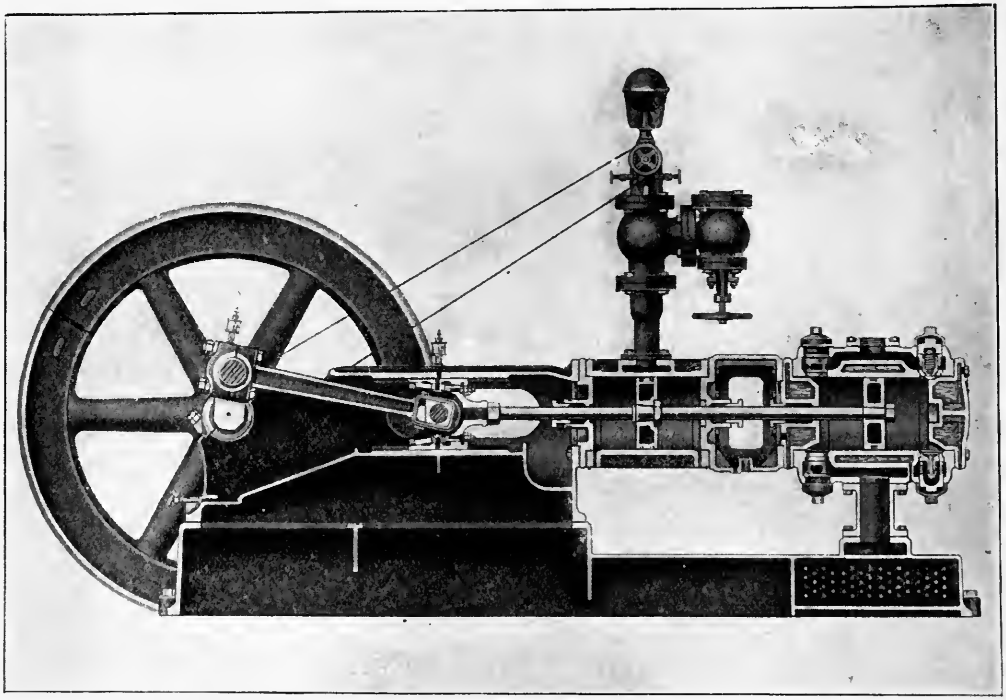


FIG. 166.—Air Compressor. Section.

should the pressure suddenly drop owing to a pipe breaking or a sudden accidental demand for air. Plate V. illustrates the complete Daw air compressor steam driven.

THE CONSOLIDATED TOOL COMPANY'S COMPRESSORS

The air compressors described and shown complete in Fig. 165, in section in Fig. 166, end view Fig. 167 showing the intercooler, are intended to meet the growing demand for higher efficiency in air compression that naturally attends the steadily increased adoption of pneumatic machinery in all branches of industry.

General designs follow the most approved steam engine practice, working along original lines only in details vital to economical air compression, avoiding any tendency to complicated mechanism, but providing unequalled strength and endurance. The chief points to be considered in the production of the most desirable air compressor, stated in the order of their relative importance to the user, are :—

Economy in power consumption. To obtain the best results, the compressor must, if steam driven, have steam valves designed and adjusted for minimum steam consumption in the development of its capacity, and must, irrespective of its actuating medium, possess efficient air valves, thorough water-jacketing of air cylinders and heads, and effectual automatic regulation.

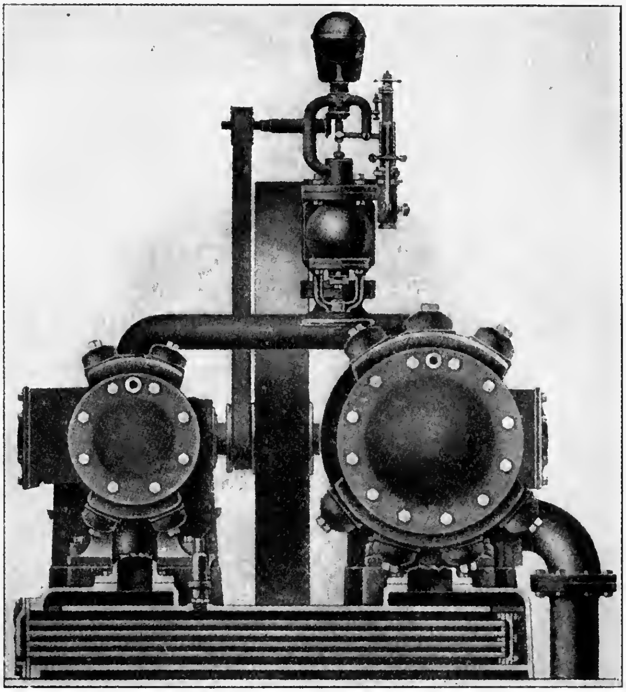


Fig. 167.—End View showing Intercooler.

Simplicity, and accessibility of parts. Second only to the consideration of the coal pile is the element of general design, which, from the practical standpoint, cannot be too strongly regarded. The desirable compressor is the one with mechanism readily accessible, and perfectly understood by the mechanic to whose care it is entrusted.

Air cylinder water-jacketing. The air cylinders and cylinder heads are thoroughly water-jacketed. Provision is made for a circulation of cold water the entire length of the cylinder, the water passing also through the heads, its cooling effect being especially concentrated around the discharge valves, which are naturally subjected to all of the heat due to compression and friction that has not been eliminated by the water jacket during the actual process of compression.

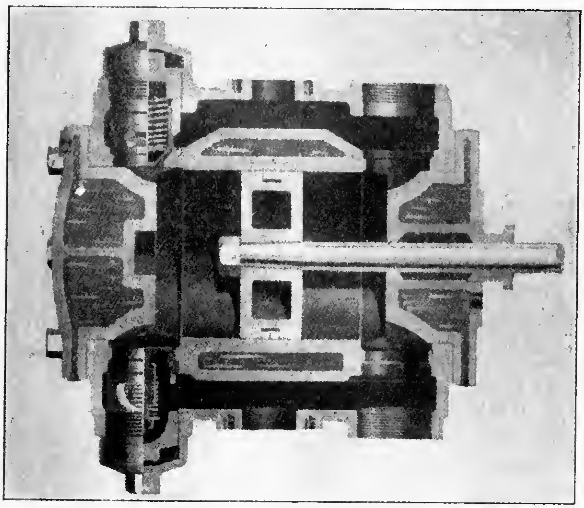


Fig. 168.—Section through Cylinder.

A novel feature, the value of which as a safeguard becomes readily apparent, is the outside water connection for conducting the jacket water between air cylinder and cylinder head, effectually preventing the possibility of serious accident through water entering the interior of cylinder should the gasket between cylinder and head become ineffective.

The air inlet and discharge valves are of the poppet type (Fig. 168) placed in the cylinder heads from the outside, and immediately accessible for adjustment or repair without removing the cylinder heads. Too much importance cannot be attached to the feature of accessibility, for the valves sustain the severest service of air compression and the heat incident thereto. Should the valves cease to perform their proper functions, the compressor is either wholly or partially disabled until the trouble is remedied; hence the great desirability of immediately accessible valves. A feature of more than ordinary importance is the fact that the valve seat is a part entirely separate from the cylinder proper, and may be removed, replaced, or renewed whenever occasion requires. We mention this because in most forms of air compressors employing poppet valves the valve seat forms an integral part of the cylinder head, affording no opportunity for renewal when it becomes worn.

In construction the valve and seat form a complete piece of mechanism, which may be examined, re-ground, and adjusted separate from the compressor.

The valves and seats are placed in position after the heads are attached to the cylinder, and are held securely by large screw plugs. As the heads need not be removed it is but a moment's work to take out a valve.

The valve springs are of steel, light enough to minimise resistance in opening, yet strong enough to promptly seat the valve in closing. The proportion of valve area to cylinder area is exceptionally liberal, enabling the cylinder to fill freely at each stroke,

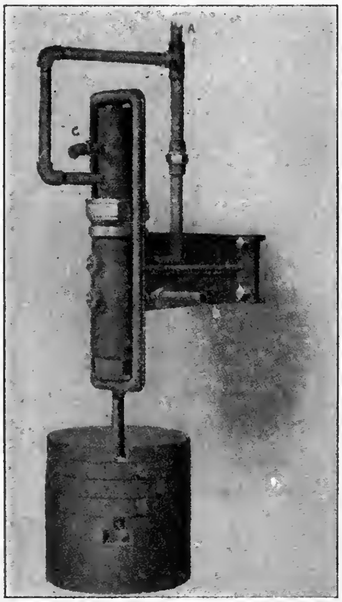


Fig. 169.—Unloading Device for Compressor.

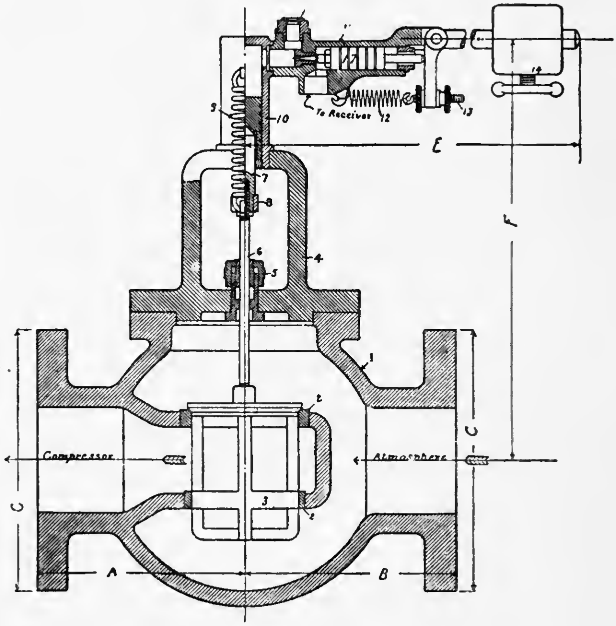


Fig. 170.—Unloader.

without volumetric loss or impaired efficiency due to the wire-drawing effect of deficient valve area.

Mechanically operated valves are excellent in theory but subject to some objections in practice, presenting large wearing surfaces and requiring a perfection of adjustment difficult to maintain in a series of cams, levers, and rods undergoing constant wear. Inlet valves operating mechanically, unless so adjusted that their opening and closing is perfectly timed, will seriously diminish the volume of air compressed, and while the adjustment may be perfect when the compressor leaves the maker, it does not remain so.

Cross-heads for single steam and belt-driven compressors are made from steel and semi-steel castings, provided with machinery steel couplings, to which steam and air piston rods are keyed by means of taper keys which draw the ends of rods up against the cross-head pin. This construction permits the cross-head to swivel around the pin, and as rods and couplings may be moved up or down on cross-head pin, alignment of pistons may be accurately maintained, avoiding cramping of rods in any direction. Bearing surfaces of cross-heads are babbitted.

All classes of duplex and compound compressors have cast-iron cross-heads of extra heavy section.

Duplex compressors have planed guides and cross-heads with adjustable shoes and guides, affording provision for taking up wear in all directions.

Compound compressors have bored guides, and cross-heads are provided with babbitted shoes at top and bottom, with wedge adjustment for taking up wear.

UNLOADING DEVICE FOR STEAM-DRIVEN COMPRESSORS

This device (Fig. 169) is furnished with all single steam-driven compressors. The pipe A is connected with receiver, pipe B with discharge valves (one or more in each head according to diameter of air cylinder), and pipe C to pressure regulator on governor. When the pressure in the receiver reaches the desired point, the unloader valve, by its

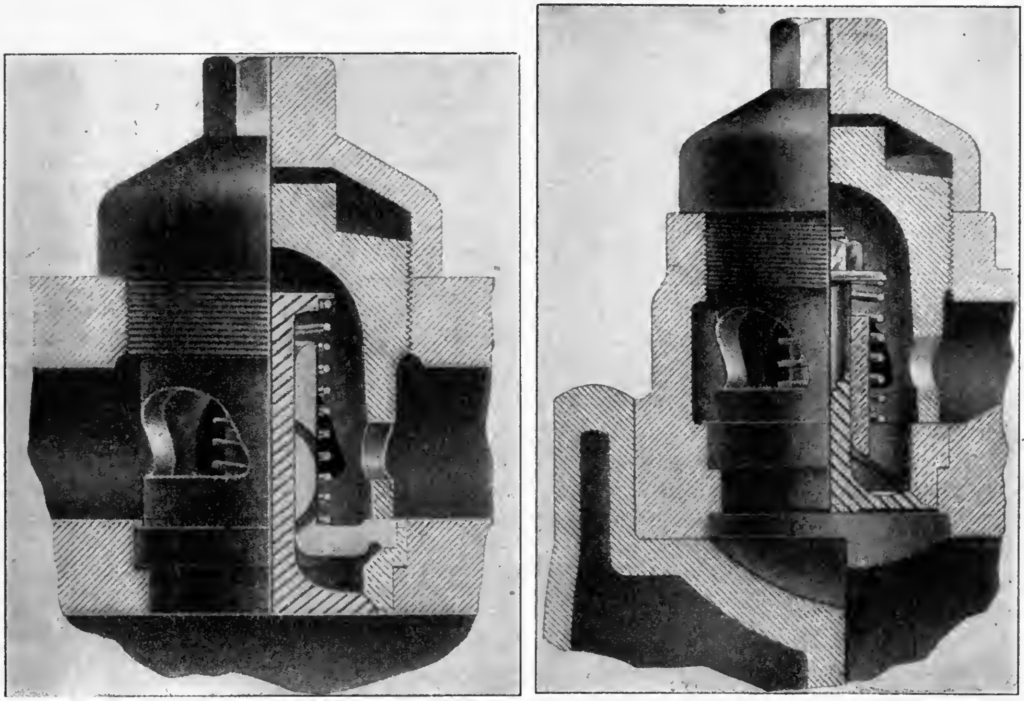


Fig. 171.—Inlet Valve.

action on dischage valves, allows receiver pressure to be carried to each side of air piston, balancing same, and compressor is unloaded. At same time receiver pressure is allowed to pass through pipe C to pressure regulator on governor, and steam is throttled down so that compressor just turns over under no load, causing an ideal economical condition. Upon a very small drop in receiver pressure a gradually increasing amount of steam is supplied, with a consequent increase of speed, until full speed is reached just before the load is thrown on again. The unloader furnished for single belt-driven compressors is exactly the same as that for steam-actuated machines, omitting connection to pressure regulator.

Duplex belt and compound belt compressors are provided with an unloader (Fig. 170) which is piped to intake and connected with receiver. When receiver pressure reaches maximum point desired, the unloader valve closes intake passage, thereby unloading compressor, and no power is required to drive it, except what is required to overcome friction. When the receiver pressure drops two or three pounds the inlet of compressor is reopened and compression resumed. The unloading and loading is accomplished so gradually that the compressor is subject to little or no shock in the operation.

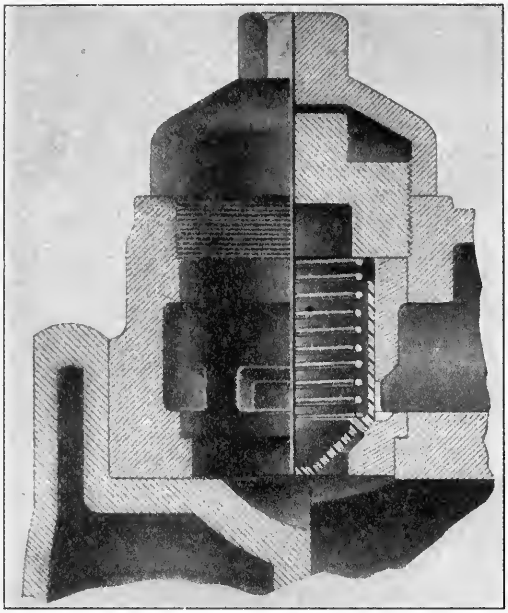


Fig. 172.—Discharge Valve.

Duplex and compound steam-driven compressors have pressure regulator only, as in these classes of machines it is practicable to stop compressor altogether when maximum receiver pressure has been reached; the compressor, having no dead centre, will start again from any point under load when pressure regulator has admitted the requisite amount of steam.

In the complete compressor the frame is of box section design, with large factor of safety to withstand the strains when working at maximum load; it is graceful in outline, with bored cross-head guide, and enclosed provisions for catching and removing drip from bearings and stuffing boxes. When furnished complete with base, as shown, the compressor is self-contained, obviating the necessity of expert services in erecting, and also reducing the cost of foundation.

Steam valves on cylinders under 12 inches in diameter are of plain slide type, accurately scraped to seat and securely fastened to rod. Cylinders 12 inches in diameter and larger are furnished with Meyer adjustable cut-off valves and gear.

The air inlet and discharge valves (Figs. 171 and 172) are of the poppet type, made from high-grade steel, having removable seats and guides, easily renewed or repaired and thoroughly guarded from entering cylinder in case of breakage. They are placed radially in cylinder, making them readily accessible, ensuring accurate seating, and reducing wear to a minimum. The air cylinder and its heads are completely water-jacketed, with thorough circulation of water, affording equal cooling at all points.

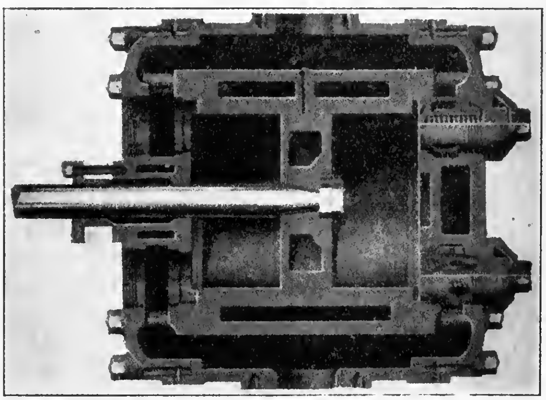


Fig. 173.—Air Cylinder. Section showing Piston Construction, Water-Jacketing Spaces, and Valve Location.

The pistons (Fig. 173) are of the solid type with cast-iron spring rings accurately fitted. The shaft is of the centre crank type, of large diameter, with exceptionally heavy crank arms, made of the best open hearth steel. The cross-head is of cast iron, with adjustable shoes at top and bottom, and the connecting rod is fitted with bronze cross-head pin boxes, having the wedge adjustment; the crank pin end is of the marine type, lined with genuine babbitt metal. The single compressor has two balance wheels, one on each side, of sufficient weight to ensure smooth operation. All bearings are of unusually liberal proportions, and only the best materials are used in their construction, with the most approved provisions for adjustment, designed to eliminate all trouble from heating and to reduce wear in working parts to a minimum. A pressure-regulating governor is provided to automatically control the operation of the compressor in accordance with the demand for air, working in connection with a speed governor for regulating the speed of the engine. An unloading device is provided to relieve the compressor of all load when the desired air pressure is obtained, and automatically cause it to resume delivery when the storage pressure becomes reduced.

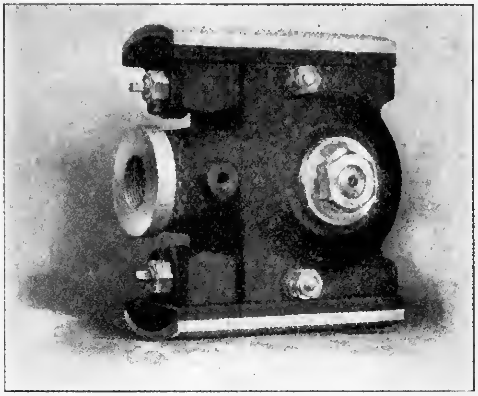


Fig. 174.—Cross-head of Compound Compressors.

