Chapter XLII.—MARINE ENGINES.

MARINE engines are made in the following forms :

1. With a single or with two cylinders receiving live steam from the boilers, and exhausting into the atmosphere. These are termed high pressure engines, let the steam pressure be what it may. They are also, and more properly, termed non-condensing engines.

In the small sizes, such as are used for launch engines, it is simply a non-condensing engine, with a link motion for varying the point of cut off as well as for reversing purposes. Fig. 3392 represents an engine of this class constructed by Chas. P. Willard & Co.

The cylinder is what is called "inverted," meaning that it is above the crank shaft.

The slide spindle or valve rod passes through a guide and connects direct to the link block or die, as it is sometimes called.

The thrust block is provided in the bearing of the crank shaft, and consists, as seen in the sectional view, of a series of collars on the crank shaft bearing.

2. The addition to each high pressure cylinder of a low pressure cylinder constitutes a compound engine, and if the engine has also a condenser, it is a compound condensing engine, an example being shown in Fig. 3392*a*, which represents an engine in which the link motions are employed to vary the points of cut off of both cylinders, as well as to reverse the engine. The engine being small, the power required to move the links is small enough to permit of their operation by hand, by means of the hand lever L, which is secured to its adjusted position on the sector T by the small lever nut shown on the side of the lever. The lever L operates a shaft D which shifts both link motions. The air and circulating pumps are at the back of the condenser, being operated from the beams B, B, each beam connecting to rods J which connect to rod *c*, which drives the air and circulating pumps.

The steam from the high pressure cylinder exhausts into a receiver or chamber between the two cylinders, and from which the low pressure cylinder receives its steam.

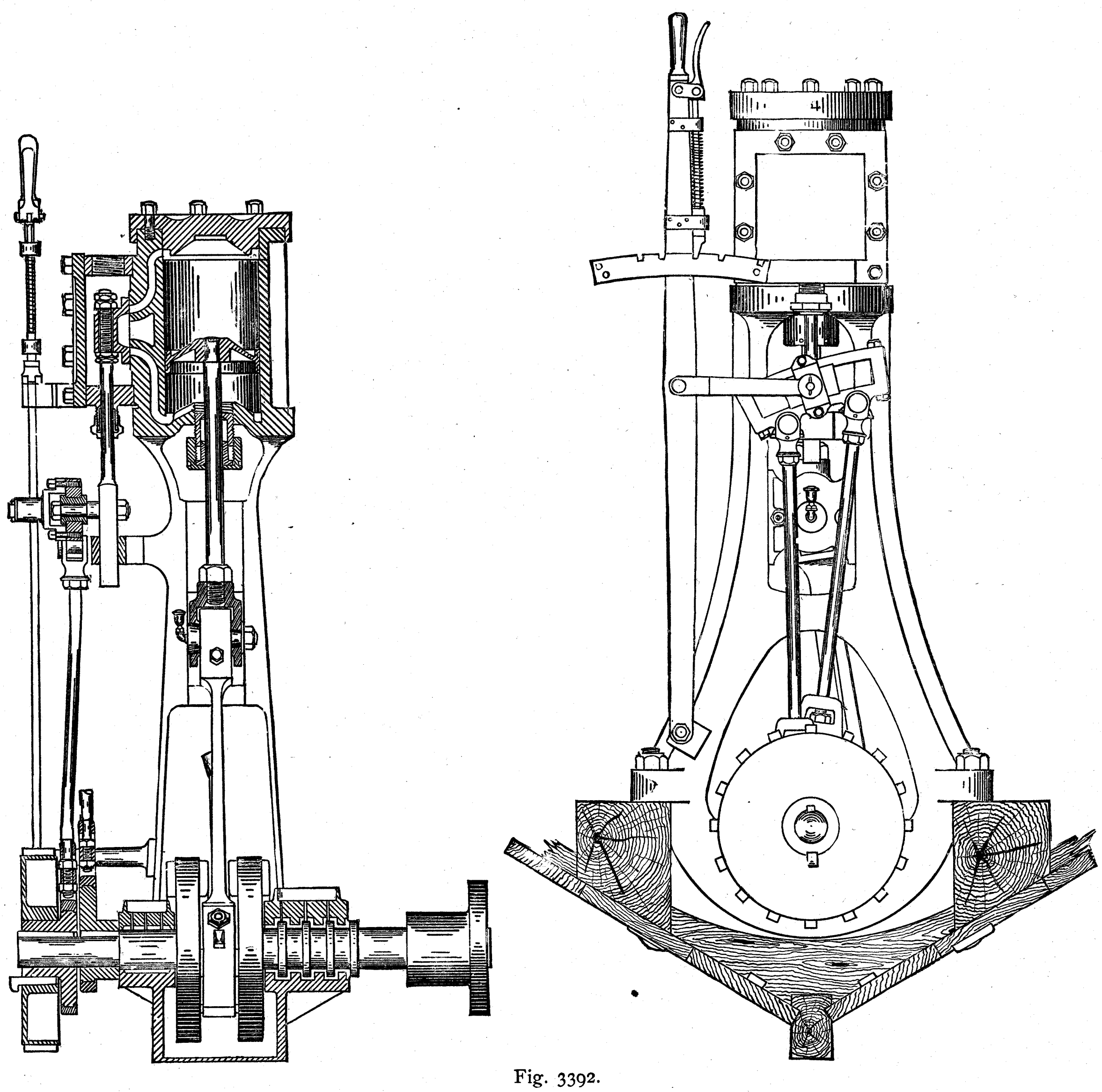

Fig. 3392.

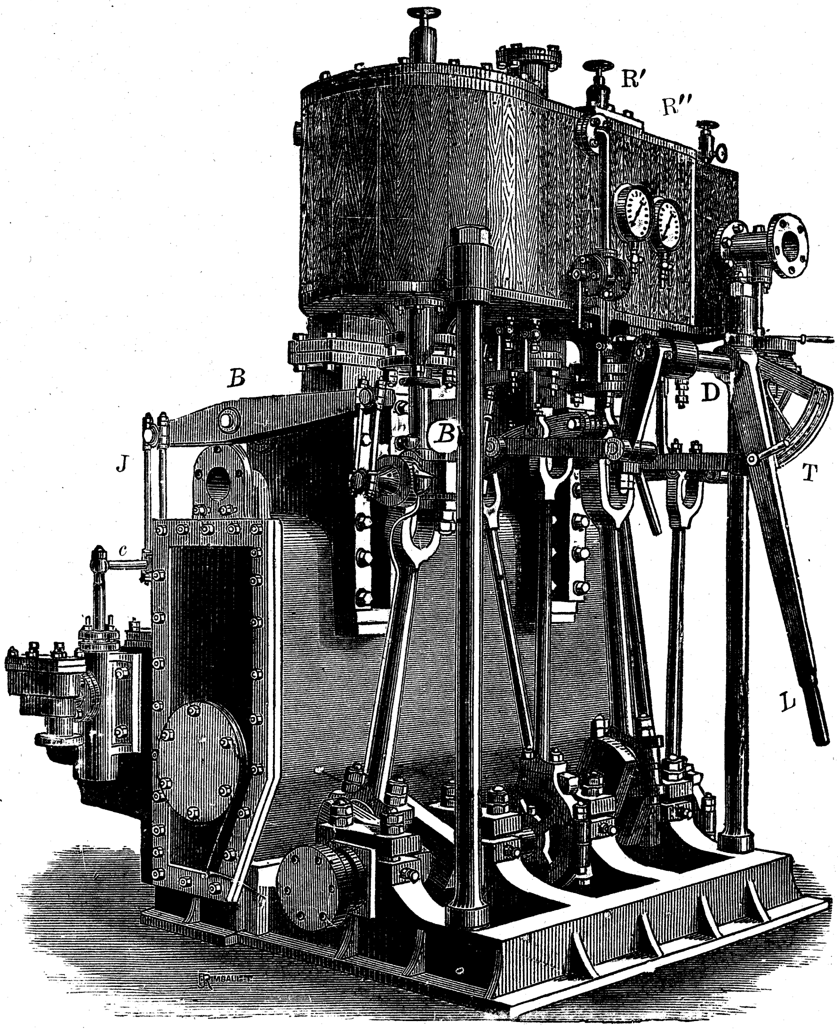

Fig. 3392*a*.

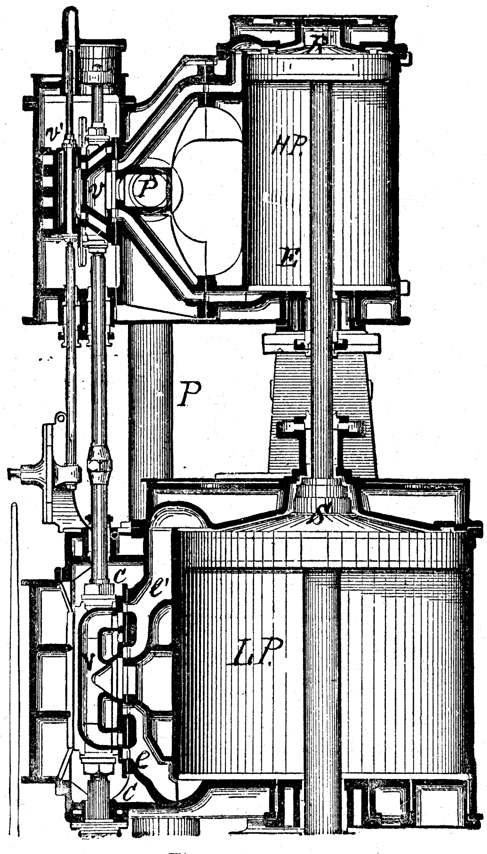

Fig. 3395.

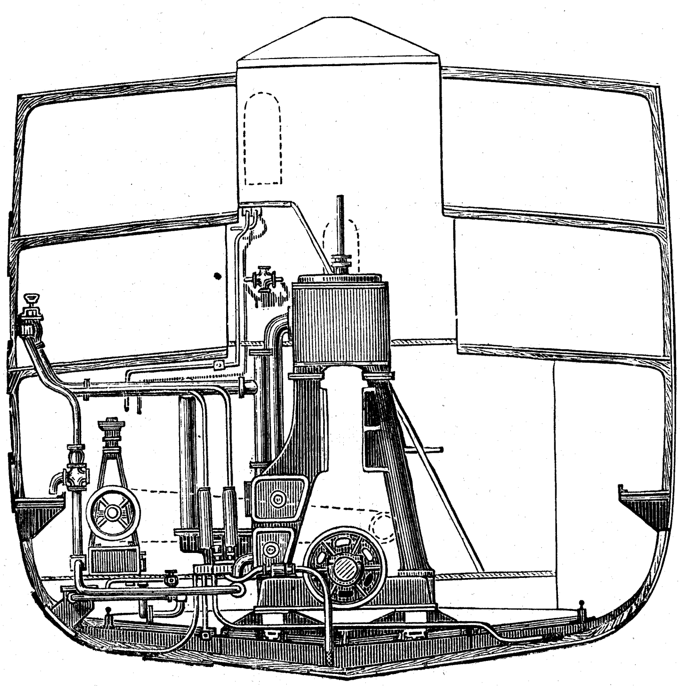

Fig. 3396.

The exhaust from the low pressure cylinder passes into the condenser, where it is condensed, leaving a partial vacuum on the exhaust side of the low pressure piston.

Figs. 3393 and 3394 show the arrangement of the pumps on a pair of compound engines for a dredger. The steam from the low pressure cylinder passes into the body of the condenser with which the air pump is in communication, as shown in the end elevation. At *a* is the foot valve of the condenser. The piston of the air pump has a similar valve, and at *e* is the delivery valve.

The circulating pump is shown in the back elevation (Fig. 3394), being a piston pump which forces the water through the tubes of the condenser.

There are two principal methods of compounding, in one of which the two cylinders are placed one above the other, with their axes in line, and both pistons connecting to the same crank, while in the other the cylinders are side by side, and each connects to its own crank, the two cranks usually being at a right angle.

When one cylinder is placed above the other, as in Fig. 3395, R being the high pressure and S the low pressure piston, no receiver is employed, the steam passing direct from the high pressure cylinder through the pipe P to the low pressure steam chest *c*. The high pressure steam valve V and the low pressure valve V are on the same stem, a cut off valve V′ being provided for the high pressure cylinder.

3. Triple expansion engines have three cylinders, a high pressure, an intermediate, and a low pressure cylinder.

In a triple expansion engine the intermediate cylinder receives the steam that is exhausted from the high pressure cylinder, and expands it further. The low pressure cylinder receives its steam from the exhaust of the intermediate cylinder, and exhausts into the condenser.

In the illustrations from Fig. 3396 to Fig. 3406 are represented the triple expansion engines of the steamship *Matabete*, constructed by Messrs. Hall, Russell & Company, of Aberdeen, Scotland. Fig. 3396 is a cross sectional view of the vessel showing the engine and its connections, and Fig. 3397 a similar view, showing the boilers. Fig. 3398 is a back elevation of the engine, showing the boilers also, and Fig. 3399 a plan of the same. Fig. 3400 is a sectional view, and Fig. 3401 an end view of the boilers. Fig. 3402 is a plan, Fig. 3403 an end elevation, and Fig. 3404 a front elevation, partly in section, of the engines. H P is the high pressure cylinder, I C the intermediate cylinder, and L P the low pressure cylinder. The high pressure cylinder has a piston valve, the steam chest being shown at A. The intermediate

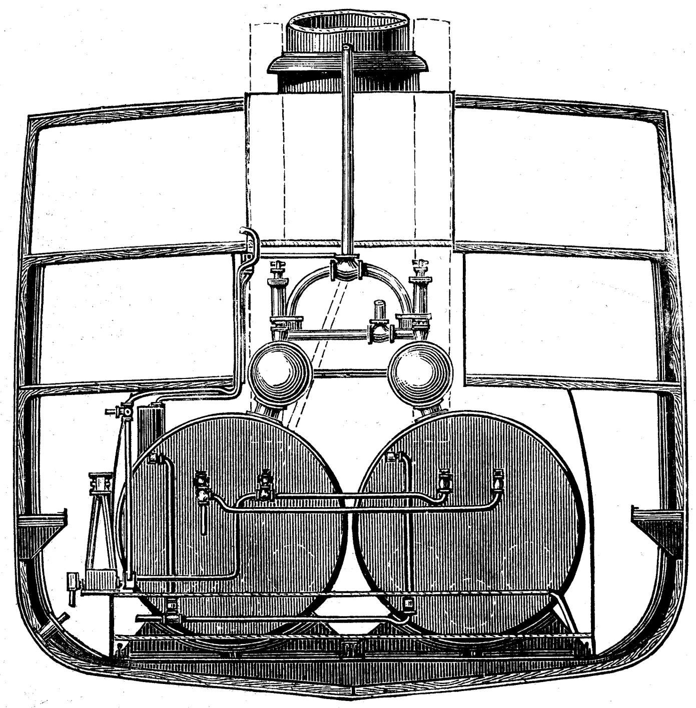

Fig. 3397.

