A TREATISE
ON
MODERN STEAM ENGINES & BOILERS

FREDERICK COLYER M.INST.C.E.

A

TREATISE

ON

MODERN STEAM ENGINES AND BOILERS.

A

TREATISE

ON

MODERN STEAM ENGINES AND BOILERS,

INCLUDING

LAND, LOCOMOTIVE, AND MARINE ENGINES AND BOILERS.

FOR THE USE OF STUDENTS.

BY

FREDERICK COLYER, M.INST.C.E., M.INST.M.E.,

CIVIL ENGINEER;

AUTHOR OF 'BREWERIES AND MALTINGS, THEIR ARRANGEMENT AND CONSTRUCTION'; 'HYDRAULIC, STEAM, AND HAND-POWER LIFTING AND PRESSING MACHINERY'; 'PUMPS AND PUMPING MACHINERY'; 'GASWORKS CONSTRUCTION'; 'WORKING AND MANAGEMENT OF STEAM BOILERS AND ENGINES.'

ILLUSTRATED BY FORTY-SIX LARGE FOLDING PLATES.

E. & F. N. SPON, 125, STRAND, LONDON.

NEW YORK: 35, MURRAY STREET.

1886.

PREFACE.

I HAVE often been asked by my clients, also by pupils and students, to recommend a book giving an elementary description of modern steam engines and boilers: I have not been able to find one suitable for the purpose, and have thus been induced to write the present work. My object is to give a description in detail of the different forms of steam engines and boilers now in use, to enable a student or an amateur to understand the construction and manner of working. Most of the leading types of engines and boilers have been treated, to enable the reader to form a fair idea of the subject. Many books have been written upon "steam," and also on the "theory of the steam engine"; any reader requiring more advanced information upon these matters should consult those treatises. I trust the book may be found useful to those for whom it is written: it is not intended for the professional engineer, as he would not require so much elementary description. I hope, however, it may prove useful to architects and managers of works and mills, who often have the charge of engines and machinery, and desire a closer acquaintance with the details of their construction. I trust the work may have a favourable reception, and fill, if in only a modest way, a want long felt by many, who have required such a book.

I have to thank Messrs. Simpson & Co., George Waller & Co., Maudslay, Sons & Field, John Penn & Sons, Thornewill & Warham, Clayton & Shuttleworth, together with the Locomotive Engineers and other gentlemen hereafter mentioned, for their courtesy in giving me drawings of their engines.

All the drawings are taken from actual working examples; they may be treated as the best modern types of the present day of their particular kind. Any one wanting details of any special kind of engine will by careful study of the drawings find what he requires.

FREDERICK COLYER, M.Inst.C.E., M.Inst.M.E.,
Civil Engineer.

18, Great George Street, Westminster, S.W.,
September 1885.

CONTENTS.

CHAPTER I.

INTRODUCTION.

CHAPTER II.

ORIGINAL ENGINES.

CHAPTER III.

BOILERS.

CHAPTER IV.

BEAM ENGINES.

CHAPTER V.

CORNISH BEAM ENGINES.

CHAPTER VI.

HORIZONTAL ENGINES.

CHAPTER VII.

OSCILLATING ENGINES.

CHAPTER VIII.

VERTICAL ENGINES.

CHAPTER IX.

SPECIAL ENGINES.

CHAPTER X.

PORTABLE ENGINES AND BOILERS, TRACTION ENGINES, ETC.

CHAPTER XI.

LOCOMOTIVE OR RAILWAY ENGINES.

CHAPTER XII.

MARINE ENGINES.

LIST OF DRAWINGS.

A

TREATISE

ON

MODERN STEAM ENGINES AND BOILERS;

FOR THE USE OF STUDENTS.

CHAPTER I.

INTRODUCTION.

The intention of this book is to describe in detail the various forms of Steam Engines and Boilers in a way suitable to the requirements of students and beginners, to enable them to understand the construction of each type, and the manner in which they work. It is somewhat difficult to give such information in a form exactly suited to the requirements of each reader; in the preliminary description of each class of machine, it is treated in a rudimentary way suitable to those who have no acquaintance with the subject; as the book advances the descriptions are more technical, but still in a form that any reader can understand who has read the first part of each particular section. It may make the matter more clear to give, in the first instance, an outline of the nature and properties of *steam*, which is the prime mover of engines; after this to describe the boilers or vessels wherein the steam power is generated, following with a description of the various types of steam engines in use for ordinary commercial purposes.

Steam.—When water is boiled in a closed vessel by the application of heat upon the outside of the vessel, the internal water is gradually raised to the boiling point, or to a heat of 212° Fahr.; if the heat is continued after this point, the water will be evaporated and steam generated; if the vessel is closed (as in the case now under consideration), the steam will fill the vessel, and not being allowed to escape, it will, by its elastic force, increase in pressure. By the amount of pressure or power in the steam mechanical force is developed, and when applied to a piston working in the cylinder of a steam engine it puts the machine into operation. The manner in which steam is generated, and the apparatus used for the purpose, will be presently described under the head of "Steam Boilers."

Steam is an elastic fluid, and may be compressed into a less bulk; or it will expand from a small space into a larger one, if passed into another vessel. The properties of steam are much the same as those of atmospheric air, both as to the elasticity and power of compression, and also as to the power of expansion. Pure steam is invisible, the vapour seen escaping from engines and boilers is not steam, but small particles of condensed water.

If water is boiled in an *open* vessel, it will be gradually converted into steam, and escape as vapour; but if boiled in a close vessel, as before stated, the steam will be compressed in proportion to the amount of heat employed on the exterior of the vessel, the capacity for the steam in the vessel, and the pressure it is allowed to attain. This pressure is equal over the entire surface of the vessel, and is usually expressed in pounds per square inch. As water is converted into steam, it largely increases in bulk: one quart of water evaporated will produce about 1700 quarts of steam. As an approximate rule to easily remember, 1 cubic inch of water, evaporated at a pressure of 15 lbs. per square inch, will produce one cubic foot of steam.

A cubic inch of water converted into steam is equal to a force sufficient to raise a ton weight one foot high. This is the *total* force: the *useful* effect in the engine cylinder is lessened by friction and other causes.

It requires about 5½ times the amount of heat to convert boiling water (at 212°) into steam as to raise water from 32° to 212° (the boiling point). There is no sensible difference in the thermometer between water at 212° and steam; this is called the latent heat of steam, and may be taken at about 1000° Fahr. One pound of good coal will evaporate from 9 to 10 lbs. of water; this result, however, can only be obtained in first-class boilers, and when they are well set and economically fired.

It will readily be seen how advantage is taken of the above-named properties of steam for use in the steam-engine cylinder, and also what an enormous power it is capable of developing by its elastic force. Only an outline is given here of the properties of steam, and the means of turning water into steam, it being considered by the author sufficient for the purpose, as many works have been written upon the subject, to which the student is referred who requires more information.

At the first introduction of steam (about the year 1710) very low pressures were used—not more in some cases than from 1 to 3 lbs. per square inch above the pressure of the atmosphere. James Watt, who may be looked upon as the first man who brought the steam engine and boiler into a practical working form, seldom used steam at a higher pressure than from 3 to 7 lbs. per square inch. The pressure of steam now used is from 50 to 60 lbs. per square inch, and in Locomotive Boilers from 120 to 140 lbs. per square inch.

Nearly all Watt's engines were condensing engines, and were worked with steam of very low pressure; the vacuum formed by the condenser and air-pump, acting on the reverse side of the piston to the steam, did the rest of the work.

It must be remembered that steam, as used in the present day, has been *gradually* developed and brought into its state of efficiency by the improvements, spread over many years, of a large number of people. Added to this, the great advance made in the manufacture of steam boilers has permitted the use of steam at very much higher pressures with perfect safety, than would have been possible with the rude and imperfect apparatus at first in use. It is an error to suppose that Watt *invented* the steam engine: he improved the means of generating steam and its application to engines, more especially by the kind of mechanism or apparatus he introduced. The first boilers used were made of cast iron, and of the "pot" or "haystack" kind; they were afterwards made in a rude manner of copper plates riveted together, subsequently of wrought-iron plates, and in more recent days occasionally of steel plates. In the next chapter an outline or short history of the early engines will be given, sufficient to enable the reader to compare those now in use with the originals. It would take up too much space, in a treatise of this kind, to enter into much historical detail; it must therefore be understood that the facts noted are not put forward as comprehending all that is necessary to be said upon the subject, but enough, in the author's opinion, to elucidate the matter and to serve the purpose of the book.

The next part of the subject treated will be "Steam Boilers," because they are the vessels or apparatus in which *steam*, the prime mover of all steam engines, is produced. These apparatus play a most important part in the working of steam engines; this section of the subject should be carefully studied. The economical production of steam is a matter of the highest importance to those who use engine power; and upon the cost of the steam produced may mainly depend the success or otherwise, of the use of mechanical power for the particular purpose.

After Boilers have been treated, a description in detail will follow, of the principal types of engines now in use, both as to their method of construction and the manner of working. Engines differing in only slight particulars from those described in each particular class are not noticed, as in many cases they do not materially differ in construction, and the system of working is the same.

In all the various classes of Boilers and Engines described, including those designed for special purposes, only those of the most improved modern types have been selected: the information is all of a practical kind, and, it is hoped, will enable the reader to thoroughly understand the subject. Theoretical matter has not been introduced, many authors having written upon the theory of the working of the steam engine. The reader is recommended to carefully study the drawings with the text of the book, as it will enable him to better understand the descriptions given of the various parts. For those who wish to design engines and boilers, or to state their requirements to manufacturers, every information and detail is given to help them to form a sound judgment as to the most suitable forms for their purpose. The general proportions and dimensions are given of most leading parts of engines and boilers, and as they are from actual practice, and the result of experience as to their efficiency, they may be relied upon as perfectly safe to follow.

CHAPTER II.

ORIGINAL ENGINES.

THE early use of the steam engine in a practical working form dates back to the year 1710, when Thomas Newcomen first used a cylinder with a piston working in it; in 1767 Smeaton made several improvements. The engines at this date were atmospheric engines—the cylinders were open at the top, and acted by admitting steam through a valve on the under side of the piston; the valve was closed when the cylinder was filled with steam; cold water, by means of another valve, was then injected into the cylinder, and by the sudden condensation of the steam, a vacuum was formed, the pressure of the atmosphere on *top* of the piston caused it to descend, and by the aid of a beam, working on a centre placed above the cylinder, to which the piston-rod was attached at one end, to pull up a loaded pump-pole attached at the other end of the beam. These engines were single and direct acting, and were only used for pumping water; they did not give *rotary motion* to any machinery.

The steam engine has been improved since 1767 by several successive inventors, and although it is difficult to say that any one solely invented the steam engine, still we may look upon James Watt as the man who effected the most marked improvements, and brought it into practical form, in about the year 1769. The early engines, as before stated, had single-acting cylinders; low-pressure steam only was used, varying from 1 to 3 lbs. per square inch. The double-acting engine was the invention of Watt in the year 1782; the cylinder cover and stuffing-box for the piston to work through were also invented by him. About the same year Watt invented the rotative engine to drive mills and machines. The crank and parallel motion were also his inventions. The engines were made on the condensing system; water being used *directly* in the cylinder to condense the steam. In 1781 or 1782 James Watt invented the separate condenser and air-pump, to increase the power of the steam on the other side of the piston. At this period the greatest difficulty to contend with was the iron castings for the various parts, especially the cylinders; also the difficulty, owing to the very imperfect machinery then available, of boring them out truly on the inside, and making the pistons accurately fit the interior of the cylinders. The early engines of Watt were nearly all of the "beam" form; and in his improved double-acting engines, the beam was made of timber loaded and bound with iron; some of these original engines still exist; one lately belonged to a relative of the author, and was, he believes, about eighty to ninety years old; it gave, when he last saw it working (about ten years ago), very good results. Engines, as before stated, were first used to pump water, they were direct-acting only, and *not rotative.* An engine of this kind was constructed as follows:—A steam cylinder of cast iron, bored out on the inside, had a piston packed with hemp to make it tight; the piston was attached to a piston-rod of iron, which worked through the top of the cylinder cover, and by means of chains, and subsequently parallel motion—to be presently described—motion was communicated to one end of the working beam. The steam was admitted by means of a long slide on to the top of the piston; this slide, admitting the steam to the cylinder, was worked by a rod and tappet motion from the beam; the rod also opened a valve to take away the exhaust steam from the cylinder. The condenser was placed next the steam cylinder, where a spray of water condensed the steam delivered into it from the cylinder, so created a vacuum under the piston, and assisted the steam on the upper side. An air-pump worked by a rod from the beam, pumped away the vapour; the air-pump was usually placed in a tank of water; the top of the pump being open, delivered into a hot well; the feed-water for the boiler was taken from this. The beam was hung upon a main centre-pin or gudgeon working in bearings, and at the opposite end to the cylinder it had a loaded plunger-pole which worked the pump, placed in most cases directly over the mine, or over the well in the case of a waterworks. A cold-water pump was also worked by the beam to supply the condenser with water, and a force-pump was also worked from the beam to supply the boiler with water.

The plunger-pole of the main pump being loaded, forced the water up the pipe in its descent; at the bottom of the stroke a short rest took place, and the steam being then admitted into the cylinder at the top of the piston, the plunger-pole was lifted through the beam by the downward stroke of the piston. After these engines had been in use some time, about the year 1782 Watt used steam expansively; that is, the steam was admitted on top or bottom of the piston, and when it had travelled from about a quarter to half the length of the cylinder, the supply was cut off, and the rest of the work done by the expansive power of the steam. Some years later, to adapt engines for mill purposes, Watt invented several pieces of mechanism to give rotary motion for driving mill machinery, but subsequently adopted the crank; the vertical motion at one end of the beam transmitted by means of a connecting rod and crank a rotative motion to a shaft at right angles to the engine. Governors to control the speed of the engine were invented by Watt. In the rotative engines fly-wheels were used to equalise the motion; the author believes they were also the invention of Watt.

Although improved in some details, the beam engines of the present day do not materially differ from the design of those in the days of Watt; this fact proves the perfect apparatus that were introduced by him, and how correct were his deductions upon all material matters relating to the steam engine.

It is not intended to give a complete historical notice of the steam engine, as several able works have been written upon the subject, to which the reader wanting information is referred. The principal facts noted in the outline given afford an idea of the gradual development of steam engines to their present forms.

The names of the several inventors and improvers of the various types of engines, and also of their special parts, are very numerous, but the principal who have rendered essential service in this respect are Wolfe, Maudslay, Field, Penn, Humphreys, Rennie, Stephenson, Napier, Boulton and Watt, Hall (of Dartford), Hick, Harvey, Simpson, Easton and Amos; many others have also introduced minor improvements in the working parts. The compound engine has been much improved since the time of Wolfe (who first introduced this system of working), by Hall (of Dartford), Easton and Amos, Simpson, Humphreys, and others. It would be impossible, in a work of this kind, to do more than glance at the chief names of those who have made improvements in the steam engine.

CHAPTER III.

BOILERS.

The Steam required to work all steam engines is generated in a boiler; at their first introduction they were made of the haystack kind. James Watt invented the wagon boiler; it was made of wrought-iron plates, the fire being placed underneath the boiler; the boilers were never worked at a higher pressure than from 3 to 7 lbs. per square inch. In generating steam in a boiler it is filled to about three-fourths of its capacity with water, and is kept closed, fire being applied on the under side; the water is first boiled, and rises to a temperature of 212° Fahr.: it is then gradually converted into steam, and increases in pressure in the closed vessel until the heat of the fire is slackened, the steam being taken away, by means of a pipe placed at the top of the boiler, to the engine. Safety valves are provided to prevent the steam rising too high, to act as a relief pipe to take off the pressure. The water was supplied to the early boilers by a stand-pipe connected with a cistern placed sufficiently high to overcome the pressure inside the boiler, the inlet of the feed-water being regulated by a float inside the boiler, connected by a rod passing through the top to the inlet cock in the feed-tube. The shapes of boilers now in use are either the Cylindrical, fired under the exterior shell, or the Tubular, that is, having a tube or flue passing through the shell; the fire is placed inside the tube or flue; these boilers are called "Cornish"; the heated internal tube is surrounded by water, which is converted rapidly into steam. Where two tubes pass through the boilers, they are called Lancashire boilers. Boilers used in the present day will now be described in detail.

Cylindrical Boilers (*Drawing No.* 1).—These boilers are very useful for small works, especially where unskilled labour only can be had to attend to them. They are also very good boilers to send abroad, as they can be more easily repaired, and also because they are of such a simple character that less skilled men can perform the work. In cases where the water is very dirty and fuel cheap, they are the best kind of boiler to use, and with ordinary care will last a long time. The boilers are made of wrought-iron plates in sections, each plate lapping over the next; they are riveted together at the joints; the thickness of the plates varies according to the diameter of the shell and the working pressure of the boiler. For ordinary sizes to 4 feet diameter the plates are $\frac{3}{8}$ to $\frac{7}{16}$ inch thick. The brand of the plates for the shells should be B.B.H. Best, B.B.H. Best-Best, R. Heath & Sons ♛, Parkgate ♛, John Brown & Co.'s best, or "Farnley-Iron Company."

The end plates are usually made in one piece, "cup" shape, and $\frac{1}{8}$ inch thicker than the shell, the edges being flanged over, to these flanges the side plates are riveted. The holes in the plates for the rivets are punched or drilled; the diameter of the rivets is $\frac{3}{4}$ for $\frac{3}{8}$ inch thick plates, and the pitch or distance from centre to centre of the holes is 2 inches. The holes in the plates are made to a standard distance, and to exactly correspond in each plate. The rivets are made of wrought iron, and put in hot; they are closed by steam or hydraulic pressure; they contract as they cool, and thus draw the plates close together at the joints. A man-hole is provided at the top of the shell, the edge of the man-hole is strengthened by a ring riveted round it; the joint between the cover and the shell of the boiler is made on the inside. Two wrought-iron bridges span the hole, and by means of two screws, which are attached to the cover, passing through the holes in the bridge pieces, the plate is held in position and the joint made; a ring of platted gasket and red-lead cement is spread on the top to prevent any leakage. A better plan than this is to rivet on a cast-iron oval frame having a saddle flange the shape of the boiler at the bottom and a flat flange at the top, this is faced; a strong cast-iron door, also faced, is provided; the holes are drilled, and the cover is bolted on. The advantage of this man-hole cover is that the joint can be easily and quickly made, and does not in any way weaken the plates of the boiler, it can also be kept perfectly tight and free from leakage. A mud-hole and door are also provided at the front of the boiler, placed at the lower part of the shell; this is for the purpose of cleaning out any deposit and dirt in the boiler. When the boilers are of moderate size—say from 4 feet to 4 feet 6 inches diameter—the longitudinal seams are made only at the sides; if the boiler is long and vertical seams must be made, the first section or ring of plates should be of sufficient length to keep the first seam or joint beyond the furnace bridge and so out of the fire. The lap of the plates is always made *from* the fire, to prevent the flame and heated air burning away the edges of the plates at the joints.

A steam chest or dome is usually provided on the top of the boiler, into which the steam rises; this is for the purpose of obtaining the steam in as dry a state as possible, it also adds extra steam capacity to the boiler. A double safety valve is provided on the top of the steam chest or shell of the boiler, to relieve it when the required working pressure is obtained. This apparatus consists of a cast-iron pillar bored out at the top and fitted with two gun-metal valves rising and falling on conical seats, the spindles at the top of the valves pressing against wrought-iron levers which are attached by pins to fulcrums at the back of the valves; these have a weight sliding on them and are so adjusted to enable the valves to lift at the required pressure, and thus relieve the steam inside the boiler. The valves are usually made double, to ensure at least one of them lifting when required.

The apparatus or fittings to record the internal working of the boiler is fixed on the front plate, and consists of a glass water-gauge fitted with a cock at each end, one communicating with the steam space, and one with the water space of the boiler; by opening the two cocks, the height of the water inside the boiler is shown in the glass tube which connects the upper and lower cocks. It is usual to supply two glass water-gauges, to ensure an accurate indication of the level of the water, and to save any risk from stoppage of the pipes or cocks; each of the gauge glasses must be tried against the other to test their accuracy. Two separate gauge cocks are provided on the opposite side of the boiler, one being connected to the steam space, and one to the water space; in case the glass water-gauges before named should be out of order, these *two* cocks will show the height of the water-line *inside* the boiler.

The feed-water is forced into the interior of the boiler by a force-pump worked by engine power; the water enters at the same level as the water-line, and is equally distributed by an internal, horizontal, perforated pipe running the whole length of the boiler. An injector, described at p. 23, is also used to force water into the boiler; this is employed as an adjunct to the pump in case of any breakdown.

At the top of the dome of the boiler a steam valve is provided, and from this a pipe is carried to the engine. As an extra precaution for safety, a float and alarm whistling gear is attached at the top of the boiler, to give warning in case the level of the water in the boiler has sunk near the point of danger. A pressure gauge is fixed at the front of the boiler to show the internal pressure. At the bottom of the boiler a blow-off cock is provided for the purpose of emptying the water, and also to cleanse the interior of the boiler by allowing the steam to rush out, carrying much of the dirt and deposit contained in the inside; when this does not receive proper attention, the dirt, &c., is deposited on the plates; this gives much trouble, and is also very injurious to the boiler.

The furnace for heating the water in the boiler is placed in the brickwork under the outer shell. The boiler is set in brickwork, with flues running round, as shown in Drawing No. 1, and described at p. 16. The heated air passes from the furnace over the bridge at the end, then through the flue under the boiler, passing to the side flues and thence to the chimney. When boilers are well set, all the heat should be absorbed before it reaches the chimney. A damper plate of cast iron working in a cast-iron slide or frame is provided; it is fitted with a chain and counterbalance weight: this controls the draught or quantity of air admitted through the fire-bars. The area or superficial surface of the fire-bars should be about three-quarters to one square foot of grate surface for each horse-power. When coke is burned, the fire surface must be increased; and when for wood, or refuse, it must be specially proportioned. The space between the bars must be adjusted to admit about 11 to 12 lbs. of air for each 1 lb. of hard coal of good quality burned in the furnace. The space between the bars must be arranged to suit the particular kind of fuel to be burned. The consumption of fuel in a boiler is about 4 to 6 lbs. per actual horse-power of the engine. Each cubic foot of water evaporated per hour = 1 horse-power. The heating surface required for each horse-power is about 12 to 14 square feet.

Rule to find the horse-power of a Cylindrical boiler:

$$\frac{\text{D in feet} \times \text{L in feet}}{7 \cdot 5} = \text{horse-power.}$$

(The diameter in *feet* × by the length in *feet* ÷ 7·5 = horse-power.)

The capacity of a boiler should be: steam chamber equal to $\frac{1}{2}$ cubic yard per horse-power; and steam space about the same.

Cornish Boilers (*Drawing No.* 2) are made with a shell like the plain cylindrical boiler, but with flat end plates, and with an internal tube or flue running the whole length of the boiler; the diameter of this tube is equal to about half the diameter of the shell of the boiler. The tube is riveted to the two end plates by means of angle irons, and in some instances the plates are flanged out of the solid. The end plates of the shell are either solid flanged on the inner side and the side shell plates riveted to the same, or they are attached by means of angle irons, the front ends by external angle irons, and the back by internal angle irons. The plates of the shell are lapped at the joints, and the rivet-holes are either punched or drilled in them; through these holes the rivets pass which hold the sections of the plates together. Each section or ring of plates is made to break joint. The holes in each plate are made to an exact gauge, and when the two plates are put together the holes should exactly correspond; the rivets should fit the holes; they are put in hot and hammered close; this is done by hand, hydraulic, or steam power. The diameter of the rivets for plates $\frac{3}{8}$ inch thick is $\frac{3}{4}$ inch and the pitch 2 inches; if the plates are $\frac{7}{16}$ inch thick, the rivets are $\frac{7}{8}$ inch diameter and $2\frac{1}{8}$ inches pitch. The laps of the plates of the tube through which the fire and heated air pass are made *from* the fire, to save the fire cutting away the edge of the plates at the joints. The internal tube is strengthened by external rings of L iron, and in most instances Galloway's patent tubes are fitted to it transversely, to increase the evaporative power. The front and end plates have gusset stays riveted to them to strengthen them longitudinally; they consist of plates riveted to angle irons, which are again riveted to the front and end plates.

A man-hole is provided, made as described at p. 9; this is placed near the back of the boiler. *Two mud-hole doors* are also provided at the front of the boiler at the lower part of the shell; these are for cleaning out the interior. A steam dome is provided as in the other boilers, and the safety and other fittings are of the same character, the sizes being proportioned to the dimensions of the boiler.

Furnaces.—These are placed inside the tube, a frame fitted with a fire-door is bolted on to the front; to this is bolted a cast-iron dead-plate, having a flange to receive one end of the fire-bars; at the other end of the furnace, a wall of fire-brick is built up, and a bar is also provided to take the other end of the fire-bars. When the length of the fire-bars exceeds 4 feet, a centre bearing bar is provided, and the fire-bars are made in two lengths. The *total length* of the bars should not exceed 6 feet to 6 feet 6 inches in any case; the bars are made taper in section on the lower side to admit the air freely, and are thicker at the ends where they rest: by this means the air spaces are adjusted to a certain known amount; the bars are not fixed but are left free, sufficient space at the ends and also at the sides being left to allow them to expand when heated; they are set with an incline to the bridge. The fire-doors are made of wrought or cast iron, and have a plate fitted on the furnace side, held about 3 inches from the door by studs: this is for the purpose of protecting the door from the heat of the fire; the doors should fit closely at the frame. The bridge at the back is made a height to allow sufficient area for the smoke and heated flame to escape to the flues; instead of fire-bricks, it is often made with a single fire-lump cut to the required shape.

When the size is above 4 feet in diameter, a Cornish boiler is the most suitable, it is also more economical in working than the cylindrical kind before named; the heating surface is much larger, having regard to the size of the boiler; steam is generated more rapidly, and the quantity of fuel consumed is much less.

The following dimensions of an average size boiler will give an idea of the proportions:—

15 *horse-power.* The diameter of the shell 5 feet, and the length 18 feet; the internal tube 27 inches diameter. The thickness of plates: shell, $\frac{3}{8}$ inch; tube, $\frac{5}{16}$ inch; end plates, $\frac{7}{16}$ inch. Steam chest, 27 inches diameter × 30 inches high. Plates, $\frac{3}{8}$ inch thick. Angle irons, if used, 3 inches × 3 inches at the junction of the shell and tubes, or it may be made with solid flanges. Man-hole, frame of cast iron, provided with a door. Four gusset stays at each end plate $\frac{3}{8}$ inch thick, with $2\frac{3}{4}$-inch L iron riveted to end plates. The front plate of the tube over the

furnace should be Low Moor iron, and made at least 5 feet 6 inches long, so as to keep the joint of the plates beyond the bridge at the end of the furnace out of the fire.