The illustration, Fig. 167, shows end view of air compressor, with section through intercooler. The construction illustrated is common to all two-stage compressors, steam driven or belt actuated.

As will be seen from the illustration, the intercooler shell forms part of the compressor base, and is located directly under the air cylinders, making the whole machine self-contained and reducing floor space and piping to a minimum. The intercooler tubes are of brass, expanded into steel tube sheets as shown. Ribs are provided in water heads and baffle plates, inserted between tubes, ensuring complete circulation of both water and air. The circulation thus obtained, together with the generous amount of cooling surface provided, affords exceptional intercooling efficiency.

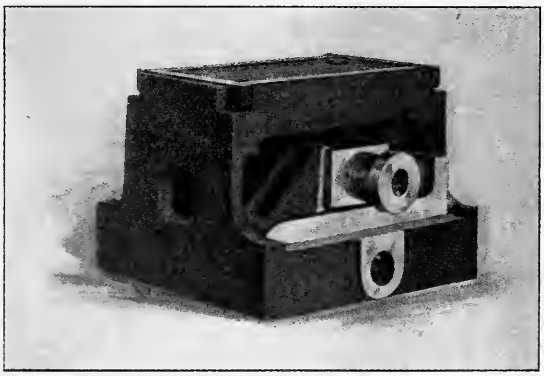


Fig. 175.—Steam Valve.

By removing bolts in outside head the entire nest of tubes may be easily withdrawn for repairs or cleaning. Drains are provided for both air and water spaces. Fig. 174 shows the cross-head, and Fig. 175 the steam slute valve.

The table (first table, page 160) does not take into consideration jacket cooling or friction of machine. Initial temperature of air at beginning of each compression is 60 degrees.

The table following (second table, page 160) will be useful for finding the capacity of an air compressor, or the cubical contents of any cylinder, receiver, etc. The first column is the diameter of the cylinder in inches, the second shows the cubical contents in feet, for each foot in length. To find the capacity of an air compressor, multiply the figure in the second column by the piston travel in feet per minute; this will show the theoretical capacity of each double-acting air cylinder; in the case of single-acting air cylinders the result should be divided by two.

To ascertain the volumetric capacity of an air compressor, multiply the cubic contents stated opposite its diameter (second column) by the piston travel in feet per minute. The result will be the theoretical capacity of each double-acting cylinder, or one-half of the result will be the theoretical capacity of a single-acting cylinder.

TABLE SHOWING HORSE-POWER DEVELOPED TO COMPRESS 100 CUBIC FEET FREE AIR FROM ATMOSPHERE TO VARIOUS PRESSURES

Gauge Pressure Pounds.	One-stage Compression H.D.P.	Gauge Pressure Pounds.	Two-stage Compression D.H.P.	Four-stage Compression D.H.P.
10	3.60	60	11.70	10.80
15	5.03	80	13.70	12.50
20	6.28	100	15.40	14.20
25	7.42	200	21.20	18.75
30	8.47	300	24.50	21.80
35	9.42	400	27.70	24.00
40	10.30	500	29.75	25.90
45	11.14	600	31.70	27.50
50	11.90	700	33.50	28.90
55	12.67	800	34.90	30.00
60	13.41	900	36.30	31.00
70	14.72	1,000	37.80	31.80
80	15.94	1,200	39.70	33.30
90	17.06	1,600	43.00	35.65
100	18.15	2,000	45.50	37.80
		2,500		39.06
		3,000		40.15

CONTENTS OF CYLINDER IN CUBIC FEET FOR EACH FOOT IN LENGTH.

Diam. Inches.	Cubic Contents.	Diam. Inches.	Cubic Contents.	Diam. Inches.	Cubic Contents.	Diam. Inches.	Cubic Contents.	Diam. Inches.	Cubic Contents.
1	.0095	5¾	.1803	10½	.6013	18½	1.867	32	5.585
1¼	.0085	6	.1963	10¾	.6303	19	1.969	33	5.940
1½	.0123	6¼	.2130	11	.6600	19½	2.074	34	6.305
1¾	.0168	6½	.2305	11¼	.6903	20	2.182	35	6.681
2	.0218	6¾	.2485	11½	.7213	20½	2.292	36	7.069
2¼	.0276	7	.2673	11¾	.7530	21	2.405	37	7.468
2½	.0341	7¼	.2868	12	.7854	21½	2.521	38	7.886
2¾	.0413	7½	.3068	12½	.8523	22	2.640	39	8.296
3	.0491	7¾	.3275	13	.9218	22½	2.761	40	8.728
3¼	.0576	8	.3490	13½	.9940	23	2.885	41	9.168
3½	.0668	8¼	.3713	14	1.069	23½	3.012	42	9.620
3¾	.0767	8½	.3940	14½	1.147	24	3.142	43	10.084
4	.0873	8¾	.4175	15	1.227	25	3.409	44	10.560
4¼	.0985	9	.4418	15½	1.310	26	3.687	45	11.044
4½	.1105	9¼	.4668	16	1.396	27	3.976	46	11.540
4¾	.1231	9½	.4923	16½	1.485	28	4.276	47	12.048
5	.1364	9¾	.5185	17	1.576	29	4.587	48	12.566
5¼	.1503	10	.5455	17½	1.670	30	4.909		
5½	.1650	10¼	.5730	18	1.767	31	5.241		

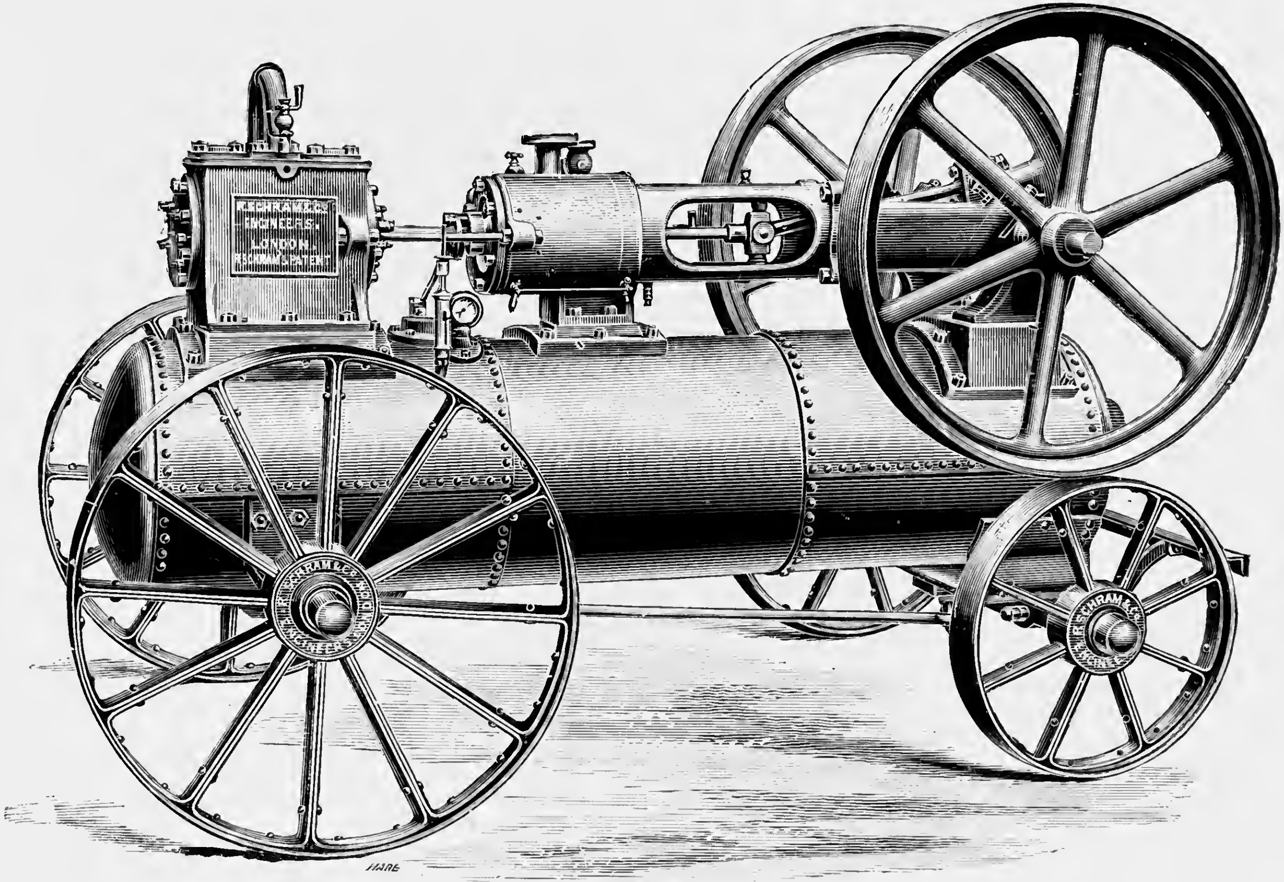


Plate VI.—Portable Steam Air Compressor.

THE INGERSOLL-SERGEANT COMPRESSED AIR MACHINERY

The steam-driven air compressor is shown in Figs. 174 and 175.

The frames are of the modified Tangye pattern, and bolted to a cast-iron base common to both engines. The air cylinders are tandem to the steam cylinders, and bolted to the same base, thus making a self-contained duplex compressor of a very compact type, and which will go into a very small space.

The air cylinders are of the water-jacketed type, as shown on page 148, provided with the latest improved vertical lift inlet and discharge valves. Special pains have been taken to make the intake area very large and the valves light in weight, so that there will be the least possible throttling of the incoming air. These valves are so located, or arranged, that in case of a broken stem no particle can be drawn into the air cylinder and wreck the machine; therefore no guards are necessary, and the intake parts are unobstructed, straight, and free. This feature will be appreciated by users of other compressors who have been constantly bothered with pieces of broken valves falling into the cylinder and ruining it. As the valves are enclosed, they are less noisy than any other type of poppet valve; they can be replaced in a few moments, and can be made at any machine shop. As their movement is vertical instead of horizontal, they will not wear down out of line with their seats, but on the contrary, will wear and stay tight. The discharge valves are of soft steel, which will not crystallise under the constant heat and vibration. Every part of the machine is easily accessible. The air cylinders are completely water-jacketed, not only around the barrels but through the heads, this arrangement being made possible by reason of the valves being placed in the cylinder, instead of in the heads; the cooling effect of the water jacket is greatest at the heads, because the greatest amount of heat is developed at the ends of the cylinders close to the heads. Clearance spaces are very small, the piston travelling close to the head, and is adjustable to compensate for the wear in the bearings.

This cylinder overcomes more than any other the objections usually urged against poppet valve compressors, and next to the high duty piston inlet device it is the very best air cylinder on the market.

The steam cylinders are covered with sheet-metal carefully packed with mineral wool or other non-conducting material. The steam cylinders may also be compounded when desired, on the sizes having 12-inch steam cylinders and larger.

The strains in an air compressor being nearly double what they would be in a steam engine of the same power, these compressors are made much heavier than any other machine of similar design. This liberal distribution of metal ensures stiffness, reduces friction by avoiding springing, and is conducive to long life of all parts, ensuring smooth, quiet running at maximum loads.

These machines are furnished with a ball governor, which prevents running away in case of a broken air pipe or consumption of air beyond the capacity of the compressor at full speed. Working in combination with this governor there is an automatic regulator, which throttles the steam more or less, according to the varying air pressure, so that the machine runs at all times at that speed which is necessary to supply the demand. In this way no more air is compressed than is used, thus economising power. The machine may be arranged to stop when no air is being used, and to start again when the pressure is lowered a few pounds, but it is better to arrange it so that it will never quite stop, thus avoiding damage from the accumulation of water in the cylinders and pipes consequent upon a long stop.

The intercooler furnished with compound machines of this type is located in the sub-base immediately under the air cylinders, and resembles in construction a surface condenser, being composed of a number of parallel tubes set close together, so as to break the air up in very thin sheets and ensure perfect cooling. Baffle plates are put in at short intervals, so that the current of air moves up and down across these tubes, and is completely and thoroughly cooled before it enters the high-pressure cylinder. Water circulates through these tubes constantly. The air space is large, so that there is a sufficient reservoir, from which the high-pressure cylinder is properly filled at each stroke. The circulating water enters the cooler first, passing from there to the high-pressure cylinder heads and jackets; next to the low-pressure cylinder heads and jackets, and from that point, it is usually led to the tank from which the boiler feed pump takes its supply. Provision is made for draining all parts of the cooling arrangement to avoid freezing in cold weather if proper precautions are taken. There is little economy in compounding unless thorough and ample intercooling is provided.

This type of machine will be found well suited for general manufacturing.

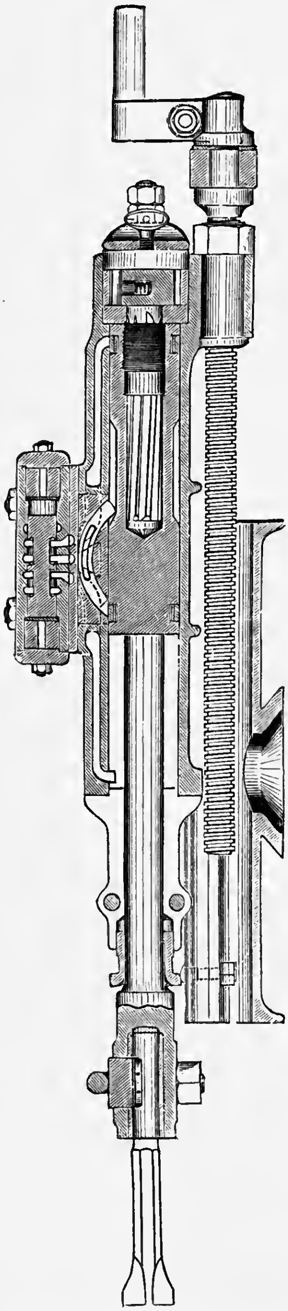


Fig. 176.—Auxiliary Valve Drill.

THE AUXILIARY VALVE AIR DRILL

The Sergeant "Auxiliary Valve" was a successful solution, carrying with its construction the strong advantages of the variable stroke with a harder blow. The essential features of this valve motion have been in practical use for many years, and have been steadily improved with a further experience covering all imaginable conditions. It is a type which has been uniformly satisfactory in its proper field of use, and uniformly successful in the harder rocks and ores.

The difference between this valve motion and that of the Ingersoll "Eclipse" type is the introduction of a plate between the independent valve chest and the cylinder, which plate carries a lug projecting into the cylinder. In this lug is milled an arc-shaped cut in which slides a light curved steel piece, provided with suitable ports. The sole purpose of this little "auxiliary valve" is to act as a trigger to operate the main valve at just the right time.

The piston in its movement in either direction slides under the curved auxiliary valve, and slips it tangentially in its arc-shaped seat. At the proper time a small port is uncovered and air released from one end or the other of the main valve, which admits the live steam or air under full pressure into the proper end of the cylinder, and drives the piston forward to strike the blow, or back for lifting the piston, as the case may be.

The auxiliary valve is simply a trigger or trip to the main valve. It is held tight upon its seat by the pressure alone, and this causes a uniform wear and ensures against leakage. As this auxiliary valve is extremely light, is made of hardest steel, and moves on the arc of a circle, it moves easily, without battering or lessening the force of the piston and with very little wear. It is guaranteed against breakage.

The use of this special auxiliary valve admits of variable stroke, a short one in blocking out the hole to start, thus avoiding "funneling" and "rifling," and a full stroke as soon as the hole is well started. Stroke variation requires no special handling, as it is effected entirely by the feed screw, and the operator does not have to bother about any extra regulating valves, as it is only necessary to feed the crank forward for a short stroke or back for the full stroke.

The auxiliary valve is automatic, positive in action, durable, and cannot get out of order. It is perhaps the greatest single improvement in rock drills since the Ingersoll "Eclipse" drill was produced.

The piston rod and chuck are in one piece, are especially heavy, hardened, and ground true. The bearing or guiding surface on cylinders and front head is very great, ensuring long life and tight parts.

The spool valve is of the balanced piston type, hardened tool steel and accurately ground. Fitting plug-like, a short travel gives full port opening instantly. We have never known of one breaking. They last indefinitely, as wear is practically eliminated. This spool valve, through the delayed action of the auxiliary valve and ports, does not move until the blow is struck, allowing a free exhaust and removing all cushion.

Fig. 176 shows a section of this auxiliary valve drill; and Fig. 177, the drill set up and at work, and Fig. 178 shows the valves.

Fig. 177.—Auxiliary Valve Drill.

The rotation device (Fig. 179) is the most perfect yet designed, being simple, positive, and durable in its parts, easily got at, and so arranged that the flat steel cushion head springs give an adjustable friction clutch effect, allowing the rifle bar to slip backward before breaking any of the parts or twisting the bar should the bit strike a glancing blow. This enables the machine to work itself free in seamy or caving ground, and is an essential feature for a perfect drill. The ratchet is drop forged, ground, and carefully hardened. The small pawls are tool-steel hardened in oil, as is also the rifle bar, which runs in a removable bronze nut screwed in the end of the piston, thus easily replaced when worn.

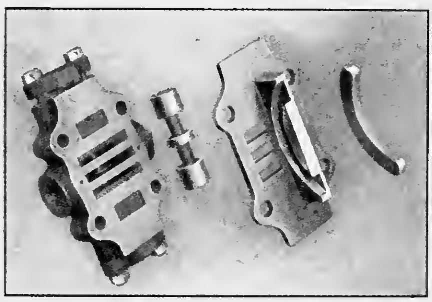


Fig. 178.—Auxiliary Valve Chest and Parts.

Feed nut and screw are spring steel, accurately made and hardened tough. The crank is adjustable for wear on the steel cross-head, and is made of malleable iron to stand rough usage.

The malleable shell (Fig. 180) gives an extra large wearing surface for the guides, and the caps are arranged to take up wear.

The largest experience in drill manufacture has shown this to be important, especially in hard, bad ground. Drills for which greater simplicity of construction is claimed will be found lacking in adjustments for wear, requiring a rejection of the entire

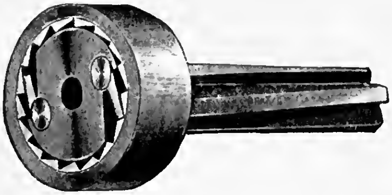


Fig. 179.—Patent Rotation.

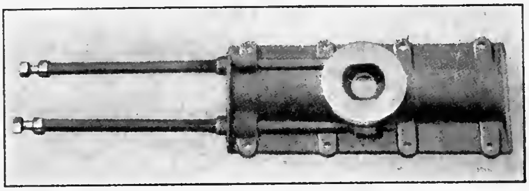


Fig. 180.—Shell and Mounting.

shell where a few strokes with a file will put our shell in condition equal to its original tightness.

The shell is attached to the mounting with the Sergeant reversed cone, so that the drill can free itself in a crooked hole, or swing aside and come back in perfect alignment: a feature appreciated by experienced miners.