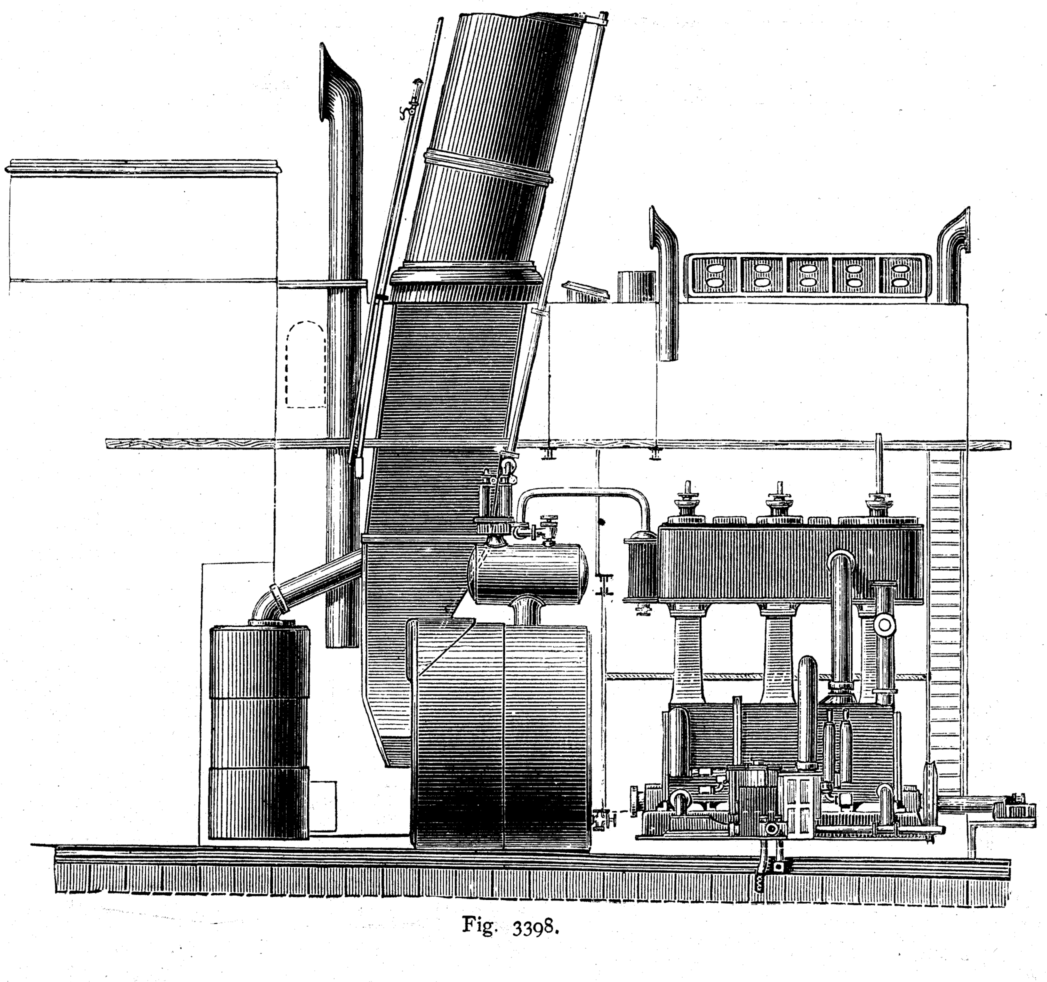

Fig. 3398.

COMPOUND MARINE ENGINE.

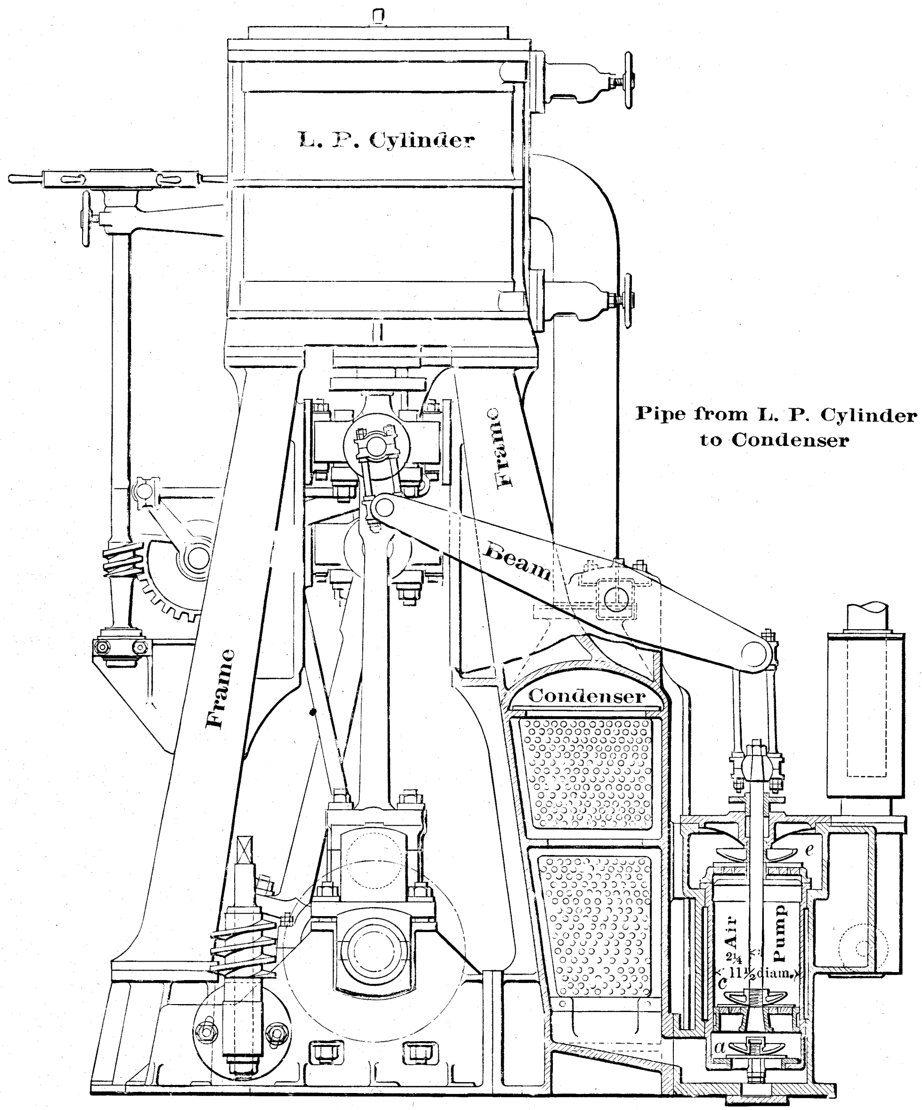

Fig. 3393.

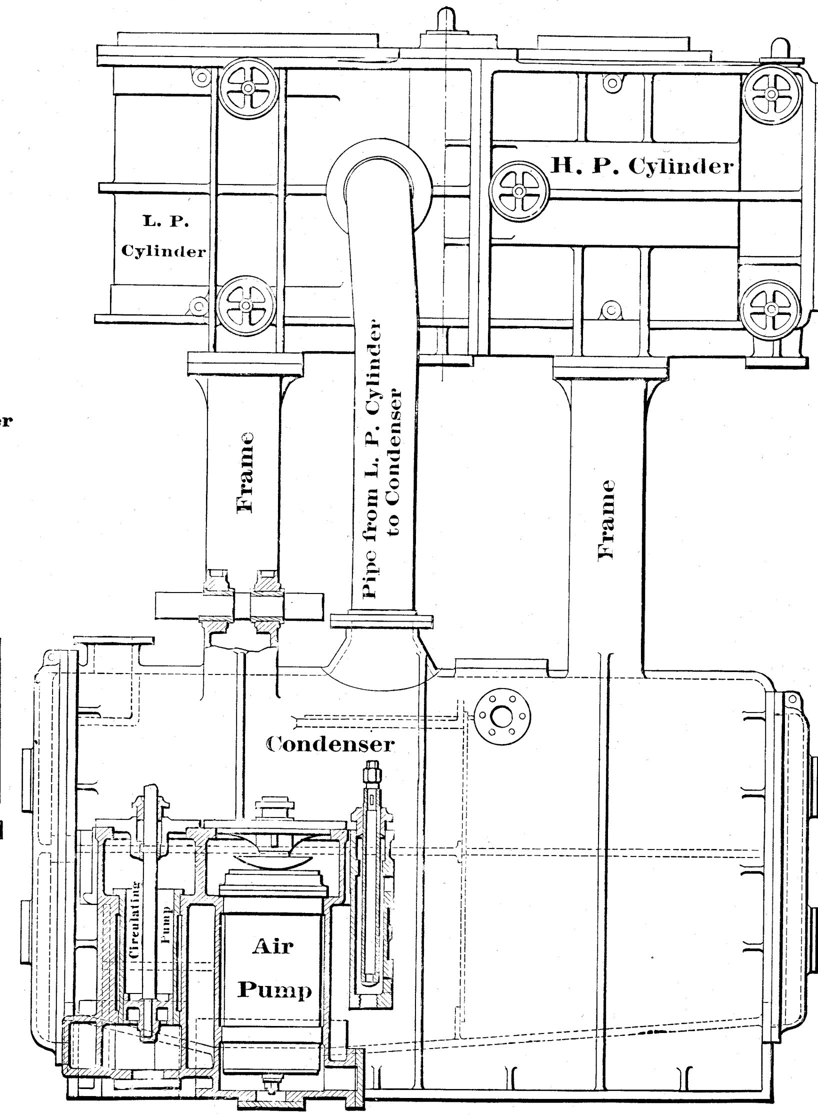

Fig. 3394.

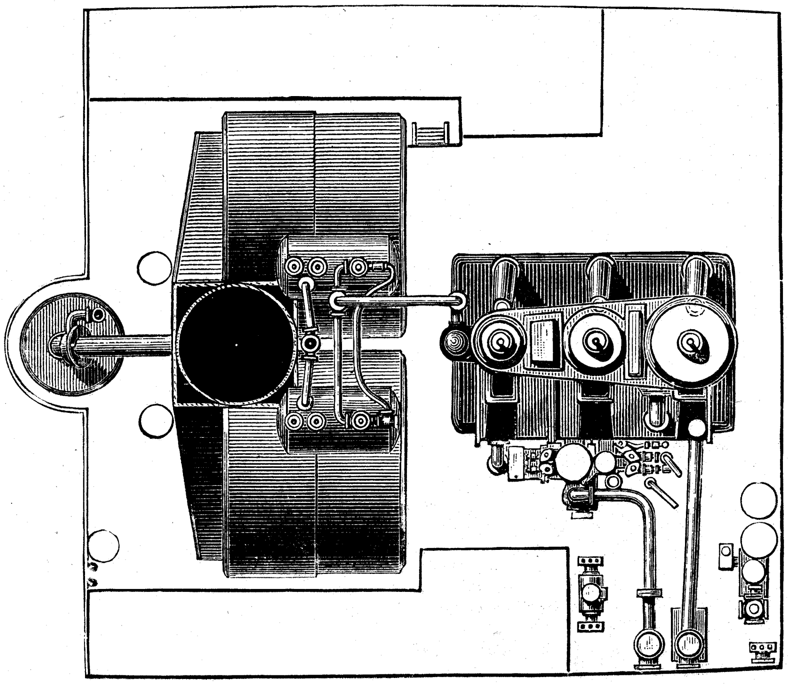

Fig. 3399.