The fittings should be:—One 3-inch diameter double safety valve; one $2\frac{1}{2}$-inch diameter stop-valve; two sets of $\frac{3}{4}$-inch glass water-gauges; two $\frac{3}{4}$-inch gauge-cocks; one 2-inch diameter feed-valve; one 2-inch diameter blow-off cock; one 2-inch diameter back pressure valve; one steam sentinel and float alarm whistling apparatus; one damper chain and counterbalance; one Bourdon's patent pressure gauge; one Gifford's patent injector; one steam pump; one feed-water tank, and one heater for the feed-water.

The height of the water-line must never be less than 6 inches above the top of the tube, the top of the side flues in the brickwork being level with the *top* of the tube in the boiler.

Rule to find horse-power of a Cornish boiler:

$$\frac{\text{Diameter of tube} + \text{diameter of shell} \times \text{L in feet}}{7 \cdot 5} = \text{horse-power.}$$

The plan of setting the boiler in brickwork is shown in Drawing No. 2, which indicates the direction of the heated air to the chimney shaft. Dampers are used to control the draught, the same as in the other boilers, and when several boilers go into one main flue, dampers are sometimes necessary in this flue.

Lancashire Boilers (*Drawing No.* 3).—These boilers are made with two tubes or flues passing through the lower part of the interior of the shell of the boiler. Each tube is fitted with a furnace at the front end, as described for the Cornish boiler; the heated air passes through each tube and meets at the end of the boiler in a brickwork flue; it then passes up the side flues in the brickwork, and thence by way of the bottom flue also in the brickwork under the boiler to the main flue and chimney shaft. These boilers are not usually made less than 6 feet in diameter at the shells, the diameter of each tube or flue being about one-third of the diameter of the shell.

Steam chests or domes are provided, and the safety fittings are the same as in the other boilers. The length of these boilers is usually about four or four and a half times the diameter of the shell. According to the present practice, the maximum diameter of the shell is seldom made more than 7 feet 6 inches to 8 feet, the number of boilers being increased when more power is required. The thickness of the plates of boilers of this class, when made from 6 feet 6 inches to 7 feet 6 inches diameter, varies from $\frac{7}{16}$ inch to $\frac{9}{16}$ inch thick, the end plates being $\frac{1}{8}$ inch *thicker* than the shell, and the tubes $\frac{1}{16}$ inch *thinner* than the shell plates.

To increase the heating surface of the tubes, transverse conical tubes (Galloway's patent) are riveted at intervals inside; the water in the shell passes through these cross tubes, which thus present a large surface to the heated flame from the furnace. The ends of the longitudinal tubes or flues are made smaller at the outlet to the back flue, for the purpose of increasing the draught of the furnaces. The exteriors of the tubes are strengthened by several rings of angle iron placed at intervals; in some instances cup-shaped iron rings are riveted on for the same purpose.

The sections or rings of the plates of the boiler are lap-jointed and are riveted together in the manner before described. The end plates are each strengthened by four gusset plates, each riveted by means of angle iron to the shell plates and to the end plates. A man-hole is provided at the top of the boiler for examination and cleaning, also two mud-holes and doors at the lower part of the shell at the front plate. Large boilers are double riveted, both in the horizontal and also in the vertical seams or joints; in some cases the plates at the joints are planed on the faces and at the edges, and the rivet-holes are drilled; the diameter of the rivets for $\frac{7}{16}$-inch plates is $\frac{7}{8}$ inch, and placed at $2\frac{1}{8}$ inches pitch; the diameter for $\frac{1}{2}$-inch plates $\frac{13}{16}$ inch, and the same pitch. The strength of riveted joints when the holes are punched is equal to ·776 of the solid plate, and for drilled holes ·846 of the solid plate. In round figures, the latter are about 9 per cent. stronger. The shearing strain of rivets equals 85 per cent. of the tensile strength. Double-riveted joints are about $\frac{1}{5}$ stronger than single-riveted.

Drawing No. 3 shows the way of making a 7-feet diameter boiler, also the leading proportions; and the way of setting the same in brickwork; it is much the same as for Cornish boilers.

It is only intended to convey a general idea of these boilers, as the proportions necessary to suit particular cases can only be settled by experienced people; it would entail a dissertation far beyond the limits that can be allotted to the subject in a book of this description. Any one wanting further and more advanced information is referred to the author's book upon 'Pumps and Pumping Machinery' (E. & F. N. Spon).

Multitubular Boilers.—Boilers containing a large number of small tubes are used for land as well as for locomotive and marine boilers. The shell and end plates of the boiler are made in the same way as above described. At the front part of the boiler an internal tube is fixed, the same as in a Cornish boiler; inside this tube the furnace is placed; the tube or fire-box is closed by a plate a little beyond the end of the fire-bars and a plate is riveted to the shell at the reverse or smoke-box end of the boiler, a large number of small tubes pass through these two plates and are riveted at each end; the flame and heated air pass through the small tubes, which, being surrounded by water, presents a large heating surface, and steam is raised very rapidly. Sometimes these boilers are made in the same form as a locomotive boiler, with a rectangular fire-box riveted to a shell or barrel; one end of the tubes is riveted to this fire-box, and the other to the plate which is riveted near the end of the shell as above described.

Boilers of this kind do not require any setting in brickwork, they can be worked with a short chimney; to increase the power of the blast in this case, the exhaust steam from the engine is allowed to escape into the smoke-shaft; in locomotives this is essential to promote very rapid combustion of the fuel and generation of steam. The internal tube or fire-box is riveted to the front plate by means of L iron, the end plate where the small tubes pass through is riveted to the main tube. At the reverse end of the boiler, the plate into which the other end of the small tubes is riveted, is of the same diameter as the interior of the shell; it is either riveted to the shell by means of L iron, or a solid flange may be formed on the plate. The shell plates of the boiler are continued beyond the tube-plate to form a space for the smoke; this is called the smoke-box; a plate is riveted at the extreme end, and in this, a door is provided for the purpose of cleaning the small tubes; the smoke is taken away at the top of the smoke-box, direct to the chimney. A steam dome is provided and fixed on top of the shell in the same manner as in the Cornish and Lancashire boilers. The safety valves and other fittings are of the same character, being properly proportioned to the power of the boiler. Boilers of this kind are specially suitable for places where brickwork setting cannot be allowed, on account of the extra weight, the room taken up, and other causes; they are also specially useful where steam power is wanted for temporary purposes, and when the boilers have to be removed when the particular work is accomplished. They are economical in their action, generate steam rapidly, and do not wear out any quicker than other kinds of boilers.

Multitubular Boilers with Return Tubes.—Boilers are made on a plan somewhat similar to those described above, except that they are set in brickwork; the fire is placed *under* the shell, the heated air passes along the bottom, round the side flues in the brickwork, and through small internal tubes within the shell of the boiler. At the front end a door is provided to clean out the small tubes; there are also side doors in the brickwork at each flue. The large amount of heating surface obtained, both on the outside shell and inside the tubes within the boiler, causes a rapid generation of steam, and effects much economy in the fuel consumed. Boilers of this kind are provided with large steam chests, as the steam space within the shell is less than in most other kinds; the fittings do not differ from those used for Cornish or Lancashire boilers; the general construction of the boiler, except the parts detailed, does not in other respects materially differ from the multitubular kind.

TABLE OF HORSE-POWER OF CYLINDRICAL, CORNISH, AND LANCASHIRE BOILERS.

Cylindrical.	Diameter.	Length.	Cornish.	Diameter.	Length.	1 Tube.	Lancashire.	Diameter.	Length.	2 Tubes.
Horse-power.	ft. in.	ft.	Horse-power.	ft. in.	ft.	in. diam.	Horse-power.	ft. in.	ft.	in. diam.
4	3 6	9	10	4 6	12	27	30	6 6	21	27
5	4 0	10	12	4 6	14	27	40	7 0	30	30
6	4 0	12	14	4 6	16	27	50	7 3	36	33
8	4 6	14	16	5 0	16	32	60	8 0	36	34
10	5 0	15	18	5 0	18	32				
12	5 6	18	20	5 6	18	32				
			25	6 0	21	34				

BRICKWORK SETTINGS FOR BOILERS.

Cylindrical Boilers (*Drawings Nos.* 1, 2, 3).—The depth of the foundations below the floor-line depends upon the nature of the soil: in ordinary cases, when a good hard bottom is found, the excavation is stopped, the top of the bed is levelled, and lime concrete from 24 to 30 inches thick is put in. The concrete is made of ground lime, used fresh, and good clean river or pit ballast, mixed together in the proportion of 6 ballast to 1 of lime; the materials are thoroughly incorporated together, and sufficient water is used to mix them thoroughly; the concrete is then thrown into the excavation and levelled at the top. The footings of the brickwork are usually made four courses, equal to about 12 inches. The lower part of the boiler is placed at a sufficient height above the floor-line to allow the furnace bars to be 3 feet above the stoking floor; the inside of the furnace is lined with fire-brick, at least 9 inches thick; at the end of the furnace a bridge of fire-bricks or lumps is formed about 9 to 10 inches above the top of the bars. The furnace frame and door are bolted on to the brickwork at the front, a bar is built into the brickwork at the middle of the furnace to support the fire-bars, and one also at the bridge end for the same purpose. At the front end the fire-bars rest upon a cast-iron "dead" plate bolted to the furnace frame; furnaces should not be more than 6 feet to 6 feet 6 inches in length; the fire-bars are set *inclined from* the fire-door. The boiler rests upon fire-lumps on each side, and is set with a fall to the front to completely drain it when the blow-off cock is opened; a flue is made under the boiler, it is also lined with fire-brick; side flues are constructed 4 to 6 inches wide, measuring at the centre of the boiler; the flues are lined with fire-brick 4½ inches thick; the level of the top of the side flues is kept at least 6 inches *below* the level of the water-line in the boiler. About 14 inches of brickwork is built above the fire-brick lining at the top of the flues, and 9 to

14 inches of brickwork outside the fire-brick lining at the side flues; the top of the brickwork is covered with York flags $2\frac{1}{2}$ to 3 inches thick; the flues round the front and the end of the boiler are constructed in the same manner as the side flues.

The flame or heated air escapes from the furnace over the bridge, and passes through the lower flue to one of the side flues by means of an up-take; it then goes round the front of the boiler and out at the end flue to the shaft. A damper and frame of cast iron are provided at the end flue, with chain and a counterbalance weight to open and close it; this chain is carried to the front of the boiler; soot and cleaning doors are provided at the front of the side flues, the top of the boiler and the steam chest are covered with non-conducting composition. At the stoking floor, iron plates are fixed at the front of the boiler about 4 feet wide; these are for the hot ashes to fall on when the fires are drawn: the other part of the floor of the house is either paved with stone flags or it may be laid with Stuart's patent granolithic concrete, this makes a very perfect floor, and wears very well.

Cornish and Lancashire Boiler Settings.—*Drawings Nos.* 2 *and* 3 will give an idea of the best form for these; the foundations are made in the same way as the last, the furnaces in this case being *inside the tubes* of the boiler, the heated air passes to the end of the internal tubes, splits at the back, and passes up each side flue, then by a " down-take " to the flue at the bottom of the boiler, and into the main flue leading to the shaft. The boilers are set with the flange at the front plates about 6 inches above the floor-line, the front projecting 4 inches beyond the face of the brickwork; this is for the purpose of keeping the L iron and the rivets out of any damp, and also permits of examination and cleaning of the joint between the front plate and shell. The height of the tubes above the bottom of the boiler is arranged to give a convenient level for firing, flue doors of cast iron are placed at the front of each side flue for the purpose of cleaning out, the side flues are the same height as the top of the internal tubes in the boiler, which is about 6 inches below the water-line. The thickness of concrete for large boilers of this class will depend upon the soil; as a rule, it is not less than 2 to 3 feet. The brickwork settings must be kept at least 3 inches clear of the walls of the house to allow for expansion when heated, otherwise the walls will be injured. When two or more boilers are set together, about 1 foot $10\frac{1}{2}$ inches between the flues at the centre part is sufficient; dampers are provided to shut off any boiler flue when out of action. Full area must be given to the main flue, and no square corners left in; this prevents friction in the passage to the chimney. A brickwork channel is formed at *the front* of the boilers to take the blow-off cocks and pipes; this should be at least 18 inches wide and $4\frac{1}{2}$ or 9 inches thick; it should be covered with cast-iron plates, capable of being removed for examination and repairs of the pipes when necessary.

Brickwork Shafts.—*The shaft or chimney* is built of brickwork, the height and area depending upon the size of the boiler, the position and height of the surrounding buildings, and other circumstances; any number of boilers may be taken into one shaft provided the area and height are properly proportioned, and that each flue from the boilers not in use is closely shut off from the main flue to the chimney. When shafts are built in the neighbourhood of London, and when circular in shape, the diameter of the base must equal one-tenth of the height: the thickness is measured from the *top*; the first 25 feet must be 9 to 14 inches thick, and each succeeding 25 feet being $\frac{1}{2}$ brick thicker to the base; as a rough idea, for a 20 horse-power boiler (in London) the shaft would be about 100 to 120 feet high, 2 feet 6 inches diameter inside at the top; the brickwork below the ground-line about 8 to 10 feet, and the concrete 4 to 5 feet thick. The shaft is lined with fire-brick for about 20 feet in height above the end boiler flue; in some cases the fire-brick lining is carried the whole height of the shaft; a soot door is provided at the bottom of the shaft for cleaning out. The cap of the shaft should be cast iron well bolted to the brickwork; this secures all the work and protects the bricks from weather; the casting is made in sections, and bolted together.

A lightning conductor made of copper wire should be provided; this must have radiating points of gun-metal at the top and stand 18 inches above the top of the cap of the shaft; it should be carried about 10 to 15 feet in a horizontal line from the shaft at the base, the copper-wire rope being attached to a copper plate, sunk in the ground and covered with charcoal to keep it damp; the diameter of the rope for a shaft this height should be $\frac{1}{2}$ to $\frac{9}{16}$ inch; the wire rope passes through eyelet-holes made of gun-metal, these are made pointed and driven into the joints of the brickwork.

Vertical Boilers.—These are a useful form of boiler where floor space is an object, and in cases where the boiler cannot be set in brickwork, also when steam is required for temporary work; they are portable, and can be moved and refixed quickly; there are several types of this kind of boiler; the leading forms of those now in general use will be described.

Multitubular Boilers.—The exterior shell of these boilers is made of wrought-iron plates from $\frac{5}{16}$ to $\frac{7}{16}$ inch thick according to the diameter and pressure per square inch at which they are to be worked; the shells for the smaller sizes (up to 4 feet diameter × 8 feet high) are made in two plates, with lap-joints; the edges of the plates are thinned down; the holes for the rivets are punched or drilled, this is done to a standard gauge, and the holes in the two sets of plates are made to exactly correspond. The rivets are $\frac{3}{4}$ inch diameter for this size, are put in hot, and closed by a steam or hydraulic riveting machine; the contraction of the rivet, as it cools, draws the two plates close together, and so forms a tight joint. The top of the boiler is formed of one plate, solid flanged, the diameter being the same as the interior of the shell; it is riveted in the same way as the sides; the top is usually made a "cup" shape, to give strength; at the bottom of the boiler a fire-box or tube is constructed *inside* the shell, the external diameter of the box is about 12 inches less than the shell, thus leaving an annular water space; the bottom of the vertical plates of this box is flanged and riveted to the outer shell. The top of the fire-box has a plate riveted in; this plate is about $\frac{1}{2}$ to $\frac{9}{16}$ inch thick; near the top of the shell another plate is riveted, and above this plate, leaving a space of 12 to 15 inches, a thinner plate is riveted, this forms the top of the smoke-box, and to this is attached the wrought-iron smoke-pipe or chimney.

A large number of small tubes are riveted in between the top of the fire-box and the smoke-box plate; these tubes are of wrought iron; the tube plates have holes in them carefully bored out to exactly correspond in the lower and upper plates.

The furnace bars are placed inside the fire-box, the fire-door hole is formed in the shell and passes through the fire-box plates, a distance piece is riveted between to keep the plates apart and make the joint; the heated air and smoke pass through the small tubes, these are surrounded by water in the same way as in the horizontal multitubular boilers already described; a large heating surface is presented to the water, and rapid evaporation is thus procured. The fire-grate is circular in shape, and the bars are made in three or four sections, having air spaces as in the ordinary separate bars; the damper is fixed in the smoke-pipe, and is made like a throttle-valve; a lever is attached to the spindle, and by means of a rod passing down to the lower part of the boiler, the draught is controlled as required.

A man-hole is provided in the shell near the lower part of the boiler, this is made in the same way as before described; two mud-hole doors are also provided at the bottom of the shell for the purpose of cleaning out the boiler when necessary.

The fittings of the boiler consist of one $\frac{3}{4}$-inch diameter glass water-gauge; two $\frac{3}{4}$-inch gauge-cocks; one $2\frac{1}{2}$-inch double safety-valve; one $2\frac{1}{2}$-inch steam or stop valve; one Bourdon's pressure gauge; one $1\frac{1}{2}$-inch feed-valve; one steam sentinel or alarm-whistle gear. A Giffard's injector is fixed at the front of the boiler, also a feed-water tank and the necessary pipes and cocks; the tank is always fixed *above* the injector. The construction of these fittings is the same as before described. The exterior of the shell is covered with non-conducting composition, LeRoy's patent is the best and the most durable, in some instances the exterior of the composition

D 2

is covered with wood staves or lagging, bound round with iron hoops. The boiler stands upon a base of stone or brickwork of sufficient depth to take the weight; the top of the base should be at least 6 inches above the floor-line, to keep the lower part of the boiler out of the damp or from any leakage of water.

The height of the wrought-iron smoke-pipe must depend upon the circumstances of the case, in instances where 6 or 8 feet is the greatest height, the blast-pipe from the engine should discharge into it; this is for the purpose of assisting the draught of the furnace.

Cross-Tube Boilers.—Vertical boilers are constructed with the shell and fire-box in the same manner as last described, except that a centre tube is attached by an L iron flange directly to the top of the fire-box, the tube being of less diameter than the box, at the top it is riveted to the smoke-box plate; the thickness of this tube is about $\frac{1}{4}$ to $\frac{5}{16}$ inch; it has one lap-joint, it is riveted in the same way as the shell, a number of tubes are fixed transversely in this centre tube, the ends of the cross-tubes are solid flanged, and are riveted to the centre tube. The water from the shell circulates through these cross tubes, it also surrounds the centre tube, very rapid evaporation takes place, and steam is raised quickly. The furnace and fittings of the boiler are the same as the last. The exterior of the shell is covered with non-conducting composition; this is covered with wood lagging, as before. These boilers are not so expensive in construction as the "Multitubular" boilers, and are not so liable to get out of order, especially as to leakage of the tubes; they are sometimes made of steel plates, both the shells and tubes, they are made thinner than when wrought-iron plates are used, and are in consequence lighter and more portable. The steam space in all vertical boilers is rather limited, they therefore require greater attention, to avoid accidents.

SIZES OF VERTICAL TUBULAR BOILERS.

Horse-power.	Diameter of Shell.	Height.	Size of Fire-box.	Height of Fire-box.	Number and Diameter of Tubes.	Weight (about).	Plates—Shell and Fire-box—Thickness.
	ft. in.	ft. in.	ft. in.	ft. in.	in.	cwt.	in.
4	2 9	6 6	2 4	3 0	16 × $2\frac{1}{2}$	$17\frac{1}{2}$	$\frac{3}{8}$
6	3 3	7 6	2 8	3 6	20 " "	24	"
8	3 6	8 6	2 10	3 6	25 " "	31	"
10	4 0	9 6	3 5	4 0	30 " "	38	"
12	4 0	11 0	3 5	4 0	30 " $2\frac{3}{4}$	45	"

Patent Field Tube Boilers (*Drawing No.* 4).—Vertical boilers are also made with the shells, fire-boxes, and centre smoke-tube in the same manner as before, but at the top of the fire-box a number of small tubes, $1\frac{3}{4}$ inch diameter, closed at the lower end, pass through the plate, and are suspended from it; these tubes have internal tubes, open at each end, suspended in the interior, the top part of the internal tubes being provided with funnels; the tubes hang down near the fire, usually within 1 foot 9 inches or 2 feet, the cold water descends through the centre tube, and when heated rises through the annular space between the two tubes, by this means a large amount of heating surface in a small space is obtained, a rapid circulation of the water is caused, and steam is generated quickly. These tubes are Field's patent, they have been used very extensively, they work efficiently, except in cases where the water used in the boiler contains lime or other deposit, in this case the tubes at the closed ends get filled with hard deposit, and quickly burn out; it may, however, be stated no accident can arise from this cause, the only inconvenience is the stoppage of the boiler until a new tube can be fixed. As in the case of other vertical boilers, it is advisable to carry the exhaust or blast pipe from the engine into the smoke-shaft to increase the draught; a baffler with a rod and lever attached is provided to act as a damper at the fire-box end to control the draught. From the rapid circulation caused by the patent tubes, these boilers may be made somewhat smaller than other kinds, and on this account are very suitable for confined spaces, or for use in steam fire-engines.

The fittings and fire-grate do not differ from other vertical boilers in any material respect; the brickwork foundation is the same as before named.

Steam of 80 lbs. can be raised in the vertical boilers above described from cold water in fifteen to twenty minutes, the heating surface is about 15 square feet per horse-power.

Horton & Son's Patent Boilers.—These boilers are made with the internal fire-box corrugated; this increases the amount of heating surface exposed to the water within the shell; steam is got up very rapidly, and the size of the boiler compared with the power is also rather less than in other forms of construction; this is often a consideration where the space at command is small; the fittings of the boiler and the construction as to the plates and riveting are the same as in ordinary boilers. The fire-boxes and tubes are very strong on account of their cross section, and the plates can be made thinner than in other kinds, thus reducing the dead weight; this is often a very important consideration, especially in the case of vertical boilers that have to be placed on a floor.

Boiler Feed-water Apparatus.

Water Heaters.—These apparatus are for the purpose of heating the feed-water, they are constructed with an outer cylinder of cast iron, from 18 to 36 inches diameter, and 6 feet 6 inches to 8 feet 6 inches high; at the top and bottom of the cylinder, plates are fixed, and into these plates a large number of small copper or iron tubes 1½ to 2 inches diameter are riveted; at the bottom of the cylinder a chamber is bolted on, and into this the exhaust steam from the engine is discharged; the water to be heated is *inside* the cylinder, and surrounds the small tubes; at the top of the cylinder a dome cover is bolted, the steam passes through the small tubes into the top chamber, and from thence it is discharged through a pipe at the top to the atmosphere. A long glass gauge at the side shows the level of the water inside the heater; the feed-water is usually drawn from a tank or reservoir, and forced through the heater to the boiler: in its passage outside the tubes the cold water is heated, and thus enters the boiler at about 100° to 120°, causing much saving in fuel, as well as ensuring purer water in the boiler; much of the deposit that would otherwise enter the boiler is deposited in the heater; a man-hole is provided to clean out the interior at stated intervals; the heaters should be fixed vertical, but in some places where the space at command will not permit this, they may be fixed horizontally. There are other forms of these heaters; the above are, however, the most simple and effective; sizes above 30 inches in diameter are made with the external casing of wrought-iron plates, with an angle-iron flange at each end; the top and bottom are made in cast iron. The exterior of the cylinder is coated with non-conducting composition.

Steam Pumps or Donkey Engines for Feed-water (*Drawing No.* 5).—There are several kinds in use, the most efficient are made horizontal, self-contained on one bed-plate; the cylinder is fixed at one end, the pump being in the centre, a cross head is keyed on between the pump and the steam cylinder, and from this cross head two side rods pass to another cross-head at the *back* of the pump; a short connecting-rod is attached to it, and at the other end to the crank-pin of the crank, which is keyed on to the crank-shaft; a small fly-wheel is fitted to the shaft, and an eccentric or small crank disc works the slide-rod and slide of the steam cylinder. The pumps are made double-acting, and are fitted with indiarubber or metal valves, air vessels are fixed both on the suction and delivery pipes; the pumps can be worked at speeds from twenty to sixty strokes per minute, and are very economical in use; they are called "The Model Pump," and are made by Messrs. Thornewill and Warham, of Burton-on-Trent. The author has used them largely for many years, has never known them to fail in their action, and being very simple in their parts do not get out of order, the wear is very small; the valve chambers are provided with bonnets at each valve, to permit of rapid examination and also for repairs when necessary.

Steam Pumps are also made with the steam valves worked by a tappet action; Tonkins' Patent Cornish Pump is a very useful and efficient pump, it works economically and is free from complication; in this case the piston rod works direct on to the pump, there is no crank-shaft or fly-wheel; very few of the other pumps of this type that are made can be recommended, as they are in many instances complicated in their parts and use a large amount of steam. Large sums of money and much ingenuity have been expended upon direct-acting steam pumps, in some cases the liability to break down precludes their use; there is great competition between various rival manufacturers, with the usual result that many of the apparatus offered to the public are of indifferent quality, and far from perfect in their action when pumping water.

Injectors.—This ingenious apparatus is used as an adjunct to the steam pumps above named to supply the feed-water to steam boilers, they are somewhat complex in their action, but are very efficient apparatus; water from a small tank placed at a higher level than the injector, is admitted to the cylinder of the injector by a valve, steam is also admitted at another part; the steam passes through a long cone, and meeting the water carries it into the boiler through a pipe communicating with the same; this pipe has a back-pressure valve in it; a small hand-wheel at the side regulates the amount of water admitted, and another wheel regulates the amount of steam admitted by means of a small taper pin working within the cone through which the steam passes. It will be seen that no steam is lost by this apparatus, as it is nearly all returned into the boiler with the feed-water. The most reliable apparatus of this kind is Giffard's patent; it is made by Messrs. Sharp, Stewart & Co., Manchester; they are made and adjusted according to the working pressure of steam in the boiler, and are capable of working either at low pressures or up to any pressure required. It must be borne in mind that, as a rule, they will not work when the feed-water supply tank is placed at a lower level than the injector, and when the heat of the water in it exceeds 100° to 120° Fahr.; when the working pressure in the boiler is very high, the water may be used at a higher temperature. There are several modifications of this apparatus; the author, however, prefers the one described, and has never known it to fail when the feed-water supply is kept clean and it has proper attention.

Smoke-consuming Furnaces.

In large boilers fired regularly and slowly, especially where Welsh coal is used, little or no smoke is made; an old Cornish system is to rake all the live or red coal at the front part of the furnace to one side, and to throw fresh coal on to the other side of the bars; as the combustion of the coal slowly takes place, the gases are consumed at the other side before they reach the bridge at the end of the furnace.

Another plan is to coke the fresh coal slowly on the dead-plate at the front of the furnace, pushing it into the fire; the gases are consumed by the live coal in front. A large number of patents have been taken out for smoke-consuming furnaces, many of which are of very little practical utility; the chief furnaces of this kind in general use are Brunton's, Juckes', Hazeldine's, Clarke's, Wright's, Vickers', and Smith's patents.