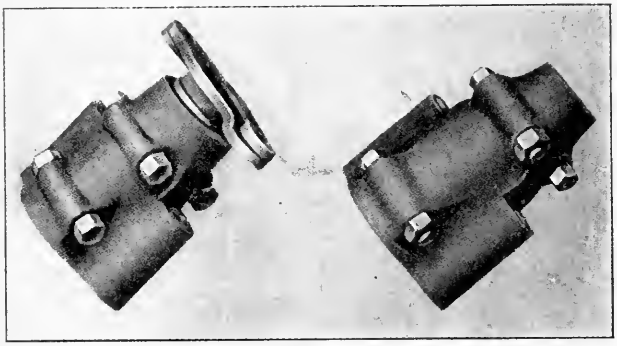


Fig. 181.—Front Heads, Air and Steam.

The new front heads (Fig. 181) are of special metal, with the best gland ever devised for this troublesome place. They are made for steam or air, and split so that they can be renewed when worn. With the steam head the gland bolt screws in an extension on the through bolt, thus referring all strains directly to the cushion springs and obviating lugs and projections on the head. This gland cannot work loose and drop off, and on account of its rigidity the drill piston is well supported when fully extended, and binding and uneven wear are avoided.

When air is used a special front head of the same type is furnished, which has a cup leather packing ring, and dispenses with the stuffing box altogether.

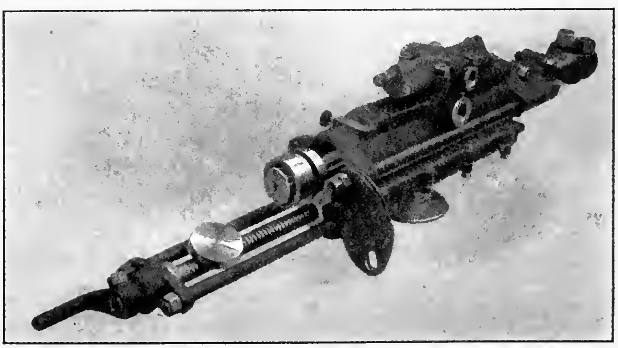


Fig. 182.—Cushion Springs and Rotation Removed.

The Sergeant patent flat cushion spring is now used on all but the "Eclipse" drills. This head cushioning device is the most simple, safest, and most durable form yet brought forward, and is an infinite improvement over rubber cushions or coil springs. The flat spring rarely breaks, oil cannot affect it, and it does not deteriorate with exposure. It protects both heads, not simply the lower head. Any blacksmith can make a new set, which is impossible with other forms. In addition, it permits the drill to be taken apart more easily and quickly than other devices, as removal of nuts from one through bolt exposes the entire rotation mechanism. This spring is, all in all, one of the most important improvements made since the introduction of rock drills, Fig. 182. It has been found that the wear of the spool valve in drills using this form of valve sooner or later allows the steam or air leakage by the body of the valve at either end to become excessive, when the drill works unequally. Heretofore it has been necessary to renew the valve to overcome this trouble.

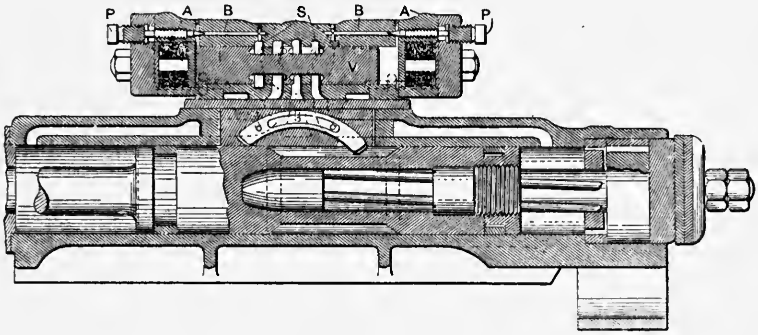


Fig. 183.—"52" Style Chest.

To obviate this, and in cases where customers wish a valve adjustable for wear, a type of chest for different (see Fig. 183) sizes of Sergeant auxiliary valve drills are made. The operation of this device is as follows:—

The chest has a port B, connecting the ends of the valve cylinder with live steam

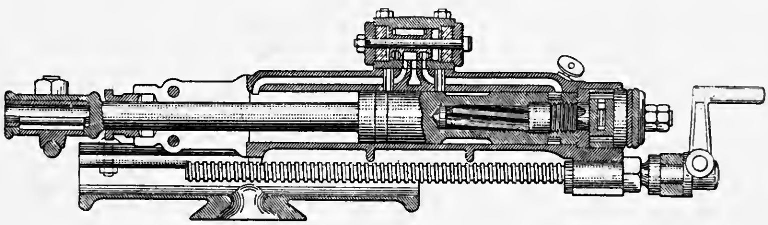


Fig. 184.—New Ingersoll Drill.

or air from the supply port S. The amount of opening in these discharge passages is controlled by two regulating screws AA, so that just the right amount of steam or air may be admitted at either end to properly operate the main valve V. By adjusting the screws AA the stroke of the drill can be changed and the machine properly regulated to drill either up, horizontal, or down holes. Should a drill after being in use for some time strike the back head or run irregularly, it would be due to the valve V wearing in the chest, in which case steam would leak past the valve V. To reduce this leak turn the regulating screws AA to the right, which restricts the leakage through the ports B and again makes the valve work properly. This regulation can be continued as the valve wears until screws AA are turned down tight, when the chest must either be repaired and a new valve fitted to the same, or a complete new chest must be purchased.

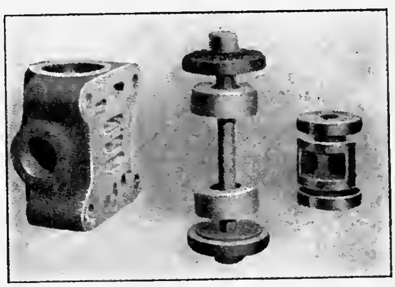


Fig. 185.—New Ingersoll Valve Guide and Chest.

The plug screws PP are intended only to cover and lock the screws AA, so as to keep them from shifting. These should always be put back in place after regulating the valve screws AA, and screwed tight to jam against the top of the adjusting screws AA.

Figs. 184, 185, and 186 show the details of the new Ingersoll-Sergeant drill.

THE ARC VALVE TAPPET DRILL

This drill is shown in Figs. 187, 188, and 189.

With wet steam the tappet drill, because of its positive valve movement, is preferred to other types. When the rock is not hard and is reasonably firm and solid this type may be preferred for open quarry work to the independent valve drill. A tappet drill will not allow of so much variation in stroke as the Sergeant "Auxiliary," because the piston must start and move far enough to work the tappet and cause the valve to uncover the port for the return stroke. This is a disadvantage in shelly or seamy rocks, or material which caves at all badly, but in even, solid rock a full stroke is wanted. The independent valve will do more work, is more durable, and will start holes on a glancing face quicker and with less breakage of shanks, but the necessity of using wet steam very often determines the matter in favour of the arc tappet. The arc valve tappet drill strikes a slightly cushioned blow, which is of benefit in some materials, as giving an elastic, springy, free action where a more dead blow would drag.

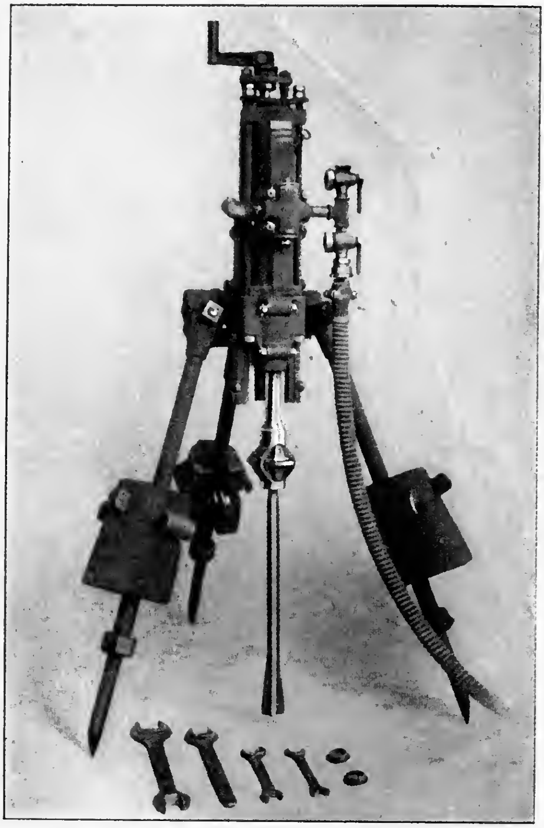


FIG. 186.—New Ingersoll Drill.

The piston is made with wedge shoulders which slide under the rocker, forward or back, not striking but lifting the valve easily in the same direction as the piston moves. The original tappet drill and others since have used a flat valve, which must move straight in a flat plane, while the rocker arm moves on a curve. These two antagonistic movements and resultant lost motion in the rocker head gouge the seat, break pins, rocker and valves, and soon interfere with the proper working stroke, as any one accustomed to that tappet movement is aware.

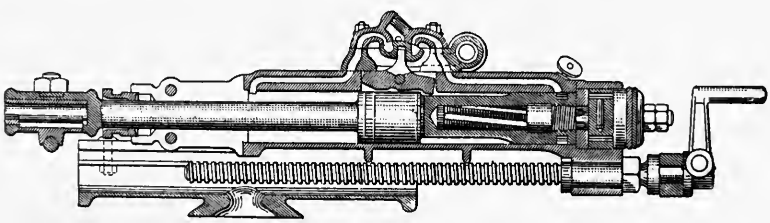


FIG. 187.—Arc Valve Tappet Drill.

With the improved "arc valve" the rocker is shorter and stronger; the valve moves on the same curve as the rocker; the motion is easy, light, and free, and the drag, wear, and breakage less than with any other tappet type. The valve will not lift off its seat except as a relief valve when water is to be worked out. The pivot or tappet pin is very large and cannot work loose; the rocker is of tool steel, of very wide section, and the valve is held to its seat by the working pressure to take up the wear, and hence must remain tight.

A steam or air-moved valve is shown in the section of the drill (Fig. 187).

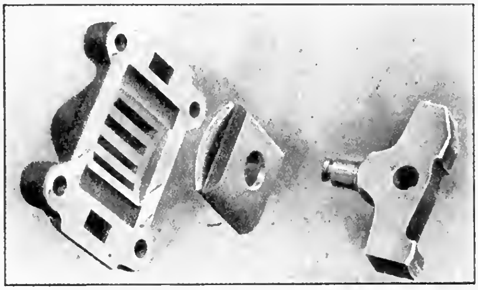


Fig. 188.—Arc Valve, Tappet, and Chest.

The valve mechanism consists of a chest containing a single moving part, a cylindrical spool valve, the chest being bolted to the front and centre of the cylinder. The ports are so arranged that the movement of the piston exhausts the accumulated pressure from one end or the other of the valve chamber, which in turn admits full pressure alternately to the cylinder at the top or bottom of the main piston.

AIR-DRIVEN COAL CUTTING MACHINE

Compressed air has been largely used in coal-cutting machinery. A handy form is shown in Fig. 190. It has the same action as the rock drill acting by percussion. Air presents peculiar advantages for percussion drills. Many attempts have been made to work percussion drills electrically, but without success. Electrically produced motion is naturally rotary. Reciprocating motion cannot be obtained economically.

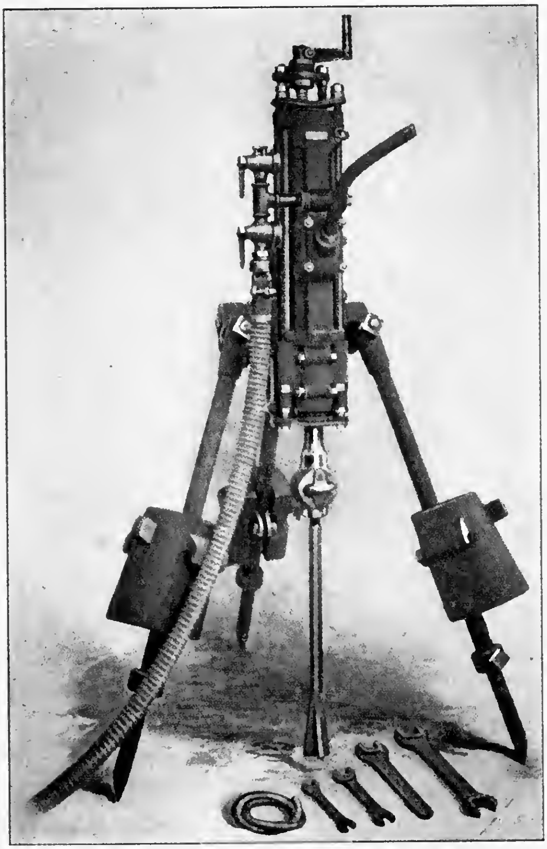


Fig. 189.—Arc Valve Tappet Drill.

THE PNEUMATIC TOOL

This machine, shown in Fig. 191, is used for hammering, chipping, and caulking, riveting, stone-cutting, etc.

THE SCHRAM ROCK DRILL

This is a compound machine having two cylinders in tandem, and is shown in section in Fig. 192, and complete in Fig. 193 set up, and also in Fig. 194.

The lower end of the cylinder is bored out to a larger diameter than the upper end, and during the forward stroke of the piston the air is exhausted from the lower end of the cylinder, and the air at full pressure is simultaneously admitted to the upper end of the cylinder, thus giving a most powerful and rapid stroke. The air that has been used to make the forward stroke, instead of being exhausted to the atmosphere (as in ordinary drills), is taken through the valve to the under side of the lower piston and utilised for the backward stroke;

the result of this, in combination with other improvements in the construction of this drill, is that the consumption of compressed air is 40 per cent. less than that of any other drill of the same size and stroke.

The operation of the machine is as follows:—Assuming the piston *e* and valve *f* to be in the position as shown in the illustration, the cylinder *a* will be in communication with the air under pressure through the port *b* (the cylinder a^1 being at the same time in communication with the atmosphere through the ports *m* and *h*); the result of this will

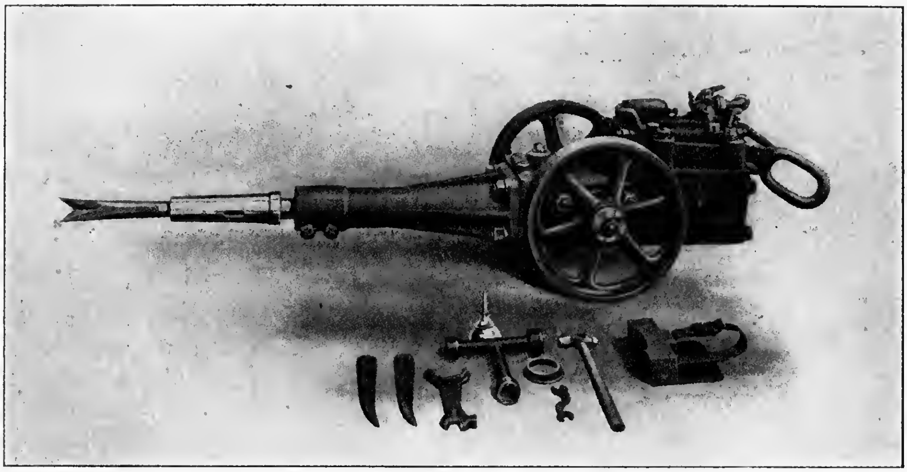


Fig. 190.—Ingersoll-Sergeant Coal Cutter.

be that the piston is forced forward, and immediately the piston *c* uncovers the small port *d* a portion of the compressed air passes into the small cylinder *r* behind the valve piston *e*, and acting on a larger area than that which is subject to the constant pressure at *l*, and the fact that there is no resistance at the other end of the valve piston *e* owing to the passage *n* communicating with the atmosphere, forces the valve *e* over to the other end of the valve chest, thereby cutting off the communication with the air under pressure, and placing the cylinders *a* and a^1 in communication through the ports *b* and

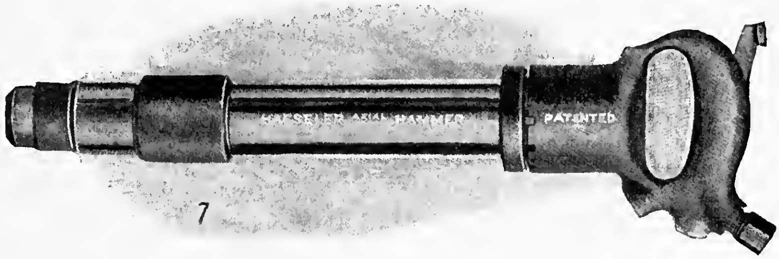


Fig. 191.—Axial Valve Riveting Hammer.

m. Then the air that has acted on the piston *c* now passes into the cylinder a^1, where it acts on the piston *g* of larger area than the piston *c*, thereby moving the piston backwards to its original position. When the piston *c*, during its backward stroke, passes the port *d*, the cylinder *r* is placed in communication with the atmosphere through the ports *d* and *h*, and the constant pressure acting on the piston valve *e* at *l* moves the valve *f* over to the position as shown in the illustration; the air again enters the cylinder *a*, and the action is repeated.

It will be seen that the air used for the forward stroke is again utilised for the backward stroke, without in any way impeding the piston in its forward stroke, and this causes a great saving of compressed air. The air being instantaneously admitted to the cylinder *a*, while cylinder a^1 is in free communication with the outlet, causes the piston to give a very powerful blow, which makes this machine more effective than any

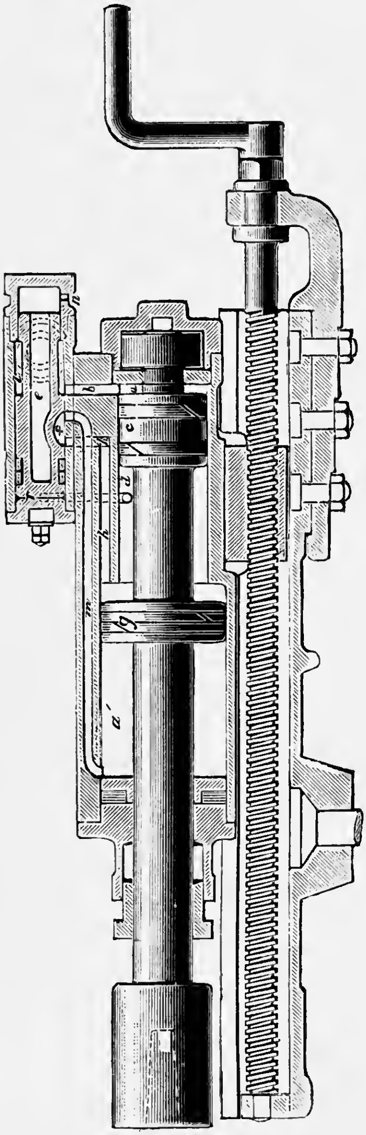


Fig. 192.

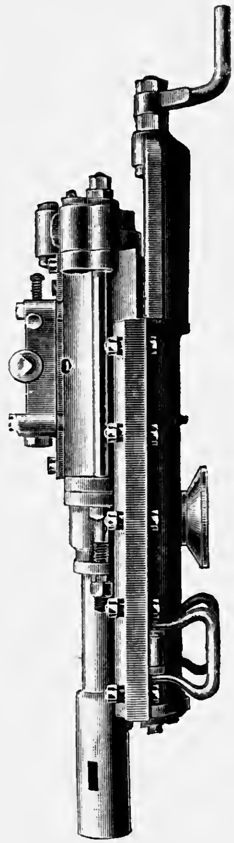


Fig. 193.