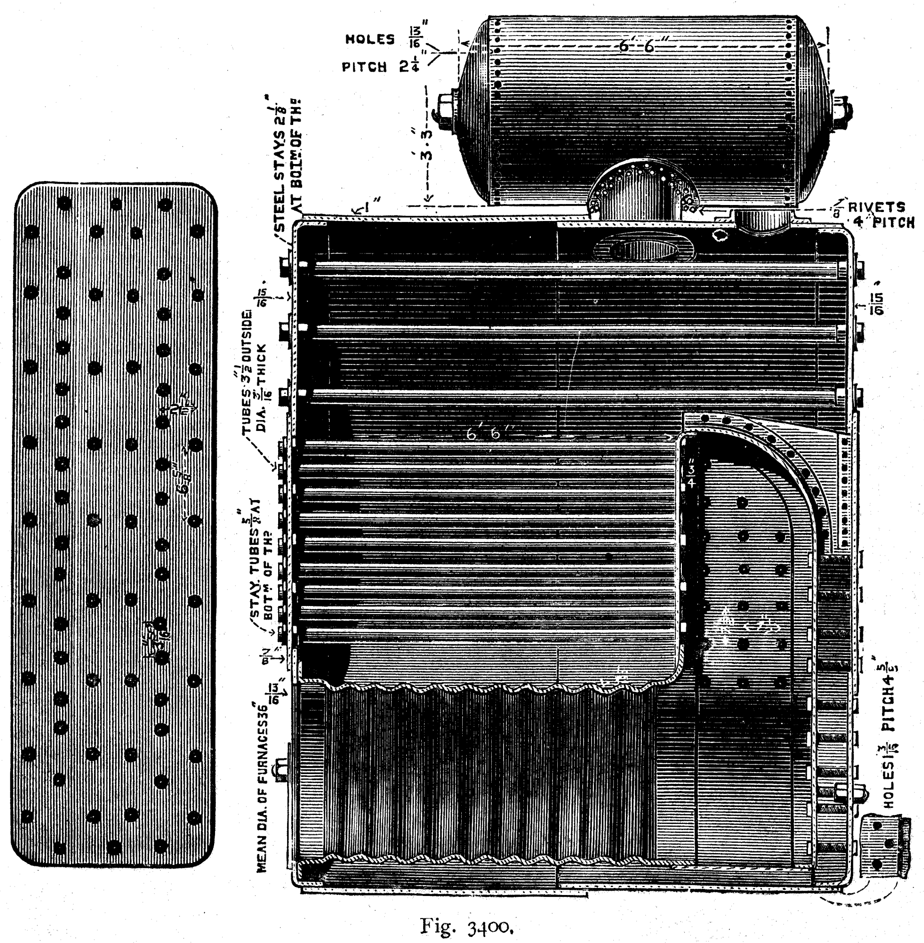

Fig. 3400.

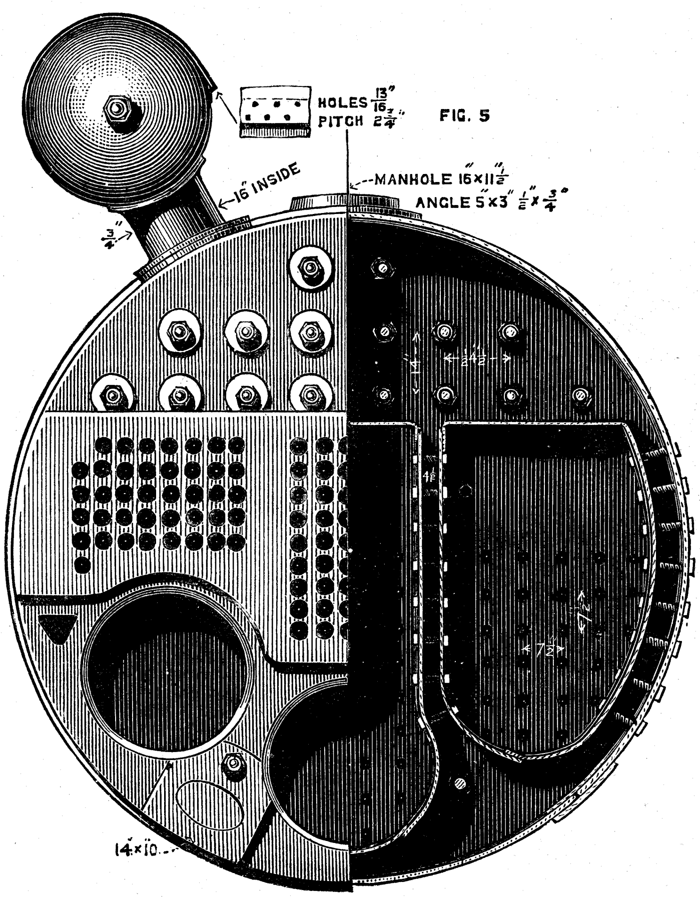

Fig. 3401.

cylinder is provided with a double ported flat valve as shown at B, and the low pressure cylinder is provided with a similar valve whose weight is counterbalanced by the small piston at E; at F are the relief valves for relieving the cylinders of water.

Each steam valve is provided with a link motion that may be used for varying the point of cut off (and therefore the expansion) as well as for reversing purposes.

The link motions are all shifted from one shaft, which may be operated by hand or by steam, the construction being as follows:

For shifting by hand, the wheel W is operated, its shaft having a worm driving the worm wheel G, Fig. 3403, which operates rod H, and through the lever J and rod K shifts the link L, one pair of eccentric rods being shown at N and P.

The shaft of the wheel W is, however, a crank shaft, and at M is a small engine, which may be connected or disconnected at will to shaft W. The lever J operates a shaft R in Fig. 3404, which connects (by a rod corresponding to rod K in Fig. 3403) to each link motion; hence all the links reverse together, and the ratio expansion of one cylinder to the other cannot be varied, or in other words, the point of cut off will be alike for each cylinder, let the link motion be shifted to whatever position it may.

The beam S, Fig 3403, for working the air, circulating and feed pumps, is driven from the cross head of the intermediate cylinder.

The boilers are of the Scotch pattern that is usually employed for high pressures, as 160 or more lbs. per square inch, and have Fox corrugated furnaces and stay tubes.

Each cylinder requires a starting valve (which is sometimes called an auxiliary valve or a bye pass valve), which is used to warm the cylinder before starting the engine, and also (when there is no vacuum in the condenser) to admit high pressure steam when the high pressure piston is on the dead centre, in which case, there being no vacuum and no admission of steam to the low press-

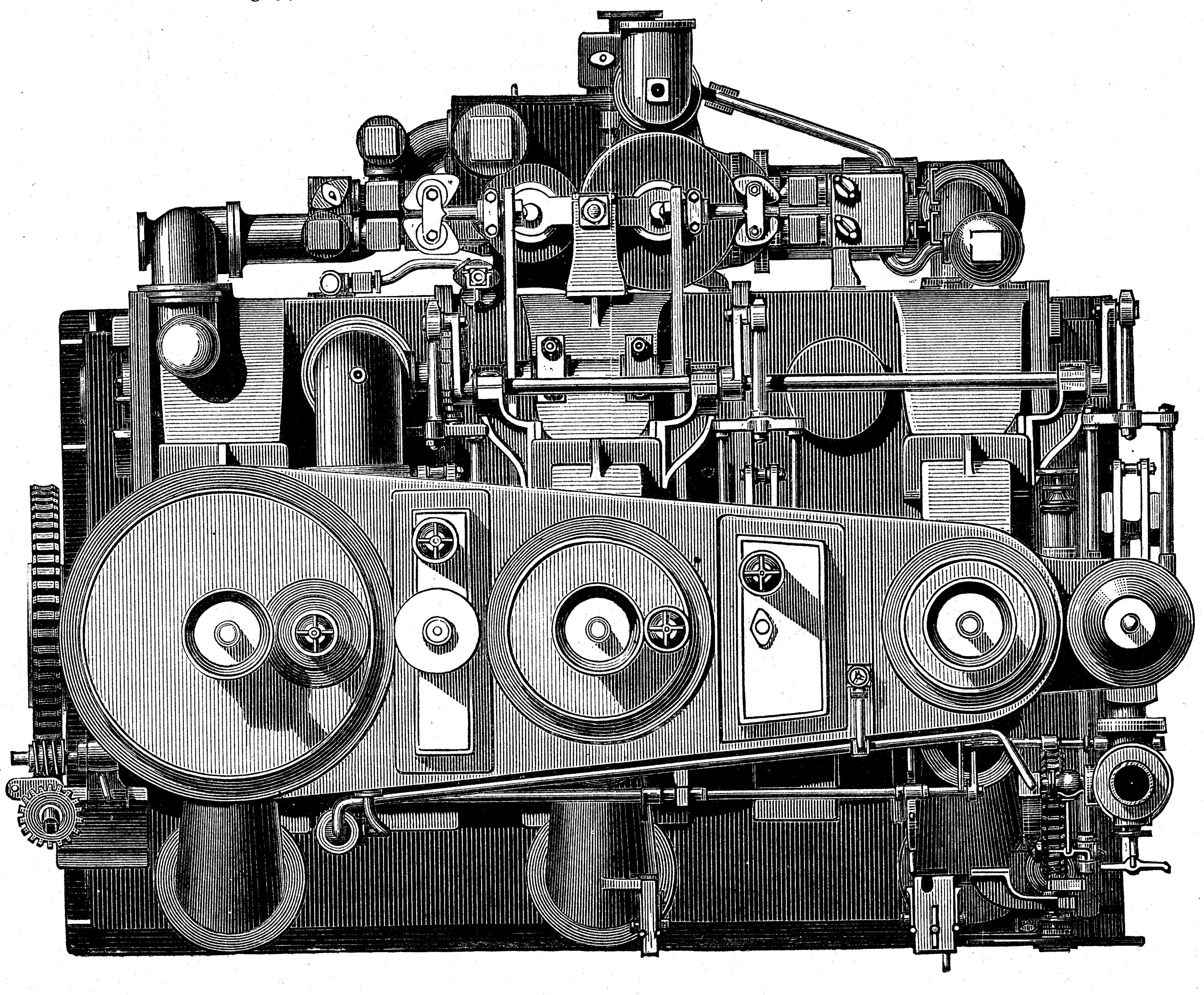

Fig. 3402.

ure cylinder, the engine would not have sufficient power to start.

In some cases the high pressure cylinder has no starting valve, the reversing gear being used to admit steam to one end or the

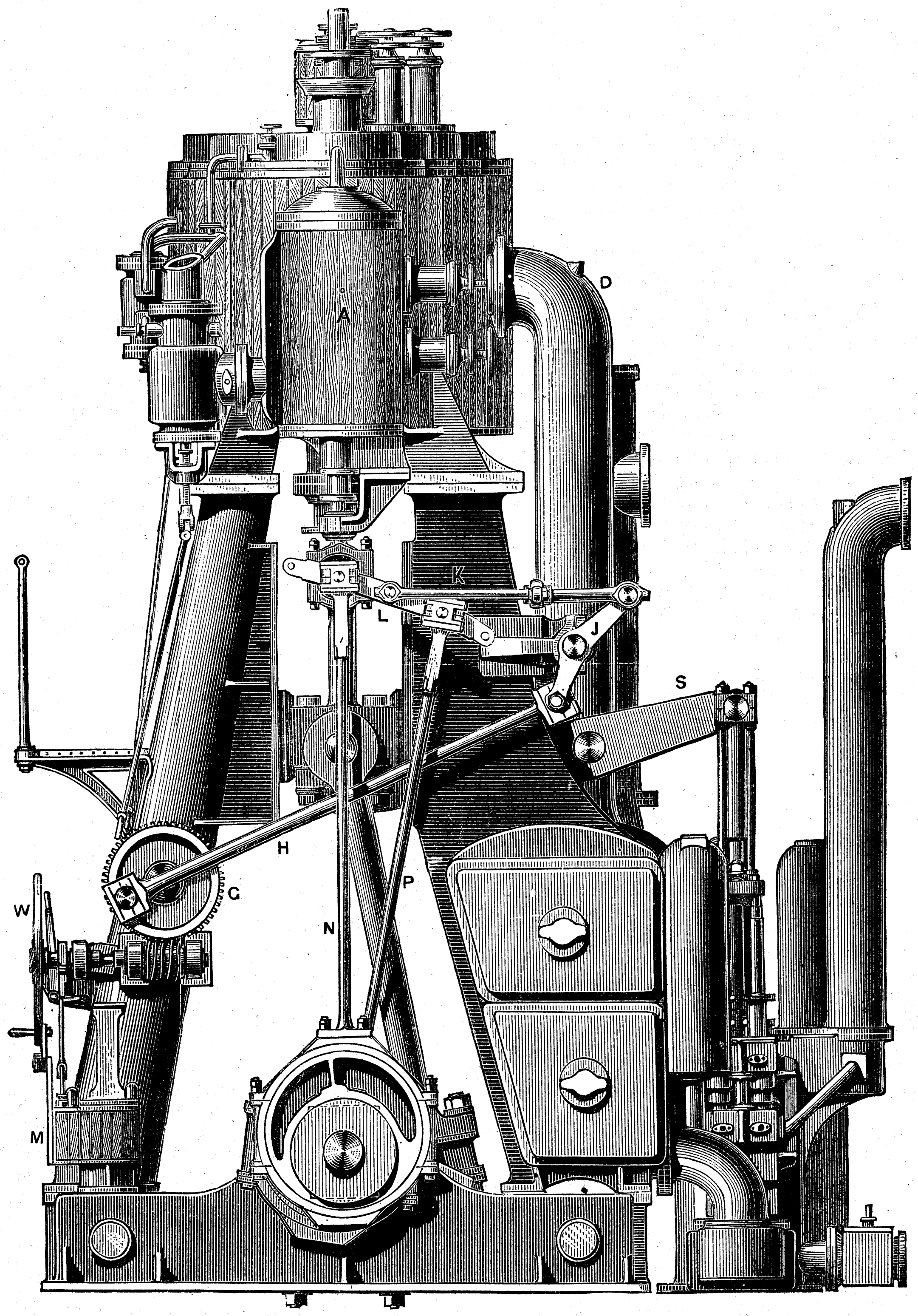

Fig. 3403.

other of the high pressure piston, and the starting valve being used to admit enough live steam to the low pressure cylinder to compensate for the absence of the vacuum.

When the vacuum in the low pressure cylinder is maintained while the engine is standing still, its starting valve obviously need not be used, except for warming purposes, before starting the engine; as soon, however, as the engine has started, the starting valve must be closed.

Each cylinder is provided with a relief valve, both at the top and at the bottom, to relieve the cylinder from a heavy charge of water, such as may occur if the boiler primes heavily.

Each cylinder is also provided with drain cocks, to permit of the escape of the ordinary water of condensation in the cylinders when the engine is started, and also for use if the boiler primes.

The low pressure relief valve also prevents the accumulation of too great a pressure in the low pressure cylinder, which, from its large diameter, is not strong enough to withstand high pressure.

The oiling apparatus for the cylinders is arranged as follows:

In some cases pumps, and in others automatic or self-feeding devices are used. Oil is fed to the steam pipe of the high pressure cylinder, and this lubricates both the valves and the cylinders, but in many cases it is also fed to the steam chest, so as to afford more perfect lubrication to the valve.