Brunton's consists of a revolving plate, the coal is fed into a hopper and is gradually brought into the fire-grate, the coal is slowly carbonised and smoke is thus prevented; this apparatus is somewhat costly, and is not very much used at the present time, it effects a saving in fuel, but is liable to break down, being rather complicated in its parts; it also takes up a large amount of room, which in most instances would preclude its use.

Juckes' may be looked upon as the most efficient apparatus for the prevention of smoke, it has stood the test of upwards of thirty years' practical working, and has proved both on a large and small scale a most economical apparatus; the amount of saving of fuel effected between these furnaces and the ordinary grates is about 25 to 30 per cent. Small coal may be used, a very regular supply of steam is kept up, and no injury is done to the boiler, as in the case of ordinary furnaces, by constantly opening the fire-door when coal has to be supplied to the fire. The fires do not require clinkering, and any ordinary refuse mixed with the coal may be burnt on the bars. At one great establishment in London there are about twenty in use, the economy effected in the cost of coal amounts to several hundred pounds per year, added to which a more even fire is secured and very little manual labour is required.

The apparatus consists of an endless chain of small cast-iron fire-bars, with two holes cast in each, through these holes in the bars wrought-iron rods, 1 inch diameter, are threaded; each line of bars are made to break joint, and of a length sufficient to allow the proper amount of air to pass through, the air spaces between the bars are formed by the thickness of the bosses at the holes being more than the width of the bars at the top. The outside bars at each side of the chain at the holes where the threading bars pass through have large long bosses cast on them. Two cast-iron side frames strongly braced together are mounted on tram wheels; at each end of the frame there are two wrought-iron shafts, on each of which two cast-iron tooth-wheels are keyed; these wheels drive the chain by means of the bosses at the outside bars on both sides of the chain, the pitch of the teeth of the wheels exactly corresponding with the bosses on the bars.

At the front of the furnace, wheel gear is attached to give motion to the endless chain of bars; the speed is about 6 feet per hour, the coal is fed into a wrought-iron hopper at the front of the furnace, and is slowly carried forward to the bridge at the end of the furnace; the slow passage of the coal from the mouth of the furnace to the bridge ensures *perfect combustion*, and thus *prevents smoke*. The furnace is driven by a small engine or by any convenient shafting, the power required is small; in cases where a donkey steam pumping engine is used to feed the boiler, the furnace gear may be driven from the crank-shaft. To prevent the fire-brickwork at the bridge from being burnt out, a "stop" water-pipe is fixed immediately in front of it; a constant circulation of water runs through the pipe, and thus prevents the fire burning away the fire-brickwork of the bridge. Experience has proved that the best pipes to use are steam tubes of wrought iron 2 inches diameter; the brickwork bridge is carried on cast-iron girders and is brought a short distance over the top of the endless chain.

There have been many imitations of this furnace, but in the opinion of the author it has never been equalled in efficient performance.

Hazeldine's and other modifications of Juckes' are somewhat upon the principle, except that the fire-bars do not revolve; they are formed in steps, are hung at the back end, and at the front end alternate bars are moved forward by a set of cams or tappets worked by gear; a layer of coal is carried forward each time by this means, and thus, as in the case of Juckes', slow combustion takes place and smoke is prevented. Vickers' patent is on much the same plan, it is however free from many of the faults of the Hazeldine furnace; it requires power to drive it, this is however very small.

Wright's patent is a system of rocking bars, worked by a hand lever at the front of the furnace; by breaking up the coal and the forward action of the fire-bars, it is gradually carried to the bridge, the gases being consumed before they arrive at the end of the furnace; this apparatus can be applied to boiler and other furnaces at a small cost, it is efficient in action, and effects much economy in the consumption of coal; as it does not require any power to drive it, there are many instances where it can be used with advantage.

The principal furnaces for the prevention of smoke, sufficient for the purposes of this work, have been described; the object to be attained in all is to *prevent* smoke, it cannot be consumed when once made. The author believes there is still a field for the inventor, as a perfect furnace capable of being applied at a moderate cost, especially for small boilers, is still wanted.

Many of the furnaces of this class prevent smoke, but do not effect any economy in the consumption of coal; all those worked by a jet of steam, in some way prevent smoke, but do not effect any economy in coal; they are open to the objection that most of them require the admission of cold air at the fire-door, this is not advisable as it cools the fire and also helps, by the sudden contraction and expansion of the plates of the boiler over the fire, to destroy them more rapidly than when the fire-door is opened at the usual intervals for stoking.

In the London district the Smoke Act is in force, and many manufacturers are led, in their attempt to satisfy the demands of the authorities, to try various kinds of apparatus, especially any offered that are cheap as to first cost. Manufacturers and mill owners are placed in a great difficulty in this respect, far greater than the general public have any idea of; any one who can solve the question as to the best form for an economical furnace, suitable for most cases, will certainly meet with success, and confer a boon upon the manufacturing community.

CHAPTER IV.

BEAM ENGINES.

High-pressure (or Non-condensing) Beam Engines (*Drawing No.* 6). —A bed-plate of cast iron A is securely fixed to a foundation of brickwork and stone, long bolts pass through the plate some distance into the brickwork for the purpose of securing a firm base for the engine. The bed-plate is made of the box section, that is, a thick plate is cast with ribs all round the edge, and cross ribs to strengthen the same, by this means great strength is secured without an excessive amount of metal; the plate is planed both on the top and bottom surfaces, and to this all the fixed parts of the engine are attached. A centre column B carries the main centre on which the beam vibrates; the bearing blocks are lined with gun-metal to reduce the friction, and have caps secured by bolts, the column on which they rest is cast hollow, it is turned at the base and cap, and is bolted to the top of the bed-plate. The beam C is usually made of cast iron strongly ribbed, the main gudgeon or pivot being in the centre; each end is equal in length, the main centre gudgeon is of wrought iron or steel, it is turned in the lathe and fitted to a bored hole in the beam, and is secured by a key to prevent it turning in the hole; at each end of the beam are wrought-iron pins or gudgeons, and at intermediate points on either side extra gudgeons are provided to work the various parts of the engine; in some cases the beams are made of two wrought-iron plates or slabs, held apart by cast-iron bosses through which the gudgeons are fitted; this is a very good form of beam, and is much used, especially for large engines.

The steam cylinder D is bolted to the bed-plate, it is placed directly under one of the gudgeons at one end of the beam; the cylinder is made of very tough and close cast iron, bored out in a lathe or boring mill, it has flanges cast on at each end and a cover with a stuffing-box and gland bored out to suit the piston-rod, through which it works, this box is packed with hemp to keep it steam tight as the piston-rod works through; the gland is usually made of gun-metal, it is turned to fit the stuffing-box, and bored out in the centre for the piston-rod to work in; it is held in its place by three screwed studs secured by nuts. On one side of the cylinder, steam passages are cast; these communicate with each end of the cylinder, terminating in a slide face having three holes or ports in it; two of these are for steam, and one for the exhaust or spent steam; one steam port communicates by means of a steam passage before named with one end of the cylinder, and one with the other end, the exhaust port is in the centre; the slide face is planed perfectly true, and the port-holes filed square and true; a slide E works on the cylinder face, and alternately opens and closes each port; a slide-rod F passes through a stuffing-box in the slide jacket F^1, it is made as before described; it is packed with hemp to keep it steam tight. The piston G is turned to exactly fit the cylinder; it is fitted with a metallic ring which is accurately adjusted to the cylinder without causing undue friction; the piston is cast in two pieces, the ring is fitted between the two halves, which are bolted together closely, but are adjusted so as to allow the ring to move freely; the ring is cast thicker on one side, it is turned and then cut in two, put into the piston and bolted up tight, it is turned again to a size to ensure it fitting the cylinder absolutely when the ring is allowed to spring out, a back plate and tongue-piece prevent the steam from leaking at the part where the ring is cut. The piston is attached to a piston-rod H, made of steel, it is turned in the lathe to accurately fit the bored hole in the gland of the stuffing-box; at the top of the rod, a cross-head of wrought iron is keyed, and to this by means of "parallel motion" one end of the beam is attached. The cylinder cover is made loose for the purpose of putting in the piston, and also for examination of the interior of the cylinder, it is secured to the top flange by bolts and nuts; the length of the cylinder is equal to the stroke or travel of the piston plus the depth of the piston, and about $\frac{3}{16}$ to $\frac{1}{4}$ inch clearance at each end of the cylinder; the piston is turned at the top and bottom, and is tapered off on one side a distance equal to the width of the passage to allow the steam to pass freely into the cylinder. The slide-valves are worked by eccentrics I fixed on the crank-shaft, the rods from which communicate motion to a short rocking shaft, on this are keyed two levers, side rods from these levers are connected by pins, and to a cross-head at the top of the slide-rod, by this means motion is given to the slide. The end of the eccentric-rod where it works upon the first lever, which is keyed at the end of the rocking or weight shaft, is made with an open or gab end, the end of the rod is formed into a handle; by means of a lever on the rocking shaft, the slide may be shifted to allow the steam to be admitted at the top or bottom of the piston; the eccentric-rod is then dropped into its position on the pin of the lever, and the engine is started. At the back of the main slide, an expansion slide is usually worked, this is for the purpose of cutting off the steam at certain points of the stroke of the piston, the rest of the stroke being completed by the expansion of the steam in the cylinder. The eccentrics consist of cast-iron circular blocks, with holes which are bored out of the centre, the eccentricity is equal to half the travel of the slide, this is called the *throw* of the eccentric; the block is turned on the periphery and has a flange at each side; a loose strap in halves bolted together clips the block and works upon it, and to this strap the eccentric-rod is attached, at the other end it is connected to the slide-rod F by a small cross-head; the position of the eccentric on the crank-shaft is adjusted to open and shut the steam ports at the proper time; a cover is provided at the slide-jacket for the purpose of setting the slides, by means of the adjusting screws.

It may, perhaps, render the matter more clear if the action of the slide and piston in the cylinder is now described; suppose the piston at the top of the cylinder; the slide is placed in a position to admit steam from the steam jacket on to the *top* of the piston; this causes it to *descend*, by the time it arrives at the bottom the *full* stroke of the piston has been made, and the *full* stroke of the slide also, the eccentric having turned with the crank-shaft equal to the full travel or stroke of the slide-valve; the steam, by the opening of the lower steam port, then gradually enters on the *under side* of the piston, thus raising it to the top of the cylinder; the exhaust or spent steam passing out through the *inside* of the slide and the centre port on the cylinder face, is discharged direct into the atmosphere (in the case of a high-pressure engine now being described). It will be readily understood that by the alternate motion of the eccentric the piston in the cylinder by means of the slide is made to travel to and fro in the cylinder, and by the action of the beam gives a rotative motion through the crank to the main shaft of the engine. In practice the length of the slide is made rather more than the distance between the ports; this is called the "lap"; the slide opens the steam port at each end rather *before* the piston *completes* its stroke; this forms a cushion for the piston, and prevents a shock to the engine; by the *cover* of the slide the exhaust port also opens rather soon upon the other side of the piston, and so relieves the shock at the end. This is a rather complicated matter, and for the beginner it need not be entered into further, as it is fully treated in more advanced books. The expansion slide, when used, works upon the back of the main slide; it is moved by an extra eccentric of the same kind as described before; the eccentric being keyed in such a position on the crank-shaft to allow of the steam being cut off at the required time; this expansion slide is made in two pieces, a brass nut is fitted into each piece, the two parts of the slide are adjusted by a "left" and "right" screw which is cut on the slide-rod; the adjustment is from the outside of the jacket; the slide is fitted with a slide-rod at each end, passing through stuffing-boxes and glands, one at each end of the jacket; the back slide-rod has a hand wheel attached, by means of which and the internal screw the steam can be cut off at any required part of the stroke of the piston, say from $\frac{1}{4}$ to $\frac{3}{4}$ of the travel (or stroke). The admission of steam and power of the engine can thus be regulated when the load or work to be done varies; great economy is effected in the quantity of steam used. The pipe for the inlet of steam to the cylinder is placed on the steam jacket, usually at the end or on the top, the amount of steam passing through the pipe being controlled by a throttle-valve, to be presently described; a starting valve J is also provided at the steam inlet, to start and stop the engine; to this valve the steam supply pipe is attached.

The piston-rod when working is retained in a vertical line by the parallel motion; one end of the front link of the motion is attached at the end gudgeon on the beam, and the back link is attached at a point between the front link and the main centre; two rods couple the front and back links together; radius rods L are attached to the lower end of the links on either side of the beam, one end of each rod being fixed to the upper frame of the engine. The cross-head to which the piston-rod is keyed is attached to a pin at the centre of the front link. The beam in vibrating forms an arc at the end; the centre of the cylinder is placed at a distance from the end of the beam equal to half the versed sine, and by the action of the parallel motion just described the piston-rod is retained in a *vertical* line; this is a most ingenious contrivance, and, with a very few modifications, is made on the same plan as that constructed by James Watt.

The quantity of steam to be admitted to the cylinder is controlled by a ball governor M; this was also the invention of James Watt, it works in the same way as a pendulum; the balls are made to revolve by means of a belt working on a pulley keyed on the crank-shaft; as the speed of the engine increases, the balls fly out, and by means of the lever and rods connected between it and the throttle-valve, the latter is partly closed, and the quantity of steam admitted to the cylinder is controlled; if the load or work in a mill or manufactory is suddenly taken off the engine, the crank-shaft revolves faster, and the speed of the governor being duly proportioned, the balls on lifting by means of the levers close the steam throttle-valve, and so reduce the speed of the engine. There are some modifications of this apparatus, but the principle in all is the same, and except in some few details the apparatus has not been materially altered since the days of Watt.

A *connecting rod* N is attached to the gudgeon O, at the reverse end of the beam C; it is made of wrought iron, with a double or fork end clipping each side of the beam in the case of a single beam, and with a single end when a double cheek beam is used; the ends of the fork are fitted with gun-metal bearings, secured by wrought-iron straps keyed on each end of the fork of the connecting rod; the eyes of the bearings are accurately bored out to fit the gudgeons on the beam; at the other end of the rod, a single gun-metal bearing is provided, secured by wrought-iron straps to the connecting rod; the eye of the bearing is bored out to fit the crank-pin P. The centre part of the connecting rod is made larger in diameter to take the thrust, the length of the rod between the centres is equal to the distance between the centre of the end gudgeon on the beam and the centre of the crank at *half stroke.* Connecting rods were originally made of cast iron, but are now universally made of wrought iron or steel; the length of the rod from centre to centre of the bearings depends upon the height of the beam above the crank-shaft.

A *crank* Q is worked by the connecting rod; this consists either of a casting or a forging of wrought iron, having a boss at one end bored out to fit the crank-shaft on which it is keyed, and also a boss at the other end which is bored out to fit the crank-pin; the pin is made of steel; the "throw" of the crank, or the distance between the centres, is equal to half the stroke or travel of the piston in the cylinder; the crank is now usually made of wrought iron, and very strong, it is keyed on to the crank-shaft by one or two keys, according to the power of the engine; the back of the boss of the crank rubs against the brasses of the main bearings, and so forms a collar; a solid collar is forged on the shaft at the other side of the bearing, and thus keeps the shaft in its proper position.

The *crank-shaft* R is made of wrought iron; it is turned all over in the lathe, and runs in the main bearing block S, which is fitted with gun-metal bearings; the other end of the shaft runs in a bearing of the same kind; this is fixed to a cast-iron wall-box which is built in the wall of the engine house; on the crank-shaft the eccentrics for working the slides are keyed, also the fly-wheel, and the driving wheels to communicate motion to the machinery of the mill or factory. The fly-wheel T is cast iron, it is used for the purpose of equalising the motion of the engine, the weight of the rim being so adjusted, having regard to the speed, as to absorb and give out power, and thus equalise the varying speeds of the piston at the change of stroke; when the crank is at *full* top and bottom strokes, it is called the "dead" centres, the fly-wheel gives out the stored-up power at these points, carrying the crank over the centres without any perceptible change in the speed of the engine. The fly-wheel is keyed on the crank-shaft at the end nearest the wall, it should be fitted with two keys; the rim is square in section, the boss or centre is bored to accurately fit the crank-shaft, the arms are six or eight in number and oval in shape, the boss is cast split, to permit of contraction in the casting as the mass of metal in the rim cools after it has been cast at the foundry; the boss is bored out, and wrought-iron hoops are shrunk on either side, the periphery of the wheel is also turned; the balance of the wheel should have careful attention. For the convenience of starting the engine, a back plate containing holes is provided, this is bolted to the wall, a lever is applied to the arms of the fly-wheel to move the engine when standing on the dead centres. A feed-pump Q is sometimes worked by the beam of the engine to supply the boilers with water, when so used this consists of a force-pump, with suction and delivery valves, it is worked by a gudgeon off the beam at a point which gives the required stroke or travel to the plunger of the pump.

The end of the connecting rod attached to the eccentric and which actuates the lever on the weight shaft is fitted with a "gab" end with a guard below; on starting the engine, the weight shaft is moved by a hand lever, and the steam is admitted at each end of the piston as desired, it is also used to allow steam to be admitted into the cylinder at either the top or bottom ports, this is to warm the interior before the engine is started; by this means the air and any condensed water are expelled from the cylinder before the engine commences working.

The piston speed of engines of this class is from 220 to 250 feet per minute, the speed will partly depend upon the work the engine has to do; in pumping water, rather a low speed is preferable; the pressure of steam used is about 40 to 60 lbs. per square inch.

The area of the steam ports is equal to $\frac{1}{8}$ square inch per horse-power; the area of the steam passages leading from the ports to the ends of the cylinder are usually made rather in excess of this to allow for friction; the area of the exhaust port and pipe is usually about 50 per cent. in excess of the steam pipes; the pipe should have as few bends as possible, no sharp angles should be allowed, the pipe should have a fall from the cylinder whenever possible to keep it free from condensed water.

The steam cylinder should be jacketed, for the purpose of using steam in the annular space to keep the cylinder warm, the exterior of the outer shell or jacket being covered with felt and staves of mahogany bound with brass bands. Condense cocks and pipes are fitted at the top and bottom of the cylinder, also at the lower part of the slide jacket, and at any part where condense water can lodge; these cocks are opened before the engine is started, the steam is admitted to the cylinder, and the water is discharged through the pipes to the drain; it is essential that the steam used in the cylinder is as dry as possible, the efficiency of the working of the engine is very much affected by accumulation of condense water at any part.

Drawing No. 6 shows an engine of 15 horse-power. The cylinder is 15 inches diameter × 24 inches stroke; the piston-rod 2 inches diameter. The length of the beam is 8 feet; fly-wheel 10 feet diameter; length of the bed-plate 11 feet 3 inches. The pressure of steam is 40 lbs. per square inch, and the speed of the piston 250 feet per minute.

Condensing Beam Engines.—These engines are constructed in the same way as the high-pressure last described, except that the following apparatus is added, the detail of which and the action of the engine will now be explained.

An *air-pump* is worked by the beam, midway between the main centre and the centre of the cylinder, thus giving half the stroke of the cylinder; this pump is cast iron, bored out and made in the same way as the steam cylinder before described, it is fitted with a bucket or piston, having a valve of metal or indiarubber, it is also provided with suction and delivery valves; the bucket is attached to a piston-rod working through a stuffing-box in the cover as before described for the steam cylinders. The valves can only lift a height equal to their area: as an approximate rule, this is equal to about one-fourth the diameter of the pump; when the valves are made of indiarubber, they are about $\frac{3}{4}$ inch thick, and rise and fall upon their cast-iron seats, these are made like a "grid," a gun-metal bush slides on the rod, this bush is attached to the indiarubber valve, a gun-metal plate is fixed to the top of the valve to keep it as rigid as possible.

The inlet or suction of the air-pump is connected with a condenser, this is a cast-iron vessel in which the condensed steam is received direct from the steam cylinder; the steam on entering this condenser is met by a jet of cold water; this is called the "injection" water, by means of which the steam is rapidly condensed, and thus combined with the action of the air-pump a vacuum is formed at the piston on the *reverse* side to which the steam is acting. Surface condensers are sometimes used, these consist of a cylinder or rectangular box, filled with a large number of small tubes; cold water passing over the exterior of the tubes very rapidly condenses the steam, these condensers are only used for large engines, they cannot be treated in much detail here. A *cold*-water pump is worked off the "beam," this is for the purpose of supplying the injection water to the condenser; this pump is of the lift-pump type, it is made of cast iron, and fitted with a bucket and valve, also suction and delivery valves; it is made of ample capacity to ensure a plentiful supply of water.

It is not necessary to describe in minute detail the other parts of the engines, as they are much the same as in the high-pressure beam engine described at pp. 27 to 32.

The action of the condensing engine differs in this respect, that the motion of the piston is assisted by the vacuum formed by the condenser and air-pump, thus adding power to the steam on the reverse side of the piston in forcing it up or down the cylinder; when the piston is forced to the top of the cylinder by the steam acting under it, the exhaust side is open to the condenser, and as before stated, the escaping steam meeting the injection water in the condenser it is suddenly condensed, a vacuum is formed under the piston and so assists the descent; in fact, it is like adding to the pressure of the steam on *top* of the piston, by taking away all resistance upon the *under* side of the piston. The condensed water and vapour, together with any air, are pumped away by the air or vacuum pump, the water for condensation being supplied by the cold-water pump, before described; it can be readily understood that condensing engines can only be used where water is plentiful, and where it can be had from the town supply at a very moderate rate,

F

or from a river or surface well containing clean water free from deposit, when it can be pumped at a cheap rate.

The position of the air-pump is as stated about half-way between the main centre and the centre of the steam cylinder, the condenser is usually placed *below* the bed-plate and *within* the foundations. The cold-water pump is placed at the other side of the main centre and is worked by a gudgeon on the beam; in some cases where a small force-pump is required for the purpose of feeding the boilers, the cold-water pump is worked on one side of the gudgeon and the feed-pump on the other, both of the pumps being fixed to the bed-plate. The pressure of steam used may be the same as before, from 30 to 60 lbs. per square inch worked expansively, and cut off at from $\frac{1}{4}$ to $\frac{3}{4}$ inch of the stroke of the piston; an expansion slide is used for this purpose, it works upon the back of the main slide, as in the case of the high-pressure engine. The approximate proportions of the various parts of the engine are: Cylinder stroke equal to about twice the diameter; air-pump half stroke of the cylinder, and about half the area of same; injection inlet about $\frac{1}{15}$ square inch per horse-power; cold-water pump about one-fourth diameter of cylinder; beam, length equal three times stroke of the cylinder, the depth at the centre about two-fifths of the stroke; connecting rod, length about twice the stroke; main links centre to centre about half stroke; steam ports about $\frac{5}{8}$ square inch per horse-power; exhaust ports about 50 per cent. in excess of the steam ports.

The piston speed of these engines does not usually exceed 220 to 250 feet per minute; they are very economical in action, and when well constructed and carefully used, wear very well; they are well adapted to drive cotton, flour or other mills, as well as any kind of machinery, where the work is regular and the speed not excessive; they require rather more expensive foundations than some other types of engines to be presently described, and in first cost are also much more expensive; this however is not always the main consideration, as their economy in working well repays in most cases the extra outlay.

These engines are sometimes worked with patent valves, such as the "Corliss" system, in which case slides are not used; the valves are opened and closed by tappets and levers worked by a rod off the beam, or by means of cams on the crank-shaft communicating motion through a train of levers to the valves; this matter is however too complicated to be entered into now; it is only noticed to show that there are other systems of working the valves of the cylinder than the plan here described.

Condensing Beam Engine.—*Drawing No.* 7 shows a modern engine of this type, by Messrs. Simpson & Co., London, to whom the author is indebted for the drawing. A bed-plate A is bolted to a brickwork and stone foundation, on this plate all the parts of the engine are attached; the surfaces to receive the various parts are planed and the plate is set dead level; at the centre of the plate a cast-iron column B is bolted, and at the cap of the column the main centre bearing blocks are bolted. The beam C is also of cast iron, and vibrates on the centre gudgeon D in the bearing blocks; from the beam all the various parts of the engine are worked. The steam cylinder E is bolted to the bed-plate at one end; the exterior is steam-jacketed; the cylinder cover is also jacketed; steam from the boiler is admitted to keep the cylinder warm; the piston is of the usual type; there are two slides, the expansion slide works on top of the main slide; the cylinder and slide jackets are covered with felt or non-conducting composition, and lagged with mahogany secured with brass bands. The slides are worked by two eccentrics F keyed on the crank-shaft, and are connected by a train of levers to a weight shaft fixed near the cylinder; it will be seen that the stuffing-boxes are placed on the bottom side of the steam jacket, and that the valve spindle of the expansion slide passes through a stuffing-box at the top of the jacket; a hand wheel and screw regulate the amount of cut-off given to the valve, the steam inlet is at G. The air-pump H is placed about half-way between the main centre and the cylinder, the pump is sunk below the bed-plate, the condenser is *under* the cylinder, the injection cock is at I, at the top of the air-pump the hot well is placed, the overflow being at J; the contents of the air-pump are discharged into this vessel, and overflow at the point indicated; a feed-pump K is worked off the beam at the same side of the centre. The air-pump and cylinder rods are kept in a vertical line by the parallel motion L L and the radius rods M; the action of this is as before described. The spring beam N carries the radius rods; they are attached at one end to the back link, and at the other to the spring beam. On the other side of the main beam, a pump is worked near the main centre, and near the end a cold-water pump is also worked; this is fixed below the bed-plate. At the end of the beam a wrought-iron connecting rod O gives motion to the crank P, which is keyed on the crank-shaft Q; this shaft runs at one end in a bearing R bolted to the bed-plate, and at the outer end in a bearing bolted to a wall box fixed in the wall of the engine-house. The fly-wheel S is keyed on the crank-shaft by two keys, and a spur ring is bolted to the arms of the wheel, from this wheel (or ring) motion is communicated to a spur wheel keyed on the first shaft of the mill. All the parts of the engine are carefully balanced and well proportioned for the work they have to perform. The cylinder is 20 inches diameter × 42 inches stroke, the engine is 40 horse-power nominal; it is capable of transmitting a power of 110 horse-power actual. The pressure of steam used is 60 lbs. per square inch, and the piston speed = 300 feet per minute. The vacuum made = 28 inches, the steam is cut off at $\frac{1}{4}$ of the stroke of the piston. These engines are largely used to drive flour, rice, oil, and other mills, as well as the machinery of large factories of various kinds. The consumption of fuel = $2\frac{1}{2}$ lbs. coal per indicated horse-power.

Compound Condensing Beam Engine (*Drawing No.* 8), by Messrs. Simpson & Co.—These engines are made in the same way as the condensing beam engine last named, except that there are two cylinders—one for low and one for high pressure; the cylinders are placed side by side, they are bolted to the bed-plate, and both work on to the beam; the connection between the beam and the piston-rod cross-heads is by means of parallel motion; steam is admitted into the high-pressure cylinder first, and the exhaust steam is discharged into the low-pressure cylinder, after which the action is the same as in the condensing engine. The steam is used expansively in the high-pressure cylinder, the slides being worked by eccentrics and cams through a system of levers and shafts to the cross-heads of the slides. The air-pumps are worked off the beam, and usually at a point half-way between the main centre and the end gudgeon; the cold-water pump to supply the injection water is of the usual construction, it is worked from the beam near the end at the crank-shaft side.