Schram Drills.

other rock drill. At the end of each backward stroke there is still some pressure left behind the piston *c*.

Plate VI. shows a Schram portable compressed air plant, on wheels suitable for colonial mining purposes. The steam boiler is separate, and also on wheels.

THE DIAMOND BORING DRILL

The cutting head or crown of this drill is shown in Fig. 195. It has a hollow core, into which a rod of the strata cut through is formed. This core or rod can be withdrawn, and gives a correct measurement of the various seams cut through. The black diamonds are set in the edge of the crown, and they cut by rotary motion.

AIR COMPRESSORS

Fig. 196 shows one of Tilghman's Patent Sand Blast Co.'s compound air compressors. This type, which is suitable for air pressures up to 130 lbs. per square inch, is made in sizes ranging in capacity from 150 to 600 cubic feet of free air per minute.

Belt, steam, and electrically driven types are made. The design is particularly suitable for the latter as having two double-acting cylinders, four deliveries of air given per revolution thus maintaining a practically constant load on the motor. This is a very essential feature of the modern air compressor, as a large proportion are now driven electrically.

It is generally admitted that in the smallest sizes of compressors automatic inlet and delivery valves are preferable, owing to the absence of complications necessary in the case of those mechanically operated.

The special feature of these compressors is the use of Mathewson's patent valves and springs on the inlet side of the cylinder ends where small clearance is necessary. These valves are exceedingly light, and occupy very small space in proportion to their effective area. One-fifteenth of the cylinder area is obtained with a clearance of less than 2 per cent. of the cylinder capacity. The weight of a 3-inch valve and spring being under 2 oz., the hammering action of the ordinary valve is entirely absent.

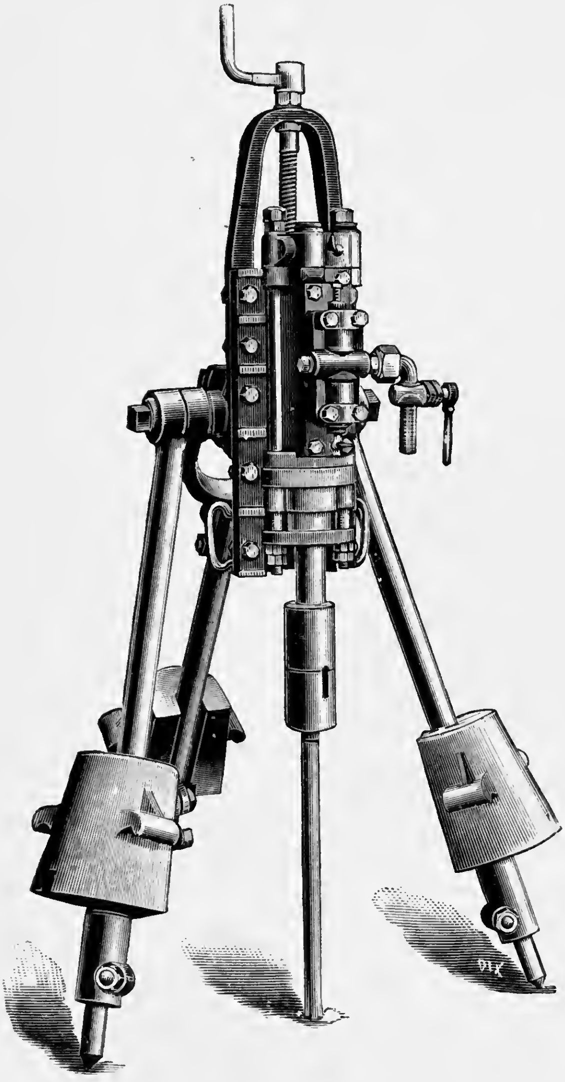


FIG. 194.—Schram Drill.

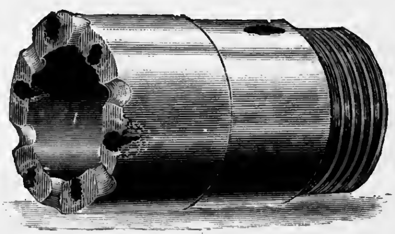


FIG. 195.—Diamond Cutter.

The valves on the delivery side (where space occupied is not important) are steel stampings held on the seat by special close coiled springs, which when compressed to the required lift of the valve are completely closed, thus avoiding the excessive shock caused by a fixed stop. The difference in pressure required to open the valve is $\frac{1}{4}$ lb. per square inch.

The makers claim that greater efficiency is obtained by utilising the cylinder ends as valve chests than by using radial valves and water-jacketing the cylinder ends. The increase valve area obtainable and reduced clearance more than compensates for any extra cooling effected. When it is considered that in a small compressor, say one of 300 cubic feet capacity, a single stroke or compression only occupies about $\frac{1}{8}$ of a second, it cannot be expected that much cooling will take place in a cylinder in that time. Undoubtedly the only place where thorough cooling can take place is in the intercooler, where the air velocity over the cooling surface is very low. As a proof of this, the

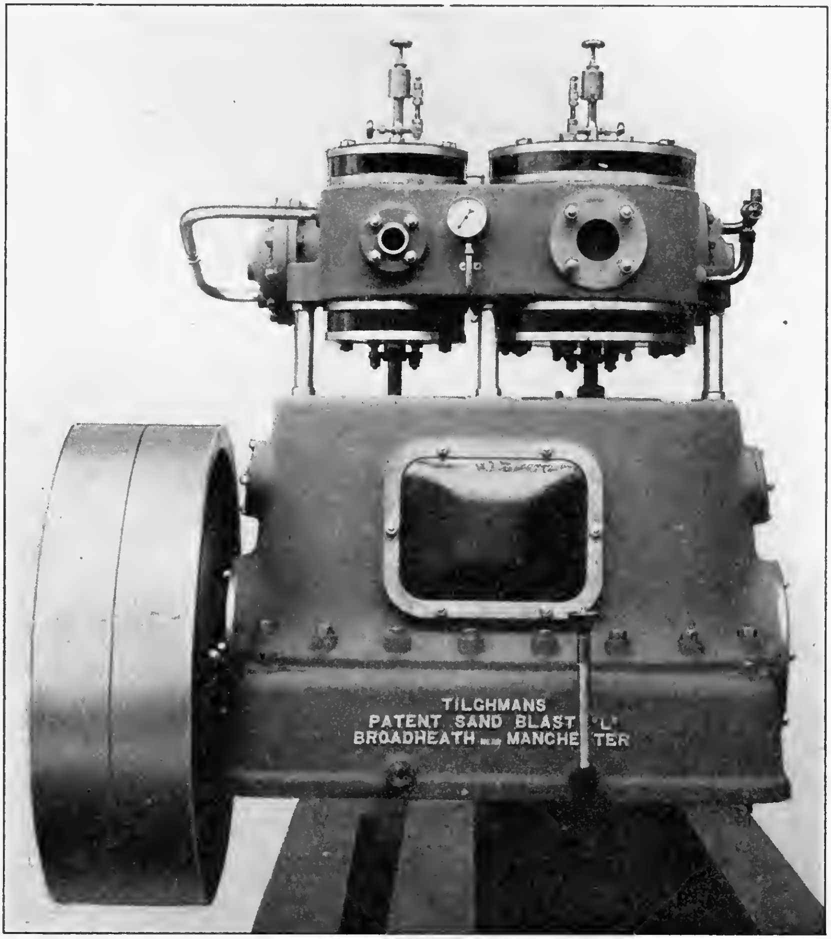


FIG. 196.—Air Compressor. Steam.

makers are able to guarantee a volumetric efficiency of over 90 per cent., and from 80 to 85 per cent. commercial efficiency, a remarkably good result for these sizes.

The makers guarantee a volumetric efficiency of 90 to 93 per cent. and a mechanical efficiency of 80 to 85 per cent. with their compound types when working at 100 lbs. per square inch gauge pressure, and with the single-gauge type a volumetric efficiency of 80 to 85 per cent. and commercial efficiency of 70 to 75 per cent. when working with a gauge pressure of 80 lbs. per square inch.

The sectional drawing (Fig. 197) is of one of their vertical cross compound closed type compressors driven by belt.

Air cylinders. Each cylinder is double acting, and fitted with cast-iron liner of special mixture, the space between the liner and the cylinder shell forming the water jacket. The low-pressure cylinder is fitted with a relief valve set to blow off at 35 lbs. per square inch, making it impossible that the low-pressure cylinder should carry the full pressure in the event of a valve breaking in the high-pressure cylinder. The cylinder ends contain all the valves, inlet and outlet.

The intercooler is of sufficient area to maintain an even pressure, and has ample cooling surface to extract all the heat generated in the low-pressure cylinder during compression. It is fitted with a number of small brass tubes through which water is circulated. Baffle plates are fitted so that the whole tube area is effective.

The patent automatic governing valve shown automatically regulates the amount of air compressed to that required, in the following manner. When the amount of air required is less than the capacity of the compressor the air pressure rises, and by means of a small weighted piston air is admitted from the air receiver to the governing cylinder, thus closing the air inlet and thereby putting the low- and high-pressure pistons

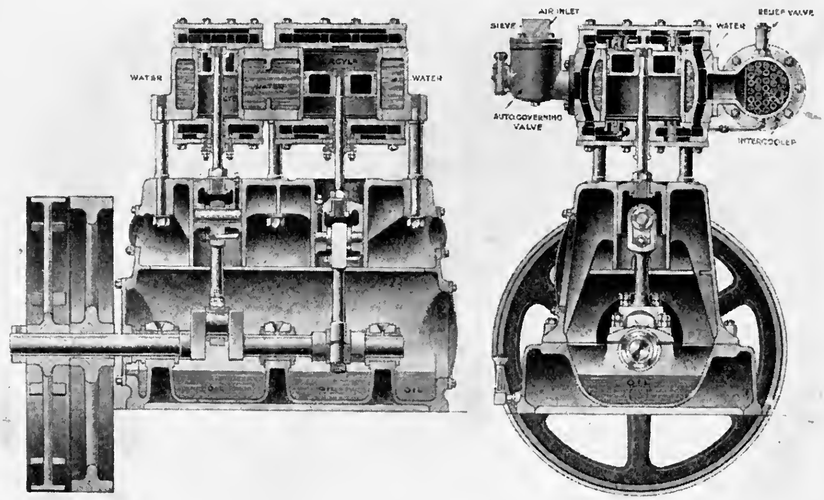


FIG. 197.—Sectional Views of Air Compressor.

into equilibrium by causing a partial vacuum on both sides of the piston. The power saved by its use is very considerable where there are frequent variations in the amount of air used. The variation in pressure required to accomplish the desired effect is from 2 to 5 lbs.

Lubrication. All the bearings are lubricated automatically by the splash system, the crank pins working in a bath of oil. The level of the oil is shown by an oil gauge fixed outside the bed-plate. The cylinders are lubricated by large size sight-feed lubricators. With this form of lubrication the compressor is quite automatic, and only requires stopping and starting.

As the inlet valves are practically inside the cylinder, the clearance space required to admit them to a great extent determines the ultimate volumetric efficiency of the compressor.

Mathewson's patent valves, as will be seen from the illustration above, occupy very small space in proportion to their effective area, ample valve area being obtainable with a clearance of only 1 to 2 per cent. of the cylinder capacity. They are exceedingly light (a 3-inch valve and spring scaling less than 2 oz.), perfectly air-tight, and practically noiseless in working. Both valve and spring are made from a special quality of sheet steel, the valve being ground on the contact side whilst held by a magnetic chuck.

The space occupied by the outlet valves in no way affecting the efficiency of the compressor, their dimensions need not be cut down. The valve is a light steel stamping held on its seat by a special close coil spring which, when the valve attains the required lift, is completely closed, thus avoiding the shock caused by a fixed stop.

The efficiency of this design is amply proved by their long life, and also by the absence of noise whilst working.

All the standard compressors, except the small single-acting type, have cylinders as shown.

The cylinders are fitted with cast-iron liners of a special mixture, the space between the liner and cylinder shell forming the water jacket. The cylinder ends are perfectly

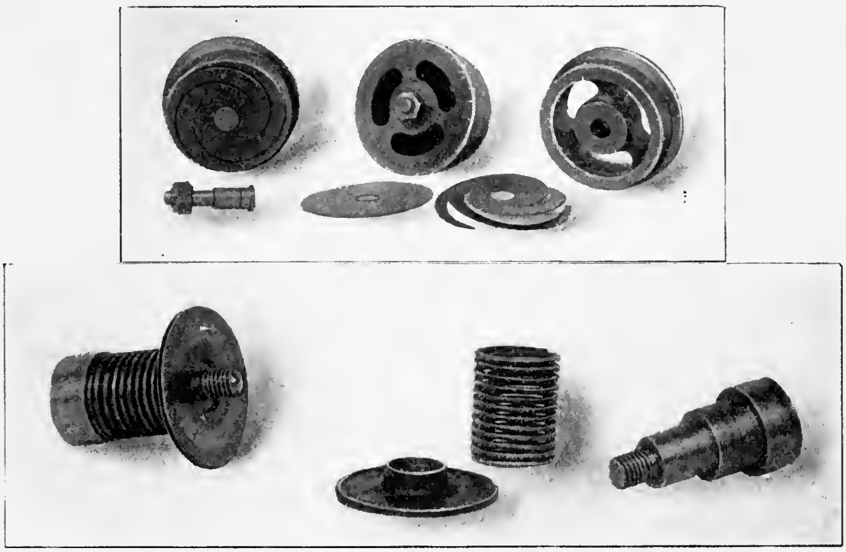


FIG. 198.—Details of Valves.

flush, and as guards are fitted to the inlet valves nothing can possibly find its way into the cylinder.

The air openings through these guards have sufficient area to allow the air to pass freely through them.

In regard to water-jacketing, it is claimed that greater efficiency is obtained by utilising the cylinder ends as valve chests than by using radial valves and water-jacketing the cylinder ends, as the increased valve area and reduced clearance more than compensates for any extra cooling obtained. When it is considered that with compressors ranging from 20 to 1000 cubic feet of free air per minute a single stroke only occupies from $\frac{1}{10}$ to $\frac{1}{5}$ of a second, it cannot be expected that much cooling will take place in the cylinder.

They claim a volumetric efficiency of not less than 90 per cent. with compound compressors, and 80 per cent. with the single-stage type—the air pressure 100 lbs. for the compound and 80 lbs. for the single stage.

BROTHERHOOD AIR COMPRESSORS

The belt-driven machine is shown in Fig. 199 in outline; the steam-driven machine in Plate VII., and in section in Fig. 200.

In the single-stage machines the intercoolers are omitted, two double-acting air cylinders of equal size are fitted. Where steam is not available the steam cylinders and distance pieces are omitted, and an electric motor is coupled to the extended crank shaft or belt pulleys, or gear wheels are fitted for driving.

Each air-compressing cylinder is carried on a cast-iron casing bolted to the crank

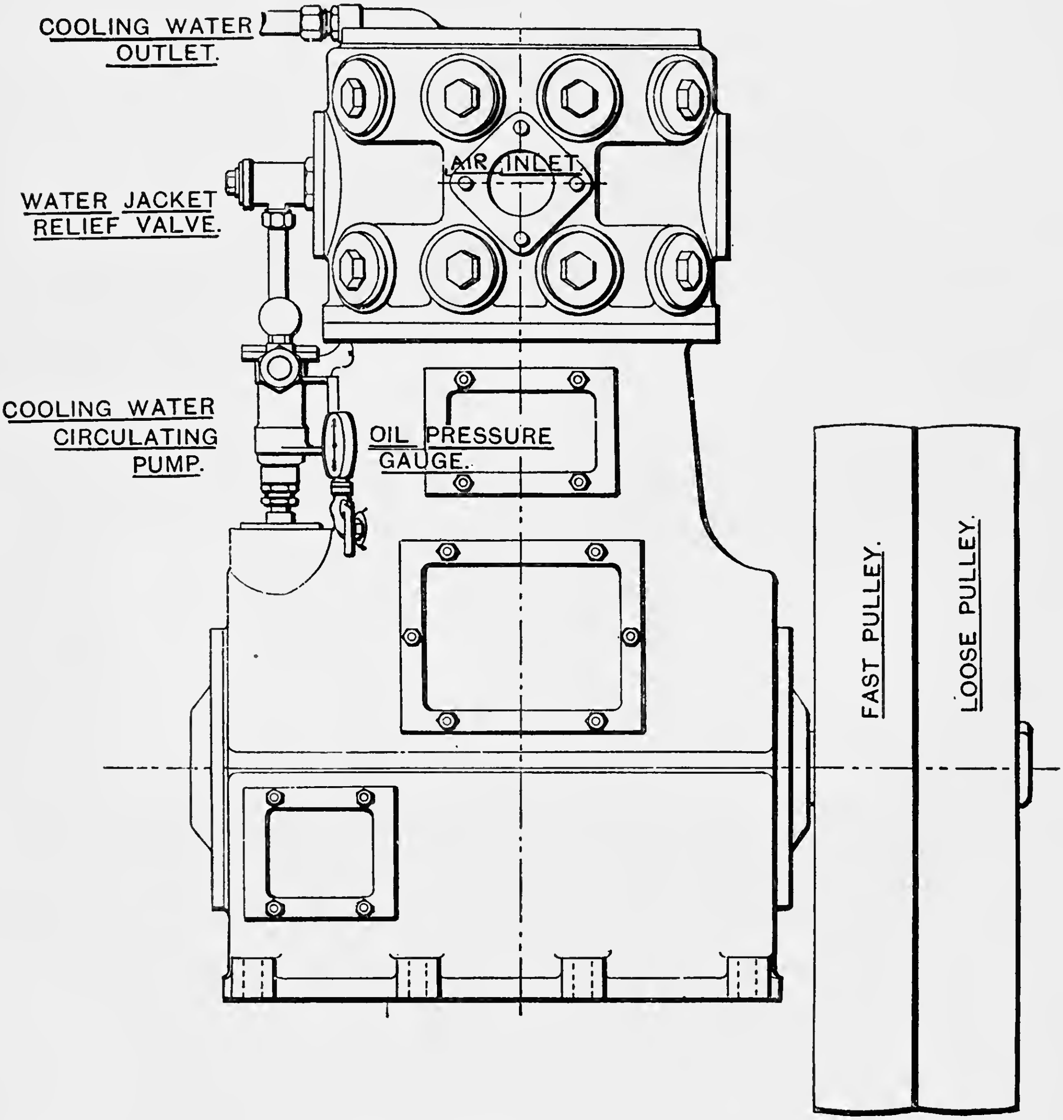


Fig. 199.—Outline of Belt-Driven Compressor.

chamber. The top cover of the air cylinder is combined with a distance piece, above which is fitted the steam cylinder.