For the low pressure cylinder the oil is fed into the receiver, and usually at a point near the slide valves.

Large marine cylinders are usually constructed with a separate lining, which may be replaced when worn or otherwise required.

A surface condenser consists of a cast iron shell or chamber forming the back of the engine frame. At each end of this chamber is a short partition, so that the condenser is divided lengthways into what may be called three compartments, of which the middle one is the longest and contains a number of thin brass tubes about $\frac{5}{8}$ or $\frac{3}{4}$ inch in diameter, the ends of these tubes being held in the plates or tube sheets forming the partitions. The object of providing tubes of small diameter is to obtain a large area of cooling surface.

The exhaust steam from the engine generally passes into the shell or body of the condenser, filling the middle partition and surrounding the tubes.

The condensing or circulating water passes through the tubes, and by keeping them cool condenses the steam and forms a vacuum or partial vacuum in the condenser, which, having open communication with the low pressure cylinder, therefore gives a corresponding degree of vacuum on the exhaust side of the low pressure piston.

In some designs, however, the steam passes through the tubes and the circulating water fills the middle compartment of the condenser. As, however, there is no pressure to counterbalance the weight of the water, it is preferable to have the water inside the tubes, so that they are subjected to a bursting pressure, in which case they may, for a given strength, be made thinner, because the strength of the tube to resist bursting is greater than its strength to resist collapsing, hence the circulating water usually passes through the tubes. The chamber at the ends of the condenser permits the water to distribute through all the tubes.

In some cases the chamber at one end is divided horizontally into two compartments, so that the water is compelled to pass through one half and return through the other half of the tubes.

The water of condensation falls to the bottom of the condenser, from which it is removed by the air pump, which delivers it to the hot well.

The hot well is situated on the side of, and extends above, the pump, whose upper end it covers, thus water sealing the top of the air pump and preventing air from passing into it through a leaky valve or bucket.

The top of the hot well is provided with a *vapor pipe*, which permits the air and gases to pass overboard. This pipe emerges through the side of the ship above the water line, and as there is no valve between the hot well and the sea, no pressure can possibly accumulate in the hot well.

The boiler feed is taken from the hot well either by the feed pump or by injectors, as the case may be.

In case the boiler feed should stop working, however, the hot well is provided with a pipe of large diameter, and called the overboard discharge pipe, so that the water of condensation may not accumulate a pressure in the hot well if the boiler feed ceases.

This overboard discharge pipe is provided with a weighted valve (placed at the side of the ship), which is constructed after the manner of a safety valve, relieving the hot well of pressure if the water accumulates, and preventing the sea water from entering the hot well.

To prevent loss of fresh water, the exhaust steam from the various engines and pumps (if any) about the ship passes to the condenser and is pumped into the hot well.

In some cases, however, a separate and independent condenser is used for the smaller engines about the ship

An independent condenser is one whose air pump and circulating pump are not worked from the main engine, and can therefore be operated when the main engine is standing still.

If the main condenser is independent, it may be started so as to form a vacuum before the main engine is started, and thus obviate the use of the starting valve on the low pressure cylinder except to warm the cylinder before starting.

Feed water for the boilers when the engine is standing is obtained by a pipe from the bottom of the condenser, so that the water of condensation of steam blown through the engine cylinders, and from the exhausts from the smaller engines about the ship, may be pumped or forced direct from the bottom of the condenser to the boiler.

This feed from the bottom of the condenser is necessary when the air pump is not working, and the water of condensation is not pumped into the hot well.

If the water thus obtained is not enough to keep the boilers supplied, an auxiliary or salt water feed admits extra water from the circulating water to the inside of the condenser to supply the deficiency.

This secondary suction pipe is provided with a valve because it must be shut off before the engine is started.

All the drain pipes from the cylinder pass into the condenser so as to save the fresh water.

The air pump is usually worked by a beam, receiving motion from the cross head of the low pressure cylinder.

The circulating pump is usually worked by the same beam as the air pump, or receives its motion from some other part of the main engine. In some cases, however, an independent circulating pump is employed.

It receives its water from a pipe leading to the sea, which is provided with an injection cock or Kingston valve, placed close to the side of the ship and well below the sea level. This valve is used to shut off the circulating water and prevent its flooding the ship in case of accident to the condenser or circulating pump.

The circulating water, after passing through the condenser, discharges overboard through the circulator discharge pipe.

This pipe is also provided with a valve placed close to the ship's side, at or above the water level, so that the opening at the ship's side may be closed, and sea water prevented from entering the ship in case of breakage to the condenser, etc.

To enable a surface condenser to be used as a jet condenser in case of accident to the circulating pump, a pipe leads from the injection cock of the circulating supply pump into the bottom of the exhaust pipe or column, where it enters the condenser.

This pipe is supplied with a spray or rose nozzle, which divides up the injection water and causes it to condense the steam as it enters the condenser.

An additional pipe is sometimes added to the suction side of the circulating pump, for use in pumping out the bilge by means of the circulating pump in case of emergency, and also for pumping out ballast tanks when the vessel is provided with such tanks.

An air valve is sometimes fitted to a reciprocating double acting circulating pump. It admits air to the water during the up stroke of the pump, and closes on the down stroke. The air thus admitted acts as a cushion to soften the shock of the water.

A snifting (or snifter valve, as it is sometimes called) is a valve fitted to the condenser and that opens upwards to permit of the discharge of the air and gases before the engine is started. It also serves to prevent any water from leaky condenser tubes from filling the condenser and flooding the engine cylinders. It is so loaded with dead weight that it opens automatically when the water in the condenser has reached a certain height and must be placed as low down on the condenser as possible, so as to receive the weight of the full height of the water in the condenser.

Condenser tubes are made water tight in the tube plates of the condenser by wooden or sometimes paper ferrules, which fit the tube and drive into the tube plate. In other cases, however, the tube ends project through the plates, and a rubber washer is placed on the end of each tube. A covering plate is then bolted over the whole of the tube ends, the holes in the covering plate being parallel for a short distance, and then reduced in diameter so as to form a shoulder. The rubber rings compress and make a joint, and the shoulders prevent the condenser tubes from working out endways from expansion and contraction. The tubes are usually about $\frac{3}{64}$ inch thick.

A blow through valve is a valve attached to the casing or steam chest, and connecting by a pipe to condenser to blow out the air and gases that may have collected there when the engine is standing still, and that also connects to the exhaust port of the high pressure cylinder, so as to supply live steam to the low pressure

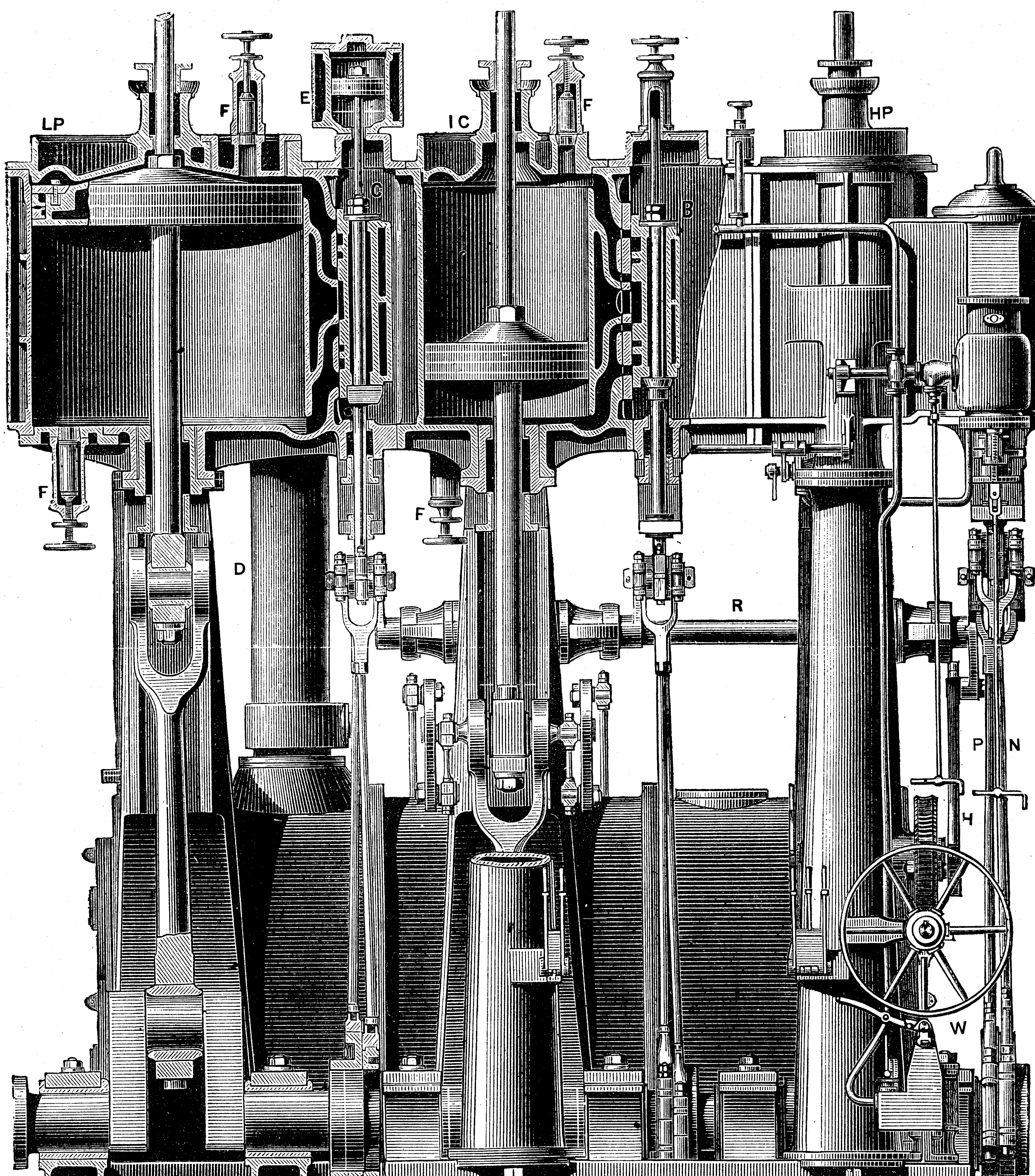

Fig. 3404.

cylinder in case the high pressure cylinder should get disabled.

A bucket air pump is one in which there is a valve or valves in the pump piston, hence the pump is single acting, drawing on the lower side of the piston and delivering on the upper, hence the capacity of the pump per engine revolution is equal to the diameter of the bucket multiplied by the length of its stroke. The suction or foot valve is at the foot of the pump, and the delivery valve at the head.

A piston air pump is double acting, since it draws on each side alternately of the piston, one side delivering while the other is drawing, hence two suction and two delivery valves are required.

A plunger air pump is one in which a plunger is used in place of a piston, the delivery being due to the displacement of the plunger.

An air pump trunk is a hollow brass cylinder attached to or in one piece with the piston or bucket of the air pump. The rod which drives the piston passes through the trunk, and connects to a single eye at the bottom of the trunk.

A trunk air pump is necessary when the pump rod is driven direct from the crank shaft, and therefore has sufficient lateral motion to push the pump piston sideways, which would cause friction and excessive wear to the gland that keeps the trunk tight. The delivery capacity of the pump is obviously diminished to an amount equal to the displacement of that part of the plunger that passes through the gland and within the pump bore, whereas in a piston pump the delivery capacity is only diminished to an amount corresponding to the displacement of the pump piston rod.

A bucket pump may in some cases be worked without either a foot or a head valve, since the bucket valve will answer for both in cases when the delivery water cannot pass back into the pump on the down stroke of the bucket.

It will, however, be more efficient with the addition of either of them, and most efficient with both.

A bucket pump with a foot valve and no discharge valve would, however, suffer more from a leaky gland than if it had a discharge valve and no foot valve, because the air would, on the ascent of the bucket and the closing of the bucket valve, pass to the suction side of the bucket and impair the vacuum.

Let the delivery valves be where they may, the foot valve will always have some water above it, and the pump bucket will dip into this water, and on lifting produce a vacuum that will cause the pump to fill with water. Notwithstanding that the gland may leak air on the other side of the bucket, this air will in a single acting pump be expelled with the water, but in a double acting pump it will impair the vacuum, and therefore the suction, on the gland side of the piston.

Bucket air pumps are provided with a valve or pet cock on the top or delivery side of the bucket and above the bucket, when the latter is at the highest point of its stroke. This valve opens on the descent of the bucket, admitting air to act as a cushion between the surface of the water and the delivery valve, when the water is about to meet the latter. It obviously reduces the effectiveness of the pump, and in a double acting pump is inadmissible, because of its impairing the vacuum and the suction.

This valve also enables the engineer to know whether the air pump is working properly.

A pet cock is also supplied to the feed pumps for this same purpose.

A bilge injection is one in which the injection water is taken from the bilge, which may be done when the ship makes more water than the bilge pumps can get rid of.

The fittings necessary for a bilge injection are a cock or globe valve placed on the side of the condenser, and at or near the foot of the exhaust pipe, with a spray or rose inside that pipe. From the cock a pipe, usually lead, leads to the bilge, having at its end a strainer or strum, and care must be taken that this strum does not get choked and let the condenser get hot from the exhaust steam not being condensed.

The water in the hot well of a surface condenser is usually kept at a temperature of about 100° Fahrenheit. A higher temperature than 100° Fahrenheit injures the rubber valves of the air pump, while lower temperatures cool the engine cylinders too much and cause waste from cylinder condensation. Moreover, it is obvious that, since the boiler feed is taken from the hot well, it is desirable to keep it as hot as the valves and as the desired degree of vacuum will permit.

An air vessel or air chamber is a vessel fitted to the delivery and sometimes also to the suction side of a pump. Its office is to maintain a steady flow of water through the pipes.

Thus, in the case of the delivery air chamber, when the pump piston is travelling at a speed above its average for the stroke, the water accumulates in the air chamber, and the air is more compressed, while, when the pump is on the dead centre, or at the end of its stroke and the delivery valve closes, the air compressed in the air chamber continues the delivery or discharge, thus maintaining a more uniform flow.