Steam at a pressure of 50 to 60 lbs. per square inch is used in the high-pressure cylinder. The cylinders have a jacket or outer cover, having an annular space into which steam from the boilers is admitted; the exterior of the jacket being covered with felt and then with mahogany in narrow staves, and bound together with brass bands; the cylinder covers, and in some cases the stuffing-boxes, are also steam-jacketed. A surface condenser is fitted to the air-pump; the vacuum obtained is 28·5 inches. The engine is fitted with a Porter's governor, and works an equilibrium throttle-valve. The indicated horse-power = 360 average.

Large engines of this kind are sometimes made by Messrs. Simpson & Co. in pairs (or coupled), the high-pressure cylinder being worked by one beam, and the low-pressure cylinder by a separate beam; the engines in this case are placed side by side, with *one* crank-shaft and fly-wheel; the cranks being keyed on to the crank-shaft at right angles to ensure the engines never being on the dead centres; when the engines are made in this way, a steam receiver is placed between the two cylinders to receive the steam from the high-pressure cylinder; this steam receiver is also enveloped with a steam jacket, into which steam is admitted; on the exterior it is felted and covered with mahogany, as before described. The average consumption of coal in the boilers with these engines is as low as 1·6 lb. per indicated horse-power. Engines of this class, as before stated, show their highest economy when doing regular pumping at waterworks; they are very economical in their action, and are principally used where the power required is great and the work regular. Many of the large London waterworks have engines of this type, giving the most economical results as to the water pumped and the fuel consumed in a fixed time.

Instead of slide-valves, double-beat valves are sometimes used in these engines on the Corliss system; they are worked by cam levers, and act in much the same way as the valves of a Cornish engine.

When pumping water at a low lift, these engines may be worked at a speed of 220 to 240 feet per minute; they give the best effect in this case when the engines are coupled, as described above; the pumps in this case are usually made double-acting, and of the bucket and plunger kind; these engines are also well adapted for driving mills and machinery; they are of necessity expensive as to first construction.

As before stated, except as to the double cylinders, these engines work in the same way as the condensing beam engine: the description now given will be sufficient to give an idea of their way of working and the kind of work they are the best adapted for.

For beam compound engines these may be taken as the highest type in modern use. Messrs. Simpson & Co. having large experience with engines of this kind have introduced many improvements which add materially to their efficiency in working. They are rather complex in their action, and somewhat difficult for a beginner to understand; the author does not intend to give details to show how engines of this class may be designed, as this would be far beyond the scope of this book; a sufficient description is given to enable the reader to form an idea of their construction and mode of working.

CHAPTER V.

CORNISH ENGINES.

Cornish Beam Engines.—These engines are principally used for pumping water for the supply of towns and for draining mines, they are suitable for deep pumping and for high lifts; they were first used in Cornwall in the mining districts, and were introduced into London about the year 1837, being used for supplying water to a part of London; they are as a rule only made in large sizes, the steam cylinders often ranging from 80 inches to 112 inches in diameter, and from 9 to 10 feet stroke of the piston; the economy of this class of engine is shown principally in countries or districts where coal is very dear: in mining districts, where the coal is not found on the spot, strict economy in the consumption is a very important consideration; in the opinion of some these engines are about the most economical in use for pumping water, especially on a large scale, for the supply of towns.

Drawing No. 9 shows a Cornish Beam engine; the engines are single, direct-acting, and *not* rotative like ordinary mill engines; a massive bed-plate A is bolted to a stone and brickwork foundation; the steam cylinder B is fixed under one end of the beam C; the piston is of the usual description, except as to the metallic packing, which differs in some respects; the cylinder cover and bottom, and the stuffing-box for the piston-rod, are steam-jacketed, that is, the working parts are entirely surrounded by steam, this is for the purpose of keeping up the temperature; no slide-valves are used; the steam passages D are bolted to the side of the cylinder; the valves for admitting the steam are made of gun-metal and upon the Cornish or double-beat equilibrium system, they are actuated by a rod from the beam to which tappets are attached; these, in ascending or descending, open and close the valves. There are four valves to the cylinder,—at the top there are three valves, and at the bottom one valve; No. 1 is on the main steam pipe, and is for starting the engine; it is worked by hand: this is called the *governor*, and is for the purpose of regulating the amount of steam to be admitted to the cylinder; No. 2 is a steam inlet valve, and is opened by the "*cataract*"; the amount of opening is carefully adjusted by a slide upon the plug-rod: this also regulates the cut-off for the steam; No. 3 is the exhaust, and is at the bottom of the cylinder, it is also under control of the *cataract;* No. 4 is the equilibrium valve, opened by the working rod in the "up" stroke. Each of these valves is connected to piston or valve rods working through the covers on the valve chambers; levers are connected at the top of each valve; these levers have rods attached, which are again connected at their lower ends to levers keyed on a rocking or weight shaft; on these shafts, levers with flat sides are keyed, these are shaped to allow the rubbers on the plug or working rod to rub on the flat sides, and thus open or close the valves according to the position of the stroke of the piston. The apparatus to regulate the motion of these levers and shafts is called the "*cataract*," it is a kind of water balance, this is fixed below the bed-plate near the cylinder. At the starting of the engine the stroke commences by opening the exhaust valve; this is to clear the cylinder on the *under* side of the piston; the steam valve is then very quickly opened by the "*cataract*," and the steam entering at the *top* of the cylinder forces the piston down; the time the steam valve remains open is regulated by the plug-rod, and is according to the amount of expansion to be used in the cylinder; that is to say, the valve is closed at any required point of the downward travel of the piston, the rest of the work being accomplished by the expansion of steam, and also by the momentum of the parts of the engine in motion; before the piston arrives at the bottom of the cylinder, the *exhaust* valve is closed and the *equilibrium* valve is opened; this connects the top and bottom of the cylinder, that is, the space *above* and *below* the piston. The loaded plunger of the pump, at the other end of the beam, to be presently described, brings the piston to the top of the cylinder, and forces the steam from the top to the under side of the piston, the equilibrium valve being closed just before the finish of the stroke.

The piston-rod is attached to the piston in the usual way, it is keyed to a cross-head working on the pins of the parallel motion. The beam C is made of cast iron or wrought iron, and is either made double or single as described for ordinary beam engines; gudgeons of wrought iron pass through bosses on the beam to take the main centre and the various rods to work the several parts of the engine. The main centre E is supported by four cast-iron columns; these are bolted to the bed-plate; on the top of the columns is a cast-iron entablature usually built in the walls of the engine-house at each end; on top of the entablature the two main centre blocks F are fixed; they are fitted with gun-metal bearings and caps, each being bolted on by four bolts. At the reverse end of the beam, the loaded pump-pole G works; a parallel motion ensures the pole working in a vertical line, it is constructed on the same plan as for the steam cylinder before described. The condenser H receives the exhaust steam from the cylinder; the air-pump I is also of the same construction as in the Condensing beam engines; the pump is worked off the beam by a rod attached to the back links of the parallel motion. Injection water is supplied to the condenser, and the action of the air-pump is the same as before described.

A tank surrounds the air-pump and condenser; the cold-water pump J, to supply the injection water, is worked off the beam near the main centre; a small air-pump is also worked from the beam, this pump forces air into the air vessel, and so keeps up the required pressure in the mains. At each end of the beam strong wrought-iron bars K are fixed; these rest upon the iron girder framing L at each end of the beam when the engine is at rest; they also take the shock if the pump misses the stroke, and thus prevent a fracture of the cylinder; in the ordinary *rotative* engine this cannot take place, because the motion of the crank-shaft, by means of the eccentrics, controls the admission of steam by the slide through the ports communicating with the top and bottom of the cylinder. The pump M is constructed on the ram and piston principle; the pole and ram, combined with the counterbalance N, are sufficiently heavy to drive the water up the rising main pipe from the pump to the height required.

The pump is made double-acting, and has a solid piston of cast iron; it is keyed on to the pump-rod; the valves of the pump are equilibrium valves of the Cornish kind; they are made of gun-metal, the suction valves having four *beats* and the delivery valves two; the suction valves are always made larger in area, to allow the water to pass rapidly into the pump-barrel on the *up* stroke of the plunger. In these engines the water is raised in the pumps by the fall of the weighted pole and counterbalance; when the piston in the cylinder is at the *bottom* of the stroke, the plunger is ready to descend, and when the full stroke is made, a rest takes place of a few seconds, which gives sufficient time for the valves to close; the *up* stroke of the plunger is made very rapidly, this is due to the sudden admission of steam at the *top* of the piston in the steam cylinder. The suction valves are only allowed to lift sufficiently high to give full area or space for the water to enter the pump-barrel without undue friction; the pumps and all their parts have to be made very strong to withstand the heavy shocks to which they are subjected; the valves are fitted to separate castings bolted on to the pump-barrel, each valve has a cover over it, to allow of examination and adjustment when required. At the level of the engine-house floor an air vessel is provided, the air in the vessel is supplied by the small pump before named, it is worked by the beam: the amount of compression of the air in this vessel controls the height to which the water is lifted; in some instances the water is pumped up a stand-pipe a few feet higher than the highest point of delivery in the town or place to be supplied, the mains are thus charged by the load or "head" of water in the stand-pipe; safety valves are provided in the delivery main, to take the shock off the pipes in case of any sudden stoppage in any part of the system of pipes in the district.

To give an idea of the large dimensions of some of these engines used for the water supply of certain districts in London, particulars are given of one of the largest of this kind of engine in use. The steam cylinder is 112 inches diameter, and the stroke or travel of the piston is 10 feet; the speed of the piston is seven strokes per minute, giving a velocity of the piston of 138 feet per minute. The pressure of steam used is 35 lbs. per square inch, the average steam for the stroke = 24·5 lbs., the vacuum = 28 inches. The piston-rod is 11 inches diameter; the beam is made double, of cast iron, and 31 feet 6 inches long × 8 feet 9 inches deep at the centre; it weighs about 40 tons; the main centre on which the beam works is wrought iron, and 1 foot 6 inches diameter. The air-pump is 56 inches diameter × 5 feet stroke; the pump-plunger 50 inches diameter × 10 feet stroke; the number of gallons per stroke is 820; the head of water pumped is 170 feet. The average effective horse-power is 292.

Drawing No. 9 shows one of a pair of Cornish Beam engines, having the following dimensions:—

The steam cylinders are 80 inches diameter × 10 feet stroke; piston-rods 7 inches diameter; steam pipes 11 inches diameter. The beam is cast iron, with two cheeks, 6 feet deep at the centre × 32 feet 6 inches long; the weight is about 17 tons; the main gudgeon or centre is 1 foot 6 inches diameter. The air-pumps are 42 inches diameter × 5 feet stroke; the water-pumps are double acting, $24\frac{3}{4}$ inches diameter × 10 feet stroke, the pumps have solid pistons attached to pump-rods $6\frac{1}{2}$ inches diameter; the pump counterbalances are cast iron, and each weighs about 23 tons; the pump-valves are on the Cornish plan, as before described. The quantity of water pumped = 200 gallons per stroke, or for the double stroke 400 gallons; the speed is 8 strokes per minute = 3200 gallons. The pressure of the steam is 40 lbs. per square inch; it is cut off at $\frac{2}{3}$ of the stroke, giving a piston velocity of about 170 feet per minute; the vacuum is 28 inches. The "duty" or work done by these engines is equal to 80 millions of pounds raised 1 foot high by each 112 lbs. of Welsh coal, or say about $2\frac{3}{4}$ lbs. of coal per effective horse-power. The slip or loss of water from the pumps is about 2 per cent.; this of course varies with the condition of the valves and also the packings of the glands. The average effective horse-power of the engines is about 200.

The author believes this pair of engines to be one of the best modern types of the Cornish beam engine; they are well proportioned, and give very high results as to cost of working; the foundations are very solid; on this much depends their efficient working, and also saving of wear of the various parts. The engine-houses are also of the most substantial kind; the walls are thick and well built to stand the heavy shocks they are sometimes exposed to. The Drawing No. 9 gives a good idea of what is required as to the house, and it may be taken as a standard for engines of the size shown.

It will be seen there is no fly-wheel to these engines, and that the steam only acts on *one* side of the piston: the valve motion is peculiar to the engine, and in many respects the construction of the various parts is different to beam engines of the ordinary kind; they are only suitable for pumping water on a large scale; they are occasionally used for pumping sewage, the pumps and valves in this case are specially constructed, this is only a small detail and varies to suit special cases.

Cornish Direct-Acting or "Bull" Engines.—*Drawing No.* 10 shows an engine of this kind; the steam cylinder A is constructed in the same way as in the Cornish beam engines; the valve motion is also on the same system, the cylinder is *inverted* and bolted to a massive cast-iron frame, the steam enters on the *bottom* side of the piston, the cylinder is steam-jacketed, both at the sides and at the covers as before; the piston-rod B passes out of the cylinder at the *bottom* through a stuffing-box and gland; the loaded plunger-pole C and counterbalance is attached direct to the piston-rod. The pump barrel is fixed directly under the steam cylinder. The valve motion is worked, by means of a plug-rod, off the rocking beam D, which is fixed under the steam cylinder as before.

The method of starting and working the engine is the same as in the beam kind. The condenser and air-pump E are fixed below the steam cylinder, the air-pump is worked by the rocking beam or arm, the pump is open at the top and is fitted with a hot well or receiver; an overflow is provided at the side; the condenser and air-pump are placed in a tank of water. The cold-water pump F to supply the injection water is also worked by the beam or rocker-arm.

The rocker-arm or beam G is made of two slabs of wrought iron, it is attached to the pump pole at one end by a pair of wrought-iron links, the fulcrum-pin is at the other end, and moves in two bearings firmly fixed in the wall. Parallel motion made in the same manner as described for ordinary beam engines is provided at the air-pump to keep the rod vertical. The water-pump is of the plunger kind; the valves are on the Cornish plan, and are equilibrium with double and treble beats, as before described. The loaded plunger and counterbalance are kept in a vertical line by two wrought-iron guide-bars on which the guides slide which are attached to the counterbalance weight.

The degree of expansion of steam in the cylinder in engines of this class cannot be carried so far as in the beam engines. There is a pause at the end of the *down* stroke to allow the pump valves to close as in the other engines; the *up* stroke is made rapidly.

The following are the dimensions of these engines, which are a good type and average size for large pumping engines for waterworks:—The steam cylinders are 70 inches diameter × 10 feet stroke; the number of strokes made per minute is seven, giving a piston velocity of 140 feet per minute. The pressure of steam in the cylinder = 40 lbs. per square inch; it is cut off at half stroke. The piston-rods are 7½ inches diameter. The air-pump is 24 inches diameter by 5 feet stroke, and the vacuum made is 27 inches. The water-pumps are single-acting, and are 42 inches diameter by 10 feet stroke. The weight of the ram, piston-rods, &c., is 35 tons. The quantity of water pumped is 600 gallons each stroke; the "head" or height of the water is 135 feet. The delivery main is 36 inches diameter.

The duty of these engines is 65 millions of lbs. raised 1 foot high by 112 lbs. of Welsh coal, at about 24*s.* to 26*s.* per ton. The average effective horse-power = 170.

Coal consumed: average per million gallons of water pumped = 1 ton 1 qr. Coal consumed per horse-power per hour, 2·46 lbs. The cost of raising water per million gallons to the height named is about 1*l.* 11*s.* The horse-power required to raise one million gallons of water 1 foot high = ·2396.

The above may be taken as very high results, and can only be obtained on a large scale, with first-class machinery and the most careful attention.

This form of engine is very compact, and the cost of the houses and brickwork foundations is considerably less than for the beam engines described at pp. 38–41; the first cost of the machinery is also much less; the small space required for them will often decide their use instead of the beam kind.

There are a few modifications of this class of engines, but they do not materially differ from the two kinds described. In this book it is not intended to enter into any complicated discussion as to the relative merits of different engines, but to give as clear an idea as possible of each particular class or type.

The author has not entered into much rudimentary detail of any parts of these engines where they are constructed in a similar manner to those described in former chapters for other classes of engines, it being considered that the reader having carefully read the former pages, will be sufficiently advanced to understand clearly the plan of construction, as well as the way of working; in the succeeding portions of the book this plan will be adhered to, in order to save as much as possible unnecessary repetitions.

CHAPTER VI.

HORIZONTAL ENGINES.

These engines are made of the following types, viz. high-pressure, or non-condensing, condensing, and compound, the same as in the case of beam engines; the high-pressure engines are sometimes made with oscillating cylinders, these will be hereafter described. A non-condensing or, as they are usually called, high-pressure engine, of a good modern type will now be described in detail.

High-pressure Engines (*Drawing No.* 11).—A long bed-plate A, made of cast iron, box section, is bolted to a brickwork and stone foundation; the bed-plate is planed on the top and bottom, all the fixed parts of the engine are attached to it, the main bearings are cast on the plate. The steam cylinder B is fixed horizontally at one end of the plate; it has steam passages cast on the back side, ending in a slide face with three ports, two for steam and one for exhaust; the cylinder has covers at each end bolted on, the cover at the top being provided with a stuffing-box and gland, through which the piston-rod works; the glands are secured by three screwed studs fitted with nuts. The cylinder is fitted with a piston C and a steel piston-rod D; the slides E work on the side of the cylinder, the slide-rod passing through a stuffing-box as shown; the slide-jacket F is provided with a cover to adjust the slide when required; the piston-rod D is attached to a cross-head, to which are also attached the two cast-iron guide-blocks G, one on each side. These blocks rub on raised planed surfaces on the bed-plate; top bars are bolted on, leaving an intermediate space, permitting the slide-blocks to work easily between, by this means the piston-rod is kept in a parallel line. A wrought-iron connecting rod H is attached at the cross-head I, and connected with the crank-pin; each end of the rod is made a T shape, gun-metal bearings are bolted at the ends, the eyes being bored out to accurately fit the crank-pin at one end, and the cross-head gudgeon at the other; the length of the connecting rod between the centres is equal to about twice the stroke of the piston; the rod gives motion to the crank or crank-disc, which is either made as described for the beam engine, or consists of a circular cast-iron plate bored out at the centre and keyed to the crank-shaft, a boss is formed near the rim, in this boss a hole is bored out, and into it the crank-pin is fitted. The distance from the centre of the pin to the centre of the shaft is equal to half the "stroke" or "travel" of the piston; this is called the *throw* of the crank. The crank-shaft J is made of wrought iron turned in the lathe; it revolves in the main centre bearing K, which is cast on the bed-plate A, the bearing is lined with gun-metal bushes; these are made in halves, a strong cap is bolted on to the blocks; the other end of the shaft turns in another bearing or plummer block, also lined with gun-metal; the block is bolted to a wall-box L, firmly built in the wall of the engine house.

On the crank-shaft the fly-wheel M is keyed; this is for the purpose of equalising the motion of the engine, as before described at p. 31, and on the crank-shaft the eccentrics N N are keyed, these work the cylinder slide valves; they consist, as before, of an eccentric block bored out and fitted to the crank-shaft, having the periphery turned; on this the eccentric straps work, and by their eccentricity the slide valves are operated. The eccentric straps have rods attached and are connected at the other end to the cross-heads, to which the steel slide-rods O O are keyed; these rods are worked through guides, they are connected to the slides, and by them the steam ports are alternately opened and closed at each end of the cylinder, thus giving motion to the piston. The eccentric straps are made in halves, and are bolted together by means of lugs on each side of the strap; the straps are adjusted to turn on the eccentric block with as little friction as possible.

The governors are for the purpose of equalising the speed of the engine, and are adjusted to close the throttle-valve when the crank-shaft obtains the maximum speed. As before stated, the governors act upon the same principle as a pendulum, and by the height of the cone and the speed, as the sliding socket connected with the balls rises and falls upon the centre spindle, it raises or lowers a lever, at the end of this lever a small rod is connected and at the other end to the lever on the throttle-valve. A steam starting valve is provided to start and stop the engine.

The piston speed of these engines is usually from 220 to 250 feet per minute. The pressure of steam about 40 to 60 lbs. per square inch; in some cases the engines are worked by an expansion slide-valve, and the steam cut off before the piston reaches the end of the stroke.

The area of the steam ports is equal to $\frac{5}{8}$ of a square inch per horse-power, the exhaust port being made about 40 to 50 per cent. larger; the steam passages are made of larger area than the ports, and the curves as easy as possible, to save any undue friction in the passage of the steam to the cylinder; the area of the steam and exhaust pipes is rather in excess of their respective ports.

To prevent condensation of the steam, the cylinders are clothed on the outside with felt and then covered with wood staves or lagging bound with brass hoops;

large cylinders are sometimes cast with a jacket into which steam is admitted to keep the cylinder warm. Condense cocks and pipes are fitted to the cylinder at each end, also at the bottom of the jacket, and at the steam and exhaust pipes; this is for the purpose of carrying away any condensed water.

The stroke or travel of the piston is usually made double the diameter of the cylinder; when the cylinders are above 8 inches diameter, they are fitted with expansion slides; these slides are for the purpose of cutting off the steam at any required point of the stroke: the steam admitted into the cylinder expands and thus completes the stroke.

In large engines with cylinders above 18 inches diameter, to take the weight of the piston it is usual to provide a piston-rod at each end, the back rod works through a gland and stuffing-box, and is fitted to a guide-block working on a guide-bar.

A lubricator is provided at the steam jacket to lubricate the interior of the cylinder and save friction from the piston; all working parts have self-acting oil lubricators; it need hardly be pointed out that most efficient lubrication is required at all moving parts and rubbing surfaces to reduce friction.

It is very important that the steam in the cylinder is used as dry as possible; before starting the engine, the condense cocks are opened, and steam is admitted to the interior of the cylinder to warm it and to drive out condensed water.

Since steel has been so much improved and cheapened many of the moving parts of these engines are made in this material, such as the piston-rods, slide-rods, connecting rods, cross-heads, and guide-blocks. All working parts of the engine should be carefully balanced, and the rubbing surfaces well proportioned according to the power of the engine; it must be borne in mind, that an increase of the *area* of the rubbing surfaces, provided the pressure is the same, does *not* increase the friction.

The action of the engine is as follows:—Suppose the piston is at the top stroke, steam is admitted at the port R through the passage R^1, this sends the piston to the bottom; by this time the slide valve, by the revolution of the crank and eccentric, closes the steam port R and commences to open the steam port S through which the steam passes by the passage S^1 to the bottom of the cylinder; at the same time the exhaust port is open to the top passage R^1, the steam is driven out above the piston through the exhaust port and is discharged into the atmosphere; the steam is admitted at each end of the cylinder just *before* the piston reaches the *end*, this is for the purpose of forming a cushion and to prevent any shock from sudden reversal of the motion. The exhaust port or passage also opens before the stroke is quite completed, and so relieves the piston upon the exhaust side before the steam is admitted on the other side of the piston. It will be observed that the action of the engine is the same as in the case of the beam engine described at page 29, the only difference being that the slide valves are worked direct from the eccentrics in the case under consideration; those in the beam engine are worked through the medium of a rocking or weight shaft, side rods, and cross-head.

There is a great advantage in using this class of engines, they are very simple in construction, do not require expensive foundations, and from their few parts as compared with beam and other kinds of engines are not so liable to get out of order; on their first introduction—the author believes about 45 years ago—it was supposed by some that the cylinders being fixed horizontally the pistons would wear them oval; the fallacy of this after many years of practical work has been shown.

At the present time this type of engine is more largely used than any other; it is very portable, the small sizes being usually packed complete, except the crank-shaft and fly-wheel. In fixing them on the stone foundation they only require to be set accurately level, which is done by placing a spirit-level upon the faced top of the bed-plate; the centre line of the crank-shaft must be set at a right angle with the centre of the engine, and the skilled work is done; all the rest of the engine is already fitted to the bed-plate. The fixing on a good solid foundation is a very important matter, and should have the most careful attention; on this mainly depends the accurate and economical working of the engine, the reduction in the wear of the working parts, and consequent saving in expenses for repairs in the future.

The foundations for engines of this kind are made of brickwork resting on a good bed of concrete, the depth of which will depend upon the soil; at the top of the brickwork a hard stone is provided, this is set dead level and tooled or faced true on the top. The bed-plate of the engine is secured by long bolts passing down into the brickwork; these bolts are held at the bottom by cottars or keys bearing on strong cast-iron plates built in the brickwork. Those requiring further detail on this matter are referred to the author's book upon 'Pumps and Pumping Machinery' (E. & F. N. Spon). In a rudimentary treatise it is not necessary to further discuss foundations, as it is rather beyond the scope of the book and is a matter requiring skilled attention.

Horizontal Condensing Engines.—These engines are constructed in the same way as those described at p. 44, except that the bed-plate is made longer, and an air-pump is fixed at the back end of the cylinder; the piston-rod passes through the bottom cover which is provided with a stuffing-box and gland, and by means of a coupling it is attached to the rod of the air-pump. The air-pump is made in the same way as for beam engines, except that it is fixed horizontally, it has a close cover, and is provided with foot and delivery valves; it is sometimes made in the "trunk" form, this saves a little room, but in other respects is not advisable. The condenser is usually formed *outside* the air-pump, but in some cases it is fixed at the side of it next the wall, at the back of the engine. The cold-water pump to supply the injection water to the condenser is worked off the cross-head of the guide-blocks; it is sometimes made double-acting, the valves are of the same kind as before described. The governors, throttle-valves, and all other details are the same as in the high-pressure horizontal engines. Where water can be had at a cheap rate these are very economical engines to work, the parts are few and simple, and the consumption of fuel in the boilers per horse-power developed in the engine is small.

It is advisable to work these engines coupled or in pairs, with one fly-wheel placed between the two engines; the machinery works more easily and with less vibration; all the parts being balanced, the strains are more equally divided; this especially applies in cases where it is desirable to work the machinery with as little vibration as possible, and at an equal and uniform rate of speed; when engines are coupled in this way they can be started at any point of the stroke, the crank-pins are set at right angles, the speed is not only more equal, but the strains upon all the moving parts are also less.

The speed of the engines and the pressure of steam used are the same as in the beam condensing engine; they may however in some cases be worked at a higher rate, all the moving parts of the engine being close to the foundation. The steam cylinders are jacketed and steam is admitted to keep them warm; the exteriors are covered with felt and mahogany staves, these are bound with brass bands. Where space, more especially as to the length of the engine, cannot be had in the engine-house, the air-pump is worked off the crank-shaft and is sunk below the level of the floor and either worked vertically directly under the crank-shaft or at an angle of about 60°. The condenser in this case either surrounds the air-pump in the form of a casing, or is made separate and fixed at the back of the air-pump and close to the cylinder; this is a very compact form, it not only saves space but much simplifies the apparatus. There are several modifications of this class of engine, but except as to details the general plan does not differ in any material manner.