The steam and air pistons are attached to a rod which passes through both air and steam cylinders, and is secured to the cross-head, which works in guides in the casing. This cross-head is coupled by a direct connecting rod to the crank shaft. The latter has a fly-wheel at one or both ends, and an eccentric which operates the piston valves of the steam cylinders, a valveless oil force pump, which supplies oil under pressure to all working parts; and also a duplex double-acting circulating water pump, which is fitted,

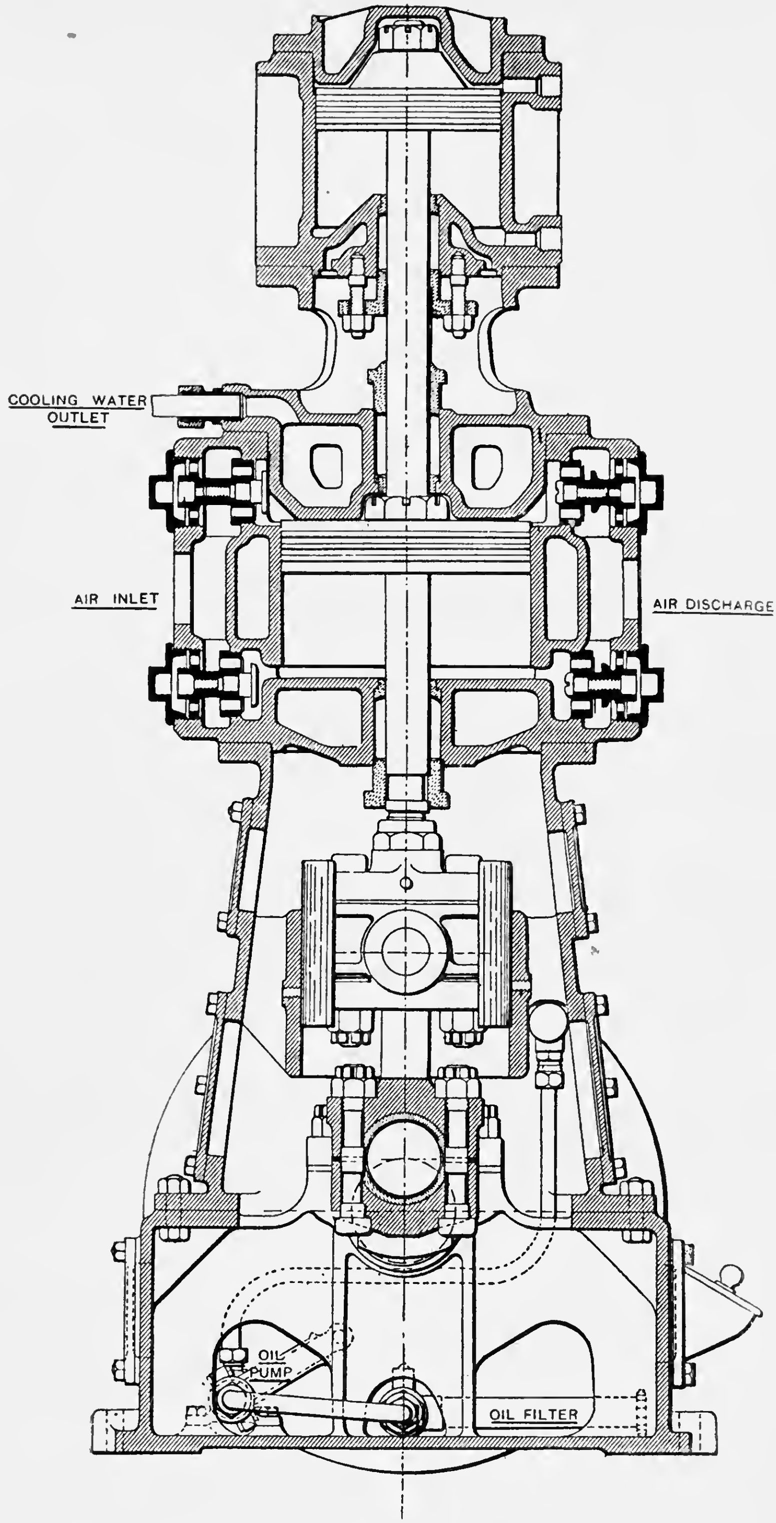


FIG. 200.—Section of Air Compressor.

if required, to maintain a steady flow of cold water through the cylinder and cover jackets and intercooler casings.

The lower part of the crank chamber forms a casing for the intercooler coils of the compound compressors, and the cooling water, circulating through this, keeps the lubricant in the crank chamber always cool.

The air valves are exceedingly light, consisting of flat metallic discs of special material pressed against removable seatings by light spiral springs. These valves have been found to be highly efficient, and practically unbreakable. Their light weight is of considerable importance, as on their prompt action the efficiency of the compressor largely depends. A further point is the reduction they effect in noise and wear and tear due to hammering action of the valves on their seats. The valves are accurately fitted and ground to their seats. They are particularly easy of access. The valve is attached to its guard by means of a central bolt. By first removing the cap and unscrewing the guard the valve seat, with valve and spring, may be removed. The valve seat is loose on the central bolt. The inlet and discharge valves are of similar design, but the discs are reversed for the changed direction of flow of the air. Each valve may thus be examined without disturbing any heavy parts, and may be renewed, if necessary, with very little trouble or expense. The joints between the valve seat and the cylinder, and between the valve seat and guard, are ground, and no packing or jointing material is needed.

For steam-driven compressors a combined speed and pressure governor (Fig. 201) is usually fitted, which will maintain the air pressure in the receiver nearly constant whilst the discharge of compressed air fluctuates from zero to the full capacity of the machine. The speed of the compressor is automatically regulated to suit the output, and can never exceed the prescribed limit. This method is the most complete and economical, and avoids all unnecessary waste of power and wear and tear of the machines. Where it is undesirable to vary the speed of the compressor, as in electrically driven machines, automatic regulators are fitted to vary the output of compressed air in proportion to the requirements, whilst the speed of crank shaft remains uniform. This method permits the use of a motor of minimum power for the output of air required, and greatly reduces the cost of the motor and the complexity of the electrical regulating switches and resistances. For belt-driven machines the above methods are also recommended. When the pressure falls, and the gear comes into action, the load on the compressor is first reduced by the automatic regulator, which then moves the belt on to the fast pulley, and the full load is afterwards gradually applied. This avoids slipping and squealing of the belts, and their rapid destruction.

DISTRIBUTION OF POWER BY GAS

There is nothing new or untried in this system. In previous systems the power is transmitted by pressure, physical force ; in gas distribution the power is carried in a latent form without force pressure or strains, except that required to move the gas through the pipes. The gas delivers its energy in the engine cylinder.

Gas has the advantage over compressed air and electricity in that it can be cheaply and easily stored up for use, so that its manufacture can go on continuously all the year round. The load factor is very high.

In every town hundreds of gas engines are connected to the lighting gas supply ; this is expensive, but for small powers it is cheaper than small steam engines.

For large schemes and large powers gas producers are employed, providing power at a price far below that possible by the best steam engines.

No electrically transmitted power from steam engines can ever hope to approach in economy the power produced by a gas producer and gas engine. And yet in this year 1905 we find so-called electrical engineers persisting in erecting steam engines to generate

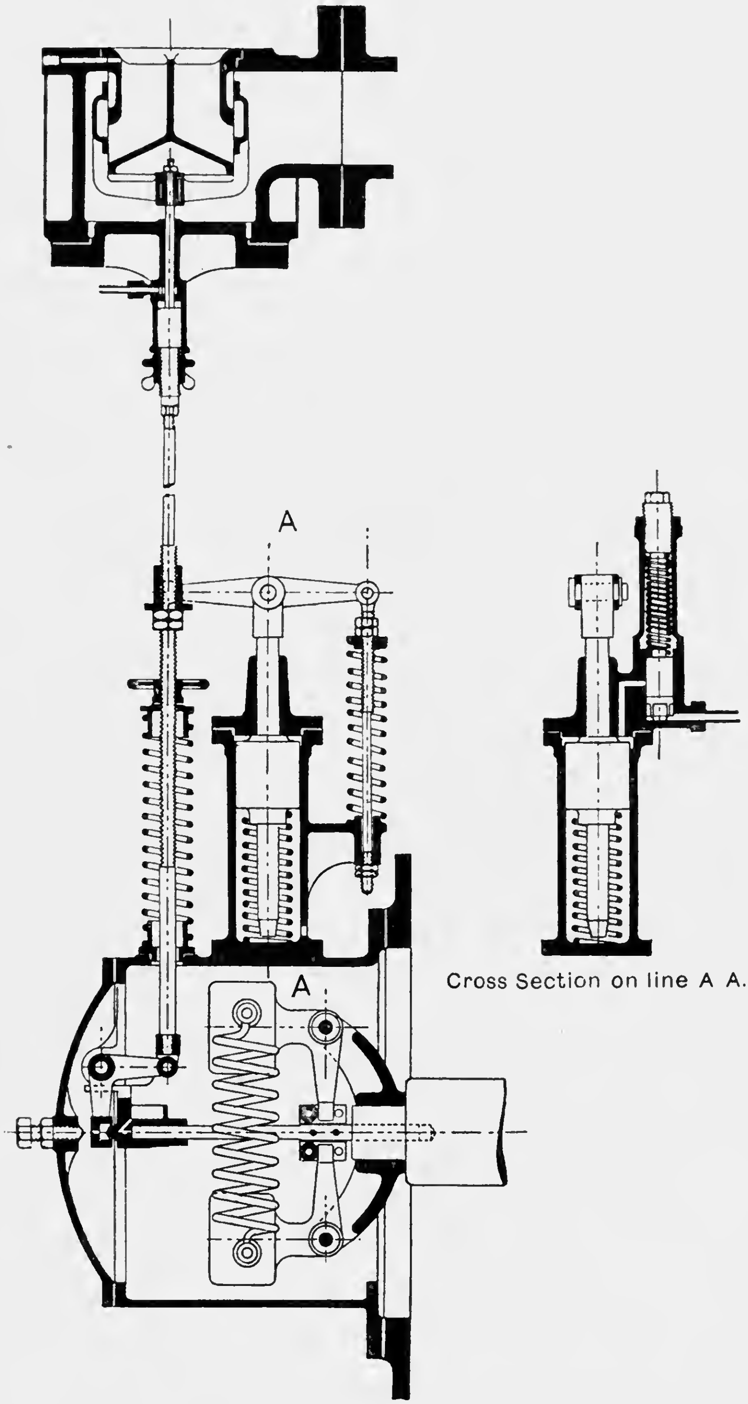


Fig. 201.—Brotherhood Governor.

electricity for transmission to a distance, while perfectly reliable gas plants and engines are available.

Competition will, of course, in time remedy this blunder at the expense of shareholders, for the gas producer must prevail over the steam boiler.

The production of gas is not in our scope at present, and we have already described the gas engines and also producers.

The gas engine has taken its place among great power producers, and has come to stay, and it needs only now to assume the turbine type of motor to eclipse the steam turbine.

ELECTRICAL TRANSMISSION OF POWER

We now come to the subject of electrical distribution of power, which at present is fashionable, although not so economical as gas. It, however, has fields of operation, such as in street railways, tramways, and, in cases where quiet, clean smooth running is desirable. There is no exhaust, and little foundation is required.

Transmission of power by electricity dates back to 1879. If we begin with self-exciting dynamos prior to that date, power had been transmitted by batteries of galvanic cells and magnet machines. The author erected an electric power transmission system for driving wood working machinery in a building situated some distance from the main buildings in an engineering works in 1880, a quarter of a century ago, yet we are told electricity is in its infancy. That may be so; it is taking a long time to grow up if it is so.

In 1884 Dr. Hopkinson patented the trolley-wire system for electric tramways, and all the essential machinery for working electric street tramway cars was ready to hand in 1885, and inventors had run cars on trolley lines in 1886. Yet only yesterday an orator says that twenty years ago, if anyone had said that electric cars would be running on the streets of our cities, he would have been considered a wild dreamer, and this before a company of municipal electrical engineers. Electric tramcars on streets was no wild dream even twenty-five years ago. The fact of the matter is, that every solid good invention is considered a wild dream by municipal, commercial, and capitalistic authorities for a period of from ten to fifteen years in this country. When it does dawn upon their intellects, deputations then set out for the Continent and America to see how it is in practice, and the foreigner, having developed the invention commercially, very properly secures the orders for supplying it in Great Britain.

By 1896 many municipal and private power users had discovered that power could be profitably transmitted by electricity, and now, twenty years after the labours (unrewarded) of the pioneer inventors, electric transmission is quite common. In the twenty years' interval little or no discoveries or inventions of any importance were made. The original inventors left very little undone, with one exception, and that was Tesla's invention of polyphase motors in the year 1888. This invention fortunately fell into the hands of an energetic company who worked it for all it was worth, otherwise it might have still been considered a wild dream.

The transformer of alternating currents with closed magnetic circuit was first made by Faraday sixty years ago. It was not understood, however, that the ratio of the number of turns of wire in the primary and secondary coils gave the ratio of the primary and secondary voltages. Thus if the primary has 10 turns of wire and the secondary 100, the ratio is 10 to 1, so that if the primary voltage is 10 volts the secondary will be 100 volts. Neither was it known that the current in the primary increased or decreased proportionally as the resistance in the secondary circuit increased or decreased. The author discovered these facts in 1880. The first transformer patents were taken out by Ziperknowski and Deri.

The essential machinery in the system of power transmission is (1) the prime mover and electrical generator; (2) the conductors for carrying the energy to the consumer; (3) the electric motors for converting the energy into motive power again.

The prime movers described in the preceding five volumes can any of them be used for the purpose. But considering all things at this date, there can be no doubt that the only economical prime mover for the purpose is the gas engine and gas producer.

The steam engine no longer holds the position as the cheapest power generator, nor is it superior in any point to a modern gas engine. And further, the latter can be located where water is not abundant; it can be run with less attention and repairs, and furthermore, gas can be stored for use in an immediate emergency. Again, the gas can be made in one place and carried in pipes for miles without losses. The advantage of gas electric generating stations are perfectly well known to the few advanced engineers who have followed the improvements recently made, but this knowledge has not percolated far into the mass of engineering practitioners. Perhaps about ten years hence it will be announced as an astonishing novelty that a gas engine can be used economically as a prime mover in electric power transmission. Meanwhile the steam engines, reciprocating and turbine rotary are almost the sole prime movers in use. No direct method of obtaining electrical energy from fuel better than a galvanic battery

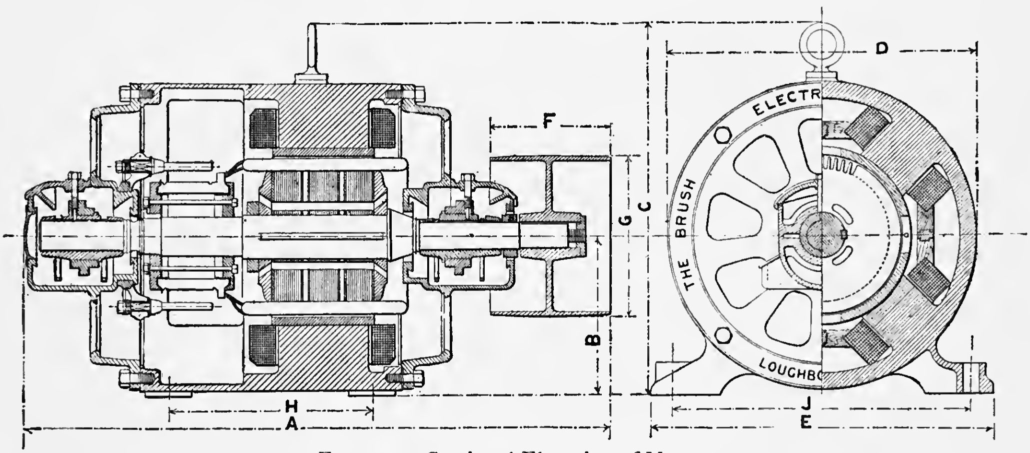


FIG. 202.—Sectional Elevation of Motor.

has been discovered. Until that discovery is made the heat engine and dynamo electric machine coupled together are the only practicable generators.

The steam and gas engines, water and steam turbines, windmills, etc., have already been treated; but the generator of electrical energy has now to be considered.

There are two kinds of electric generators—

1. Alternating current generators, commonly called "Alternators."
2. Continuous current generators, commonly called "Dynamos."

Both machines went through many changes during the past twenty years, but now a common type has become established, and nearly all manufacturers make the same machines. Here and there a machine is met with in which some nostrum is made a feature of, generally designed to cure some imaginary ills the generators may be supposed to suffer from. The American machines and German machines were first brought to perfection of construction and design, and their model has been faithfully copied by most manufacturers.

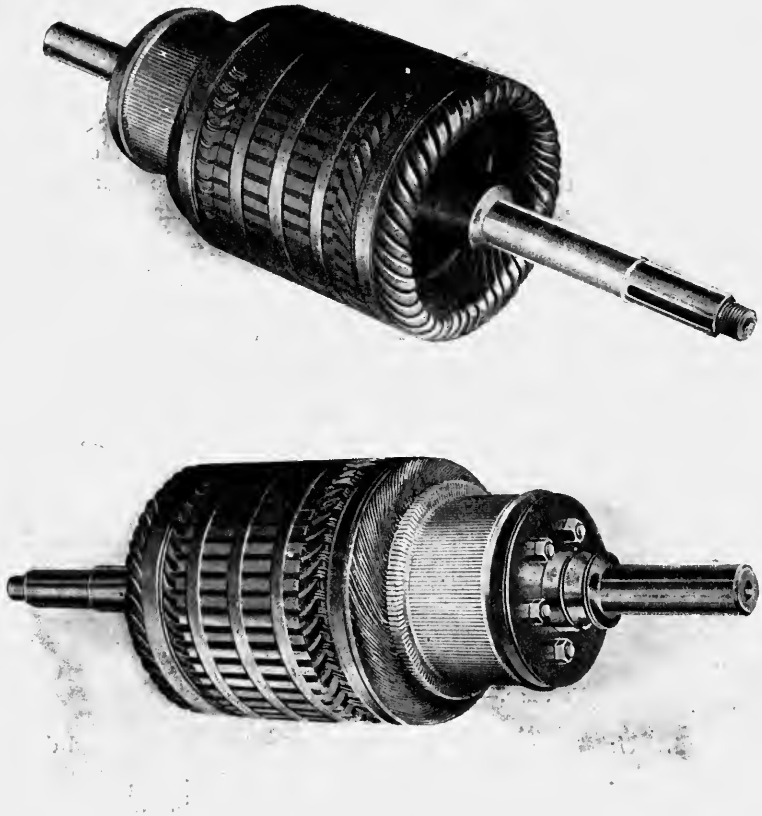
The dynamo electric alternator and continuous-current dynamos cannot be in this work fully treated. There are many works on the subject, such as *Electrical Installations*, in four volumes, by the author of this work.

The motors are of more general interest to engineers. We shall therefore select a good type of motor as made by the Brush Company as an example.

The Brush direct-current motor is of the slotted drum-armature ironclad type, with four poles, and may be shunt, compound, or series wound.

The open type is shown in Fig. 202.

The armature core consists of charcoal-iron discs of the highest permeability, insulated from one another by a special method, and securely keyed to the shaft. The armature winding is symmetrical. The wire, of the highest conductivity copper, is thoroughly insulated from the core by the best and most durable material for the purpose, and is firmly held in position in the slots of the core by bands of special



Figs. 203, 203A.—Motor Armatures.

binding wire sunk below the surface. The winding can be arranged, if required, so that the motor may be connected for different voltages.

The commutator segments are of the best hard-drawn copper insulated from one another by carefully selected mica, and are of such a depth as to permit turning down in diameter by the following amounts :—

Types E.O., E., or E.T.	Permissible Reduction of Diameter in Inches.
$1\frac{1}{2}$ to 3	$\frac{7}{8}$
5 to 9	1
12 to 30	$1\frac{1}{2}$
40	2

By a special arrangement of the clamping rings allowance is made for the expansion and contraction of the segments due to varying temperature.