Pumps sometimes have an air or vacuum chamber on the suction side, from which the air is exhausted when the pump starts, leaving a vacuum which causes a steady flow of water up the suction pipe.

Both these chambers are more effective as the speed of the pump increases. The chamber on the delivery side is apt to lose its air, which is gradually absorbed by the water, which should be let out when the pump is standing still.

Feed escape valves or feed relief valves are fitted to the feed pumps, so that in case all the feed water cannot pass into the boiler it may pass back to the hot well.

The construction of a feed escape valve is as follows:

It is an ordinary mitre valve held to its seat by the compression of a spiral spring, whose pressure upon the valve may be regulated by an adjusting screw, whose end abuts upon a stem provided for the purpose.

In proportion as the valve is relieved of the pressure of this spring, a greater proportion of the water delivered by the feed pump will pass back into the hot well, hence the amount of boiler feed may be regulated by the feed escape valve, which also acts as a safety valve, preventing undue pressure in the feed pipe.

When no feed escape valve is employed, the delivery water from the feed pump must pass unobstructed to the boiler, or the feed pipes may burst from over pressure, and it follows that the feed check valve on the side of the boiler must not be restrained in its amount of lift, hence it must not have a lift adjusting screw.

The amount of the boiler feed must, in this case, be regulated from the suction side of the pump, the suction pipe being fitted with a cock or valve whose amount of opening may be adjusted so as to regulate the amount of water drawn per pump stroke from the hot well.

If the feed valve on the suction side, or the escape valve on the delivery side of the pump, as the case may be, is adjusted to permit of a proper amount of boiler feed, and yet the feed is insufficient or ceases altogether, it may occur from the following causes:

1st. From the suction valve sticking or being choked, or from the delivery valve being choked and not seating itself, thus either letting the suction water pass back into the hot well, or the delivery water pass back into the pump.

2d. Through leaks in the joints of the pump or of the suction pipe.

3d. From the water in the hot well being too hot.

4th. Through the spring of the escape valve having become disarranged.

5th. If two or more boilers are connected, and one has less pressure in it than the other, it may take most of the feed water, or the water of the other may empty itself into it.

Bilge Injection. The injection water for a common or jet condenser may be obtained in one of two ways: first, direct from the sea, which is that for ordinary use; and secondly from the bilge, which is resorted to to assist the bilge pump in cases of emergency.

The necessary fittings for a bilge injection are, a pipe leading from the condenser to the bilge, with a cock at the condenser end and a strainer at the bilge end.

This pipe should be fitted with a check valve, which opens by lifting upwards so that no water can pass down it into the bilge, or otherwise, if the main and bilge injections should happen to be left open together, the water from the main injection might pass down into the bilge. This check valve should be so constructed that its amount of lift can be regulated and as much of the bilge water used for injection as the circumstances may require.

In the case of surface condensers, the bilge water is drawn off by the circulating pump and used to supplement the main circulating water. The pipe from the bilge in this case leads to the suction side of the circulating pump, and requires a strainer at the bilge end, a cock at the circulating pump, and a check valve.

A ship's side air pump discharge valve is an ordinary dead weight mitre valve that opens to let the water pass out into the sea, but seats itself and closes if the water attempts to pass inwards. It differs from a common stop valve in being weighted, and therefore self-acting. It requires to be lifted before starting the engine, as such valves are liable to stick in their seats.

The course of the main injection water of a jet condenser is as follows: From the rose plate or strainer, through the injection valve and pipe to the condenser, where it mingles with the exhaust steam and from which it is pumped with the products of condensation into the hot well. From the hot well it passes mainly overboard through the Kingston valve, but that part of it used for the boiler feed passes through the suction pipe and valve into the pump, and thence through the delivery valve, pipe and check valve into the boiler.

The course of the main circulating water of a surface condenser is through the Kingston valve (on the ship's side or bottom), and the circulator inlet pipe, either direct to the condenser, from which it is *drawn* by the circulating pump, or else it passes through it, and is *forced* through the condenser. It circulates through the condenser twice or thrice according to the construction, and is forced overboard by the action of the circulating pump, passing through a valve on the ship's side or bottom.

The advantages of surface condensation are, first, that the feed water is obtained at a higher temperature than if injection water was fed to the boiler. Second, the feed water is purer, and therefore less water requires to be blown out of the boiler in order to keep it clean. Third, the boiler does not scale so much, hence its heating surface is maintained more efficient; and fourth, the boiler suffers less from expansion and expansion strains when hot feed water is used.

Surface condensers foul from the grease with which the cylinders are lubricated and from the salt in the injection water. The condenser is cleaned by the admission of soda with the exhaust steam and by washing out.

A condensing engine has the following cocks and valves on the skin of the ship in the engine room: The main Kingston valve for the injection, or circulating water, the main delivery valve from the condenser, the bilge delivery valves, and the water service cocks for keeping the main bearings of the engine cool with streams of cold water.

A donkey engine is a small engine used to feed the boiler, and has the following connections: A steam pipe from the boiler to drive the donkey engine; and exhaust pipe into the condenser; a suction pipe from the hot well or from the sea, as the case may be; and a delivery pipe to the boiler; a suction pipe from the bilge, so that the donkey pump can assist in pumping the bilge out; a suction pipe to the condenser, to circulate the water when the main engines are stopped, and thus maintain the vacuum; and a suction pipe from the water ballast tanks, to pump them out when necessary.

The pipes that lead from, or go to, the sea are: Boiler blow off pipe, sea injection or circulator pipe, condenser discharge pipe, and, in some cases, donkey feed suction pipe.

The parts of an engine that are generally made of wrought iron are those in which strength with a minimum of weight and size is desired; for example, the piston rod, cross head, connecting rod, crank shaft, crank, eccentric rods, link motion, valve spindle pump rods, and all studs, bolts, and nuts.

The parts generally made of cast iron are those where strength and rigidity are required, and which are difficult to forge, while weight or size is of lesser importance, such as the bed plate, cylinders, pistons, condensers, and pumps.

The parts sometimes made of steel are those subject to great wear, and for which strength with a minimum of size is necessary, as piston springs, piston rods, connecting rods, cranks, crank pins, and valve rods.

The parts generally made of brass are those subject to abrasion or corrosion, as the connecting rod brasses, the bearings for the crank shaft, the pump plungers or pistons, and their rods, linings for the pump barrels or bores, the bores of the glands, the condenser tubes, and all cocks and valves.

White metal or babbitt metal is sometimes used in place of, or in connection with, brasses, serving as an anti-abrasion surface. It is easily renewed, as it is cast into its place, but will melt and run out at a temperature of about 600° Fahrenheit.

Muntz metal is used where iron or steel would suffer greatly from corrosion when in contact with salt water. It can be forged.

The difference in the composition of cast iron and steel has never been determined; the difference lies in the percentage of carbon they contain and the structure of the metal. Cast iron will not weld.

Cast iron is brittle, of granular structure, and always breaks short, having a very low elastic limit.

Wrought iron is tough and fibrous, will weld but will not harden, and is stronger than cast iron.

Steel is stronger than wrought iron, and will weld and harden and temper. The breaking strain of wrought iron varies from about 42,000 to 60,000 lbs. per square inch of section.

Steel is tempered by first being heated red hot and suddenly cooled (usually by plunging it into cold water), which hardens it. The surface is then brightened, and on being repeated the tempering colors appear, beginning at a pale yellow, and deepening into red, brown, purple, and blue, the latter gradually fading away as the metal is re-heated to a red heat. The higher the temperature to which the hardened steel is reheated the softer or lower it is tempered.

These colors merely indicate the temperature to which the piece is reheated, since they will appear on steel not hardened and upon iron.

Case hardening is a process that converts the surface of wrought iron into steel, which is accomplished by placing them in a box filled with bone dust, animal charcoal, or leather, hoofs, etc. The box is sealed with clay, heated red hot for about 12 hours, and the pieces are quenched in water.

The parts usually case hardened are the link motion, and other light working parts that are of wrought iron.

The forgeable metals used in engine work are wrought iron, steel, copper, and Muntz metal. The brittle or short metals are cast iron and brass.

Welding is the joining of two pieces solidly together. Wrought iron, steel, and Muntz metal can be welded.

All the metals used in the construction of marine engines expand by heat, and this is allowed for in adjusting the lengths of the eccentric rods, or of the valve spindles when setting the valve lead. In the case of two marine boilers being connected together, the steam pipe is fitted with an expansion joint, one pipe end having an enlarged bore to receive the other. The joint is made by packing, which is squeezed up by a gland, whose bore fits on the outside of the pipe which moves through the gland bore, from the expansion and contraction.

The piston of a marine engine steam cylinder is a disc of cast iron, into which the piston rod is secured. Its body is cored out to lighten it. Around its circumference is a recess to receive the packing ring or rings, each of which is split across so that it may be expanded (to fit the bore of the cylinder) by means of the packing or of the springs. The split is closed in the centre by a tongue piece let into the ring, and fastened to one end of the ring.

To hold the piston rings or ring in place, a junk ring is employed, being an annular ring bolted to the piston. The piston rings are set out to fit the cylinder bore by suitable springs. The round plugs seen on the piston face merely fill the holes used to support the core in the mould and to extract it from the finished casting.

Cylinder drain cocks sometimes have a check valve upon them, so that while the water may pass out of the cylinder the air cannot pass in and destroy or impair the vacuum.

Cylinder escape or relief valves are provided at the top and at the bottom of the cylinders, and consist of a spring loaded valve with an adjusting screw to regulate the pressure at which they shall act. They are most needed when the boiler primes heavily, and the water might knock out the cylinder heads or covers. They should be enclosed in a case with a pipe to lead the water away, thus preventing it from flying out and scalding the engineer.

A link motion is a valve gear by which the engine may be reversed (caused to run in either direction), or which may be used to vary the point of cut off. The advantage of the link motion is its simplicity and durability.

A link motion for a marine engine is usually of the Stephenson type, and consists of two eccentrics or eccentric sheaves fixed upon the crank shaft, and so set as to give more lead at the bottom than the top ports, because the wear of the journals, brasses, and pins gradually increases the lead at the upper, and correspondingly diminishes that at the lower port. In addition to this, however, more lead is required at the bottom port, to counterbalance the weight of the piston at the end of its descending stroke. The eccentric hoops or straps drive the rods which connect to the ends of the link.

The link may be a curved, solid, or a slotted bar, and in either case has fitted to it a block or die which connects to the valve spindle.

The link is pivoted at its centre to a swinging arm or suspension link,* and by this arm may be moved endways to bring the required end of the link beneath the valve rod or spindle. From the positions in which the eccentrics are set, one end of the link operates the valve to go ahead, while the other end operates it to go astern; hence all that is necessary (so far as the link motion is concerned) to reverse the engine is to move the link endwise to the requisite amount, which, for full gear, is so that the block is at or near the end of the link.

In proportion as the link block is (by moving the link endways) brought nearer to the middle of the link, the valve travel is reduced and the point of cut off is hastened, thus increasing the expansion.

When the link block is in the middle of the link, the latter is in mid gear, and the valve only opens the ports to the amount of the lead, and the link action is the same, whether the engine moves backwards or forwards.

The motion of the link is as follows:

The two ends are vibrated by the eccentrics from the central pin of the link hanger (or suspension link) as a centre of motion, while at the same time this end of the link hanger swings in an arc of which its other end is the centre of motion.

In small engines the link is sometimes used for varying the expansion as well as for reversing the direction of engine revolution.

In large engines it is used for reversing only, a separate expansion valve being used for varying the point of cut off.

In small engines the link is moved endwise for forward or backward gear by a simple arrangement of hand levers. In large engines these levers are supplemented by a worm and worm gear, and in still larger engines a steam reversing gear is used for shifting the links from forward to backward gear, or vice versa.

When there is no link motion, a Joy valve gear, a Marshall valve gear, or a loose eccentric may be used. A loose eccentric is one that can be moved around the shaft to reverse the engine. It may be moved around the shaft by mechanical means, or the eccentric rods may be disconnected, and the valve worked by hand, to cause the engine to run in the required direction, until a pin fast in the shaft meets a lug on the eccentric and drives it, there being two such lugs or shoulders spaced the requisite distance apart on the eccentric. This plan is obviously only suitable for small engines.

A separate expansion valve is a valve employed to effect the cut off and vary the expansion. It does not affect either the admission or exhaust of the steam to the cylinder.

It is used because by its means an early point of cut off and high rate of expansion may be obtained with a fixed point of exhaust, a fixed amount of compression, and a fixed amount of lead, whereas with the link motion alone the exhaust occurs earlier in the stroke, and the compression and the lead increase as the link is moved from full gear towards mid gear. The expansion valve should, when the engine is to be started, be set for the latest point of cut off. The eccentric for the expansion valve is set opposite to the crank, in order that its action may be the same, whether the engine runs backward or forward.

The small cylinders on top of the steam chests are for the purpose of guiding the upper ends of the valve spindles, and are fitted with pistons having steam beneath, the space above being in communication with the condenser. The steam pressure on the piston supports the weight of the valves and valve gear.

The friction of a slide valve may be relieved or reduced by excluding the steam from its back, which is done by various means, such as by a ring cast on its back and working steam tight against a plate held independently of the valve. The interior of the ring should be open to the exhaust.

The friction of a slide valve is caused by the steam pressing it to its seat, the amount of this pressure varying with the fit of the valve to its seat, and its position over the ports, or, in other words, upon how much of the valve area has steam pressing on one side only.

The travel of the eccentric rod is the distance it moves measured on a straight line. It is equal to twice the throw of the eccentric.

The throw of an eccentric is the distance between the axis of its bore and the centre or axis from which its circumference was turned in the lathe.