In all condensing engines steam gauges are provided on the steam supply-pipe near the steam cylinder to indicate the pressure of the steam, a vacuum gauge at the air-pump is also provided to show the amount of vacuum obtained, this seldom exceeds 28 lbs. per square inch, in some instances it may rise to 29 lbs. per square inch, but this cannot usually be obtained. The packing of the rod and piston in the air-pump and their perfect fit, also the amount of injection water admitted to the condenser much affect the vacuum; these matters should always have the greatest care and attention.

Horizontal Condensing Engines.—*Drawing No.* 12 shows a pair of coupled engines by Messrs. Simpson & Co., London ; the cylinders are 28 inches in diameter × 42 inches stroke. These engines are run at a high speed, and the driving belt or strap is taken direct from the rim of the fly-wheel; the cylinders are steam-jacketed, that is, provided with an external casing, leaving an annular space for the admission of steam from the boiler; this is for the purpose of keeping the cylinders hot. The steam slide-valves are two separate valves, the exhaust valves are circular, one at the bottom of each end of the cylinder, these valves also efficiently drain the condensed water from the cylinders; there are expansion valves to each cylinder, they are adjusted by the screw gear at the back end of the slides. The piston-rod in each cylinder passes out at the back end through a gland and stuffing-box to work the air-pumps, these are fixed behind the steam cylinders, they are trunk pumps fitted up in the usual way, and are single-acting. There are two eccentrics to each cylinder to work the slides; one crank-shaft is common to the two engines, a fly-wheel is keyed on in the centre; the cranks are set at right angles and are forged on the shaft with solid flanges at each end to which the first motion shaft may be attached. The governor is fixed on the top of the guide-bars, and is connected to an equilibrium throttle-valve by levers and rods. There is no continuous bed-plate, two horizontal side frames to each engine are attached to the front of the cylinders, on these frames are the guide-bars, between which the guide-blocks work, and at the end the main bearing blocks; the cylinders and these side frames are bolted direct to the stone bed, the air-pumps are also bolted direct to the stone bed, they are each stayed to their respective steam cylinders by distance pieces. These engines are run at a high speed and indicate 500 horse-power, they are most economical in their action, and of their particular type may be looked upon as the best modern engines for mill purposes.

Horizontal Compound Engines (*Drawing No.* 13).—These engines are by Messrs. Simpson & Co., and are constructed in the same way as described above for the condensing engines, but with the following additions:—The low-pressure cylinder is fixed next to the guide-bars and the high-pressure cylinder at the back; except that this cylinder is smaller than the low-pressure one, it is made in the same manner; the piston-rod of the low-pressure cylinder passes through the end-cover which is provided with a stuffing-box and gland, it is attached to the piston of the high-pressure cylinder. The steam is discharged from the high-pressure cylinder into the low-pressure one, and from this into the tube condenser fixed at the back of the engines on the fly-wheel side; the condensed water and air are pumped away by the air-pump. The condenser is fixed at an angle, and at a lower level than the main engine bed-plate. The air-pump is worked off the crank-shaft by an eccentric, and is fixed vertically directly under it, or in some cases in an inclined position. The cold-water pump to supply the condenser is sometimes worked off the cross-head of the low-pressure cylinder, and fixed in a horizontal position on the top of the bed-plate. In cases where the length of the engine is not an object, the bed-plate is made longer and the high-pressure cylinder is fixed next the guides, the low-pressure cylinder at the back of it, and the air-pump is worked at the back end of the low-pressure cylinder, by the piston-rod passing through the end-cover in the same way as in the case of the horizontal condensing engines; the condenser in this case usually surrounds the air-pump in the same way as described for the condensing engines. Engines constructed like this work very steadily; the wear may be rather less than in the former arrangement of the air-pump, but it is open to the objection of the extra space taken up; this in some instances would be prohibitory. The action of the engine is the same as in the compound beam engines described at p. 36; the speed and pressure of steam are the same. These engines are very suitable for pumping water, and also for driving heavy mill gear, where the work is regular, and where an equal and uniform speed is essential; when it can be so arranged, they should be worked in pairs with *one fly-wheel* for the two engines. The cylinders are steam jacketed and covered with felt and mahogany staves and bound with brass bands. The cost of the foundations is much less than in the case of the compound beam engines, but the increased length of the bed-plates requires a much larger engine house, and so the expense is increased in another direction, and in this case on the whole, the brick-work, &c., of the house will cost more for the horizontal than for the beam engine.

The engines give the highest results in the economy of fuel in the boilers, and also in the wear and tear of the various parts. A skilled mechanic is required to drive them; when in good hands there is not perhaps a better form of engine adapted to the purposes above indicated.

Pair of Compound Engines by Messrs. Simpson & Co., to whom the author is indebted for the particulars; there are two bed-plates, the high-pressure cylinder being fixed on one and the low-pressure cylinder on the other; a steam receiver is fixed between the two bed-plates and into this vessel or receiver the steam from the high-pressure cylinder is discharged. Both of the cylinders are steam-jacketed, in the same way as described at p. 49; they are fitted with variable expansion valves, there being two valves for each cylinder. The high-pressure cylinder is 19½ inches diameter × 4 feet stroke, and the low-pressure cylinder 30 inches diameter × 4 feet stroke. The feed and circulating pumps are worked at the back end of the high-pressure cylinder by the piston-rod passing through a stuffing-box and gland in the end-cover. The air-pump is worked in the same way by the low-pressure cylinder. One crank-shaft and one fly-wheel are common to the two engines. One governor controls the inlet of steam to both engines. The piston speed is about 400 feet per minute and the pressure of steam used is 60 lbs. per square inch. The yearly average consumption of coal in the boilers supplying this engine is about 2 lbs. per indicated horse-power; this is about the highest economy ever obtained in any engine within the author's experience. The steam is expanded first in the high-pressure cylinder and afterwards in the low-pressure cylinder, it is cut off a little before half-stroke in each of the cylinders. The cranks of these engines are placed at right angles to equalise the speed of the engines when passing over the dead centres, it also equalises the strains on all the moving parts of the engine, and keeps all of them in more perfect balance.

Boiler steam is admitted into each cylinder jacket, the cylinders being placed above the level of the boilers allows the condensed steam to flow back to the boilers, and in this way a perfect circulation is maintained; by this plan dry steam is constantly supplied to the cylinder jackets without any attention from the engine driver: this is a very unique arrangement, it not only effects much economy in the steam used, but being automatic is certain in action. The condensers are eight in number and are Cochrane's patent evaporative surface condensers; they are placed in the open air; each consists of two cylinders, one inside the other; the diameters are 3 feet 4¾ inches and 3 feet 8½ inches respectively by 12 feet 6 inches long; the total surface is 2200 square feet. The water is pumped to the top of the condenser, and allowed to trickle down the outside and inside of the cylinders, the exhaust steam being discharged into the annular spaces; these condensers produce good vacuum, and are economical in the consumption of water, this is a matter of great moment in London and most large towns where the water has either to be pumped on the spot or purchased from the water company or local authorities. In cases where this class of condenser cannot be used, it may surround the air-pump and be fitted with injection valve as before described for condensing engines; surface condensers are sometimes supplied. This is a very good form of compound engine, and for two-cylinder (high-pressure and low-pressure) engines is about the best type to use.

CHAPTER VII.

OSCILLATING ENGINES.

High-pressure Horizontal Engines (*Drawing No.* 14).—The difference between this class of engine and those described at p. 44 consists principally in the construction of the steam cylinder; this is cast with two hollow trunnions A A, one on each side, these trunnions are bored out and are fitted with glands and stuffing-boxes, packed with hemp in the usual way; the steam pipe B passes through on one side and the exhaust pipe C on the other. The slide face D is on the top of the cylinder, and is provided with steam ports and passages E E, communicating with the top and bottom of the cylinder as before described. The trunnions turn in bearings F cast on each side of the bed-plate, the bearings being lined with gun-metal and fitted with caps secured by bolts and nuts. The steam pipe and exhaust pipes are *fixed* and pass through the *moving* trunnions of the cylinder. The general construction of the cylinder in other respects does not much differ from fixed cylinders. The piston-rod is keyed on to a gun-metal cross-head bearing G, which works *direct* on to the crank-pin H; no intermediate guides or connecting rods are required. The slide-rod I, works at the bottom of the slide jacket, passing through a gland and stuffing-box; the slides are operated by the oscillation of the cylinder; the cross-head J to which the slide-rod is attached, rubbing on a fixed quadrant set in a proper position to give the required travel to the slide. In some instances this quadrant is keyed to a hand-lever and is made to turn on a centre-pin, by this means the motion of the engine can be reversed, this is often convenient, especially when working winding gear for sack tackle or for lifting work of any kind; in this case the small compass in which the engine can be placed is often of great advantage; in many cases the oscillating cylinders are attached by means of cranks direct to the winding barrel or other machine shaft requiring rotary motion. A force-pump K is sometimes provided for the purpose of feeding the boiler, it is worked by the oscillation of the cylinder from a pin on the slide jacket L by means of the rod M; the plunger N of the pump is cast hollow and the rod is attached to the lower end by a pin; the valve-box O is made separate, and is fitted with bonnets to examine the valves. The governors are of the usual type; they are driven by a belt or strap working on a pulley P, keyed on the crank-shaft Q. The fly-wheel is keyed to the crank-shaft outside the bed-plate; the end of the shaft runs in a bearing on the side wall of the engine-house. The dimensions of the engine shown in Drawing No. 14 are:—Cylinder, 6 inches diameter × 12 inches stroke; piston-rod, $1\frac{1}{4}$ inch diameter; crank-pin, $1\frac{1}{2}$ inch diameter; crank-shaft, $2\frac{1}{2}$ inches diameter; fly-wheel, 4 feet 6 inches diameter × $2\frac{3}{8}$ inches wide, weight about 6 cwt.; bed-plate, 4 feet $8\frac{3}{4}$ inches × 2 feet $8\frac{3}{4}$ inches. The steam pressure required to work the engine is 40 lbs. per square inch, and the speed of the crank-shaft is 130 to 150 revolutions per minute. The engine is about 4 nominal horse-power. The engine can be made entirely independent of the walls of the building by using a double crank: in this case it is forged upon the crank-shaft, two bearing blocks are cast on the bed-plate, they are fitted with gun-metal bushes, and with caps bolted on. The fly-wheel in this case is keyed on close to the bed-plate, the driving pulley may either be keyed outside the fly-wheel or on the other end of the crank-shaft in front of the engine. The engine in each case is held to the foundation by six 1-inch diameter bolts about 3 feet 6 inches long.

These engines are principally used when floor space is an object, especially as to the length; they are not to be recommended in any other case; the friction is rather more than in other kinds, there is also some trouble in keeping the joints at the trunnions steam-tight.

These engines are worked with steam at a pressure of 60 to 70 lbs. per square inch, and at a piston speed of 350 to 400 feet per minute; the diameter of the cylinders in these cases does not usually exceed 9 to 10 inches and the stroke 15 to 16 inches.

When the engines are self-contained with the crank-shaft working in two bearings, one on either side of the bed-plate, the fly-wheel working outside and close to the bed-plate, they can be bolted to a timber frame, or to the wall of a building; they are easily and rapidly fixed.

Engines of the oscillating class are also used for marine purposes and will be noted hereafter; for this purpose the cylinders are worked vertically and in pairs; the way of working is the same as in the fixed cylinder engines; the steam cannot however be used expansively, and on this account the cost of working this kind of engine is higher than the others.

Vertical Oscillating Engines are constructed in the same way as the horizontal, as far as the cylinder is concerned, except that they hang on trunnions turning in bearings cast upon the bed-plate, the lower part of the cylinder hanging below the bed-plate. The slide is worked at the side by means of a quadrant, the slide-rod having a gun-metal block attached to it; this works inside the quadrant, and by the oscillation of the cylinder the slide is operated and the steam and exhaust ports and passages opened and closed as before. The crank-shaft in these engines is usually carried in bearings cast on an entablature supported by columns, or on two A frames, held apart by wrought-iron stretchers or stanchions. The piston-rod has a cross-head bearing keyed on, working direct on to the crank-pin of the crank or disc which is keyed on the main shaft; in most instances, a double crank is forged on the shaft, which runs in two bearings on the frame. The fly-wheel is fixed on the reverse end of the crank-shaft, and works outside the entablature or frame. The governors are usually fixed on the top of the table, and driven by bevel wheels direct from the crank-shaft. The main driving pulley is keyed on close to the fly-wheel, in some instances the driving belt is put on the rim of the fly-wheel. A bed-plate carries all the parts of the engine, which is thus made self-contained; small engines can be moved in one piece. This class of engine is only useful where the *length* and *height* of the engine room are very limited, and when the power required is small; there are, however, many instances where they can be employed with advantage.

In some cases the oscillating cylinders, as in the case of the horizontal engines, are attached to a machine direct, and by means of cranks work the same, without the aid of pulleys, belting, or any other gear. This is the case in many forms of hoisting machinery, cutting machines, or in any instance where a high rate of speed can be used with advantage. The motion of the crank-shaft can be made to reverse by means of a link or quadrant, to which a hand lever is attached.

Oscillating engines are sometimes made with two vertical cylinders working on to one crank-shaft, one cylinder being placed on either side of the entablature or A frames; in some instances they are set at an angle of 60°, and work on to the crank-shaft at the front side of the engine; by the use of two cylinders a very equal and uniform motion is obtained, as there are no dead centres; a fly-wheel is not so essential in a case of this kind, and if used one of a much less size and weight may be provided. Another advantage obtained by the use of two cylinders is, the engine may be started at any point of the stroke, as the *two* cyclinders are never on the top and bottom stroke at the same time. These double-cylinder engines can also be made to reverse the motion by means of link gear in the same way as the single engines just described.

The friction in both vertical and horizontal oscillating engines is much higher than in horizontal engines with fixed cylinders. Engines of this class are sometimes made with the trunnions at the bottom of the cylinder, in this case the cylinder bottom is specially constructed, the steam and exhaust passages being cast on the cylinder as before; this plan is only adopted in the case of very small engines, the principle of construction is the same, the position of the trunnions is merely a modification of the engines described above.

There are some other modifications in the form of this class of engine, but the way of working is the same, and as they are not much used, any further detail would not be of much value. Oscillating engines are still great favourites with some people, especially where small power only is required; the small space they take up, their portability, and the ease with which they can be fixed will always tempt many to adopt them in preference to other kinds.

CHAPTER VIII.

VERTICAL ENGINES.

High-pressure Engines.—There are several types of these engines, viz. :—

No. 1. *Table Engines* with the cylinders fixed upon a table or A frame (Drawing No. 15).

No. 2. *Table Engines* with the steam cylinders inverted (Drawing No. 16).

No. 3. A *Frame or Entablature Engines*, with cylinders fixed to the bed-plate and crank-shaft on the frame or entablature (Drawing No. 17). These engines are manufactured by Messrs. George Waller & Co., London, to whom the author is indebted for the drawings.

No. 1. Table Engines (*Drawing No.* 15).—A cast-iron bed-plate A, of the box form, is bolted to a brickwork and stone foundation, the top of the plate is planed to receive four columns, they are each secured by bolts to the bed-plate, and on these the *table* or entablature B rests. The top of the table is planed, and the cylinder C is bolted to it, the cylinder is constructed in the same way as the horizontal engines as to the piston, slides, and steam passages; it is fixed vertically, and the piston-rod is keyed to a cross-head C^1. At each side of the cross-head a cast-iron guide-block D is keyed, these blocks are worked in the planed guide-bars E bolted to the top of the cylinder, the cross-head passes through these bars, and at either side is attached to a connecting rod or side link F F; these are made of wrought iron, round in shape, with gun-metal bearings at each end; at the lower end and *under* the table a wrought-iron cross-head G is connected to these side rods, the cross-head is bored out in the centre, and keyed on to a short connecting rod H, having a gun-metal bearing at the end, this works upon the steel crank-pin I, fixed in the crank or disc J. The crank-shaft K revolves in a bearing L cast upon the lower bed-plate, it is lined with gun-metal and fitted with caps which are bolted on; the shaft is wrought iron, and has the crank keyed on at one end outside the bearing; the fly-wheel is between the entablature and the wall, the end bearing of the shaft is fixed in a wall box, which is built in the wall; the driving pulley is keyed on between the entablature and the fly-wheel. The slides are worked by eccentrics M on the crank-shaft, by means of connecting rods N, rocking shafts O, and cross-heads P; engines with cylinders above 8 inches diameter are often worked expansively.

The crank-shaft being close to the foundations, enables them to work very steadily; they can be run at a low rate of speed if required. The details of the engines in other respects do not differ from the various parts more minutely described under the head of Horizontal Engines. Where floor space is an object, this class of engine can be usefully employed, they are rather more expensive in first cost than horizontal engines, but as the wear in constant use is small and being simple in construction they are often used; one important thing in their favour is, they seldom give trouble or get out of order; they should not be worked at a higher piston speed than 250 to 300 feet per minute. The pressure of steam may be from 40 to 50 lbs. per square inch; when an expansion slide is attached, the steam can be cut off at from one-eighth to half of the stroke, according to the work to be done by the engine at any particular time.

No. 2. Table Engines with Cylinders Inverted (*Drawing No.* 16).—In this kind of engine, a bed-plate of the same form as No. 1 is used, a hollow rectangular side frame is bolted to it, the top is planed, and to this the steam cylinder is fixed in an inverted position, that is, the stuffing-box is inside under the top of the frame, and the piston-rod works in and out at the bottom of the cylinder; the top of the cylinder is provided with a cover for the purpose of taking out and replacing the piston without removing the cylinder. The piston and rod are made in the same way as before described, the rod is keyed to a cross-head fitted with two cast-iron guide-blocks. The slide-jacket in which the slide works has the stuffing-box and gland inverted in the same way as the cylinder; the slide-rod is made of steel, and is attached to a wrought-iron connecting rod which is keyed at the lower end to the strap of the eccentric; the eccentric is made in the same way as for the horizontal engines. At the lower part of the frame near the stuffing-box of the cylinder, guide-bars planed on their faces are provided, between these the guide-blocks slide. At the centre of the cross-head, a connecting rod of wrought iron is attached; this rod is made in the same way as before described, it has eyes bored out at each end, these are lined with gun-metal and fitted with keys to adjust the same, or they may be made with strap ends and fitted with gun-metal bearings and adjustable gibs and keys; the rod works on to the steel crank-pin which is fitted to the crank or disc, this is keyed on a wrought-iron crank-shaft. The main bearing is cast upon the bed-plate; it is lined with gun-metal, and provided with a cap secured by bolts, the other end of the shaft runs in a bearing fixed in a cast-iron box built in the wall. The fly-wheel and driving pulley are keyed on the crank-shaft *outside* the bed-plate. The governors are either placed on top of the cylinder or on a bracket connected with the vertical frame, but in the case of high-speed governors they are attached direct to the throttle and starting valve. The crank-shaft, as in the former case, is close to the foundations; and although from this cause they work with but little vibration, they are not quite so steady as the other types described, as they are not so well balanced in the working parts from the piston to the crank. One objection to this form of engine is, the cylinders being inverted, the packings at the glands are rather more difficult to keep steam tight; they are also not quite so accessible in all their parts for repairs, and although in some cases they may usefully be employed, they are not to be recommended for such general use as the others described. The pressure of steam and the speed of working may be the same as in the last engine; as a general rule, these engines work more satisfactorily when the piston speed does not exceed 250 to 300 feet per minute. The foundations should be very solid, and the holding-down bolts carried well down into the brickwork.

No. 3. Table or Frame Engines (*Drawing No.* 17).—The construction of this class of engine is as follows:—

A cast-iron bed-plate A, the same as Nos. 1 and 2 engines, is bolted to the stone and brickwork foundation, the top is faced, the vertical frame B is bolted to it; a facing at the top of the bed-plate receives the cylinder, all the points of attachment being planed or turned on their faces. On the top of the frame the main bearing blocks C C are cast; these are fitted with gun-metal, and have caps secured by bolts. The steam cylinder D is vertical, and is bolted to the bed-plate at the front of the frame; the construction of the cylinder, piston and rod, with slide-jacket and slide-rod, are the same as before described. The piston-rod is keyed on to a cross-head and guide-blocks E; guide-bars F of cast iron are attached to the frame, they are planed on the faces, between these bars the guide-blocks work. The connecting rod G is made in the same way as before of wrought iron, with gun-metal bored eyes at each end, the upper end of the rod is connected to the crank-pin H, fitted in the disc or crank I, which is keyed on the wrought-iron crank-shaft J. The shaft revolves in the main blocks or bearings C C, which are cast on the top of the frames. The eccentric K for working the slide is keyed on inside the first bearing and *within* the frame. The fly-wheel L and driving pulley M are keyed on to the crank-shaft *outside* the other frame. The governor N is placed on a bridge spanning the top frame, or if a high-speed governor is used, as in the last engine, it is made and fixed in the way before described.

The advantages of this class of engine are, that it is self-contained, works very steadily, and where floor space is an object, it is perhaps one of the best types of engine to use, it can be worked at a piston speed from 250 to 300 feet per minute, and at a pressure of steam of about 40 to 50 lbs. per square inch. As in the other case, when the cylinders are above 8 inches diameter, an expansion slide is usually provided and the steam is cut off at a quarter to half of the stroke of the piston according to the work to be done. In cases where it is required to work force or pressure pumps for any special purpose, this is a convenient form of engine to adopt: the pump or pumps in this case are placed *inside* the frame, and are bolted on the bed-plate; the valve-boxes of the pumps are placed one on each side of each of the pumps, with a bonnet over each valve to give easy access in case of any stoppage, or to examine or make repairs. If a vacuum or air pump for exhausting air from any apparatus has to be worked, or a pump for forcing air into any vessel or chamber, the pump may be fixed on to the bed-plate and worked by a large eccentric, or a double crank may be forged on the crank-shaft: the connecting rods are made in the same manner as before. The air-pump in this case is usually made with a trunk, or a kind of hollow piston-rod, the internal diameter of the trunk is made of sufficient size to allow the rod to which it is attached to clear when working; the connecting rod working within the trunk has an eye in the end bored out, it is attached to the bottom part of the trunk by means of a pin; by this plan no guides are required to keep the piston-rod vertical when working. The trunk causes a loss of power on one side of the piston by the diminished area; as the pumps are, however, usually made double-acting, this difference between the two sides of the piston is not much felt.

No. 4. Entablature Engines.—These engines are made in much the same way as before, except that in place of the side frames four round hollow columns are bolted to the bed-plate; when they are used to work several pumps a long entablature and six columns is used; these carry on top a cast-iron entablature or frame; passages are cast on the under side of the bed-plate, and also under the entablature, these are connected with two of the columns, the steam going up one and the exhaust down the other, thus enabling the steam and exhaust pipes to be attached to one side of the bed-plate and taken away in a trench instead of overhead. The main bearings are cast on the entablature, they are lined with gun-metal and fitted with caps secured by bolts, in these bearings the crank-shaft revolves. When several separate force or air pumps have to be worked they are fixed inside the columns and bolted to the bed-plate, and are worked by eccentrics keyed on the crank-shaft; one or more air-pumps may be fixed if desired between the columns, and worked with eccentrics or by double cranks forged on the crank-shaft. In some cases these engines have double cylinders, one being placed on either side of the entablature; the fly-wheel in this case may be small in diameter, rather light, and keyed on between the columns inside the entablature, or the crank-shaft may be prolonged on one side, having a double crank forged on; the outer end of the shaft being carried in a bearing fixed to a wall box built in the wall of the engine-house. The general details of this engine do not differ much from the A-frame engine, the purpose for which the engine is required will decide the general arrangement.

There are several modifications of this type of engine, but they are not material, and the plan of working is the same in all; engines of this kind are very suitable where any large number of force or air pumps have to be worked, because the top entablature and lower bed-plates can be made to any required length; a centre bearing for the crank-shaft is usually introduced in these cases to ensure rigidity and freedom from vibration.

NOTE.—These and other forms of vertical engines are easily made into condensing engines by adding an air-pump and a condenser, the pump being worked by an eccentric; the position of the air-pump and condenser with regard to the cylinder is not material, it can be varied to suit special cases.

Engines of this kind adapted to work two or more force-pumps and air-pumps outside the entablatures are suitable for work in sugar-houses of moderate size, the air-pumps in these cases are used to form a vacuum in the boiling pan, and the pumps for forcing the fine sugar liquor up to the store tanks which are placed at the top of the house. In large sugar-houses, beam engines have mostly been used for these purposes, working two large air-pumps and four or more force-pumps. This class of engine admits of several other modifications to suit special purposes; sufficient detail has been given to enable the reader to adapt it to the particular purpose for which the engine may be required.

Trunk Engines have been made in the vertical as well as the horizontal form, but as they are now seldom used, a detailed description does not seem essential; the friction in this kind of engine is much higher than the types above described, especially in the small sizes when run at a high speed; their general form and the points in which they differ from other kinds of engines are described under the head of Marine Horizontal Engines. No guides are required, the height of the engine is reduced in the case of vertical engines because the connecting rod works *within* the trunk at the lower end, the other being attached direct to the crank-pin; when only one cylinder and trunk are used, the weight of the trunk and piston must be properly balanced, the same as an ordinary piston with its connecting rod would be.

Vertical Condensing Engines.—These engines are usually made with A frames or an entablature in the same form as Nos. 3 and 4, described at pp. 58 and 59. *Drawing No.* 18 shows a pair of engines made by Messrs. George Waller & Co., London, to whom the author is indebted for the drawing. The bed-plate, A frames or entablature, the crank-shaft, and fly-wheel are the same as before, but instead of a high-pressure cylinder a low-pressure one of a larger size is fixed. A condenser made in the same manner as described for the beam engines is placed under the steam cylinder, into this the exhaust steam from the cylinder is discharged; a cold-water "injection" is used as before to condense the steam as it enters the condenser from the cylinder. An air-pump fitted with a cover having a stuffing-box and gland, and provided with suction and delivery valves, is worked off the crank-shaft by a double crank forged on the shaft; the air-pump is usually partly sunk in the bed-plate, level, or nearly so, with the top cover; the construction of the pump is similar in other respects to the one previously described at p. 33; at the top of the air-pump cover two cast-iron guide-bars are fixed; these are planed on their faces. A wrought-iron cross-head is keyed to the pump-rod, and at each end cast-iron guide-blocks are attached, these blocks slide between the two guide-bars; a wrought-iron connecting rod made in the same way as before, with eyes at each end bored out, works on the cross-head at one end and on to the pin of the double crank at the other. The governors, throttle-valve, and other parts are the same as in the high-pressure vertical engines. The condenser is sometimes formed in the lower part of the bed-plate, being part of the same casting.

The action of these engines is the same as in the condensing beam engines, the speed and pressure of steam are also the same, they are somewhat less costly in manufacture when compared with beam engines, and in many cases are suitable for working mills and other machinery, they are portable, and being self-contained can be readily fixed without much expense and trouble. The engine-houses required are of smaller size than in the case of horizontal engines, and in this way some economy is effected; the space at command will usually determine the kind of engine to be used. These engines give very good results in working, they wear very well, and are free from complication; a pair of them have been working for many years, the author is informed they still compare very favourably with more modern engines; the main features of this engine represent modern practice, except the governors, which are now made in the form of high-speed governors. Vertical condensing engines admit of considerable modification of their parts, but the system of working does not much differ in any.