Carbon brushes are employed with a holder specially designed to ensure even wear of the carbons and sparkless commutation. The field frame up to and including the 30 size consists of a single steel casting of high permeability. In the larger sizes two castings are used. The poles have each a separate winding, easily detachable, and securely held in position by special wedges. Two large openings are provided, one on each side of the frame, giving easy access to the brushes. These openings may, as in the E.T. type, be provided with special covers, so that the machine is rendered dust and water-tight.

The end covers are in the E. and E.T. types of cast iron, ventilated in the case of the former and completely closed in the latter.

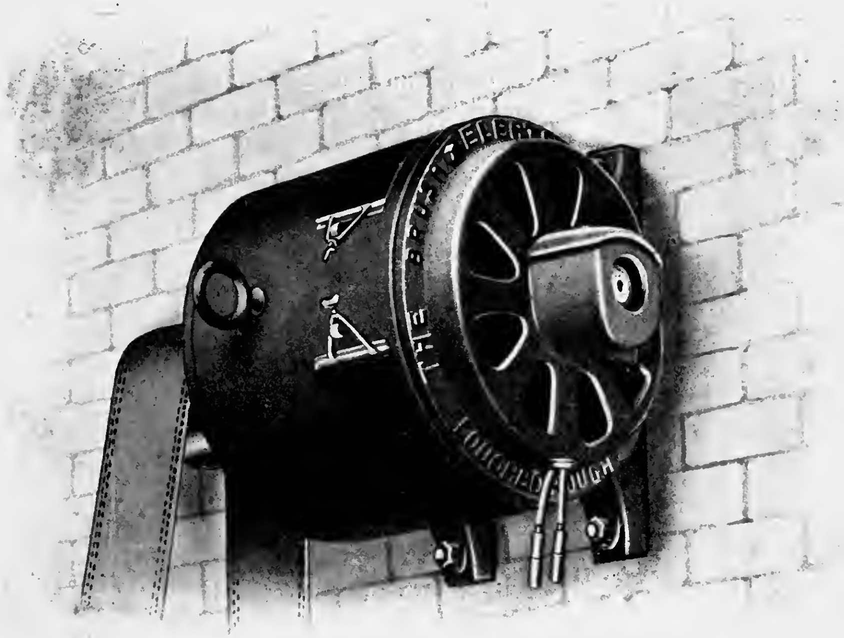


Fig. 204.—Wall Motor.

The bearings consist of solid phosphor-bronze bushes supported in a dust-proof and oil-retaining case, which is in one piece with the end cover in the E. and E.T. types, and forms part of the bearing bracket in the E.O. type.

This is effected by means of oil rings dipping into a well of ample capacity—a thoroughly reliable method.

After a six hours' run at normal full load the temperature rise does not exceed 70° Fahr., measured by a thermometer on any accessible part of the armature of E.O. and E. motors. For E.T. motors the limit of rise is 90° Fahr. under the same conditions.

The motor is equally suitable for belt or direct driving, and is provided with feet for bolting to the floor, wall, or ceiling, either with or without slide rails.

All machines are made strictly to jig and template, thus no trouble will be found in fitting new or spare parts.

The motor is shown partly in sectional, end, and side elevation in Fig. 202, and the following table will show the leading dimensions referring to the lettering:—

TABLE OF MOTOR DIMENSIONS. BRUSH COMPANY.

Type.	A.		B.		C.		D.		E.		F.		G.		H.		J.	
	ft.	in.	ft.	in.	ft.	in.	ft.	in.	ft.	in.	ft.	in.	ft.	in.	ft.	in.	ft.	in.
EO 5	2	8 3/4	0	9 1/2	1	10 3/8	1	6 7/16	1	7 3/4	0	5	0	7	0	9 5/8	1	4 1/4
EO 7	2	11 1/2	0	10 5/8	2	0 1/2	1	8 1/2	1	10 3/4	0	6	0	8	0	11 1/4	1	6 1/4
EO 9	3	2 7/16	0	11 1/2	2	4	1	10 1/4	1	11 1/2	0	7	0	9	1	0 3/4	1	7 1/2
EO 12	3	5 1/4	1	0 5/8	2	5 7/8	2	0 3/8	2	3 1/4	0	7 1/2	0	10 1/2	1	2	1	10 1/2
EO 15	4	1 5/16	1	1 1/2	2	7 1/2	2	2	2	4 3/4	0	8	1	0	1	5 1/2	1	11 3/4
EO 20	4	3 1/16	1	2 5/8	2	9 7/8	2	4 3/8	2	6 3/4	0	9	1	1 1/4	1	6 1/4	2	0 3/4
EO 25	4	6 13/16	1	3 1/8	2	11 3/4	2	5 3/8	2	7 3/4	0	10	1	2 1/4	1	8	2	1 3/8
EO 30	4	10 1/16	1	4	3	1 1/4	2	7	2	10	0	11	1	3 1/4	1	9 1/2	2	3
EO 40	5	2 15/16	1	5 1/4	3	3 3/4	2	9 1/8	2	11	1	1	1	5 1/4	1	10	2	4

The armature is shown in Figs. 203 and 203A. In Fig. 203A note the commutator is bolted up, and the shaft is of ample weight for any purpose.

Fig. 204 shows the motor fixed to a wall for a downward belt drive. Fig. 205 shows

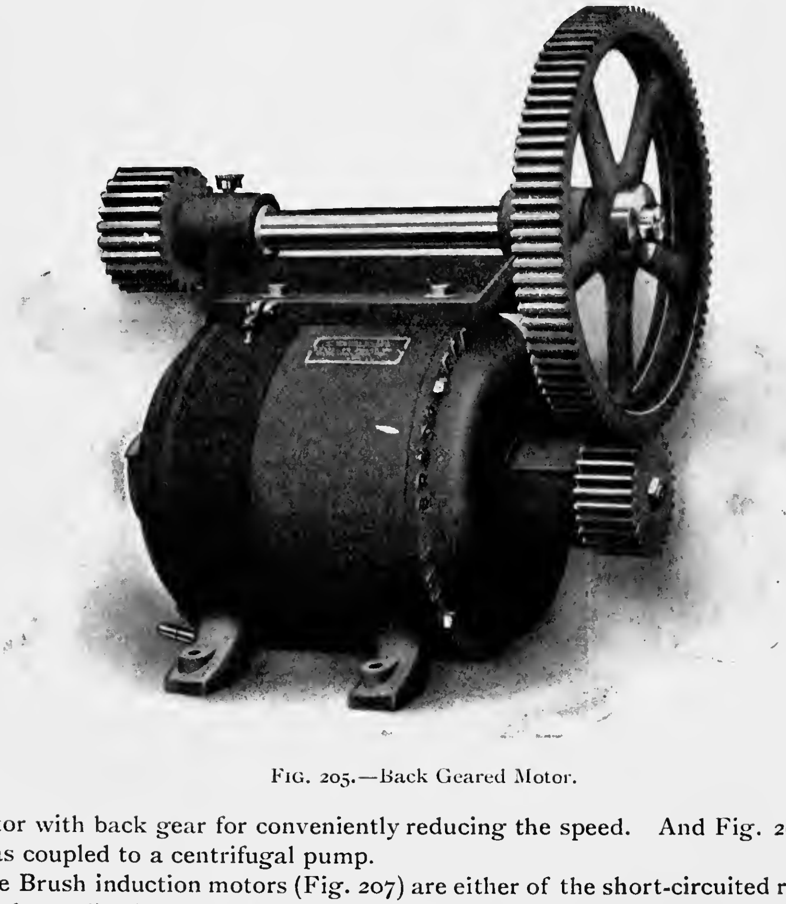


FIG. 205.—Back Geared Motor.

the motor with back gear for conveniently reducing the speed. And Fig. 206 shows the motor as coupled to a centrifugal pump.

The Brush induction motors (Fig. 207) are either of the short-circuited rotor, squirrel cage, or have slip rings and wound rotor. They are, in the standard sizes, suitable for two- or three-phase currents, with a periodicity of 40 or 50 cycles at all voltages up to 500.

The core is built of best charcoal-iron stampings, varnished on both sides to insulate them from each other; the inner periphery is slotted to receive the winding, and the core, fixed in a solid cast-iron frame, is provided with ventilating ducts.

The core, also built of best charcoal-iron stampings, is mounted direct on the shaft for all sizes up to 20 horse-power, and for those above that size it is carried on a special cast-iron spider. Ventilating ducts are provided in the rotor core to correspond with those in the stator, and slots are punched on the periphery to receive the conductors.

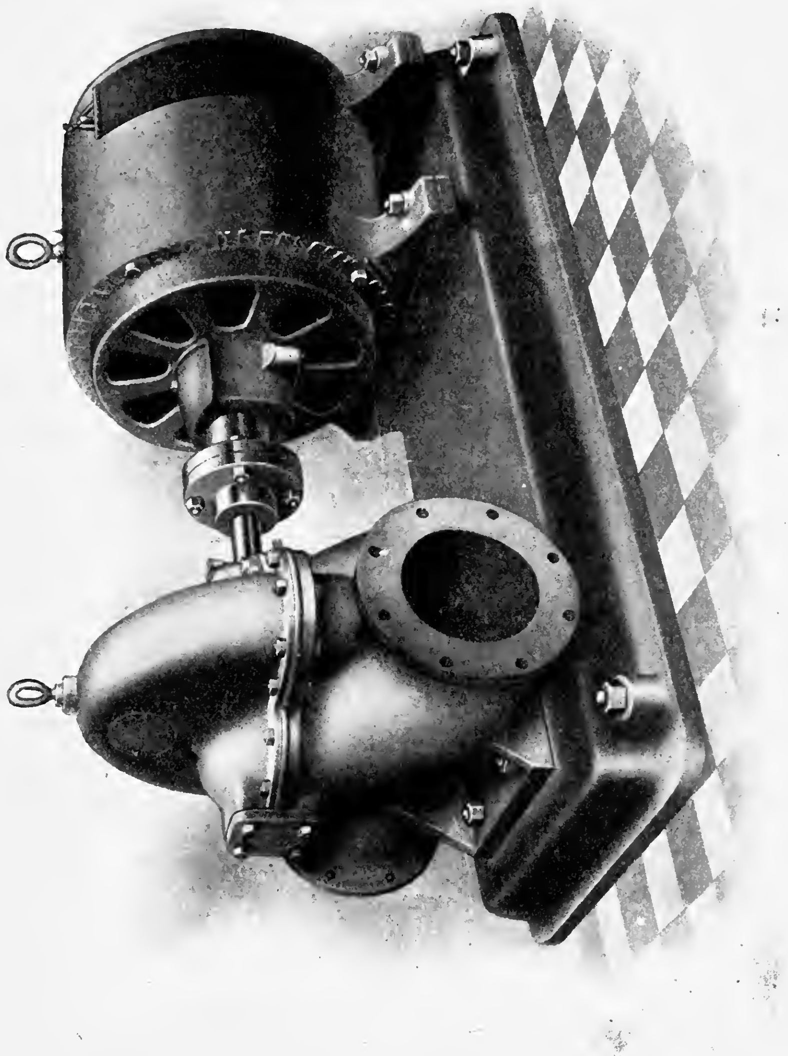


FIG. 206.—Motor and Pump.

High-conductivity copper is employed, and is carefully insulated from the cores by press-spahn and oiled cloth for low tensions, by micanite troughs for 500 volts.

In the squirrel-cage type (Fig. 208) the rotor conductors consist of copper rods of circular section, which are securely connected at each end to the two short-circuiting rings.

In the wound type (Fig. 210) the rotor winding consists of round copper wire for sizes up to 20 horse-power, and of rectangular bars for the larger sizes. A very solid cylindrical barrel winding is thus obtained.

The ends of the rotor winding are connected to hard bronze slip rings. Sizes up to 30 horse-power are fitted with carbon brushes in duplicate, and the larger sizes with copper brushes also in duplicate; a short-circuiting device is provided when required.

The frame has two end shields bolted to it which contain the bearings, and also serve to protect the windings.

For the smaller sizes (up to 30 horse-power) the bearing bushes are of gun-metal, in one piece. For the larger sizes the bearings have removable caps and split bushes of gun-metal, lined with white metal.

All the bearings are self-oiling, by means of rings dipping into an oil well of ample capacity.

The rise of temperature after a run of six hours at normal full load does not exceed 70° Fahr., measured by a thermometer on any accessible part of the stator or rotor.

STARTING DEVICES

The wound type of motor must be supplied with a three-phase resistance for insertion in the rotor circuit at starting. This resistance consists of German-silver wire

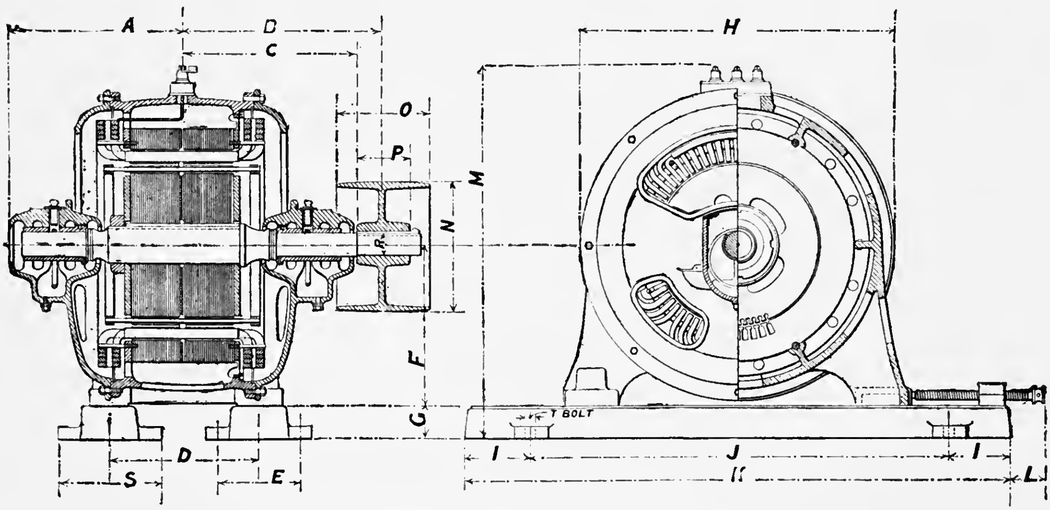


FIG. 207.—Sectional Elevations of Induction Motor .

or strips mounted in an iron frame. Motors provided with these resistances will start with full-load torque, when taking full-load current. The switch is fixed upon a slate base mounted on the resistance frame.

Only small motors of the squirrel-cage type can be switched direct on to the mains, as the starting current in that case is from 3 to 5 times the value of the full-load current. When such a heavy starting current is not permissible an auto-transformer (compensator) must be used; the ratio of the auto-transformer being generally chosen so that the starting current shall not exceed the full-load current. The starting torque will in this case be only $\frac{1}{4}$ to $\frac{1}{3}$ of the full-load torque, so that if a motor is required for starting with a heavy load the wound type must be used.

Fig. 207 shows in an end and side sectional view the construction of the squirrel-cage motor, and referring to the lettering the following table gives the dimensions:—

Dimensions in Inches.																			Weight in Lbs.
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	R	S	T	
9½	10 13/16	9 11/16	9½	5	9½	2	18	4	30	38	5	22	6	4	2⅞	1	6¾	⅝	290
10½	12¼	10¾	10	5	10	2	19	4	30	38	5	23	7	5	3⅞	1⅜	6¾	⅝	420
10¾	12½	11	10	5	11	2	21½	4	30	38	5	25½	7	5	3⅞	1⅜	6¾	⅝	550
12⅛	14⅛	12⅜	11	5¾	12	2½	23½	5¼	33	43½	8	28	8	6	4½	1½	7¾	¾	690
12⅛	14⅜	11⅜	11	5¾	13	2½	25	5¼	33	43½	8	30	9	7	4¾	1⅝	7¾	¾	790
13¾	16⅛	14	13	5¾	13	2½	25	5¼	33	43½	8	30	10½	7½	5⅛	1⅞	7¾	¾	980
14¾	17⅜	15	14	5¾	14	2½	27	5¼	33	43½	8	32	12	8	5⅞	2⅛	7¾	¾	1140
15⅛	17⅞	15⅜	14	5¾	15	2½	29	5¼	33	43½	8	34¼	13¼	9	6	2¼	7¾	¾	1300
15¾	18⅝	16	15	5¾	15	2½	29	5¼	33	43½	8	34¼	14¼	10	6¼	2⅜	7¾	¾	1420
17½	20⅝	17¾	14½	7	17	3½	33¾	7	36	50	8	39⅜	15¼	11	6⅞	2½	9¼	⅞	1685
18¾	22⅛	19	17	7	17	3½	33¾	7	36	50	8	39⅜	16¼	12	7⅜	2⅝	9¼	⅞	1975
18¾	22¼	19	16	9	19	4	37¾	9	44	62	10	43⅞	17¼	13	7⅝	2¾	11½	1	2175
19½	23	19¾	17½	9	19	4	37¾	9	44	62	10	43⅞	17¼	13	7⅝	2¾	11½	1	2360

It is called the squirrel-cage type, on account of the armature consisting of a drum of laminated soft iron surrounded by a series of copper bars joined up to two conducting rings at each end, as shown in Fig. 208, a photo of the armature.

Fig. 209 shows the stator of a two-phase machine with the wire winding laid in slots in a laminated ring.

Fig. 210 shows the wound type of armature with three slip rings for introducing resistances into the armature circuit when starting up.

These examples are typical motors as now most generally in use for power transmission.

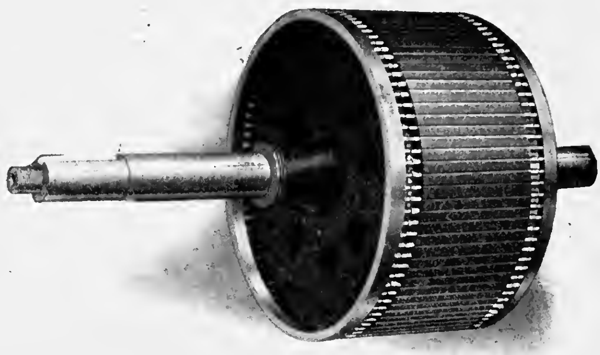


FIG. 208.—Induction Motor Armature.

TRANSFORMERS

The losses in transmission along cables are proportional to the square of the current with continuous current transmission.

With alternating current the losses are also as the square of the current, with some slight losses due to electrical capacity and induction.

It is clear, then, that if large currents are used the cables must be very large, for the losses are equal to $C^2 \times R$. R, the resistance of the cable, being inversely as the sectional area of the cable.

The energy transmitted is equal to $C \times E$, wherein E is the electric pressure or voltage, so that we can increase the energy transmitted by increasing E and leaving C small; for instance, if we take a current of 50 ampères at 20 volts, the energy in watts transmitted would be $200 \times 50 = 10{,}000$. The same cable carrying 50 ampères at a pressure of 5000 volts would carry $50 \times 5000 = 250{,}000$ watts, with the same loss in each case. In the latter case the loss per cent. would be very small indeed. The loss becomes heat in the cable, and the result is a fall in voltage or pressure at the consumer's end.

The high pressures are, however, not safe, and motors are very expensive to build for pressures over 500 volts, and lamps are not made for more than 250 volts pressure;

hence some means of reducing and increasing pressures is necessary. We want high pressure for transmission and low pressure for the consumer.