Double beat valves are composed of two discs or mitre valves, one above the other on the same stem, so that as the steam presses on the opposite faces of the two discs the valve is balanced. The objection to their use as safety valves is, that they are balanced and would not lift unless the area of the upper disc was made larger than that of the lower one, in which the objection would remain that the two discs do not expand equally, hence they are apt to leak. They are sometimes used instead of slide valves, but are objectionable because a separate admission and exhaust valve is required at each end of the cylinder, and because at quick speeds of revolution they fall to their seats with a shock or blow which wears out both the valve and the seat. When a high piston speed is obtained by great length of piston stroke, and not by high rotative speed, their use is less objectionable.

Expansion joints are joints which permit the parts they connect to expand and contract without straining them. They are necessary on the steam pipe connecting one boiler to another, and on the main steam pipe from the boilers to the engine. The working surfaces require to be of brass, so that they will not corrode.

They require the collar on the internal pipe of the joint (on which the gland fits) to be permanently fixed by soldering or brazing, and check nuts on the studs, so that the internal pipe shall not be blown out from the steam pressure.

This pipe is also sometimes fitted with chains or stops, in case the studs should break, or the nuts or collar strip.

An oil cup is either a cavity cast in the piece or a cup shaped vessel or hollow cylinder screwed in. It contains a pipe extending up about three-fourths of its height, and through this pipe the oil is fed to the surface required to be lubricated. A hinged lid or, in some cases, a screwed cap covers the oil cup to exclude dust, etc.

The syphon or worsted consists of a number of threads of worsted or lamp wick of equal lengths; a piece of lead or copper wire is laid across the middle of the worsted, the copper wire is doubled and twisted and is then pushed down the tube, carrying the doubled end of the worsted with it. The upper ends of the wire are bent over the end of the tube so as to hold the worsted, whose lower end should pass down below the level of the bottom of the oil cup. The oil feeds (on the syphon principle) through the medium of the wick or worsted, which should not fit the tube tight but quite easily, its upper ends hanging over the top of the tube to the bottom of the cup.

The worsted may be cleaned with scalding water, or by water thrown upon it from the boiler.

Tallow cups for high pressure cylinders must have two cocks, so that after the cup is filled the top cock may be closed and the bot-

* See page 383 for the construction of a link motion.

tom one then opened. The top cock prevents the tallow or oil from being blown out of the cock by the steam. For the low pressure cylinder a cup with a single cock will answer, as the cock may be opened when the vacuum is at that end of the cylinder, and the air will force the oil or tallow in.

A steam lubricator or impermeator is an automatic oil feeding device placed on the steam pipe of the high pressure cylinder. Steam lubricators are made in various forms, some having a positive feed by a pumping arrangement, while in others the oil floats upon water in the body of the lubricator to which steam is admitted; the condensation of the steam increases the quantity of water and causes the floating oil to overflow and feed through a pipe leading into the steam pipe or steam chest, as the case may be. Cooling the impermeator causes more rapid condensation, and increases the amount of oil fed to the steam.

Cylinder escape or relief valves do not let all the water out of the cylinder because of the clearance,* hence the amount of water left in will equal the amount of clearance.

The small cylinders on top of the steam chest are for the purpose of guiding the upper ends of the valve spindles, and are fitted with pistons having steam beneath, the upper end being in communication with the condenser.

The effort of the piston to rise supports the weight of the valves and valve gear.

The valves of a marine engine that are worked by hand are, the stop valves for letting on steam from the boiler, the safety valve, which is lifted to see that it is in proper working order, the Kingston valve for letting in the circulating water, the blow through or starting valve for warming the cylinders and starting the engines. The valve for adjusting the rate of boiler feed has its lift adjusting screw operated by hand. The slide valve may also be operated by hand before the engine is started, or it may be operated by a steam reversing gear. The expansion valves are also set by hand to regulate the point of cut off or amount of expansion. The valves that are operated automatically, or from the motion of the parts, are the slide and expansion valves, the suction and delivery and check valves of all pumps, the air pump bucket valves, the snifting valves, and the ship's side overboard discharge valves. When the engine is stopped and the steam shut off, close the dampers to check the draught and open the drain cocks on the high pressure cylinders.

If the engine is soon to start and the pressure in the boiler is at the blowing off point, start the boiler feed, if the height of the water in the boiler will permit it, and this is a good time to clean the fires. If the engine is to stop for any length of time, shut off the impermeator and the injection supply.

A vacuum gauge is an instrument for measuring the total or absolute pressure, or pressure above a perfect vacuum, and it is used to indicate the degree of vacuum that exists in the condenser, which, when the various joints about the cylinder and condenser are tight, averages about 27 inches of mercury when the temperature in the hot well is about 100° Fahrenheit.

In round numbers a column of mercury 32 inches high equals the weight of the atmosphere,† hence taking the weight of the atmosphere at sea level to be 15 lbs. per square inch, then each two inches of mercury represents an atmospheric pressure of 2 lbs. Suppose then that a bent U shaped tube, each leg of which is 30 inches high, is half filled with mercury, and that one end is in communication with the condenser, and the other end is open to the atmosphere, and if there was a perfect vacuum in the condenser, the pressure of the atmosphere in the open leg would force all the mercury into the leg that communicated with the condenser, hence there would be a column of 30 inches of mercury in one leg, and air in the other.

If there was in the condenser a pressure of $1\frac{1}{2}$ pounds per square inch above a perfect vacuum, the mercury would stand 27 inches high in one leg, and 3 inches in the other, and so on, hence from the height of the column of mercury above its natural level the degree of vacuum in the condenser may be known. But the pressure of the atmosphere varies with its temperature, and the weight of mercury also varies with its temperature.

* See page 372, on clearance.

† See "Barometer," Chapter XL.

To find the total pressure in the condenser, therefore, we subtract height of the column of mercury given by the condenser from the height of the column in the barometer, and divide the remainder by 2.

Examples.—The barometer stands at 29.5 and the vacuum gauge at 26, what is the absolute pressure in the condenser?

Here,

$$29.5 - 26 = 3.5 \div 2 = 1.75$$

Answer, $1\frac{75}{100}$ lbs. per square inch.

A dial vacuum gauge of the Bourdon construction is similar to the Bourdon steam gauge, that is used upon the boiler, except that the inside of the elliptical tube is in communication with the condenser and the atmospheric pressure bends the tube into a curve of smaller radius (instead of to a larger one, as in the case of the steam gauge).

Obviously, therefore, the zero of the dial vacuum gauge is atmospheric pressure.

Suppose the dial vacuum gauge shows 10 lbs., the steam gauge 120 lbs., and the barometer 15 lbs., and we may find the total pressure or pressure above vacuum of the steam in the boiler is as follows:

One-half Pressure by steam gauge =	60 lbs.
A perfect vacuum =	15 lbs.
Total pressure supposing condenser had a perfect vacuum =	75 lbs.

To make the correction necessary because there is not a perfect vacuum in the condenser, we then proceed as follows:

Barometer 30 inches of mercury =	15 lbs. per sq. in.
Dial vacuum gauge =	10 " " " "
Actual pressure in condenser =	5 " " " "

Then

Total pressure supposing condenser had a perfect vacuum =	75
Actual pressure in condenser =	5
Actual pressure of the steam =	70

Racing means a sudden acceleration of the engine speed, and occurs when the propeller is not fully immersed in the sea, as by reason of the pitching of the ship. Racing augments the strain on the working gear of the pumps, and is likely to lead to accident. It is obviated by the use of a governor or by partly shutting off the steam by hand.

A marine governor is a device for controlling the engine speed, by reducing the supply of steam to the engine cylinder whenever the engine begins to race. The governor is driven by band or rope on the crank shaft. Governors are made in various forms; thus, in one the shaft has a fly wheel and a friction clutch, one half of which is fast on the governor shaft, while between it and the other is a spiral spring which connects the two halves. If the speed accelerates, the sliding half of the clutch is moved along the governor shaft, and by means of links it closes the throttle valve of the main steam pipe, thus wire drawing the steam, reducing its pressure and thereby controlling the engine speed.

A common paddle wheel has a cast iron centre into which the wrought iron arms are set and secured by wrought iron bolts and nuts.

The bolts have hook heads to grip the back of the arm, and receive a nut and plate to secure the paddles.

Paddle wheels are sometimes provided with cast iron floats to act as counterweights to some unbalanced part of the engine. They are mostly required on side lever engines having a single crank; they are placed nearly opposite to the crank, but not quite, so that they may prevent it from stopping on the centre, and be difficult to start again.

Paddle wheels for engines having a single crank sometimes have their floats of varying breadths, so as to keep the speed of revolution as uniform as possible. This is accomplished by making some of the floats wider than the others. The broadest floats are in action when the crank is at its points of greatest power, and the narrowest at the time the engine is on a dead centre, hence there are four general graduations of breadth in the circumference of the wheel.

A radial paddle wheel is one in which the floats are fixed to the paddle arms, and their ends are in a line radiating from the centre of the paddle shaft.

A feathering paddle float is pivoted at the centre of its ends, and so arranged that by a mechanical movement it will remain vertical when in the water, notwithstanding the circular path it revolves in.

The object of feathering is to cause the thrust of the float to be as nearly as possible in a horizontal line, and therefore more nearly parallel to the line of the ship's motion, and thus utilize more of the paddle power to drive the ship.

The eccentric for feathering the floats is fixed to the ship's side, and sometimes carries a plummer block or pillow block for the paddle shaft bearing. The centre of the eccentric sheave or wheel is placed ahead of and level with the paddle shaft axis. The working surfaces of a feathering wheel are of brass, and the bushes of the paddle arms of lignum vitæ.

The surfaces are lubricated by the water, but sometimes oil lubrication is provided for the eccentric sheave.

A disconnecting paddle engine is one in which the paddles may be driven separately or together. This is effected at the inner port bearing by a clutch wheel, which slides endways on the shaft and is driven by feathers seated in the shaft. This clutch wheel is operated by a lever so as to engage or disengage with the crank pin, which is fast in the outer crank.

Disconnecting paddle engines are always fitted with loose eccentrics, such engines being used for steam tugs and ferry boats, where quickness of turning and of reversing is of great importance.

The thread of a screw propeller is its length measured along the outer edge of the blade.

The angle of the thread is its angle to the axial line of the propeller shaft.

The length of the thread is the length of the outer or circumferential edge of the blade.

The area is the surface of one side of the blade.

The diameter is the distance apart of the two points on the edges that are diametrically opposite and furthest apart.

The pitch of a propeller is its degree of spirality, and is represented by the distance it would move forward if the water was a solid. It is measured by drawing a line representing the axis of the propeller shaft, and at a right angle to it a line representing in its length the circumference of the circle described by the tips of the blades; from the point of intersection of these two right angle lines a diagonal line is drawn representing the angle the blade at its outer edge stands at the propeller shaft axis. The greatest distance between the diagonal line and the line representing the propeller circumference is the pitch of the propeller.

A left handed propeller has a left hand thread or spiral, and revolves from left to right to move the ship ahead.

A right hand propeller has its blades inclined in the opposite direction, and of course revolves in the opposite direction to a left hand one.

The slip of a propeller is the difference between the distance the ship is moved by the propeller and the distance it would move if the water was solid. Slip is usually expressed in the percentage that the distance the ship actually travels bears to the distance she would have travelled if there had been no slip. From 10 to 20 per cent. is lost in slip.

A screw of increasing pitch is one in which the angle of the face of the propeller blade to the axis of the shaft increases as the thread recedes from the shaft, or from the centre to the circumference of the blade, or in both directions.

In a uniform pitch the angle of the blade to the propeller axis is the same at all distances from the axis.

An example of a screw of uniform pitch would be a piece of angle iron wound around a parallel shaft. If wound on a tape shaft, the largest diameter being nearest to the ship's stern, it would have an increasing pitch. If wound around a parabola, the pitch would vary at every point in its diameter and thread.

A thrust bearing is a journal bearing provided with a number of corrugations or collars fitting with corresponding corrugations or recesses in the thrust block, the area thus provided serving to resist the end thrust placed by the propeller upon the shaft.

It must be freely lubricated by ways leading to each collar or corrugation, and so situated that it is accessible for examination. It is sometimes at the end of the first length of shaft aft of the engine.

A stern tube is a sleeve enveloping the aft end of the propeller shaft to protect it from the sea water, which would corrode it. At the aft end of the stern tube is a gland and stuffing box. At the inner end, which extends to the aft bulkhead, it has a flange which is bolted to the bulkhead.

The bearing area of the shaft and stern tube are lined with brass (about half an inch thick) to prevent their oxidation from the action of the sea water.

A lignum vitæ bearing is a wooden bearing generally fitted to the outer end of the stern tube in propeller engines, or to the outer ends of the paddle shaft of paddle engines. It consists of strips of lignum vitæ dovetailed into the bearing or bush, and running lengthwways of it. These strips are prevented from working out by a check plate at each end of the bearing.

Screw propellers may be fastened to their shafts in several ways, as by a key or feather sunk in the shaft, and projecting into a keyway in the propeller bore, and a nut on the end of the shaft with a safety pin outside the nut, or by a key passing through the boss of the propeller, and a safety pin or plate upon the key.

The principal pipes of a marine engine and boiler, and the parts they connect, are, the main steam pipe, connecting the stop valve on the superheater to the steam chest of the engine cylinders; the waste steam pipe from the safety valve to the open air; the blow-off pipe, connecting the blow-off cocks on the bottom of the boiler with the blow-off Kingston cock on the ship's side; cylinder jacket pipe from the stop cock on the boiler to the steam jacket.

The circulating suction pipe, connecting the main Kingston valve with the bottom of the circulating pump; the circulating delivery pipe, connecting the discharge compartment of the condenser with the main delivery valve on the ship's skin; the air pump suction, connecting the body of the condenser with the suction side or bottom of the air pump; the main exhaust pipe, connecting the exhaust passage of the low pressure cylinder with the condenser; the feed water suction pipe, connecting the donkey feed pipe with the hot well; the feed water delivery pipe, connecting the donkey feed pump with the check valve on the boiler; the bilge suction pipe, connecting a strum box in the bilge with the bilge pump; a suction pipe from the strum in the bilge to the donkey pump; the bilge pump delivery pipe, connecting the bilge pumps with bilge delivery valves on the ship's side.