Vertical Compound Engines.—The main parts of these engines are the same as above, except that two cylinders are used, one for high pressure and one for low pressure. The cylinders are fixed at the front of the A frames or entablature; they are inclined at an angle of 60°, and by means of connecting rods work on to *one* crank-pin; at the crank end one of the connecting rods is made with a single end, and one with a double or fork end. The crank-pin is made longer to take the *two* rods, or the cylinders may be fixed one on either side of the side frames, with separate connecting rod working on to a crank fixed at each end of the crank-shaft. The main steam supply is at the jacket of the high-pressure cylinder, the steam is discharged from it into the low-pressure cylinder, and the exhaust steam from this goes into the condenser, the vapour is removed by the air-pump; these are arranged as before described at p. 61. In some cases the high-pressure and low-pressure cylinders are fixed inside the side frame, and are worked by two double cranks; the air-pump in this case is fixed *outside* the A frames, and in the same place as the steam cylinders in the former kind. The way of working is precisely the same as in the case of compound beam engines, and the economy effected as to the consumption of fuel in the boilers per indicated horse-power is also about the same.

There are several modifications of this form of engine, but the general principle is the same in all. They are only suitable for pumping water or driving mills and machinery where the work is regular, the speed of working and the pressure of steam used are the same as in the compound beam engines; the cylinders are steam-jacketed, and clothed on the exterior with felt and mahogany staves bound with brass bands. The foundations are made solid to ensure very steady working and absolute freedom from vibration.

Drawing No. 19 is a good example of a Vertical Compound Engine adapted for mill purposes; it is manufactured by Messrs. Simpson & Co., of Pimlico, to whom the author is indebted for the drawing. In this design, the cylinders are fixed outside the side frames, the high-pressure at one end and the low-pressure at the other end of the bed-plate; a massive cast-iron bed-plate carries all the engine, to which the several parts are securely bolted; the side frames are planed at the feet and rest upon corresponding planed surfaces on the bed-plate, they are well strutted together. The steam cylinders are each sunk below the bed-plate; the guide-bars are bolted to the cover and to the side frames; the pistons and connecting rods are of the usual type; the piston-rods are keyed to wrought-iron cross-heads having cast-iron sliding blocks attached, these work between the faces of the guide-bars. The cranks are of wrought iron, and are shrunk on to the wrought-iron crank-shaft, this runs in bearings formed in the side frames, they are lined with gun-metal and have caps bolted on. The fly-wheel, which also acts as the driving wheel, is keyed on the crank-shaft *between* the two side frames; it is made smaller in diameter than in other kinds of engines, but the rim is made much heavier. The steam first passes into the high-pressure cylinder, and is discharged into the central receiver, from this it passes into the low-pressure cylinder; from the low-pressure cylinder the exhaust steam passes into the condenser, which is placed below the bed-plate, and after it has been condensed by the "injection" water, it is pumped away by the air-pump; this is made in much the same way as those described for the beam engines. A governor is fixed on the bed-plate near the low-pressure cylinder, it is connected to the throttle-valve by levers and rods.

This is a very compact form of engine, and may be used for mill or for pumping purposes. The foundations are rather more expensive than in the case of horizontal engines, but much floor space is saved; the engines work very steadily and are free from vibration, the economy in the consumption of steam is as good as with the horizontal engines of this type, which the author finds from his experience to be the best for most purposes where a very low consumption of coal is desired. The consumption of steam in these engines has never exceeded 15 lbs. per horse-power per hour.

CHAPTER IX.

SPECIAL ENGINES FOR PARTICULAR PURPOSES.

An outline is hereafter given of engines designed and adapted for special purposes, viz.:—Air-blowing Engines, Winding Engines for mines, Ventilating Engines for mines, Air-compressing Engines, and Pumping Engines for water. In all these cases the engines are constructed and adapted for their special purposes, and differ in certain details from the ordinary mill engines already described; they are made both in the horizontal and vertical forms, and on the high-pressure or non-condensing, condensing, and compound systems. It would take up too much space to describe each kind, and as the vertical and horizontal types are less complicated and more generally used for the purposes named than beam engines, a description of one for each special purpose named above will be given.

Air-blowing Engines.

Vertical Engines of large sizes are constructed with inverted cylinders fixed upon powerful A frames or on entablatures and columns; they are usually made in the form of coupled engines. The dimensions of a large engine of this kind are:— Steam cylinders 47 inches diameter × 5 feet stroke; the blowing or air-pump cylinders 100 inches diameter × 5 feet stroke, they are fixed directly below the steam cylinders and rest upon the A frames, to which they are bolted; the steam cylinders are fitted with pistons made in the usual way, the piston-rods pass through stuffing-boxes and glands at the bottom of the cylinders direct to the pistons of the blowing cylinders; stuffing-boxes and glands are provided at each end of the cylinders. The piston-rods on the lower side are attached to wrought-iron cross-heads having cast-iron guide-blocks keyed on at each end; these blocks slide in guide-bars fixed to the lower frame of the engines. A connecting rod works on to the cross-heads at one end, and on to the crank-pin at the other end. The crank-shaft revolves in bearing blocks cast on the bed-plate, a fly-wheel is keyed on the crank-shaft at the centre between the two engines. The blowing cylinders are made double-acting, and are provided with valves at each of the covers; the valves have leather flaps, the inlet valves are placed in the covers, and the outlet valves on the sides; the cylinders are encased in air-tight boxes or outer cylinders, these are usually made of wrought iron; into these casings the air is discharged. The supply pipe to the furnaces is taken direct from the jackets, the pressure of the blast is from 4 to 5 lbs. per square inch. The valves of the cylinders are made circular, and are worked by eccentrics on the crank-shaft. These are very powerful engines, and are used to supply the blast to furnaces or to smiths' forges; engines on the same plan are also made, but smaller in dimensions, suitable for other kinds of work where air-blast is required.

Horizontal Engines (*Drawing No.* 20).—These engines are constructed in the same way as the horizontal engines described at pp. 44 to 49, as far as the general parts of the engine are concerned; they are made with double cylinders and are coupled; they work on to one crank-shaft, to which one fly-wheel is keyed. The leading dimensions of the engines shown are as follows:—The two steam cylinders are 40 inches diameter × 5 feet stroke; the covers at each end are fitted with stuffing-boxes and glands; the pistons are fitted with piston-rods at each side, one end being attached to the cross-heads and guide-blocks at the crank-shaft end, and the other or back end connected direct to the blowing cylinders; these are 54 inches diameter × 5 feet stroke, the guide-blocks slide upon raised surfaces on the bed-plates. Connecting rods of wrought iron with forked ends work on the cross-heads at one end, and at the other on to the pins of the crank discs, which are keyed on at each end of the crank-shaft. The crank-shaft is common to the two engines; the fly-wheel is keyed on in the centre; the eccentrics for working the valves of the steam cylinders are also keyed on the shaft. The blowing cylinders are fixed behind the steam cylinders, the piston-rods are connected by couplings, to which slipper guide-blocks are attached, these slide in guides cast on the bed-plates; the admission and expulsion of air from the blowing cylinders is regulated by piston-valves placed on top of the cylinders. The steam cylinders are fitted with equilibrium lifting valves, both for steam and exhaust; they are worked by cams from a lay shaft driven by mitre-wheels from the crank-shaft. Each engine is carried on a separate bed-plate of the "box" section, which is bolted to a massive stone and brick foundation; they are very powerful machines, and are made in various sizes, slightly differing in details according to the work to be done.

Beam Engines.—This class of engines is also used for air-blowing: they are made either on the high-pressure or non-condensing, condensing, or compound systems; the details of the engines do not much differ from those described at pp. 27 and 32; the blowing cylinders are usually attached at the crank ends of the beam at half stroke, one being placed at each side of the main centre on the beam. The construction of the blowing cylinders does not much differ from those described above, except in the arrangement of the valves; when the engines are made in the beam form, they are mostly used for supplying the blast for smelting furnaces or forges; in the large ironworks they are made of considerable size, the blowing cylinders exceeding in some cases 100 inches diameter. Except in large places the beam form is not suitable, the engines are more costly in construction, the foundations and engine-houses are also more expensive than those required for the vertical or horizontal types.

Horizontal Hauling and Winding Engines.

These engines are for the purpose of winding up the cages or trucks from coal or iron-stone mines, or for hauling trucks up inclines, either in coal pits or in ironworks or places of like kind. A large pair of this type of engine will now be described; they do not much differ from ordinary high-pressure horizontal engines; there are two steam cylinders, 36 inches diameter × 6 feet stroke; the cylinder valves may either be made double-beat of the Cornish kind or ordinary slide-valves with expansion valves working on their backs. Two eccentrics are provided to each cylinder, they are fitted with link motion to permit the engines running either way. The winding drums are sometimes made conical in shape, and from 18 to 30 feet in diameter; they make about 22 revolutions for each winding, the depth of which (in one case) is about 638 yards; the speed of working is 55 seconds, or at the rate of about 24 miles per hour. No fly-wheels are required in these engines, nor any governors to control the admission of steam. Two cylinders work on one crank-shaft, to which the winding drum is attached, the cranks being set at right angles; the engines can be started at any point of the stroke, as they are never on the dead centre.

Drawing No. 21.—For small depths these engines are made with a plain drum, the rim of which is wood, it is bolted to two or more large iron wheels, keyed direct on the crank-shaft; brake-wheels and brakes are seldom used, the raising, lowering, and stopping is done by the slide-valves according to the position in which they are placed by the link motion, this is worked by two eccentrics to each cylinder, the eccentrics being keyed on the crank-shaft. They can also be worked by a centre valve-box with three ports and slide-valve and a single eccentric to each cylinder; by means of this central slide-valve the steam can be put on either side of the pistons according to the direction in which it is desired to run the engines and the winding drum. They are worked at a rather rapid speed and with a high pressure of steam; the details of the other parts of the engines do not differ from ordinary horizontal coupled engines; the drawing is in full detail.

Beam Engines are also used for winding purposes; the cylinder, bed-plate, and beam, with the other working parts, are the same as an ordinary beam engine; they are worked either as non-condensing, condensing, or compound engines. In the Colliery districts the main centre for the beam is usually fixed on the side wall of the engine-house, the crank end of the beam works *outside* the house, the crank-shaft revolves in bearing blocks carried on brick piers, the winding drum is constructed as before, and keyed direct on the crank-shaft. The ropes used are made of iron or steel wire, the grooved pulleys over which they pass from the winding drum are made of large diameter, the grooved rims and the centre bosses are cast iron, the arms are made of wrought iron. These engines are generally made with single cylinders, the eccentric rods are fitted with a gab end, as described at p. 28, and by means of a hand lever on the weight shaft working the slide, steam can be put either on one side or the other of the piston, and the engine run in either direction required.

In all these winding engines, the coal or other materials are raised from the mines in tubs or buckets made of wood or iron, and in the case of deep mines, a cage of wrought iron powerfully framed together is employed; the coal, &c., in this case are raised in trucks or wagons, one or two at the time; the cage runs on guides of timber fixed on each side of the shaft; they are carried down the whole depth. Safety catches are fitted to the top of the cages to hold them securely in the event of the ropes breaking. The depth of these mines is considerable, in some cases as much as 650 yards.

Ventilating Engines.

These do not require any special description; they are either horizontal, vertical, or of the beam kind; they either work large air-pumps, much the same in construction as in the case of the blowing engines, or in some cases a fan of large diameter and special construction is used. The sizes of these engines vary very much according to the work to be done, and the special circumstances of the case; they are principally used for mines and underground workings, and are only noticed here as forming a type of engine for a special purpose. The beam engine is the most usual form for mining purposes; they are either worked in pairs, or as single engines.

Air-compressing Engines.

Drawing No. 22.—These engines are a very special kind, and are principally used for the purpose of compressing air for the driving power of underground machines, and for tunnelling work; a pressure of 60 lbs. per square inch is in some cases obtained. Great care has to be used in making the joints of the pipes and valves, also as to the attachments to the various machines, as the compressed air leaks out very quickly and the pressure is thus very rapidly reduced. There are many forms of these engines, they are made vertical and horizontal, and on the non-condensing, condensing, and compound systems; the horizontal form is principally used; the engines in this case consist of bed-plates, cylinders, connecting rods, cranks, and shaft; these are constructed upon the same plan as the ordinary horizontal engines described at pp. 44 to 49. There are usually two steam cylinders, they are made with piston-rods working out at the back ends of the cylinders; these are attached direct to the pump-rods of the compressing cylinders, which are fixed at the back of the steam cylinders. These compressing pumps are made double-acting, with several valves in the covers at each end of the pump; the pumps are surrounded with water to keep them cool. The compressed air is discharged into a wrought-iron reservoir or chamber fitted with valves and pipes, through which the compressed air is conducted to the various machines, in the same way as with steam. The inlet valves are of the clack kind and made of leather, there are three to each cover; the outlet valves are gun-metal and of the spindle kind, there are two to each cover.

The following are the dimensions of the pair of engines shown in the drawing; they are made by Messrs. Fowler & Co., Leeds:—Two steam cylinders, 34 inches diameter × 6 feet stroke; and two air cylinders, 40 inches diameter × 6 feet stroke. The pressure of steam used is 40 lbs. per square inch; the pressure of air is 40 lbs. per square inch. The valve motion is of the Cornish kind. The speed of the pistons is 240 feet per minute, and the indicated horse-power = 482. The air receiver is wrought iron, 5 feet diameter × 30 feet long. The useful effect at 40 lbs. per square inch pressure of air is 25·8 per cent., and with 19 lbs. per square inch pressure = 45·8 per cent. It will be noted that the higher the pressure of the air per square inch, the less useful effect is produced; it is therefore more economical to work at rather a low pressure, say at an average of 20 lbs. per square inch.

Sturgeon's Patent Air-compressing Engines.—These engines are high-pressure horizontal single-cylinder; they are of a special kind, and are very effective machines; the air cylinders are placed in this case between the crank-shaft and the steam cylinders; all the parts are attached to a bed-plate; the air-pumps are made on the trunk plan, and are surrounded with a casing filled with water to keep them cool. The valves are of a peculiar kind and are kept to their faces by spiral springs; the inlet valves are at the bottom of the trunks; the delivery valves are in the bottom of the cylinders; they have white metal faces, and are kept up to their seats by spiral springs. The trunks are coupled by cross-heads and connecting rods to the piston-rod of the steam cylinder; one pump takes the air and the other compresses the charge. Any one requiring more information upon this subject is referred to the author's book on 'Pumps and Pumping Machinery' (E. & F. N. Spon).

Water Pumping Engines.

Engines specially constructed for this purpose are made in various forms, both horizontal, vertical, and "beam," and on the non-condensing, condensing, and compound systems; the latter is now most usually adopted in the case of large waterworks or for sewage works. Cornish engines, both Vertical direct-acting, and of the Beam kind, are specially used for this purpose, and particularly when the work to be done is large; they have been described at p. 38. Davey's Patent Engines are also very useful, they are very economical in action, and possess many advantages in working. Any one wishing to read a detailed description of these engines, and their working results, should refer to the book before named; the engines are of a special construction, and are different in form and also in the manner of working to ordinary pumping engines.

Compound Beam Engines (*Drawing No.* 23).—These are made in the same way as an ordinary beam engine, except that a water-pump is worked by the beam at or near the crank end; the pumps are made double-acting, of the bucket and plunger kind; the valves are "double or treble beat" and made of gun-metal. In the case of large engines, they are usually worked in pairs, the cylinders in some instances being placed side by side, or the high-pressure cylinder is worked by one beam and the low-pressure cylinder by the other; one crank-shaft only is required and one fly-wheel.

The following dimensions of a pair of large Beam engines of this kind made by Messrs. Simpson & Co., will enable the reader to form an idea of their proportions:—High-pressure cylinders 28 inches diameter × 5 feet 6 inches stroke; low-pressure cylinders 46 inches diameter × 8 feet stroke. One water-pump to each engine 23½ inches diameter × 6 feet 11 inches stroke. The fly-wheel is 21 feet diameter and the weight = 13 tons. The beams are 26 feet 6 inches long centre to centre, and 5 feet deep at the main bearing. The crank-shaft is 16½ inches diameter. The air-pumps are 30 inches diameter × 3 feet ⅝ inch stroke; they are worked off the beam on the same side as the steam cylinders; the condensers are below the floor-line. The pressure of steam used = 40 lbs. per square inch. The coal used per indicated horse-power per hour = 1·61 lb. The water is pumped through a 30-inch diameter main 10½ miles long, under a "head" of 200 feet, the speed of the crank being 14 revolutions per minute. These are most useful and effective engines, they are very economical as to the fuel consumed, they work steadily and at a uniform speed, and give the highest results in the amount of work performed in proportion to the fuel used per indicated horse-power of the engine. All parts are most carefully proportioned, well balanced, and the strains equalised as much as possible on all the working parts. This is a matter of great importance in the construction of engines for pumping water, in order to ensure regular and even performance, and also as a precaution against accidents to the moving parts caused by unequal strains.

Horizontal Compound Engines.—Horizontal engines for water-pumping are also constructed on the non-condensing, condensing, and compound systems. In the compound engines they are coupled and are made in the same way as described on p. 50, except that the water-pumps are fixed at the back of the cylinders, and are worked direct off the piston-rods, which are fitted with guide-blocks and rub on planed surfaces on the bed-plates. The pumps are double-acting and of the bucket and plunger kind. The air-pumps are placed at the crank end of the bed-plate and are worked off the cross-heads of the cylinders. The engines have one crank-shaft and one fly-wheel. The high-pressure cylinder is fixed on one bed-plate and the low-pressure cylinder upon the other. The circulating or feed pump is worked off the cross-head of one engine and the air-pump off the other, a steam receiver is placed between the two bed-plates both of the cylinders are fitted with expansion slide-gear.

The following dimensions of a pair of engines of this kind, by Messrs. Simpson & Co., will give an idea of their proportions:—High-pressure cylinder, 30 inches diameter × 4 feet stroke; low-pressure cylinder, 54 inches diameter × 4 feet stroke. Air-pump, 13 inches diameter × 4 feet stroke. Water-pump, 15¼ inches diameter × 4 feet stroke. Fly-wheel, 17 feet diameter. Crank-shaft, 12½ inches diameter. The cylinders are steam-jacketed and lagged with mahogany.

The above outline of the principal forms of engines used for pumping purposes will give the reader a good general idea of the subject; the author has described engines of a large type, thinking it would be more useful and interesting; this subject is very fully treated in the more advanced book by the author, already named; a description of engines for water-pumping is sufficient to form a book itself, it would not be possible to go further into detail in a book of this kind.

CHAPTER X.

PORTABLE ENGINES AND BOILERS, TRACTION ENGINES, ETC.

Portable Engines.—These are principally used for agricultural purposes, and for driving pumps and other machines for temporary works; they are drawn by horse-power from place to place, no fixing is required, the weight of the engine and boiler is sufficient to keep them steady when working. One of a modern type will now be described to give an idea of the general construction of this class of engines.

Boilers.—These being the most essential part of the machine, will be described first; they are made in much the same way as the multitubular boilers described at p. 14; they have a fire-box with semicircular top and vertical sides; the shell of the boiler is either riveted by means of angle iron to the fire-box or attached by a solid flange, and within about 15 inches of the other end of the shell a tube-plate is riveted; at the end of the shell plates an end plate is riveted on; a door is provided in this to allow the tubes to be cleaned. The space between the end plate and the tube-plate forms a smoke-box, and at the top of the shell at this part a smoke-pipe or funnel is provided, this funnel is jointed near the top of the smoke-box, and at the top has a plate riveted on, leaving space for the smoke to pass out, this plate is for the purpose of arresting the sparks from the fire; when working in farmyards, this is a necessity to prevent accidents. A large number of small wrought-iron tubes are riveted at either end to the tube-plates; the fire-box is well stayed to the outer casing by long bolts passing from the front plate of the fire-box to the end tube-plate in the smoke-box, the top of the fire-box is also well stayed; a steam dome is sometimes fixed on top of it; the furnace bars are fitted inside the fire-box, with door and frame as before. The water inside the boiler surrounds the fire-box on all sides, also the small tubes in the shell of the boiler. A man-hole is made in the shell at the smoke-box end, with cover, &c., as for other boilers; one is also made at the fire-box; two mud-hole doors are provided at this end to clean out the boiler. A wrought-iron pan is attached under the fire-box to receive the cinders and ashes. The fittings consist of a safety valve fitted with a spring balance instead of a counterbalance weight, a steam valve is also fitted near the cylinder, one or two sets of glass water-gauges, and two gauge-cocks are fixed at the furnace end of the boiler; an injector is fixed at this end clear of the fire-door; one feed-valve and back-pressure valve, and one blow-off cock are also provided; a steam whistle is usually supplied to act as a signal for various purposes.

The boiler is either mounted on a wrought-iron frame and wheels, or the axles are attached direct to the shell of the boiler, the front carriage being made to swivel in the same manner as a wagon, a powerful skid for the wheels is provided, the shafts are made to unship when the engine is at work, and an extra length of smoke funnel is then added to increase the draught of the furnace. A feed-water heater is in some cases provided, this consists of a cylinder fitted with a large number of small tubes; the exhaust steam is passed through the heater on its way to the smoke funnel, and in its passage heats the water which is drawn through the heater by means of the pump attached to the engine. The boiler is covered with two layers of hair felt, and is then encased with sheet iron secured by iron hoops. The pressure of steam used is about 40 to 50 lbs. per square inch. The fire-box of the boiler is made of Low Moor iron, the shell and other parts of best Staffordshire or Yorkshire iron.

The engine is fixed on top of the boiler, and consists of a steam cylinder, the size varying with the horse-power; the exterior of the cylinder has a steam jacket, it is fitted with a piston and rod, slide-valves and rods, and is made in the same way as before described for the horizontal fixed engines; on the cylinder cover two guide-bars planed on their surface are bolted, and at the other end they are attached to an oval bracket connected to the upper and lower guide-bars; the bracket has a foot cast on, and is bolted at this part to the side of the boiler. A guide-block of cast iron works between the guide-bars, this block is cast hollow, and is fitted with a pin, to which one end of a wrought-iron connecting rod is attached; the other end of the rod works on to the double crank forged on the crank-shaft; in some cases two sets of guide-bars are fitted to the cylinder, and the connecting rod works between the bars. Two cast-iron brackets are bolted to the boiler at the smoke-box end, these brackets are fitted with bearings lined with gun-metal, and in these the crank-shaft revolves. A fly-wheel is keyed on one side of the shaft outside the bearing, and if required a pulley is keyed on the other side to take the driving strap; in some cases where a high speed is essential, the strap is put on the rim of the fly-wheel and the machinery driven direct. The two eccentrics for working the slide are keyed on the crank-shaft, they are attached to the slide-rods by connecting rods and pins as before described. A governor is fixed near the slide-jacket of the cylinder; this by means of a throttle-valve controls the speed of the engine according to the varying load or work upon it. A feed-pump is worked by the slide-block pin, or by an eccentric off one end of the crank-shaft; the pump-barrel is bolted to the boiler, and is fitted with suction and delivery valves, the water is drawn from a temporary cistern placed on the ground, this is supplied from any convenient water-pipe; when the engine is likely to be wanted in one place for any period, a small iron tank fitted with ball-valves is used. In some instances for large engines there are two steam cylinders, each fitted with piston, slide and connecting rods, and with guide-bars and guides the same as before, the connecting rods work on to separate double cranks set at right angles, forged on the crank-shaft; double-cylinder engines work more steadily than those made with single cylinders, they can be started at any point of the stroke.

The other details do not differ from the engine above described; the cylinders and steam pipes are covered with non-conducting material, and with sheet iron outside this is secured with iron bands; the engines are usually worked expansively, in the same way as ordinary horizontal engines; the cylinders and slide-jackets are fitted with condense cocks and pipes, to keep them free from condensed steam. There are various modifications of the details, according to the ideas of the makers, but essentially they do not much differ from the above description; the engines are worked at a higher speed than fixed engines, they are made strong to withstand the shocks and strains to which they are subjected, especially when being moved from one place to another on rough country roads.

This class of engine is principally used for agricultural purposes, or in any case where temporary power is required at a particular spot; they are also used for driving pumps during excavation for foundations, for pile-driving, for driving mortar mills, circular saws, stone-sawing machinery, and kindred purposes, in the same manner as the vertical kind described below.

Drawing No. 24.—This shows an 8 horse-power engine, made by Messrs. Clayton & Shuttleworth, of Lincoln, to whom the author is indebted for the drawing and dimensions; it may be taken as one of the best types of this class of engine, and being of medium size will illustrate the general form and proportions according to the practice of the most skilful makers in this department of manufacture; it will be noticed that the general details do not materially differ from the description given before. The cylinder is 10 inches diameter × 12 inches stroke; it is steam-jacketed and lagged on the outside. Crank-shaft, 3¼ inches diameter, the bearings 3¼ inches diameter × 5¼ inches long; crank-pin, 3¼ inches diameter × 4 inches long; fly-wheel, 5 feet diameter; speed of crank-shaft, 120 revolutions per minute. Boiler-shell, 2 feet 9 inches diameter × 6 feet 3 inches long; fire-box casing, 2 feet 9 inches wide × 3 feet 3 inches × 4 feet high; the internal fire-box is 2 feet 3 inches × 2 feet 8 inches × 2 feet 9 inches high; it is stayed to the outer casing by 24 stays; the top or crown of the box is stayed by four powerful bridge stays. There are thirty tubes of wrought iron 2 inches diameter. Seven long bolts pass through from the front plate at the fire-box end, to the tube-plate of smoke-box end. The boiler is lagged with sheet iron, and secured by iron hoops. The heating surface is 165·23 square feet. The wheels on which the engine runs have wrought-iron spokes and cast-iron tyres and bosses.

Portable Engines with Vertical Boilers.

When made in this form the boilers are bolted at their base to a wrought-iron frame, which is carried on four wheels as before; the engine in this case is usually made with an inverted cylinder bolted to a frame, the crank-shaft being carried in bearings fixed near the boiler frame; the boilers are made in the same forms as described for vertical boilers at pp. 18 to 21; the exterior of the boilers is covered with felt and lagged with wood or sheet-iron, and the furnace work and safety-fittings are of the same kind as before described. The engines are sometimes fixed horizontally on the boiler frames; in this case the frame is made rather longer; when made in this way, they work more steadily; double cylinders are used in each case, and are to be preferred to single cylinders, as they can be started at any point of the stroke; when used for hoisting engines, this is essential. They are a very convenient form of engine, being light, portable, and easily set to work, and as they are self-contained, they can be put into a barge for use when pile-driving, coal-whipping, driving pumps at cofferdams, for dock work, and for clearing excavations of water during the progress of tidal and other works. There are several forms of these portable vertical boilers and engines, some being adapted to special purposes, but the general principles as to working and the engine details do not materially differ.