There is no simple means for converting continuous current from one pressure to another. If we want 10,000 watts transmitted at, say, 2000 volts we would send along 5 ampères current. At the consumer's end we find, say, a motor made for 500 volts; the pressure must be reduced in the ratio of 4 to 1. $\frac{2000}{500}=4$, and consequently the current increased by 4 to 1, so that we send $2000 \times 5 = 10{,}000$ watts, and convert it into $500 \times 4 \times 5 = 10{,}000$ again; but the current is now 20 ampères.

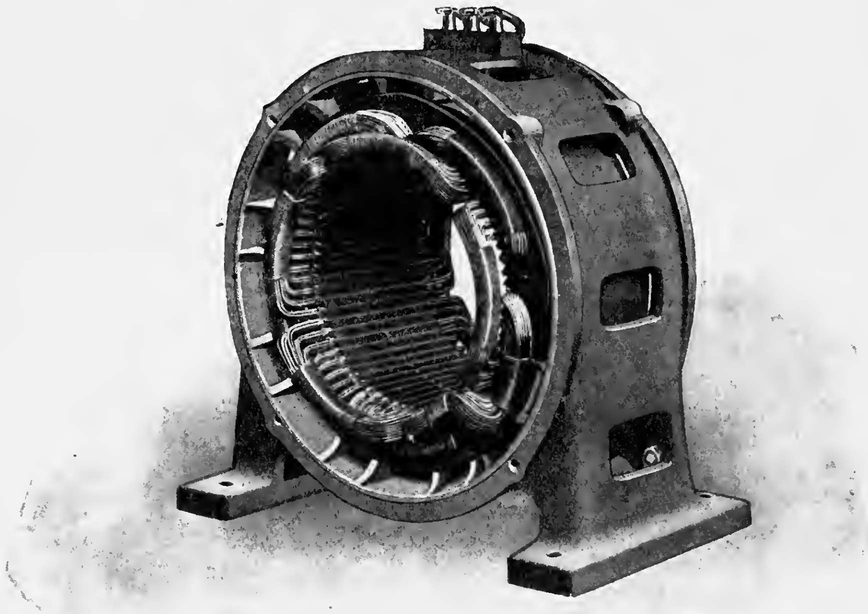


FIG. 209.—Stator of Induction Motor.

The motor generator is the only method for converting continuous currents. It is not a system to be recommended except for very special purposes: it is expensive and not efficient.

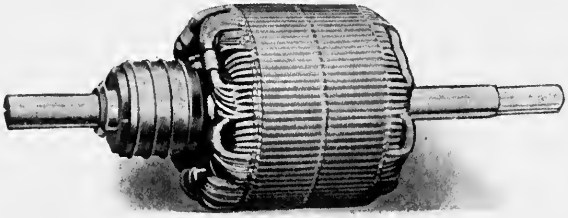


FIG. 210.—Wound Motor Brush Company.

Under the name of a rotary transformer it is of some value for converting continuous currents into alternating or polyphase currents, or converting alternating or polyphase currents into low-pressure continuous current—the energy being transmitted at high pressure by the alternating current.

The alternating current transformer is an exceedingly simple stationary device with no moving parts. It consists of an iron core with a primary and secondary coil or coils. If the ratio of conversion required is 10 to 1, then the one coil has to be made with ten times the number of turns than that of the other coil, and the thickness of the wires are proportional to carry ten times the current in the coil with the smaller number of turns than that in the coil with ten times the number of turns.

If the short coil had 10 turns and the long coil 100 turns, the current in the 100 turns might be 1 ampère, the current in the 10 times would then be 10 ampères. The wires, if of equal length, would require to be in section proportional to the square of the current, *i.e.* as 1^2 is to $10^2 =$ as 1 is to 100; but the wires are not of equal length, but nearly proportional to the number of turns. The short coil will therefore be only $\frac{1}{10}$ the length of the long coil, so that its resistance will be $\frac{1}{10}$ of what it would be if of equal length. Hence if the resistance of the long coil is 2 ohms and the current 1 ampère, the loss will be $1^2 \times 2 = 2$ volts. If now we make the short coil of 10 times the sectional area we get 0.2 ohms, and $\frac{1}{10}$ the length of wire we get 0.02 ohms; and this, multiplied by the square of the current $10^2 \times 0.02 = 2$ volts, the same loss as in the long coil.

The sectional area of the two wires are proportional to the currents and to the ratio of conversion.

There are also losses in the iron core, so that careful design is required to find its proper sections and weight.

There are many forms of transformers. We shall examine only one form, that of the Brush Company.

The core (Fig. 211) is built up of high premeability iron stampings 0.014 inch thick, carefully varnished to ensure individual insulation, and to prevent eddy currents. The iron is of low hysteresis loss, and is practically non-ageing.

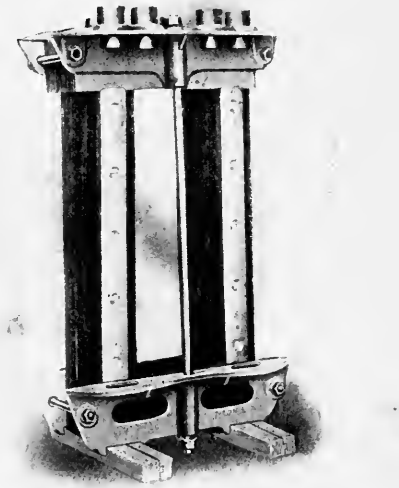


FIG. 211.—Transformer Core.

The transformers are arranged with both primary and secondary windings on each limb; the secondary winding is placed next to the core, and the primary on the outside of the secondary. The secondary windings of transformers for use on 3-wire systems are cross-connected, so that perfect regulation is obtained on each side of the middle wire with unbalanced loads.

The primary and secondary coils are each wound independently on formers, and baked in a vacuum oven to dry out all moisture thoroughly (see Fig. 212).

The primary winding is divided into several coils (Fig. 215) to keep down the voltage between layers, and also to facilitate repairs. Each coil is separately taped with oiled linen. The insulation between layers consist of the finest paper, carefully selected; the paper projects beyond the end of each layer, thus ensuring immunity from breakdown through short circuit between layers.

The insulation between secondary and iron, and between primary and secondary, consists of special tubes of insulation as shown in Fig. 213.

Over the iron core is slipped a tube of insulation on which the secondary coil is directly wound. Over the secondary coil is then slipped another tube of insulation, and over this are slipped the primary coils, which are then connected up in series (Figs. 214 and 215).

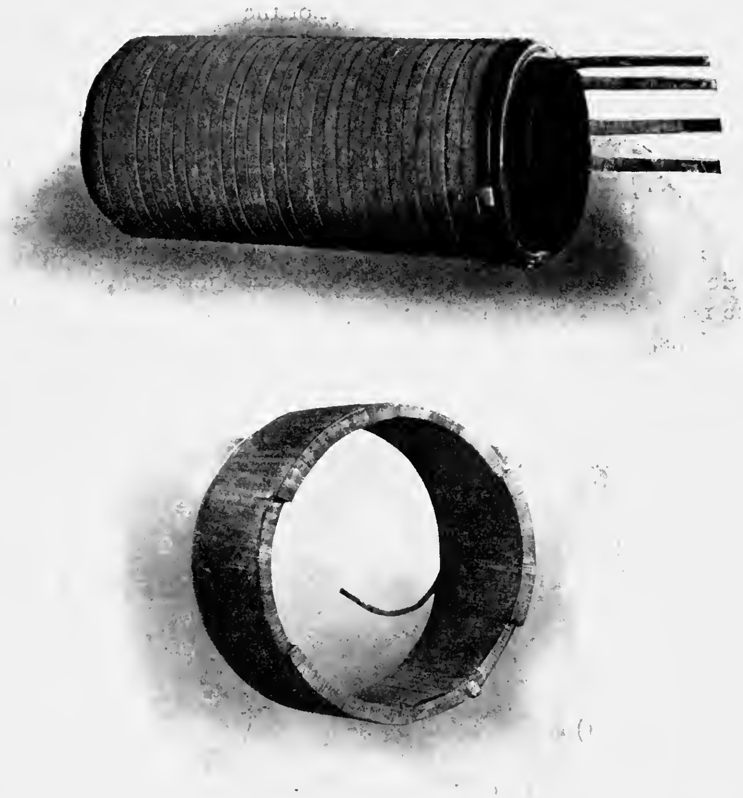


FIG. 212.—Transformer Coils.

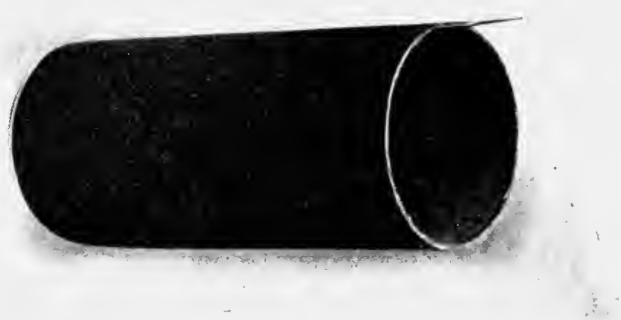


FIG. 213.—Insulating Tube.

It will be seen that in case of a breakdown the transformer can be easily repaired *in situ*, the damaged coil being merely removed and a spare one substituted. If spare

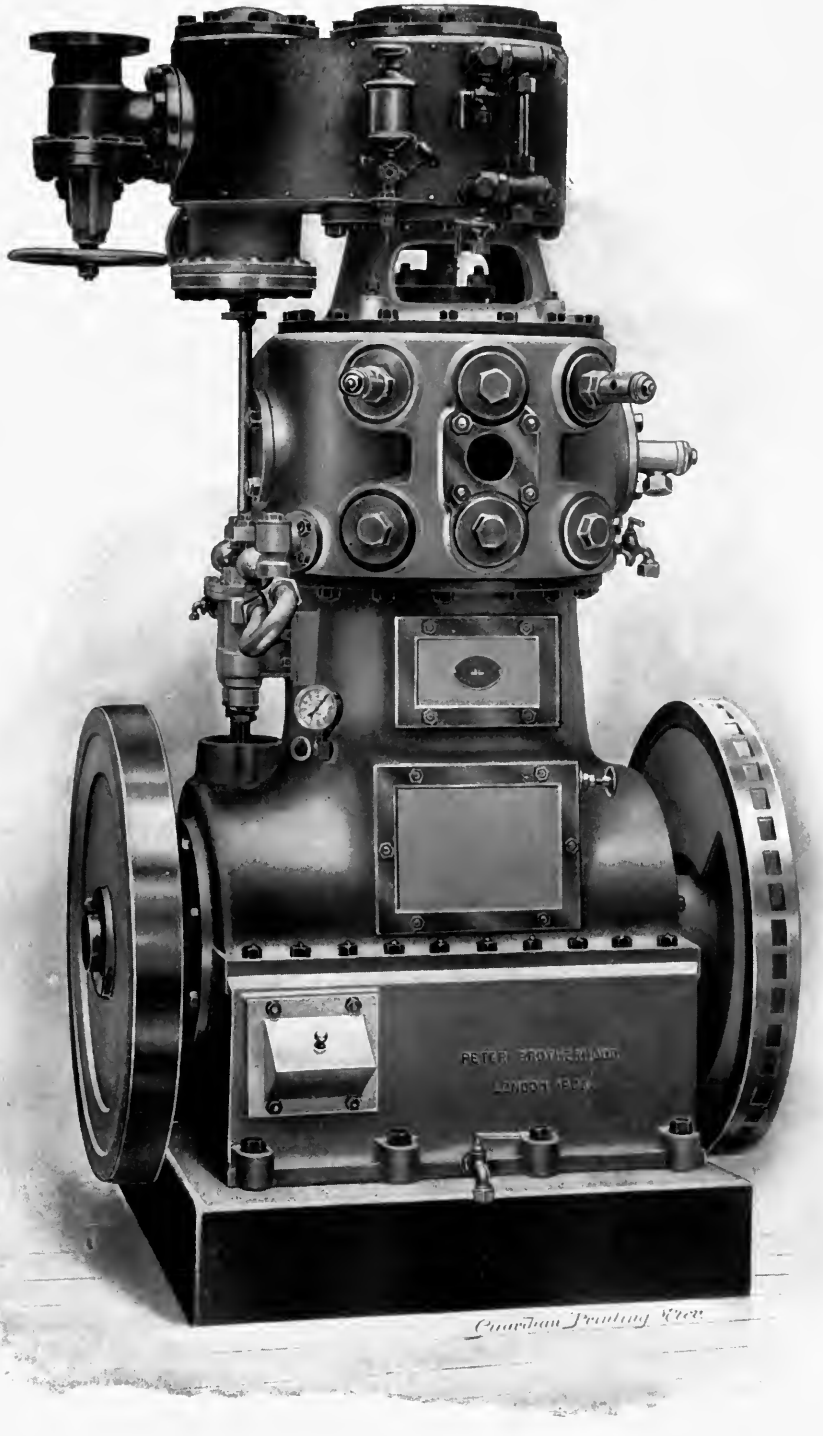


Plate VII.—Brotherhood Vertical Air Compressor.

coils and insulation tubes are kept in stock, a transformer can readily be repaired in an hour or two, and set to work again. The cost of repairing the core type is consequently a very small item, only the part of the winding that is actually injured being replaced,

FIG. 214.—Coil on Tube.

whereas with many transformers a breakdown means sending back to the works and a complete re-wind.

The transformers can be supplied with or without earth shields.

Oil is recommended for use when transformers have to be run continuously at full load in a closed case.

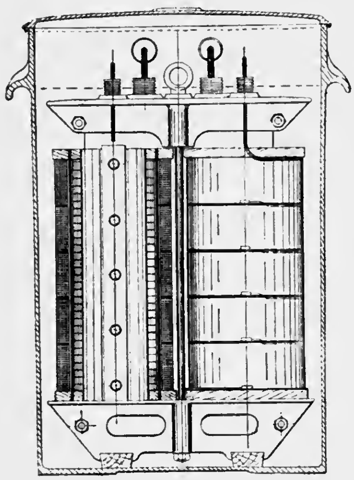


FIG. 215.—Transformer Section.

FIG. 216.—Transformer.

The oil used with transformers must be carefully selected. The flash-point is about 350° Fahr., which ensures absolute safety even when working in the highest temperatures.

The temperature rise of oil-cooled transformers after a continuous run at full load in box will not exceed 90° Fahr., when measured by increase of resistance of the primary winding.

When measured by thermometer in the oil, the temperature rise will not exceed 80° Fahr.

The transformers are fitted in a cast-iron box, provided with a cover which is

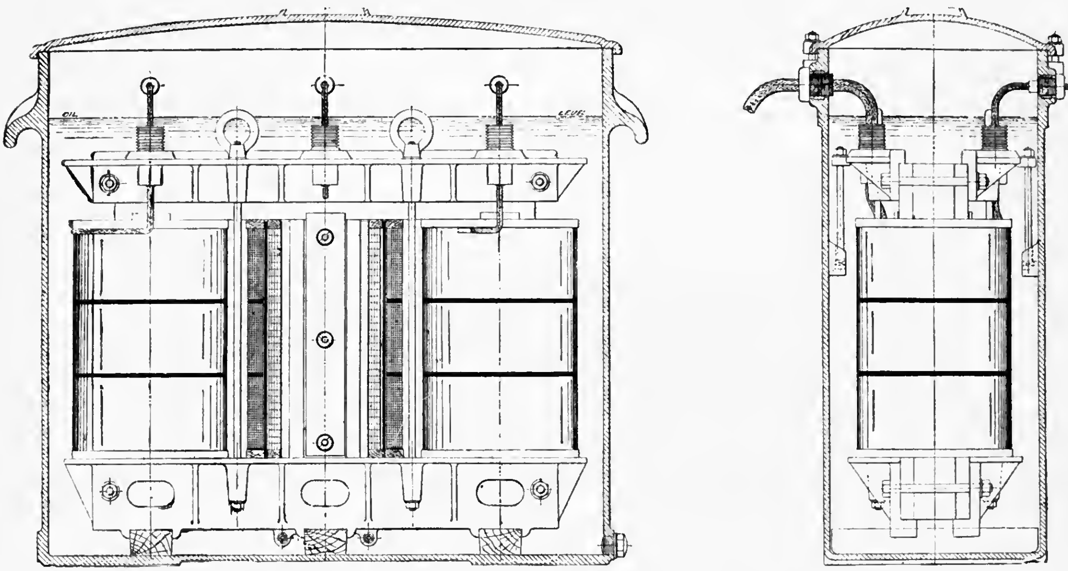


FIG. 217.—Complete Transformer in Section.

bolted to the box (Fig. 217). The box is perfectly oil-tight, and is provided with a screw plug for emptying the oil when required.

Flexible leads provided with connectors, suitable for taking cables, are brought out through glands in the box 2.

The usual voltages are 2000 volts primary and 200 or 400 volts secondary, but transformers can be wound for any desired voltage.

A table of particulars regarding these transformers is given below.

FOR LIGHTING.

Output in KW.	Code Words.	Efficiency at				Open Circuit Loss in Watts.	Percentage Drop in Volts on Non-inductive Load.	Weight without Oil in Cwts.	Oil required in Gallons.
		Full load.	¾ load.	½ load.	¼ load.				
1	Strophoma	93	92.7	91.7	87	35	4	1½	6
1½	Strown	93.4	93.4	92.6	88.5	45	4	2	7
2	Strucia	94.1	94.1	93.1	89.2	55	3½	2½	8
3	Struciola	94.6	94.6	93.8	90.2	75	3¼	3½	9
4	Strudel	95.1	95.1	94.6	91.6	85	3	4¼	10
5	Strudelst	95.7	95.7	95.0	92.0	100	2½	4¾	11
7½	Struggeva	96.1	96.1	95.7	93.7	120	2½	6¼	17
10	Struggiamo	96.3	96.4	96.1	94.1	140	2¼	7½	20
15	Struggo	96.7	96.8	96.7	95.0	180	2¼	10	25
20	Struix	97.0	97.1	96.9	95.3	220	2	13½	30
25	Strumatic	97.1	97.2	97.0	95.5	260	2	14½	37
30	Strumelle	97.1	97.2	97.1	95.7	300	2	17	40
40	Strumenti	97.3	97.4	97.3	95.9	380	2	21	50
50	Strumeux	97.5	97.6	97.5	96.0	460	2	24½	55
60	Strumosos	97.5	97.6	97.5	96.1	540	2	28½	65
80	Strumous	97.6	97.7	97.6	96.2	700	2	35	80
100	Strunk	97.7	97.8	97.6	96.4	850	2	42	90

FOR POWER.