A mud box is a rectangular box usually placed in the engine room, and serving to clear the bilge water from foreign substances, as small pieces of wood, coal, etc.; the construction is as follows: It is on the suction side of the bilge pumps, and is provided with a hinged lid that affords access to clean it out, and that must obviously close air tight, or the bilge pumps will not draw. The box is divided into two compartments by a loose division plate that stands vertical, and is perforated so as to act as a strainer.

The steam from the boiler passes through the superheater, main stop cock or valve, main steam pipe, separator, regulating and throttle valve, steam chest, steam port, steam passage into cylinder, returns through steam passage and port, exhaust cavity of valve into either the condenser or the low pressure cylinder, as the case may be, finally exhausting into condenser, whence the water of condensation is pumped by the air pump into the hot well. In the case of a jet condenser part only of the condensed steam goes back to the boiler, the rest going into the sea through the injection discharge pipe.

A steam jacket * is an outer casing to a steam cylinder, the space between it and the cylinder being filled with steam direct from the boiler, with the object of preventing condensation of the steam in the engine cylinder.

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* See page 374 on steam jackets.

A drain cock is supplied to the bottom of the jacket to pass off condensed water. Steam jackets should be lagged or felted to prevent condensation.

The parts of an engine that require to be felted or lagged are the cylinders and the steam pipes ; the boilers also should be felted or otherwise covered to prevent loss of heat by radiation, and the uptake protected by means of thin plates, kept, by means of distance pieces and bolts, at a distance of two or three inches from the plates of the uptake.

Various non conducting substances are employed to prevent radiation, as, for example, felt, mineral wool, asbestos, and various kinds of cement.

The pieces of the engine through which the steam pressure is received and transmitted are as follows :

The piston, piston rod, cross head, cross head gudgeon, connecting rod, crank pin, crank shaft and couplings to the propeller shaft.

Trunk engines are generally used in war vessels where it is required to have the engines below the water line. The trunk passes through the cylinder and the piston is upon the trunk, the connecting rod passes down into the trunk and connects direct to the piston. A stuffing box and gland in each cylinder cover keeps the trunk steam tight. The trunk forms a guide to the piston in place of the ordinary cross head and guides, and thus saves the room required by those parts.

The cylinders for a right handed propeller should be on the starboard side of the vessel, so that the pressure on the piston, when the engine is going ahead, shall be in a direction to lift the trunk in the cylinder, and thus act to relieve the gland and cylinder bore of the weight of the trunk and piston.

An oscillating engine is one in which the cylinder is mounted on bearings called trunnions, so that the cylinder can swing and keep its bore and the piston pointing to the crank at all parts of the engine revolution. This enables the connecting rod and slide bars to be dispensed with. The trunnions are hollow, one containing the steam and the other the exhaust passage.

Oscillating engines are used for paddle steamers, because their construction permits of a good length of piston stroke, while still keeping the engine low down in the vessel.

The valve motion for an oscillating engine consists of an ordinary eccentric gear or motion, with the addition of various mechanical arrangements to accommodate the valve gear to the vibrating motion of the valve chest.

The stuffing box of an oscillating engine is made deeper than usual because the gland bore has more strain on it, and extra wearing surface is therefore required to prevent its wearing oval.

Geared engines are those with gear wheels to increase the revolutions of the shaft above those of the engine, and thus obtain a high propeller speed without a high piston speed.

The pressure that propels a vessel is taken by the thrust block in a screw propeller engine.

The pressure that drives a paddle steamer is applied to the hull at the shaft bearings and their holding beams, and to the bed plates. The amount of fuel required per horse power per hour, by modern compound engines, is from about 1½ to 3 lbs., and by common condensing engines from 3 to 5 lbs. per horse power per hour.

The unit or measure of a horse power is the amount of power required to lift 33,000 lbs. one foot high in a minute.*

Nominal horse power is a term used to represent the commercial rating or power of an engine, and is usually based upon the area of the piston. It gives no measure of the engine power, however, because it does not take the piston speed into account.†

In a surface condensing engine the duty of the air pump is to merely pump the condensed steam and vapor from the condenser to the hot well, whereas in a jet condensing engine it has to also take the condensing water from the condenser, hence an air pump for a surface condenser may be made smaller than that for a jet condenser. As the air pump works against the pressure of the atmosphere, therefore the smaller it is the less of the engine power is absorbed in working it.

* See page 407, Vol. II.
† See page 374, Vol. II.

The injection cocks are regulated for opening by rods having handles attached. If the injection cocks are not open wide enough, the condenser will get hot and impair the vacuum, while if opened too wide, the water in the hot well will be cold and the boiler feed will be cold. These cocks should be so regulated as to keep the temperature in the hot well at about 100° Fahrenheit.

The parts of a marine engine that are exposed to danger in a cold climate are all pipes through which cold water circulates, and are liable to freeze.

The precautions necessary to prevent freezing in cold climates are to cover all pipes liable to freeze, to keep the water circulating through them, or to let it out of them if necessary, as in the case of the engine standing.

A marine engine may fail to start, or may be prevented from starting by the following causes :

1st. The H. P. slide valve may be off, or away from its seat, thus admitting the steam to both sides of the piston at the same time.

2d. The engineer may have forgotten to disengage the hand turning gear from the crank shaft.

3d. The propeller may be fouled with a piece of timber, or by a chain or rope (these causes sometimes occurring when the ship is in port), or there may be something wrong with the outer bearing of the propeller shaft.

4th. In the case of a propeller fitted with a banjo frame (for the purpose of raising the propeller) the propeller may be locked.

5th. An obstruction, as a block of wood, in the crank pit may prevent the crank from turning.

6th. The slide valve nut may have slackened back, thus loosening the slide valve.

7th. The slide valve spindle may have broken.

8th. When an engine has no auxiliary or starting, but an *impulse* valve that merely lets a puff of steam into the receiver, this impulse valve may leak, and if the escape or relief valve on the receiver is too much loaded, it may gag the H. P. piston by giving it high pressure steam on both sides, and this may throw the valve off its seat. Similarly, if the engine has an auxiliary or starting valve, and it leaks, high pressure steam may be admitted to both sides of the L. P. piston, thus gagging it and causing its slide valve to throw back and away from its seat.

9th. The cylinders may be choked with water, and the drain cocks choked up.

10th. The crank shaft bearings may be screwed up too tightly.

11th. The air or the circulating pump may be choked with water, either the air pump overflow valve or the circulating discharge valve being secured down.*

12th. From the engines being allowed to stand a long time in one position, and the glands being too tightly packed. An engine should be turned a little daily when not in use.

13th. From the piston rings being set out too tight to the cylinder bore.

14th. From the throttle or stop valve being shut, as from its spindle being broken.

15th. From the eccentric sheave, or wheel, having shifted on the shaft, some eccentrics having a key that is not sunk in the sheave, which is done so that the eccentric may shift rather than break if it should seize in its strap.

16th. From the H. P. piston leaking badly, or its ring being

* The air pump overflow valve should never be permanently fastened down. More engines have been broken down from this than from almost any other neglectful cause, because, from great leaks in the condenser tubes and engines standing for a length of time, a larger quantity of water may require to be got rid of during the first few strokes of the pump than can pass through the small air or vapor pipe, which is usually fitted from the hot well either into the bilge or else overboard. Unless the valve in this overflow pipe is heavy enough of itself (which is very rarely the case), it should be loaded by a spring or weight, so that when the puff of the air pump causes it to lift, and the vessel is rolling, sea water may not pass into the hot well. To avoid this, some engineers erroneously fasten this valve down. An experienced engineer states that in his experience five engines have been broken down from this cause alone.

broken, which will permit the cylinder to fill with steam and the slide valve to unseat.

17th. If the engine has been overhauled, the forward eccentric may have been connected to the wrong end of the link, thus giving an improper motion to the slide valve.

18th. The expansion may be set to cut off too early in the stroke.

19th. From the air pump rod, or from the circulating pump rod being broken, or from the valves being broken.

20th. From the cylinder casing or the receiver being cracked so as to admit steam to both sides of the piston at the same time.

A defective vacuum, or loss of vacuum, may occur from the following causes:

1st. From the glands of the low pressure cylinder leaking.

2d. From the pet cock of the air pump being left open.

3d. From the joints of the connections about the condenser leaking.*

4th. From the condenser being cracked, and therefore leaky.

5th. From the injection cock or valve being closed.

6th. From the condenser tubes being foul for lack of being cleaned. From the L. P. cylinder escape valves or cylinder cocks being leaky, and therefore letting in air.

7th. From the slide valve and piston of the L. P. cylinder leaking.

8th. From the air pump valve being leaky or broken. From the circulating pump being defective, as from having leaky valves.

9th. From the Kingston injection valve not being properly opened, or from its outside orifice being choked.

10th. The bilge injection may be so connected with the air pump or condenser as to impair the vacuum when its valve is accidentally stuck and its stop cock is left open.†

The principal causes of heating are:

1st. The bearing caps being screwed down too tight.

2d. The bearings being left uncovered, thus allowing the brick dust used for cleaning the machinery, the dirt from coaling the ship, or the sand used for cleaning the decks, to get into the bearing.

3d. The oil grooves in the brasses being worn out or too shallow, or the brasses not being cleared at the sides.

4th. Improper fitting of the distance pieces or fit strips between the brasses.

5th. Bad oil or too light an oil.

6th. If the brasses are too slack and thump or pound, the back of the brass may be stretched by pening, causing the sides of the brass to close in upon and bind the crank journal or crank pin, and this will cause heating.

For other information concerning the engine see as follows:

* To discover a leak about a condenser, pass an exposed light, as a candle, about the joints, etc., and where there is a leak the flame will be drawn in towards the condenser.

† It is obvious that a defective vacuum may or may not prevent an engine from starting, according to the degree of defectiveness.

Figs. 3405 and 3406 represent a triple expansion marine engine, the construction being as follows:

The high pressure cylinder has a piston valve and the intermediate and low pressure cylinders flat valves. Each cylinder has a link motion, and all three link motions are shifted from the same shaft, which is moved by a steam reversing gear. At *a*, Fig. 3405, are the eccentrics for the link B, for the high pressure cylinder; *b'*, *b'* are those for link B', for the intermediate cylinder; and *c' c'* are those for the link C', for the low pressure cylinder. From each link are rods E, Fig. 3406, connected to arms on the shaft F *f*, to an arm on which is connected the rod G, from the worm wheel H, whose actuating worm I is on a crank shaft operated by the small steam cylinder J. The slide spindles D work in guides, and their cross heads C span the edges of the links, gibs being provided to take up the wear.

The gear for turning the engine when there is no steam in the main boilers is constructed as follows:

On the shaft of the wheel *m*, Fig. 3405, is a worm *n* operating a worm wheel *p*, on whose shaft is a worm which operates the large worm wheel shown on the main crank shaft.

Figs. 3407 and 3408 represent the compound engines of the steamship *Poplar*, concerning which *The Engineer* (from which the engravings are taken) says:

"Both the cylinders of these engines are fitted with piston valves, placed at the back of the cylinders and worked by the single eccentric valve gear, which has been so largely adopted and so successfully carried out by this firm in triple expansion as well as compound engines. It will be noticed that whilst this valve gear permits of the cylinders being close together, it allows of the crank shaft being made in two similar pieces, and affords exceptionally long main and crank pin bearings, of the former of which there are only three, instead of the usual four. In the case of the *Poplar* the cylinders are 29 in. and 55 in. in diameter and 33 in. stroke, and the crank pins are 11 in. long, whilst the centre main bearing, which does duty for both the engines, is $23\frac{3}{4}$ in. in length, each of the outer bearings being 18 in. in length, the diameter of the crank shaft being $9\frac{1}{2}$ in. Another very interesting feature about these compact little engines is the design of the front framework. Instead of the ordinary upright columns in front of each engine there is an arrangement which gives exceptional stiffness to the whole structure whilst affording the fullest possible accessibility to the main working parts, and which has the appearance of an arch, from the shoulders of which there are branches worked up to receive the feet of the cylinders, thus accommodating the close centres and providing for the support of the reversing wheel without in the least obstructing the gear below. The condenser is divided horizontally through the centre on a plan strongly advocated by the builders, the whole of the base of the engines being cast in one piece and made level on the under side, so as to enable it to receive support from, and be bolted to, the engine seating immediately beneath the crank shaft, as well as round the margin."