Portable Steam Pumping Engines (*Drawing No.* 25).—These engines are made by Messrs. G. Waller & Co., of Southwark, S.E., to whom the author is indebted for the drawing; they have been successfully used for heavy pumping works for about forty years. They are constructed in much the same way as named at p. 71 for the portable engines, with the following additions:—At the smoke-box end, three lift-pumps, fixed on a cast-iron frame, are attached to the main boiler frame, which in these engines is prolonged for the purpose; the pumps are fitted with buckets and rods, and have separate suction and delivery valve boxes bolted on; each pump has a separate valve chamber both in the suction and delivery; the valves are made either of leather or indiarubber, and in some cases gun-metal clacks are used. The machinery for working the pumps consists of two large side frames fixed to the boiler frame, one on each side; they are fitted with two bearings each, one for the crank-shaft, and one for the three-throw pump crank-shaft. The engine crank-shaft has a spur toothed pinion keyed on; this works a spur-wheel, which is keyed on to the treble crank-shaft which works the pumps, and motion is thus transmitted;

the wheels are proportioned in diameter to give a speed of about thirty to forty strokes per minute for the pumps; the side frames are well stayed together, and are strongly braced at the pump end to keep them rigid. The suction pipes are flanged and bolted on in 9-feet lengths as required, the pumps will draw from a depth of 25 to 26 feet below the suction valves; the *horizontal length* of the suction or delivery pipes is not taken into account, except that an addition must be made to the power, equal to an extra lift of 12 feet per mile of the delivery main, this allows for friction in the pipes at the bends, valves, &c. In cases where it is required to pump from greater depths, the pump end of the engine is placed directly over the spot, the pumps are removed from the boiler frame, and are lowered by sling rods as required, according to the depth to be pumped from.

These engines can be set to work in a very short time, and in cases of emergency are most useful machines, no other kind of steam pumps will throw the same quantity of water; the size of the engines is proportioned to the pumps. The following gives the sizes of these engines and the quantity of water pumped by them under a low head:—

No. 1.	4 horse-power (nominal),	Three	7-inch diameter pumps	=	10,000 galls. per hour.
„ 2.	6 „	„	9 „ „	=	20,000 „
„ 3.	10 „	„	12 „ „	=	40,000 „

The water can be drawn 25 feet below the suction valves of the pumps, and delivered 10 feet above the pumps; when the lift is higher than this, a less quantity of water is raised; it may be noted, that when pumping from excavations the water is usually delivered at about the level on which the engine stands.

The pressure of steam used in the engines is from 40 to 50 lbs. per square inch. The engines drive the pumps direct, without the aid of straps or other gear; they are on this account the most suitable kind of pumps for outdoor work, and from the facility with which they can be removed from place to place, being self-contained, are to be recommended in the case of temporary pumping of any kind when the head or pressure is not great.

Steam Fire Pumping Engines.

These engines are of a special kind, and are almost beyond the province of this work to describe in detail; they were first introduced by the late Mr. Braithwaite, C.E., about thirty-five years ago, but have of late years been improved and brought to a great state of perfection. They are made as light as possible, considering the heavy work they have to perform, and the shocks to which they are subjected in passing rapidly through the streets and roads to fires.

They are constructed in the following manner:—The boilers are vertical, and are usually fitted with small tubes as described for the vertical boilers at pp. 18 to 21; the shells and fire-boxes, &c., are made of steel; the furnace and the other fittings do not much differ from ordinary vertical boilers. There are two steam cylinders, which are placed either in a vertical or horizontal position, the latter is the best form; the cylinders work direct on to the pumps; the best kind are made with a crank and connecting rod, with eccentrics to work the slide-valves. The pumps are double-acting, of the bucket and plunger kind, the barrels of the pumps are gun-metal, they are provided with copper air-vessels. A feed-pump worked by the steam cylinder or a Gifford's injector is used to supply the boiler with water. The fittings of the boilers are much the same as those used for portable engines. An engine with a cylinder 7 inches diameter × 7 inches stroke, gives 30 indicated horse-power, and will throw 350 gallons of water per minute 160 feet through a $1\frac{1}{16}$-inch diameter "jet." Steam can be raised from cold water to 100 lbs. per square inch in seven to eight minutes. The boiler and engine are fixed to a frame of wrought iron, which is hung on four wheels; the two front ones swivel in the same way as an ordinary carriage; the hose pipe for the pumps is carried under the driver's seat in a box. The total weight of these engines is about 28 cwt. In larger sizes they are sometimes made with three steam cylinders and three pumps, as above described, only one crank-shaft is used; when made with three steam cylinders, no fly-wheel is required. The engines are fitted with a pole at the frame or carriage, and are drawn by two horses; the steam is got up as the engine is run to the fire, very small steam room is allowed in the boilers, and as the steam is generated very rapidly, they require very great care and attention.

Steam fire-engines are also placed in boats, which are propelled by screw engines in the same manner as an ordinary steam vessel, the pumping engines do not much differ from the land engines; these floating machines are very powerful, some of them are capable of throwing 1120 gallons of water per minute about 200 feet high, through jets $1\frac{1}{16}$ inch diameter.*

Special Kinds of Portable Engines.

There are several forms of engines made for particular purposes: such as *Traction Engines* for drawing loads on common roads without the aid of tram rails; *Ploughing Engines*, specially adapted for the purpose, fitted with wire-rope drums; *Steam Road Rollers* for rolling roads, and *Travelling Steam Cranes*; an outline description of each class will now be given.

Traction Engines.—These are made in much the same way as portable engines described at p. 73, as far as the steam cylinder and most of the parts to the crank

* For details of these Steam Fire-Engines, see the author's book upon 'Pumps and Pumping Machinery' (E. & F. N. Spon).

shaft are concerned; the frames are made of wrought iron and are mounted upon four iron wheels; the back wheels are made large and very broad, and have pieces of iron riveted on the rims at an angle, these are for the purpose of getting a grip or bite upon the surface of the road; the front wheels are made in the same way, but smaller in diameter, they are fixed to a swivel carriage, motion is communicated from the engine crank-shaft to the main wheels by means of a powerful pitch chain, or by tooth-wheel gear. The front wheels are steered by a kind of chain windlass, worked by a worm and worm wheel, actuated by a rod and hand-wheel placed near the foot-plate of the boiler. The starting gear of the engine is of the usual kind; the steering gear is worked by the same man by means of the hand-wheel described above. The cylinders are fixed at the smoke-box end of the boiler, the crank-shaft being at the fire-box end, this allows the gear to be connected direct to the large driving wheels. The engines are fitted with link motion of the same kind as a railway locomotive, this allows the engine to be run backwards or forwards; sliding clutches are provided to throw out the gear to the driving wheels, and a powerful brake is also supplied. The boilers are the same kind as used for ordinary portable engines, they are attached to iron frames by powerful castings; a small coal hopper is provided, also a tank of water to supply the boiler.

One of these engines with a 10-inch diameter cylinder will draw a load of 35 to 40 tons beyond its own weight upon an ordinary level road. They are very easily worked, well under control, and are specially useful in country districts on common roads where heavy loads or machines have to be moved, this is specially the case when used for farming purposes on a large scale, as the various machines required can be moved long distances rapidly and economically. These engines are sometimes made with a crane jib at the funnel end, they can thus be made capable of raising a load of 40 to 50 cwt., special gear is in this case provided, which is rather too complicated to minutely describe.

Ploughing Engines.—These are made in the same way as the portable engines, except that a winding drum is worked by the engine; this is for the purpose of winding the wire ropes, by which means the ploughs are worked. These engines are usually fitted with self-propelling gear; they are of necessity made in a very powerful way. With the exception of the winding drum, the other details do not much differ from the ordinary portable engine, and on this account no further detail seems requisite. They have been brought to a great state of perfection, and for farming upon an extensive scale are most valuable machines; in ploughing large fields, two engines are used, the wire ropes being of great length, and the requisite gear being somewhat extensive, they are of necessity rather costly machines. They have done good service, and by their means large tracts of land in rough countries have been brought into successful cultivation; previous to the use of ploughing engines, these places were only waste and unprofitable tracts of land.

Steam Road Rollers.—These engines are made in the same way as a traction engine, except that the two front wheels are made in the form of heavy rollers; these are set in a powerful carriage, and are made to swivel. The boilers and engines are much the same kind as for ordinary portable engines. The gear to drive the engine and the steering gear is also about the same. These engines are used to roll in stones on common roads, they do the work in a most efficient way; taking into account the quality of the work done, much economy is effected as against the use of the ordinary horse-power roller, added to which the work is done not only better, but very heavy work for horses is dispensed with. They are now almost universally used for road making and repairs, and by their use an extensive road may be made in a very much shorter time than under the old system.

Portable Steam Cranes, as well as other special kinds of engines, are only as a rule used in particular cases; they are only noticed here to call attention to the fact that such apparatus are made, and that they do very useful work; this especially applies to steam cranes in a large works, they are easily moved on the railway lines from point to point; cranes of this description are described in the author's book upon 'Hydraulic and Steam Lifting Machinery' (E. & F. N. Spon), to which the reader is referred who requires more details as to construction and the work done by these machines.

CHAPTER XI.

LOCOMOTIVE OR RAILWAY ENGINES.

THERE were several attempts prior to the year 1829 to work locomotive engines on railways; the first practical working engine was introduced by George Stephenson in 1829, who may be looked upon as the inventor of the locomotive as used in the present day; the first great improvement was the multitubular boiler and the discharge of the exhaust steam into the chimney to obtain a good draught for the furnace; also the ingenious fork system for disengaging the eccentrics to enable the engine to run forward or backward, and in later years the beautiful link motion almost universally now used for the same purpose.

Trevithick was the inventor of the locomotive in 1805; George Stephenson and his son Robert may, however, be looked upon as the first to introduce it on passenger railways; they made improvements of the same value in the locomotive as James Watt did for the land or mill engine; considering the great difficulties under which they laboured, it is surprising the perfection at which they arrived in the first engines they produced and successfully worked.

The first engine practically worked was named the "Rocket" in 1829, it was tried at Liverpool, the boiler was constructed on the multitubular plan, and fitted with twenty-five 3-inch diameter copper tubes; the engine ran upon four wheels, the two front ones being the driving wheels, they were 4 feet 8½ inches diameter, and the two back or trailing wheels were 2 feet 6 inches diameter. The steam cylinders were fixed in an inclined position at the fire-box end of the boiler, the connecting rods driving the *front* wheels; the cylinders were 8 inches diameter and 16½ inches stroke. The weight of the engine loaded with water, 4 tons 5 cwt., and the tender loaded, 3 tons 4 cwt.; total, 7 tons 9 cwt. The speed attained was 35 miles in 48 minutes; the total load drawn, including the engine and tender, being 17 tons.

The locomotive named the "Planet" was built by G. and R. Stephenson in 1830, and may be considered the form of engine from which most of those of the present day, with some modifications, have been constructed; it was the first locomotive made with horizontal cylinders working cranked axles in combination with a horizontal multitubular boiler; the two steam cylinders were placed in the smoke-box under the boiler; they were 11 inches diameter × 16 inches stroke. The engine had four wheels; the two driving wheels were 5 feet diameter, and the two leading wheels 3 feet diameter. The boiler was 3 feet diameter × 6 feet 6 inches long, exclusive of the fire-box; it was fitted with 129 copper tubes $1\frac{5}{8}$ inch diameter. The weight of the engine and tender loaded was 13 tons. The engine could draw a load of 76 tons, *not* including the weight of the engine and carriages, from Liverpool to Manchester in 2 hours and 39 minutes, being equal to a speed of $15\frac{1}{2}$ miles per hour.

The engines differed in many details from those at present in use (1884) upon the various railways, but the general principle and design are much the same. It is not intended to give more than a short sketch of the first introduction of the locomotive; those wishing to enter into the history of it, are advised to consult the excellent books that have been written on the subject.

A general description of railway locomotives will now be given to enable the reader to form a good general idea of their construction and mode of working; dimensions and working particulars are also hereafter given of several good types of engines in use on the chief English railways, from which the power and speed under the circumstances detailed can be seen, and a comparative idea may be formed of the advantages of the various types of the engines in use at the present day.

Locomotive Engines.

The boilers are all made on the multitubular plan, with a fire-box at one end and a smoke-box at the other; the construction is in some respects the same as those described for the portable engines.

The boilers are made with fire-boxes either of steel or copper, the latter metal is almost universally used in England; they are powerfully stayed to the outer casing by screwed copper stays at about 4-inch centres; the joints of the shell are either made with butt joints and cover plates closely riveted, or with lap-joints; the fire-box shell or casing is attached to the body or barrel of the boiler by solid flanges, it is made semicircular at top, with vertical sides; the fire-box is formed within the outer shell, leaving a space for water all round; the back plate of the box, where the shell is riveted on, is drilled with holes, and through these holes the tubes pass and are riveted; at the smoke-box end of the shell of the boiler another tube-plate is riveted, and through holes in this plate the other ends of the tubes pass and are also riveted. The space between the back tube-plate and the end plate of the shell of the boiler forms the smoke-box, and at the top of this the funnel is attached by a flange and is riveted; at the end plate a door is provided for the purpose of cleaning out the small tubes; the furnace is contained in the fire-box, the grate-bars being the same kind as in smaller locomotive boilers already described; the bars are inclined from the fire-door to the back of the fire-box, an ash-pan is provided under the furnace.

The fittings of the boilers usually consist of a double safety-valve, gauge-cocks and glasses, steam valves, and feed and back-pressure valves; a Giffard's injector is used to feed the boiler. A steam dome is fixed on the shell of the boiler; it is usually covered on the outside with a brass casing; the exterior of the boilers is felted and covered with a thin sheet-iron casing. The frame to which the boiler is bolted is made of wrought-iron plates strongly riveted together, the boiler being attached by L iron riveted to web or gusset plates; the frames are carried on six or eight wheels, two or four of which, according to the type of engine, are the main driving wheels, to be presently described; all the wheels are flanged on one side, the tyres are made of steel, and are turned in the lathe slightly conical at the periphery; the nave and arms are wrought iron welded into the rim. In the case of outside cylinder engines, the crank is formed in the arms of the wheels; and when made with inside cylinders, the cranks are forged on the main axle, as described hereafter.

The Tender for carrying coals and water is made of wrought-iron plates riveted together, it is also attached to a wrought-iron frame; the water tank is formed all round the interior, leaving a space for coke or coals in the centre part; the size of the tender depends upon the distance the engine has to run without stopping, so as to enable it to carry the requisite amount of fuel and water for the journey. On the London and North-Western Railway but little water is carried; shallow water-troughs are placed at certain points on the line, the water is scooped up as the train passes over them; this is a patent system, this railway has the sole right of using it.

There are several types of engines, some being used for goods, slow, and local traffic, express trains, and for shunting at the stations. The steam cylinders are sometimes carried *outside* and sometimes *inside* the boiler frames; for passenger traffic the cylinders are usually preferred *inside* the frames, as they are considered to work more steadily. The engine work in all cases is fixed below the boiler, the frame for carrying the various parts being bolted to the shell of the boiler, and to the wheel frame; there are always two steam cylinders, these are sometimes steam-jacketed on the outside, and covered with felt and thin sheet-iron lagging secured by bands. The pistons, covers, bottoms, slide-jackets and slides, are made in much the same manner as for horizontal engines before described; the piston-rods are steel, and are attached to a steel cross-head and sliding block combined, this is made much longer than in the case of fixed engines; the guide-bars to each cylinder are either two or four in number, made of steel or wrought iron, planed all over, bolted at one end to the covers of the cylinder, and at the other end to a strong bracket fixed to the wheel frame and the boiler shell. The connecting rods are of steel, with gun-metal bearings and strap ends; the gibs and keys are secured by screws and nuts cross-pinned to prevent them being shaken out by oscillation when running on the road;

the other end of the connecting rods is attached to the cranks forged on the axle carrying the main driving wheels; the wheels are shrunk on the crank-shaft axle and keyed to it; these shafts are made of steel, the two double cranks being forged out of the solid; the crank-pins are made large in diameter; the crank-shaft or main axle runs in bearing boxes of gun-metal sliding in grooves formed in the main frame; the springs are attached to these bearings, to relieve the engine as much as possible from the shocks caused by the jolting on the rails. The slides of the steam cylinders are worked by steel slide-rods connected to eccentrics keyed on to the crank-shafts; there are two eccentrics to each cylinder, the rod of one eccentric is attached to one end of a link, and the other one to the other end; this is the same in the two eccentrics working the other cylinder; a sliding block works in each link, and by means of a system of levers keyed on to a short shaft, the links are raised or lowered, and the *backward* or *forward* eccentric is brought into play, that is to say, the steam is let into the cylinders at the *top* or the *bottom* of the pistons according to the position in which the slides are placed with regard to the steam ports, thus enabling the engine to run in the direction desired. A rod is attached to a lever keyed on the "link" shaft, and at the other end to a lever working on a fulcrum at the foot-plate of the engine; a quadrant rack fitted with a spring ratchet and pawl, holds the lever in any desired position; counterbalance weights are fixed to levers keyed on the link weight shaft, these are for the purpose of keeping the parts in balance in any position.

Two force-pumps are sometimes worked off the cross-head, they are fitted with gun-metal valve-boxes and ball-valves; these are used for supplying water to the boiler when the injector is not used. The forward and back wheels are not always coupled to the main axle driving wheels on which the cranks are forged, except in the case of goods engines, which differ in some respects from the one under consideration.

Most of the large engines upon the English lines are fitted with a bogie frame at the front of the engine; this consists of a strong wrought-iron frame, to which four front leading wheels are attached; it is provided with a centre-pin having longitudinal and side movement in the top frame; this is for the purpose of accommodating the long wheel base to the curves on the line. All the axles run in gun-metal bearing boxes fitted in the same way as the main axle; very strong steel springs are fitted to each axle, both at the engine and at the tender; spring buffers are fixed to the main frame in front of the engine and two at the back of the tender. Powerful automatic brakes are used, they are applied by special gear to the tyres of the wheels; there are several kinds of these brakes in use, but those worked either with compressed air or steam are the most approved; the hydraulic brakes were not a great success, the chain brakes once used on some of the lines have almost been discontinued.

The starting valve is placed at the top of the fire-box casing, and by means of this valve, steam is admitted into a pipe having a junction-piece and branch to each of the cylinders; before opening the valve, at starting, the condense cocks in the cylinders are opened by a lever and rod communicating from the foot-board to the cocks at the cylinders; the slides of the cylinders are placed in the centre position by means of the lever and rod connected with the link motion; steam is let in to warm the cylinders and drive all the condense water out; the slides are then placed in a position to admit the steam into the cylinders to run forward or backward as desired. The weight of the engine and boiler causes the main wheels to revolve on the rails; when the engines are first started a certain amount of slip takes place on the rails, but as soon as the wheels bite this ceases and the speed is practically uniform; in wet and greasy weather, the slip of the wheels somewhat affects the speed; a sand box is carried on the main frame at each side, and by means of a valve and pipe sand is carried down in front of the main wheels on to the rails and so prevents the slip and assists the wheels.

The starting valve lever is fitted with a quadrant notched at certain points to indicate the amount of opening, and by practice, according to the weight of the train and the speed to be run, the driver gives the cylinders the amount of steam required; the exhaust steam passes from each cylinder by means of branch pipes to a central pipe, and is taken into the funnel; the pipe is carried near the top, and coned at the end to give a sharp blast and to increase the draught of the fire; the amount of air required through the bars varies according to the fuel used and the speed of the engine; means of controlling the air are provided at the fire-box end.

The pressure of steam used varies from 120 to 150 lbs. per square inch, and the speed from 30 to 50 miles per hour of the engine. The average consumption of coals in well-made modern engines is about 26 to 28 lbs. per mile.

Locomotive Engines in use upon English Railways.

Detailed particulars will now be given of the most modern types of locomotives at present in use on the leading lines of railway; they are valuable examples of actual engines in work, and will convey the best idea of the practical construction of locomotives of the highest excellence, both as to design and working results. Several of the leading locomotive engineers of the largest railways have favoured the author with drawings and particulars of the engines hereafter named; the student is recommended to carefully examine the drawings with the text, as all the details of the various parts are shown and described; by this means he will be able to master the matter and make himself conversant with all the parts in detail.

Great Northern Railway Express Locomotives.—Through the courtesy of Mr. P. Stirling, M.Inst.C.E., the locomotive engineer of this railway, the author has been able to put before his readers full particulars of these magnificent engines; they were first made in 1869 for the Scotch traffic, to compete in speed with the other railway companies running to the same places.

Drawings Nos. 26 *and* 27 show sections of engine and tender. The cylinders are 18 inches diameter × 28 inches stroke; it may be noted these are the longest stroke of any locomotive engines made in this country; the pistons are fitted with two steel rings, the piston-rods are of steel 3 inches diameter, and are secured to the pistons by screwed end and nut. The steam pipes are 3¾ inches diameter and the exhaust pipe 4¾ inches diameter. The slide-valves are gun-metal, and the slide-rods 1⅞ inch diameter. The connecting rods to the cylinders are rectangular in shape, and 6 feet 11 inches long from centre to centre. The crank-pins are 4½ inches diameter × 5 inches long. The main axle bearing of the large driving wheel is 8½ inches diameter × 8 inches long, the two leading axles are an average diameter of 5¼ inches and 9 inches long, the axle of the trailing wheels is 5¾ inches diameter. The main driving wheels are 8 feet 1½ inch diameter, the trailing wheels 4 feet 7½ inches diameter, and the front or bogie wheels 3 feet 11½ inches diameter. The total number of wheels is eight. The length of the wheel base is 22 feet 11 inches, and the extreme length over the buffers is 29 feet 9 inches. The bogie frame is wrought iron, 9 feet 6½ inches long × 4 feet ½ inch wide, the centre pin is 5 inches diameter × 13 inches long, the depth of the frame at the centre is 1 foot 2¾ inches. The cylinders are placed outside the frames of the engine, the connecting rods drive direct on to the outside crank-pins in the large driving wheels. There are two eccentrics to each cylinder, the blocks are cast iron 1 foot 4⅛ inches diameter × 2¾ inches wide, the straps are wrought iron lined with white metal; the gear to work the slides is a link motion of the usual kind controlled by a hand lever from the foot-plate of the engine.

The Boiler barrel or shell is 4 feet diameter × 11 feet 5 inches long, the smoke-box is 2 feet 8¼ inches long × 4 feet 2 inches wide, the external casing of the fire-box is 6 feet 2 inches long × 3 feet 11½ inches wide outside; the internal fire-box is made of copper plates, it is 5 feet 5½ inches long × 3 feet 3½ inches wide; it is stayed to the outer casing by copper stays at 4-inch centres. The tubes are 1¾ inch diameter, 2⅜ inches centre to centre, and 194 in number. The total length of the boiler 20 feet 4¾ inches. The smoke funnel is 1 foot 1 inch inside diameter, and 3 feet 6 inches above the smoke-box; the height from the rails to the top of the funnel is 13 feet 3⅛ inches.

The heating surface of the tubes is	1044	square feet.
„ „ fire-box	109	„
Total	1153	„

The area of the fire-grate surface = 17⅔ square feet.

The Tender is 15 feet 1½ inch long outside the tank × 6 feet 1⅝ inch × 4 feet 1½ inch deep inside × ¼ inch thick; the wheels are six in number, 4 feet 1½ inch diameter, the distance from centre to centre of the front and back wheel is 13 feet; the diameter of the axles at the bearing is 5 inches average × 10 inches long, and 6¼ inches diameter at the eyes of the wheels. The total length of the tender frame is 20 feet 4 inches × 6 feet 9 inches wide, the height of the tender from the rails to the top of sides is 9 feet 2¾ inches; the water tank holds 2800 gallons of water, and is sufficient to run from King's Cross to Grantham, 105 miles, without stopping, at an *average* speed of 50 miles per hour.

The Engine can draw a load of 365 tons on a level road at a speed of 45 miles per hour, working with steam at 140 lbs. per square inch. The coal consumed with sixteen carriages of 10 tons each = 28 lbs. per mile or 2·05 lbs. coal per indicated horse-power per hour; the average consumption of coal, of eleven engines of the same class, for one month on this railway was 27·8 lbs. per train mile. The weight of the trains, including engine and tender, but exclusive of passengers and luggage = 200 tons. The weight of the engine and tender is about 46 tons, the load on the driving wheels is 17 tons, the weight of the engine and tender when loaded and in full working order is 76 tons. The cost of maintenance and renewal is about 2½*d.* per mile.

The author can speak from experience of these splendid engines, as he often travels by them between London and Doncaster; during the year 1884 he has often had runs on one of the Leeds express trains well loaded, at a speed of 51 miles in 55 minutes; for a continuous run he believes this speed surpasses that attained on all other railways in the world, and the constant perfect performance of these engines has proved the excellence of this type for express service, and the talent of the designer.

Midland Railway Express Passenger Engine.—This engine runs upon eight wheels, the two back wheels on each side are coupled; the front wheels are four in number and are set in a " bogie " frame of the same type as described before. The tender has six wheels. The following are the leading dimensions of the engine: the four driving wheels are coupled, and are 7 feet diameter, the bogie wheels are 3 feet 6 inches diameter. The cylinders are 18 inches diameter × 26 inches stroke. The heating surface of the fire-box of the boiler is 110 square feet, and the tubes 1203 square feet; total surface 1313 square feet. The weight of the engine when loaded and in full working order is 42 tons 1 cwt., and the tender 25 tons 10 cwt.; total 67 tons 11 cwt. The tender will carry 2950 gallons of water and 3½ tons of coal. These engines can draw a load of fourteen carriages at the rate of 50 miles per hour on a level road; the total load, including the engine and tender, being

221 tons; they are fitted with either steam or vacuum brakes, both kinds are very effective in action. The trains run very steadily round curves of rather small radius, especially on the portion of the line between Derby and Manchester. The fast express trains are run to Leicester without stopping, a distance of about 95 miles; the water for the journey has to be carried in the tender.

London and North-Western Railway Express Passenger Engine (*Drawing No.* 28).—The steam cylinders are two in number and placed *inside* the frames at the smoke-box end of the boiler; they are 17 inches diameter × 24 inches stroke; the piston-rods are steel $2\frac{1}{2}$ inches diameter; the pistons are $4\frac{1}{2}$ inches deep, they are fitted with steel rings of the Ramsbottom type. The steam ports of the cylinders are $1\frac{1}{2}$ inch × 14 inches, and the exhaust ports $3\frac{1}{4}$ inches × 14 inches; the steam pipe is $3\frac{3}{4}$ inches diameter, and the exhaust pipe 6 inches diameter, coned to $4\frac{1}{2}$ inches diameter. The guide-blocks are 12 inches long. The crank-shaft bearings are 7 inches diameter × 9 inches long; the crank-pins $7\frac{1}{2}$ inches diameter × 4 inches wide; the connecting rods are rectangular in section and 5 feet 11 inches centre to centre; the eccentrics for working the slides are four in number, two to each cylinder; the links are straight, and are worked by weight shaft, levers and gear from the foot-board of the engine in the usual way.