Output in KW.	Code Words.	Efficiency at				Percentage Drop in Volts on Non-inductive Load.	Percentage Drop in Volts on Inductive Load, Power Factor 0.8.	Weight without Oil in Cwts.	Oil required in Gallons.
		Full load.	¾ load.	½ load.	¼ load.				
1	Struppig	90.5	89.1	85.8	76.5	3½	5	1½	6
1½	Struses	92.2	91.3	89.0	81.5	3½	5	2	7
2	Struthion	93.0	92.4	90.5	84.1	3	4½	2½	8
3	Struthus	93.7	93.3	91.7	86.4	3	4½	3½	9
4	Struttura	94.6	94.2	92.9	88.2	2½	4½	4¼	10
5	Struzio	95.0	94.6	93.3	88.9	2¼	4½	4¾	11
7½	Struzza	95.6	95.3	94.4	90.8	2¼	4½	6¼	17
10	Strybele	96.1	95.7	95.1	91.8	2	4	7½	20
15	Strychni	96.6	96.4	95.7	92.9	2	4	10	25
20	Strymonis	96.8	96.7	96.0	93.4	2	4	13½	30
25	Stuarties	96.9	96.8	96.2	93.7	2	4	14½	37
30	Stubble	97.0	96.9	96.3	94.0	1¾	4	17	40
40	Stubby	97.2	97.1	96.5	94.3	1¾	4	21	50
50	Stubera	97.4	97.2	96.7	94.5	1½	4	24½	55
60	Stucateur	97.6	97.3	96.8	94.6	1½	4	28½	65
80	Stuccando	97.6	97.4	96.9	94.7	1¼	3½	35	80
100	Stuccassi	97.8	97.6	97.1	95.0	1¼	3½	42	90

The standard voltages are: primary, 2000 volts; secondary, 200 or 400 volts.

The above transformers may be used on any frequency from 40 to 60 cycles. The efficiency figures are for 50 cycles. For other periodicities they would vary slightly.

THE MOTOR BUS

We have already, in Volume III., treated internal combustion engines on road vehicles. In this place a brief reference may be made to the motor bus, which within the past

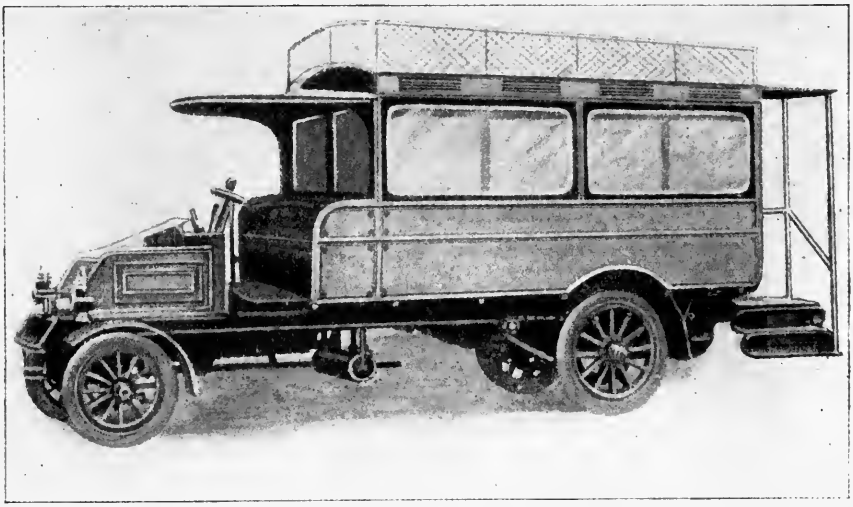


FIG. 218.—Motor Bus.

year has come very prominently to the front for street traffic. The phenomenal success of electric railways, electric tramways, etc., has compelled attention to some other means of working street traffic by vehicle. The electric tramways system are very expensive, and is inflexible. It can go along its rails, but nowhere else. If one of its own trams breaks down, or any other vehicle, for that matter, meets with a mishap across the tram lines, the whole service is brought to a standstill, as has been demonstrated more than once whenever anything serious happens at the central station which provides the electric current. If there is a stoppage of the traffic on the road it is equally paralysed. None of these disadvantages are shared by a motor bus service. If one motor bus should happen by accident to break down, it influences none of the others. The rest of the service goes on running. If a waggon or lorry comes to grief in the middle of the road, and cannot be removed for several hours, the motor buses dodge round it, and if there is no room in that particular street they take side streets.

These are advantages of the motor bus as compared with the electric tram. But the most enormous advantage of all is to to be found in the difference of initial cost. Articles are appearing in a variety of papers pointing out the enormous burdens which have been placed on the ratepayers in the past, and the enormous financial barrier that exists to the propagation and organisation of electric tram services in the future. The cost of the motor bus service is the cost of vehicles only. In an electric tram service the cost of the vehicles is relatively insignificant. It is the huge cost of the permanent track that runs away with the money. The permanent way of the electric trams promoted and organised by the London County Council is said to have amounted to some £26,000 per mile, and altogether some 60 millions is declared to have been spent altogether on electric trams. The tramways are destined to have a keen competitor in the motor bus services which are being organised, and this competition will possess the advantage that, if the demand for locomotion on any particular route on which the buses are placed diminishes, the motor bus can be transferred to another more populous and paying route without any additional expenditure. The motor bus has, in fact, come to stay. It is now a commercial and reliable vehicle, though there is no doubt whatever that in the near future it will be still further improved.

This refers to free buses with pneumatic tyres for road running. It is a question, however, whether it would not in many cases be better to run on rails as to use steel wheels. The cost of tyres will be a considerable item in motor buses working on common roads. Be that as it may, there is no doubt many towns and places where the motor bus will offer a first-class service for passengers, and the local authorities in smaller towns should seriously consider this system before committing themselves to the expensive electric trolley system. In many small towns the electric tramway has proved a sort of white elephant. The interest on the huge outlay and the cost of running the generating plant goes on all the day, while but few passengers are carried for many hours on many days. In these small towns there is a great rush of passengers on certain days and at certain hours only. In such places motor buses can be put on or put off as demand requires, and their engines are only working while they are earning money.

ELECTRIC SHUNTING LOCOMOTIVE

The Brush Company's small shunting locomotive is shown in the line drawing (Fig. 219). It has one of their standard 1002 B motors, capable of driving at $9\frac{1}{2}$ miles per hour, with single reduction gearing wheels are coupled. The following are the constructive particulars :—

Voltage		500.
Weight nett		7 tons.
Weight shipping		$7\frac{3}{4}$ tons.
Weight of suitable rails (per yard)		20 lbs.
Minimum radius of curves		90 feet.
Gross load, exclusive of its own weight, that the locomotive can draw up the following gradients	level	63 tons.
	1 in 100,	24 tons.
	1 in 60,	14 tons.
	1 in 30,	5 tons.

One controller is provided, and all necessary switches, lightning arresters, trolley and usual accessories.

The motors are rated upon a similar basis to tramway motors; that is to say, full load is the load which the motors can do for one hour without the temperature of either fields or armatures rising more than 150° Fahr. (measured by thermometer). The motors can do more than their rated full loads for short periods, or less than their rated full loads for longer periods.

In shunting operations a locomotive is not in constant work. It may be used for a few minutes only, and have intervals of idleness for an hour or so. A steam locomotive may be idle, but its furnace must be kept working all the time, so that the fuel they consume is very great per actual horse-power-hour of work done. The electric locomotive consumes power only during the time it is in actual work, and when idle consumes no fuel.

The Brush Company also make these locomotives with accumulators, instead of trolley, supply of electricity, in which case they can run over ordinary lines.

LIGHT PARAFFIN LOCOMOTIVE

Messrs. Kerr Stuart & Co.'s oil engined locomotive is shown in Fig. 221—one a side view showing the general arrangement of the engines, and the other an external view of the driving end.

These engines are designed mainly for use on very light railways, having rails as

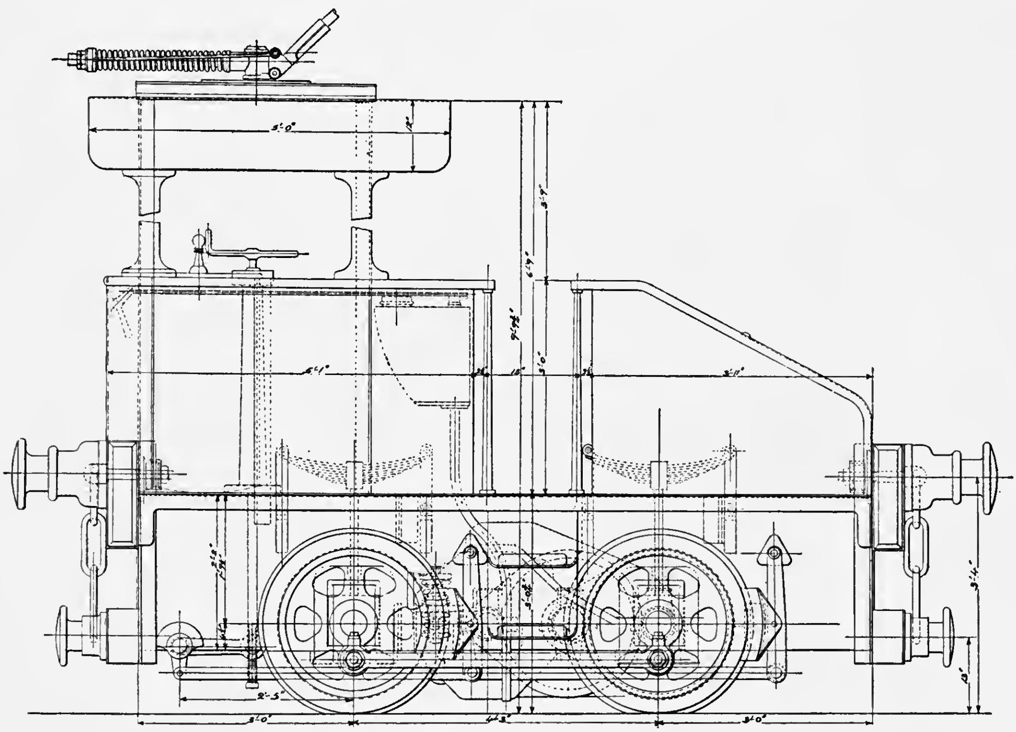


FIG. 219.—Brush Company's Shunting Locomotive.

light as 10 lbs. per yard, and for other work in which the ordinary steam locomotive is impracticable. They are easy to manipulate, and free from the constant breakdowns and complications so common to motor-driven vehicles.

The following are some of the advantages claimed for the locomotives.

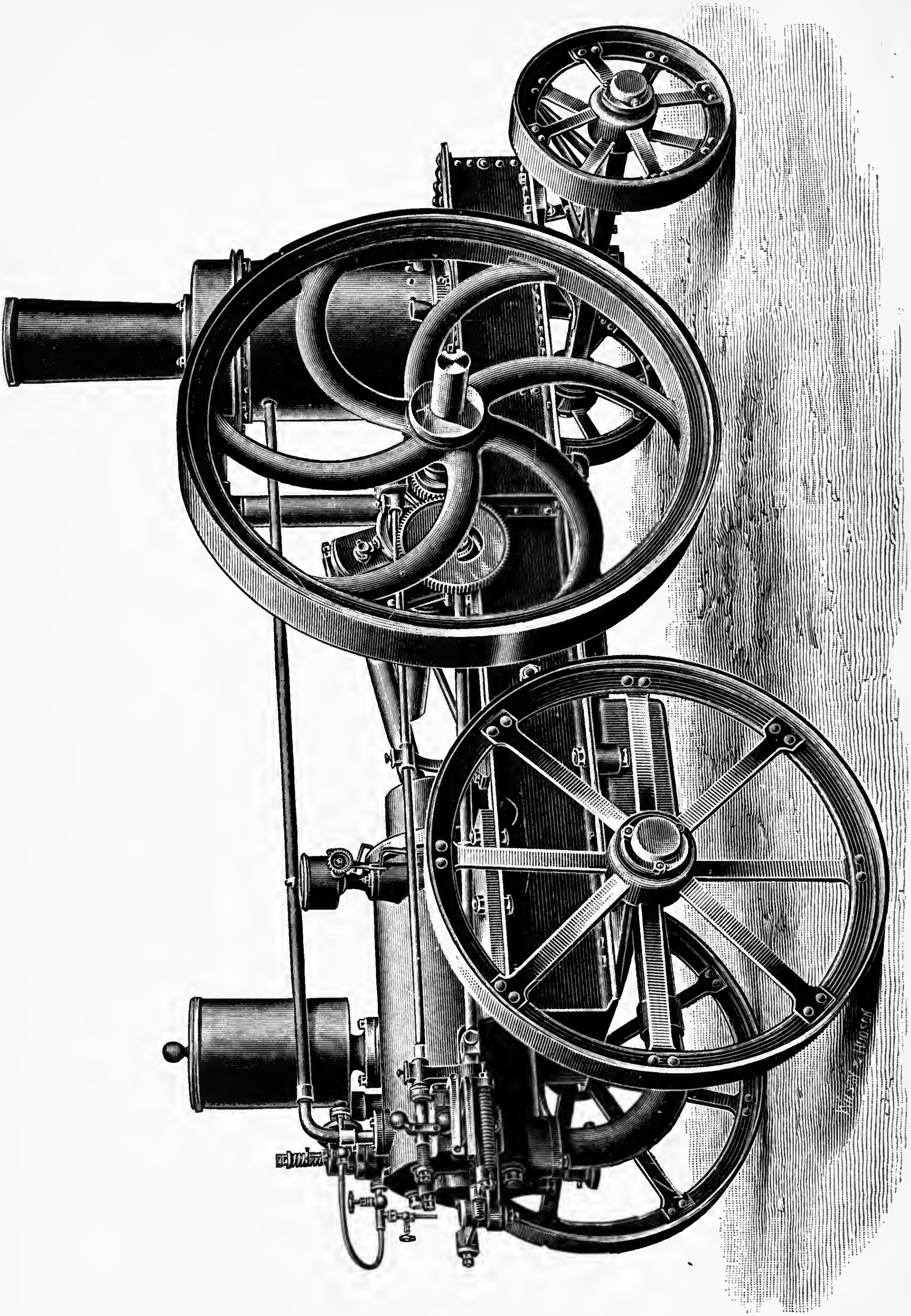


FIG. 220.—Portable Oil Engine.

They may be used on a gauge as narrow as 16 inches (400 millimetres), and rails as light as 10 lbs. per yard (5 kilogrammes per metre).

They can be worked equally well with either ordinary kerosene (petroleum used for illuminating purposes), petrol, or alcohol.

The consumption of kerosene is 0.75 lb. per brake horse-power per hour, and petrol or alcohol in proportion.

They can be heated up and started in a few minutes, and during the short rests in working hours the supply of fuel is regulated automatically, or may be cut off altogether. The same conditions occur when the engine is running on a down grade or hauling a light load. Consequently, no more fuel is consumed than is actually required for the work that is being done.

In starting, the load is, by means of patent clutches, picked up gradually, thus avoiding violent strains.

As a motive power for passenger tramways, these engines are very suitable.

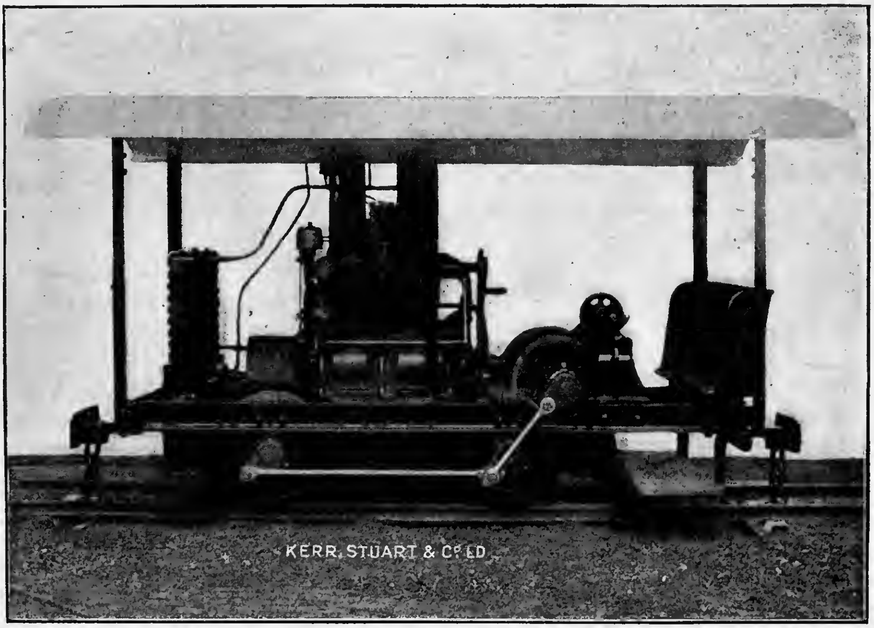


FIG. 221.—Electric Locomotive.

They do not occupy much more space than the machinery of an ordinary electric tramcar, are perfectly under control, and can be carried on light tramway rails.

PORTABLE OIL ENGINES

These have become exceedingly popular, and are of great value in agricultural work. The Campbell portable oil engine, arranged on a carriage to be moved about by horses, is shown in Fig. 220.

Suction gas portable engines have quite recently been introduced geared, so that they can move themselves from place to place.

Suction gas has considerable advantage over oil as a fuel, besides being cheaper. It, however, requires electric ignition, or ignition by a hot tube kept at a bright red heat by a good paraffin lamp. This is not a satisfactory ignition, but a simple magneto run by band from the engine fly-wheel has been introduced, and this with an automatic spark plug gives a most satisfactory ignition for all suction gas engines.

CONCLUDING REMARKS

It will be noted from what has been said about the two leading prime movers, steam and gas, that the latter is effecting a considerable revolution in more directions than those of the mere power user. Under the régime of steam alone every power user was compelled to plant a steam generator and engine with a tall chimney; hence towns and cities were disfigured by forests of chimneys pouring forth smoke and soot. Much has been said and written about the abatement of this smoke nuisance, but nothing short of abolishing the steam boiler could effect any substantial cure or abatement.

During the past twenty-five years, however, the gas engine has been supplanting the small steam engine, and thereby the increase in the numbers of tall smoking chimneys has been checked naturally; and now that the gas producer has been perfected, and offers a prime mover of any power whatever, without the need for a tall chimney, there is every prospect that these eyesores will gradually diminish in numbers, and finally remain only as monuments of a past stage in human progress.

The distribution of cheap producer gas for power purposes is at present somewhat neglected. Great hopes are centred just now upon electrical distribution of power, which in this country is just entering upon crucial trials commercially. No doubt electrical distribution will in many cases prove profitable and successful, in which case there will be hundreds of small steam plants consigned to the scrap heap. But there is looming in the near future a struggle between electrically distributed power and gas distributed power. Like most other rivalries, it will end in the recognition of the fact that there is ample scope for both systems, and that each has a field of its own in which it is supreme.

The young modern engineer should be provided with a training directed more towards internal combustion engines, and the transmission and distribution of power, the generation of power gas, and electricity, than to the now less important steam and steam engine subjects. Only in marine work is steam likely to prevail for a long time, especially so as the steam turbine has been adopted as the engine, but even in this field the rival gas has appeared, and some smaller vessels are now propelled by suction gas engines with tolerable success.

The prime mover of the future for stationary purposes will be driven by gaseous fuel supplied from central gas producers, or the power will be transmitted from gas-driven dynamos supplying electricity from centres of generation. For traction and portable purposes electricity will be best for some cases, such as tramways and railways; for others the internal combustion engine will be adopted for direct driving.

No responsible engineer can afford to neglect the question of gas *versus* steam prime movers, nor should the possibilities of power transmitted from gas producers or from electric generators from a centre be overlooked by any one purposing to employ motive power. In laying out new factories these questions must be carefully considered by all concerned.

GENERAL INDEX

The Roman numerals i., ii., iii., iv., v., *and* vi. *indicate the volumes, and the Arabic figures* 1, 2, 3, 4, 5, *etc., the pages in each volume where the reference will be found.* ff. *after a page number means* "*and following pages.*"

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