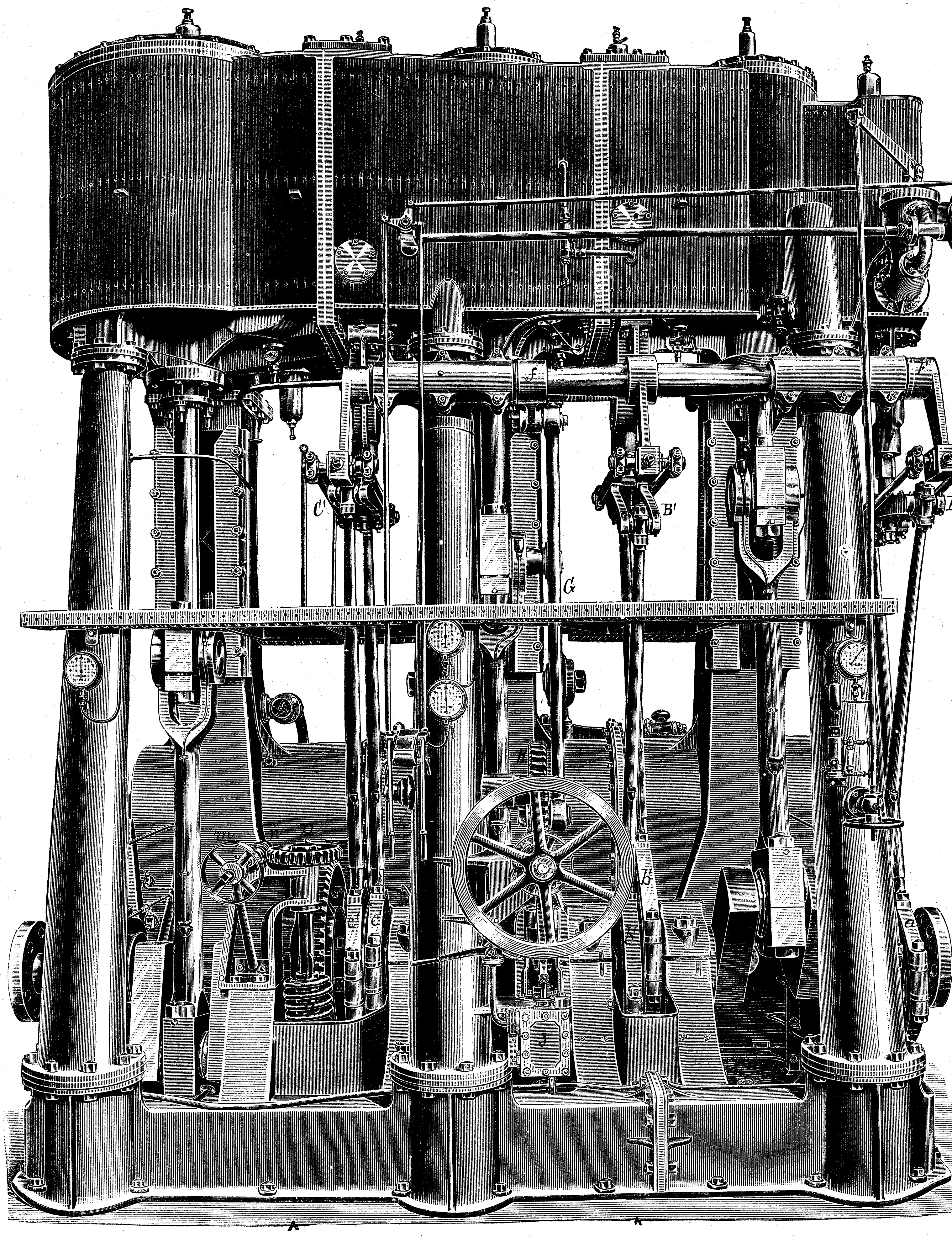

Fig. 3405.

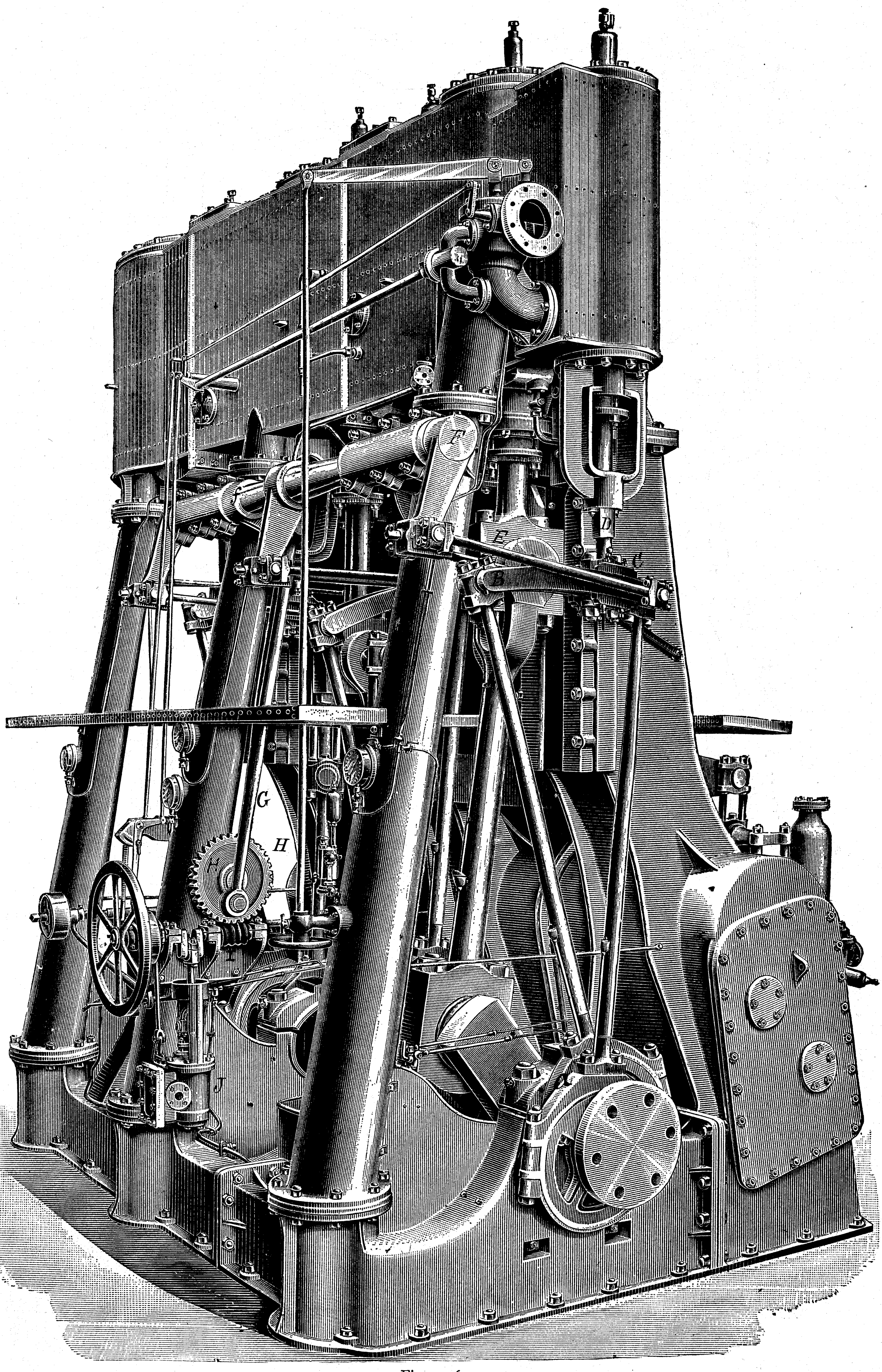

Fig. 3406.

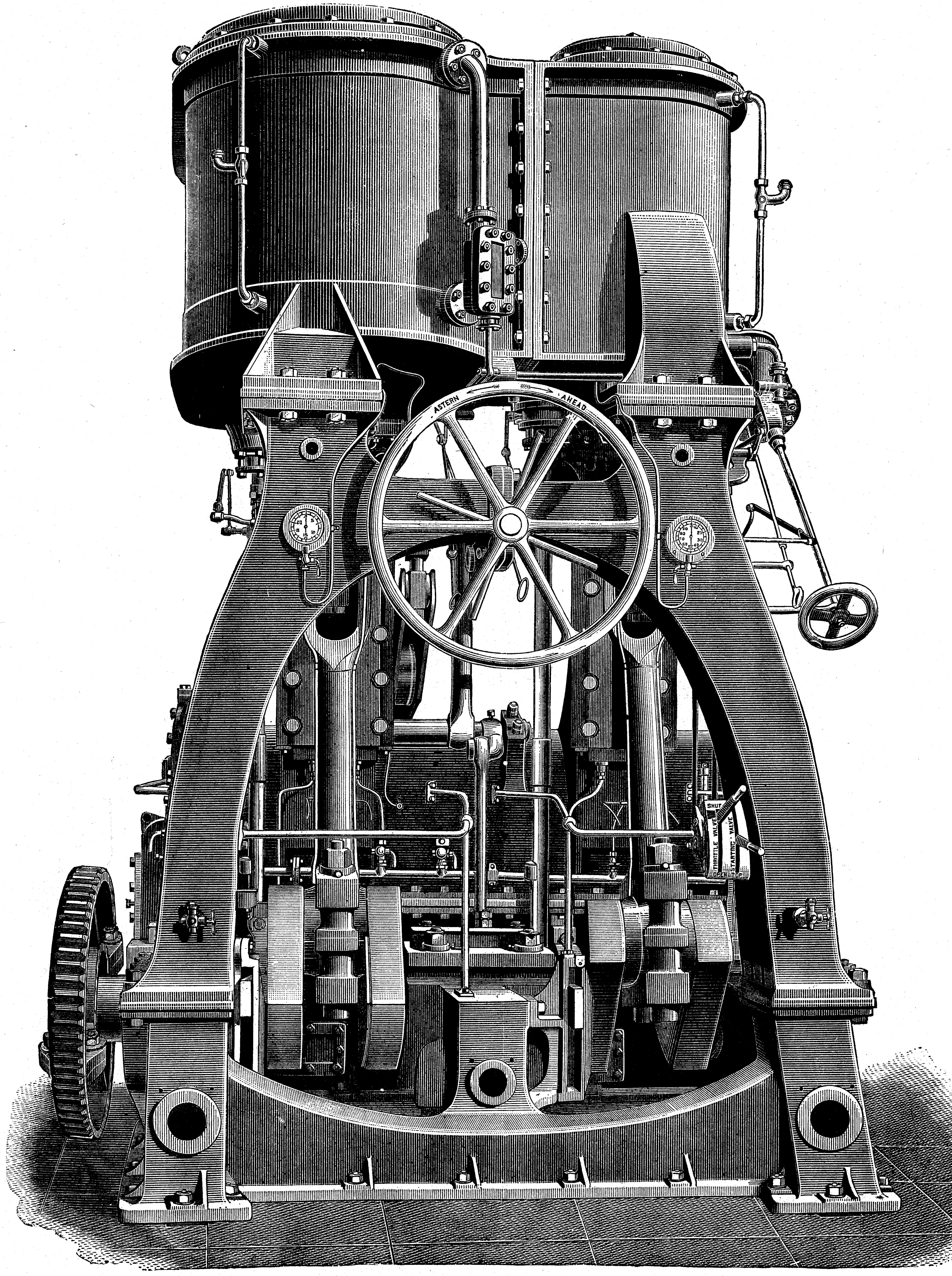

Fig. 3407.

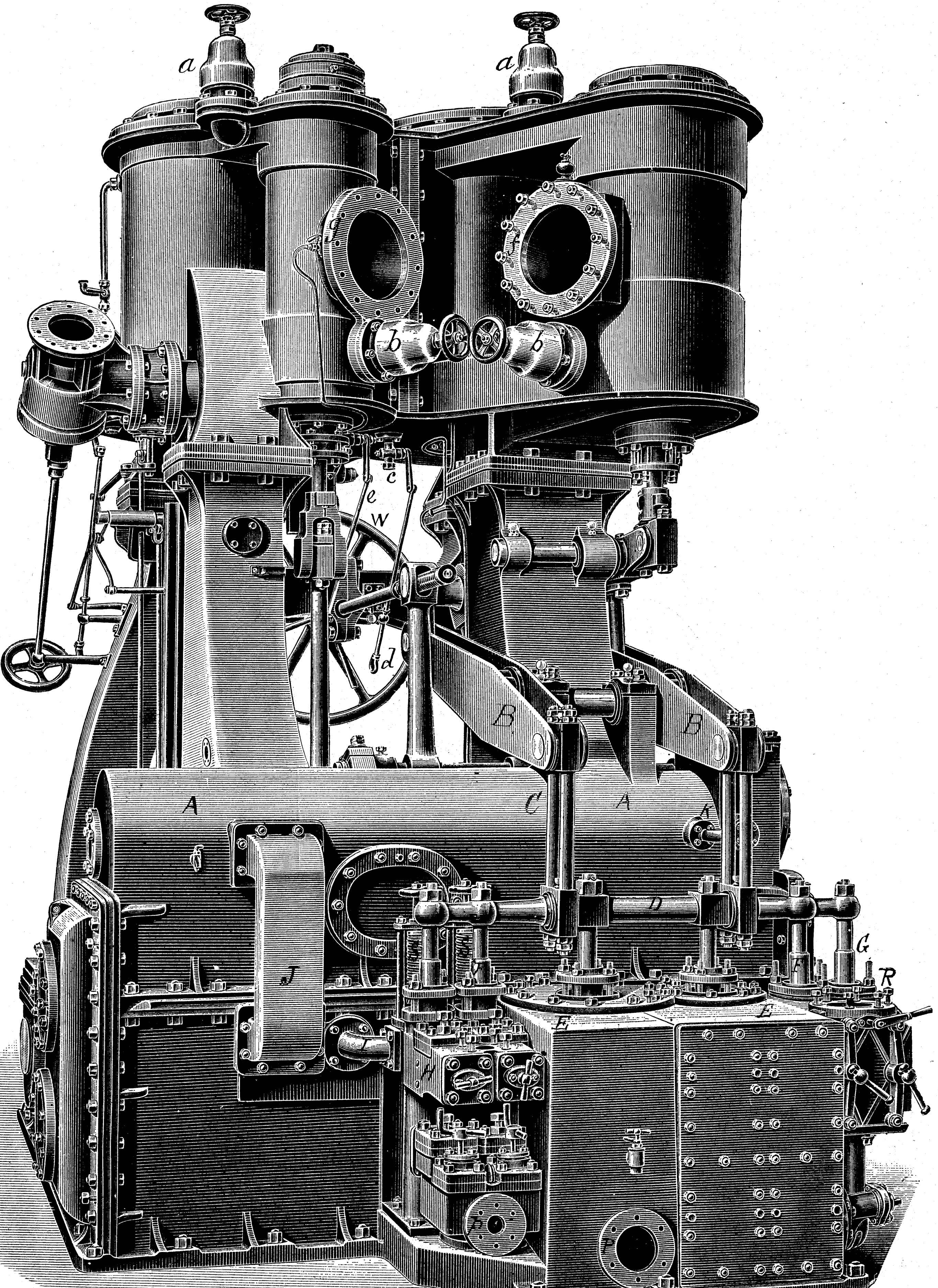

Fig. 3408.