The boiler is telescopic, 4 feet $\frac{7}{8}$ inch mean diameter × 9 feet 10 inches long at the barrel; the thickness of the plates is $\frac{13}{32}$ inch of mild steel, lap-jointed; the smoke-box is 2 feet 9 inches long × 4 feet $7\frac{1}{4}$ inches wide; the internal fire-box is made of copper and is 4 feet $9\frac{1}{8}$ inches long × 3 feet 6 inches wide, it is stayed to the external casing by 208 copper stays on each side at about 4-inch centres. The distance between the tube-plates is 10 feet 1 inch. The tubes are brass, 198 in number × $1\frac{7}{8}$ inch diameter outside; the tube-plate at the smoke-box end is $\frac{3}{4}$ inch thick. The steam dome is 2 feet diameter × 2 feet 9 inches high. The funnel is 1 foot 4 inches diameter at the bottom and 18 inches at the top, and stands 13 feet above the top of the rails.

The frames are steel $\frac{7}{8}$ inch thick × 1 foot $4\frac{1}{2}$ inches deep; they are 4 feet 2 inches apart. There are four large driving wheels, 6 feet 6 inches diameter, they are coupled on each side *outside* the frames; there are two leading wheels, 3 feet 6 inches diameter, the front axle is $5\frac{1}{2}$ inches diameter, and the axle bearings are 6 inches diameter × 10 inches long; the distance from centre to centre of the large driving wheels is 8 feet 3 inches, and between the front wheels and centre driving wheels 7 feet 5 inches. The extreme length of the boiler frame over the buffers is 23 feet 9 inches, the height from the top of the rails to the centre of the boiler is 7 feet $4\frac{3}{4}$ inches; the buffers are 3 feet $4\frac{1}{2}$ inches above the rails; the boiler is covered with a sheet-iron casing in the usual way. The pressure of steam is 140 lbs.

per square inch. The total heating surface is 1083 square feet. Area of the fire-grate, 17 square feet. Total weight about 32 tons 15 cwt. The engine is capable of drawing on a level road 293 tons at a speed of 45 miles per hour, with steam of 140 lbs. per square inch. Coal consumed per mile = 26 lbs., with an average of ten carriages. The average miles run per engine per year = 31,202.

These fine engines were designed by Mr. F. W. Webb, M.Inst.C.E., for the London and North-Western Railway, to whom the author is indebted for the drawing and particulars.

London and North-Western Railway Compound Locomotive Engines.—The author has also been favoured by Mr. F. W. Webb, M.Inst.C.E., locomotive engineer of the company, with drawings and particulars of locomotive engines of the above class. *Drawings Nos.* 29 *and* 30 show the engine; one of this kind was first run in 1881, it was used for express service, and ran about 319 miles per day, this is more than the usual distance run by engines in the time. The engine has three cylinders, the two high-pressure cylinders are placed *outside* the frames, and the low-pressure cylinder *inside* the frames; the high-pressure cylinders are 13 inches diameter × 24 inches stroke, and the low-pressure cylinder is 26 inches diameter × 24 inches stroke; the steam chests of the high-pressure cylinders are placed underneath, so as to allow the valves to fall from their faces, this saves wear when the steam is shut off.

The outside cylinders are placed between the leading and middle wheels, the cranks to which the connecting rods are attached are placed at right angles, and keyed on the trailing wheels; the low-pressure cylinder works on to a single crank on the axle of the middle pair of wheels. The steam is admitted through two 3-inch copper pipes to the high-pressure cylinders, the exhaust steam is returned by two 4-inch pipes running alongside the high-pressure pipes, it then enters the steam chest of the low-pressure cylinder; the steam and exhaust pipes in passing through the smoke-box cause the steam to be superheated; the final exhaust steam escapes from each side of the low-pressure cylinders to the blast pipe in the usual manner into the chimney; there are only one-half the number of blasts as compared with the ordinary engines. The steam-chest cover of the low-pressure cylinder has a relief valve, so adjusted that the steam is never admitted at a pressure above 75 lbs. per square inch, and arrangement is made whereby steam direct from the boiler can be admitted to the low-pressure cylinder at starting. The valve motion is Joy's patent, which dispenses with all eccentric-rods, and reduces the number of working parts per cylinder, and also the weight of the valve gear.

The travel of the high-pressure valves is $3\frac{1}{8}$ inches, the "lap" is $\frac{3}{4}$ inch and the "lead" $\frac{1}{8}$ inch; the port opens $\frac{3}{4}$ inch, and closes at 70 per cent. of the stroke;

the steam ports are 1⅛ inch × 9 inches, and the exhaust port is 2½ inches × 9 inches. The valve motion of the low-pressure cylinder is separate, and differs slightly from the others; the travel of the slide-valve is 4½ inches, the "lap" is 1 inch, and the "lead" $\frac{3}{16}$ inch; the steam port opens 1 inch, and is closed at 75 per cent. of the stroke, the exhaust port closes at 93 per cent. of the stroke; the steam ports are 2 inches × 16 inches, and the exhaust 3¼ inches × 16 inches. All the expansion of steam is done in the high-pressure cylinders. The consumption of coal per mile run is 26·6 lbs. compared with 34·6 lbs., the average consumption of the ordinary express engines with 17 inches × 24 inches stroke cylinders, the boilers being much the same. There are six wheels to the engine, two leading wheels 3 feet 6 inches diameter, two middle driving wheels 6 feet 6 inches diameter, and two back driving wheels also 6 feet 6 inches diameter. The length of the wheel base is 17 feet 7 inches. The leading axle is provided with a radial box having a lateral movement of 1¼ inch to each side of the centre line of the engine; the journals are 6 inches diameter × 10 inches long; the journals of the front driving axle are 7 inches diameter × 13½ inches long, the crank journal is 5½ inches long × 7¾ inches diameter, and the trailing axle journals are 7 inches diameter × 9 inches long.

One of the principal features in this engine is the adoption of a boiler with the water space of the fire-box carried under the grate, the space between it and the fire-bars forming the ash-pan. The object is to do away with the rigid foundation ring which is always a source of trouble, to obtain better circulation for the water, and to prevent the lodgment of dirt on the sides of the fire-box, where subject to the most intense heat. A flanged mouth-piece, similar to that of the fire-hole, is formed in the centre of the water space and covered with sliding doors worked from the foot-plate so that the ashes can be easily removed or dropped; while any sediment that may collect in the water space can readily be removed through the wash-out plugs in the side of the fire-box, there being a clear passage from side to side, when the covers are taken off. The mouth of the ash-pan is made of such a width that the tube-plate can be taken out, and replaced by a new one, without disturbing the other parts of the fire-box:—The barrel is 4 feet 1$\frac{3}{16}$ inch mean diameter × 9 feet 10 inches long. Fire-box, 4 feet 9½ inches to 4 feet 10½ inches at bottom × 3 feet 5½ inches wide; the height of the fire-box from top of fire-bars to crown, 5 feet 5½ inches. Length of tubes, 10 feet 1 inch; diameter of tubes, 1⅞ inch, the number of tubes is 198.

Heating surface of fire-box	=	103·5	square feet.
" " tubes	=	980	"
Total ..	=	1083·5	"

Area of fire-grate = 17·1 square feet.
Ratio of heating surface to grate surface = 63·35 to 1.

The steam dome is 24 inches diameter × 2 feet 9 inches high. The shell of the boiler is lap-jointed. The smoke funnel is 1/foot 4 inches diameter at the bottom and 18 inches at top, it stands 13 feet above the rails. The centre of the boiler is 7 feet 4¾ inches above the rails. The total length of the frame is 24 feet; the steam pipe leading from it is 4¾ inches diameter.

The weight of the engine empty	=	34·75 tons.
Weight of engine in working order:—		
Leading wheels	=	10·40 tons.
Front driving wheels	=	14·20 „
Hind driving wheels	=	13·15 „
Total	=	37·75 „

These engines have been a splendid success, and reflect much credit on Mr. F. W. Webb, the designer, as well as on the great railway company which first used them. The small extra weight of the engine when loaded is due to the system, used solely on this line of railway, of taking up the water at certain points on the journey from shallow troughs without any stoppage. It will be noticed that these engines effect a saving in coal of about 8 lbs. per mile run. The strain on all the working parts of the engine and the liability to fracture is much reduced by use of the compound system. The pressure of steam used in the high-pressure cylinders is 150 lbs. per square inch. A compound engine of this kind will take sixteen carriages between Euston and Crewe, 158 miles, in 3 hours 36 minutes, stopping twice on the journey; as a very severe test, one of these engines was run on one journey 528 miles.

The author has given an outline of this class of engine as the latest improvement made in modern locomotives; the success attending the working of this type of engine has demonstrated the economical working of the compound system as applied to locomotives. It is very fortunate for the public that this great railway, through their energetic and talented locomotive engineer, has had the courage to try an experiment upon so grand a scale; the author cannot help feeling proud that his countrymen are again in the front, as they have hitherto been, in the improvement of the locomotive engine.

London and South-Western Railway Express Locomotives.—The author has been favoured by Mr. W. Adams, M.Inst.C.E., the locomotive engineer of the above railway, with drawings and particulars of the express passenger engines on this railway.

Drawing No. 31 shows the above engines in detail. The steam cylinders are 18 inches diameter × 24 inches stroke, the pistons are fitted with cast-iron rings, the rods are $3\frac{1}{2}$ inches diameter; the valve spindles are of Yorkshire iron and are $1\frac{7}{8}$ inch diameter, the slide-valves are gun-metal. The steam-ports are 14 inches × $1\frac{3}{8}$ inch and the exhaust ports 14 inches × 3 inches. The connecting rods are flat in shape, 2 inches thick and 5 feet $10\frac{1}{2}$ inches long; each end of the rods is fitted with gun-metal bearings. The crank-pins for the connecting rods are $4\frac{1}{4}$ inches diameter × $4\frac{3}{4}$ inches long, and for the coupling rods $3\frac{1}{2}$ inches diameter × $3\frac{1}{2}$ inches long; the coupling rods are $1\frac{1}{2}$ inch × 4 inches; the driving and trailing axles have bearings $7\frac{1}{2}$ inches diameter × 9 inches long, and are 7 inches diameter in the middle. The bogie axles have bearings $5\frac{1}{2}$ inches diameter × 10 inches long.

The engine is carried on eight wheels; the leading wheels, four in number, are attached to a bogie frame; the diameter of each of these four wheels is 3 feet 4 inches; the diameter of the driving and trailing wheels is 6 feet 7 inches, and the width of tyres is $5\frac{1}{2}$ inches; the wheel seat is $8\frac{1}{2}$ inches diameter. The bogie frame is made of wrought iron, $1\frac{1}{4}$ inch thick and 2 feet $7\frac{1}{4}$ inches wide inside the frame; the bogie centre-pin is 3 inches diameter, and is fitted to a cast-iron frame having radial and lateral movements. The length of the wheel base is 21 feet $11\frac{1}{2}$ inches, and the total length of the frame is 28 feet $11\frac{1}{2}$ inches.

The steam cylinders are placed outside the frames, and the steam chests on the inside; each cylinder is fitted with one slide-bar 6 inches wide and 3 inches thick, made of best crucible cast steel, which is bolted to the cover at one end and to a wrought-iron bracket attached to the side frames at the other end. The sleeve or upper part of the cross-head is made of cast iron, 16 inches long, while the lower part which takes the piston-rod is made of best Yorkshire iron; these two parts are held together by bolts. The slide-valves are worked by a link motion of the Stephenson type in the usual way. The steam pipes in the smoke-box are $3\frac{1}{2}$ inches inside diameter and are made of copper.

The boiler barrel or shell is 4 feet 4 inches outside diameter × 10 feet $2\frac{1}{2}$ inches long, the plates are $\frac{1}{2}$ inch thick; the fire-box is 6 feet long outside; the internal fire-box is made of copper plates $\frac{5}{8}$ inch thick, and is 5 feet $4\frac{5}{8}$ inches long × 3 feet $3\frac{1}{4}$ inches. The tubes are steel, 218 in number, and $1\frac{3}{4}$ inch outside diameter; the tube-plate at the smoke-box end is of wrought iron $\frac{3}{4}$ inch thick, and at the fire-box $\frac{7}{8}$ inch thick.

The heating surface of the tubes is	= 1055	square feet.
" " fire-box	= 100	"
Total	= 1155	"
Area of the fire-grate surface	= 17·3	"

The fire-bars are of cast iron, made in two lengths. The chimney is $15\frac{1}{2}$ inches inside diameter at the bottom. The centre of buffers is 3 feet 5 inches from the rails, and 5 feet 9 inches centre to centre. The extreme width of the platform is 8 feet. The distance from centre to centre of the cylinders is 6 feet 1½ inch; the width between the main frames is 3 feet 11½ inches. The engine is provided with a cab or covering of the usual type to protect the men. The engine at the driving and trailing wheels is carried on steel springs of eleven plates, each 5 inches × ½ inch, and at the bogie end on steel springs of thirteen plates, each 5 inches × ½ inch.

These engines are used principally for the West of England express traffic, and also for the Weymouth service; they are very powerful and run very steadily. The average speed is 42 miles per hour, and the load drawn 150 tons over a road of varying gradients. The consumption of coal equals 30 lbs. per mile. The pressure of steam is 160 lbs. per square inch. The weight of the engine and tender when in full running order is 70 tons 9 cwt. These engines are Mr. W. Adams' design, who has also introduced many improvements in the class of engines formerly used by the company, by which means they are now able to compete as to speed with any of the other companies, the train service having been very much improved both as to speed and regularity as to time of arrival.

North London Railway Passenger Engines.—Mr. Park, M.Inst.C.E., has favoured the author with drawings and particulars of the engines upon this railway.

Drawings Nos. 32–4 show in detail the construction of the engines. All engines used on this railway are of the tank kind, without tender, and are more particularly used for short traffic with frequent stoppages; they have eight wheels; four coupled driving and the four in front are fitted to a bogie frame made in the same way as before described; the diameter of the four leading wheels is 2 feet 10 inches, the main driving wheels are 5 feet 5 inches diameter, the trailing wheels the same. The cylinders are 17 inches diameter × 24 inches stroke; they are fixed outside the frame at an angle of 1 in 10, and are 6 feet 1½ inch across from centre to centre; the pistons are each 4¼ inches deep, and are fitted with two cast-iron rings; the piston-rods are steel 3 inches diameter, they are fitted to the pistons by conical ends secured by nuts which are cross-pinned; the rods are keyed to a cast-iron sliding cross-head. The guide-bars are steel, 4 inches × 2 inches, there are four to each cylinder; they are bolted to the cylinder covers at one end, and to cast-steel wing plates bolted to the framing at the other end. The valve-spindles are iron 1¾ inch diameter, and at the guide sockets 3 inches diameter; they work through bushes at the back end of the steam chests. The steam ports are 1⅝ inch × 14½ inches, and the exhaust ports 3 inches × 14½ inches; the main steam pipe is made of copper, 4 inches inside diameter, branching into two pipes

$3\frac{1}{4}$ inches inside diameter; the main exhaust or blast pipe is 5 inches inside diameter at the top. The connecting rods are $1\frac{7}{8}$ inch wide and 6 feet $1\frac{1}{2}$ inch centre to centre; the crank-pin ends are fitted with brasses and cottared, the ends of the rods being slotted out to receive the bearings; distance pieces with shoulders are fitted in, and bolts are passed through to hold the bearings in position. The slide-valves are each worked by a pair of eccentrics $6\frac{1}{2}$ inches stroke; the eccentric-rods are 5 feet $3\frac{1}{4}$ inches long. The link motion is of the Stephenson's shifting link type.

The main axle is 7 inches diameter, and $7\frac{1}{4}$ inches in the bearings; the length of the main bearings is 8 inches. The crank-pins are forced into the driving and trailing wheels by hydraulic pressure, they are $4\frac{1}{2}$ inches diameter $\times$ $4\frac{1}{2}$ inches long. The driving and trailing wheels are fitted with coupling rods, 8 feet long centre to centre; the trailing axle is 7 inches diameter, the bogie axles are 5 inches diameter; the bearings are 5 inches diameter $\times$ 9 inches long. The bogie frame is made on Mr. W. Adams' plan, with 2 inches lateral play each side. The centre-pin is $2\frac{1}{2}$ inches diameter. The driving and trailing wheels have underhung steel bearing springs, each consisting of ten plates $\frac{1}{2}$ inch thick and one plate $\frac{5}{8}$ inch thick; the length of the springs is 3 feet 6 inches centre to centre. The bogie wheels are each 2 feet 10 inches from the centre of axles to the centre of the bogie-pin, viz. 5 feet 8 inches centre to centre. From centre of driving axle to centre of bogie-pin is 9 feet $10\frac{1}{4}$ inches. The driving and trailing wheels are 8 feet from centre to centre.

The total length of the frames is 27 feet 7 inches, and the width between is 4 feet $1\frac{3}{4}$ inch; the length over the buffers is 31 feet 4 inches. The buffer beams are of oak $5\frac{1}{2}$ inches thick bolted between two wrought-iron plates, the front one is $\frac{1}{4}$ inch thick and the back one $\frac{5}{8}$ inch thick. The engines are fitted with Mr. F. W. Webb's steam brakes and two injectors, and the other fittings are of the usual kind.

The Boiler barrel is 4 feet 1 inch inside diameter $\times$ 10 feet 1 inch long between tube-plates; the shell plates are $\frac{1}{2}$ inch thick, they are riveted with $\frac{13}{16}$-inch diameter rivets at $1\frac{7}{8}$-inch pitch. The fire-box is copper, $\frac{1}{2}$ inch thick, it is stayed by copper bolts at $3\frac{7}{8}$-inch centres; the dimensions of the box inside are 4 feet $5\frac{1}{2}$ inches long $\times$ 3 feet $4\frac{3}{4}$ inches wide, the top of the fire-box is supported by eight solid roof stays with $1\frac{1}{2}$ inch space between. The external casing of the fire-box is in one sheet, and is 5 feet 2 inches long $\times$ 4 feet $0\frac{3}{4}$ inch wide, and $\frac{1}{2}$ inch thick. The smoke-box is 2 feet 4 inches long and 4 feet $11\frac{1}{2}$ inches wide, it is fitted with a door 3 feet 11 inches diameter. The tubes are of brass, $1\frac{3}{4}$ inch external diameter, and 193 in number. The tube-plate is $\frac{3}{4}$ inch thick at the smoke-box and $\frac{3}{4}$ inch at the fire-box end. The funnel is $15\frac{1}{2}$ inches diameter $\times$ 3 feet $8\frac{3}{4}$ inches high above top of smoke-box, and 13 feet from the rails to top. The heating surface of the tubes is

893·59 square feet, fire-box 91 square feet; total = 984·59 square feet. The area of the fire-grate 16·62 square feet.

The total length of the boiler is 15 feet 0¼ inch. The lagging is of sheet iron, No. 15 B.W.G. The steam dome is 2 feet diameter inside × 2 feet 2 inches high; there are two safety valves of the Ramsbottom's type; the working pressure of steam is 160 lbs. per square inch. The foot-plate is 4 feet 1 inch from top of the rails. The cab is 7 feet 6 inches high × 7 feet 4 inches wide inside.

The two side tanks hold 850 gallons of water. The buffers are 6 feet centre to centre, and 3 feet 4½ inches above top of the rails; the length of the buffers is 16⅛ inches and 7⅝ inches diameter in the sockets, and are of solid wrought iron with Spencer's patent indiarubber springs. The front draw-bar is 2 inches diameter × 5 feet 7 inches long. The draw springs are G. Spencer's indiarubber No. 78 cones, held between cast-iron washer plates.

These engines are specially adapted for their particular traffic, and have stood the test of many years' working; the heavy traffic on this railway is of much the same character as on the Metropolitan Railway; the stations are very near together, averaging ¾ mile apart. The speed is rapid between the stations; the engines have to draw out of the stations quickly, and, as a rule, the steam is not shut off before the train enters at one end of the platform. All the parts of these locomotives are well proportioned; they are made very powerful to stand the heavy strains to which they are subjected, and the wearing surfaces are large. The author believes the bogie frame was first used on this line.

The speed of the engines is at the rate of 45 miles per hour when drawing a load of 180 tons on a level road. The consumption of coals is 30 to 35 lbs. per mile. The average number of miles worked per year by each engine is 47,000. The load upon the four front wheels is 13 tons, on the centre or driving wheels 16, and on the back wheels 16 tons. The total weight of the engine when in full running order is 45 tons. The weight empty is 39 tons.

By the courtesy and liberality of Mr. Park, the author is enabled to place before his readers the drawings in full detail, and also the actual working results of these engines.

Great Eastern Railway Passenger Express Locomotives.—By the courtesy of Mr. T. W. Worsdell, M.Inst.C.E., the locomotive engineer of the above railway, the author has been supplied with drawings, showing the Passenger, Goods, and Local traffic engines of that line.

Drawing No. 35.—These are a new class of engines built by Mr. Worsdell for express traffic, twenty have been built; each engine usually takes eighteen to twenty-four fully loaded carriages, of about 12 tons each; the speed attained is from

42 to $47\frac{1}{2}$ miles per hour. The average consumption of coal over the stock of this class of engine is 30·7 lbs. of South Yorkshire coal per mile run.

The cylinders are placed inside the framing, they are 18 inches diameter × 24 inches stroke; the pistons are fitted with two cast-iron rings; the piston-rods are steel, 3 inches diameter, secured to the pistons by screws and nuts. The slide-valves are placed on top of the cylinders, they are gun-metal, and the valve-spindles of wrought iron $1\frac{7}{8}$ inch diameter. The steam ports are $1\frac{3}{4}$ inch × $11\frac{3}{4}$ inches, and the exhaust $4\frac{1}{8}$ inches × $11\frac{3}{4}$ inches; the lap of the valve is $1\frac{1}{8}$ inch, and the lead $\frac{3}{16}$ inch; the maximum travel of valve is 5 inches; the main steam pipe is $4\frac{1}{4}$ inches diameter, and the exhaust pipe $4\frac{3}{4}$ inches diameter at the top of the cone; the valve gear is Joy's patent. The cross-heads are wrought iron, they are keyed to the piston-rods; the cross-head pin is also wrought iron, 3 inches diameter; there are two cast-iron slide-blocks 15 inches long to each cylinder and four slide-bars of steel, they are $3\frac{1}{4}$ inches wide × $2\frac{3}{8}$ inches thick. The connecting rods are wrought iron, $3\frac{3}{4}$ inches × $4\frac{3}{4}$ inches wide by 2 inches thick, and 6 feet 10 inches centres; the rods have strap ends, and gun-metal bearings working at one end on to the crank-pins 8 inches diameter × $4\frac{1}{2}$ inches wide; the straps are secured by two bolts each, and by steel cottars. The crank-shaft is 7 inches diameter and the main axle bearings $7\frac{1}{2}$ inches diameter × 9 inches long, and at the ends where it passes through the bosses of the main driving wheels it is 9 inches diameter × $8\frac{1}{8}$ inches long. The two hind wheels are coupled and are 7 feet diameter, they have twenty arms; the crank-pins for the coupling rods are 12 inches throw and $4\frac{1}{4}$ inches diameter × $4\frac{1}{16}$ inches long; the distance between the centres of the wheels is 8 feet 9 inches; the two front wheels are 4 feet diameter, they have twelve arms, the bearings are 7 inches diameter × 11 inches long. The length of the wheel base is 17 feet 6 inches, and the extreme length of the frames 26 feet 3 inches. The framing is 1 inch thick × 1 foot 9 inches deep. The front springs are composed of fourteen plates 4 inches × $\frac{1}{2}$ inch, placed *above* the wheels; the centre springs have thirteen plates $\frac{1}{2}$ inch × 5 inches placed *below* the wheels; and the back springs have twelve plates $\frac{1}{2}$ inch × 5 inches also *below* the wheels.

The boiler is made of steel, 4 feet 2 inches diameter outside at the shell or barrel × 11 feet $9\frac{1}{4}$ inches between the tube-plates; the plates of the shell are $\frac{7}{16}$ inch thick, and the tube-plates $\frac{3}{4}$ inch at the smoke-box end; the rivets are $\frac{13}{16}$ inch diameter and $1\frac{13}{16}$ inch pitch. The tubes are brass, $1\frac{3}{4}$ inch diameter outside, and 201 in number. The smoke-box is 2 feet $7\frac{1}{2}$ inches long, the smoke funnel 12 feet 11 inches from top of the rails. The fire-box is 5 feet 2 inches long × 3 feet 7 inches wide at top, it is made of copper $\frac{1}{2}$ inch thick, and 1 inch thick at the tubes; the stays are also copper, 1 inch diameter, screwed, twelve threads per inch, and placed at 4-inch centres. The fire-box shell is 6 feet long × 3 feet 11 inches wide outside; the fire-bars are made in two lengths, 2 feet 7¼ inches each; they are 4 inches deep × ⅝ inch thick.

The heating surface of the fire-box	=	117·5 square feet.
" " tubes	=	1082·5 "
Total ..	=	1200 "

The fire-grate area is 17·3 square feet.

The steam dome is 1 foot 9 inches diameter × 1 foot 9½ inches high × ½ inch thick; there are two safety valves 3 inches diameter. The total width over the platforms is 8 feet; the buffers are 5 feet 8 inches centres, and stand 3 feet 4½ inches above the top of the rails. The centre of the boiler is 7 feet 6 inches above top of rails. The brakes are on the Westinghouse system. The drivers are protected under a cover 5 feet 6 inches over all. The boiler is supplied by two of Gresham and Craven's injectors No. 8 and No. 10. The working pressure of steam is 140 lbs. per square inch. The weight of engine when in full running order = 41 tons 3 cwt.

Great Eastern Railway Goods Engines (*Drawing No.* 36).—These are six-wheel coupled engines; the cylinders are fixed *inside* the frames and are placed in an inclined position; they are 17½ inches diameter × 24 inches stroke; the pistons are made in the same way as in the passenger engines before named; the steam ports are 1⅜ inch × 15 inches, and the exhaust ports are 3 inches × 15 inches; the slide-valves are gun-metal fitted to iron valve spindles 1¾ inch diameter, connected to the valve-rods 3½ inches diameter at the guides; the piston-rods are steel 2¾ inches diameter. There is only *one* slide-bar to each cylinder, 6 inches wide × 3 inches thick, slide-blocks 14 inches long work upon these bars, and to them the connecting rods are attached by pins 3 inches diameter. The connecting rods are flat bars 5 feet 11¼ inches centres, and are fitted with strap ends 2¾ inches wide, and brasses in the usual way. The crank-pins are 7 inches diameter × 4 inches wide; the crank-shaft or main axle is 6¾ inches diameter, the two cranks are forged upon the shaft, the bearings are 6¾ inches diameter × 7½ inches long, and the ends at the bosses of the wheels 8 inches diameter × 6⅞ inches long. The slide-valves are each worked by two eccentrics and link motion of the usual kind, the eccentric-rods are 4 feet 2 inches long centre to centre. The wheels are cast iron 4 feet 10 inches diameter and have fifteen arms, the cranks 11 inches throw; the wheel base is 16 feet 1 inch, the side frames are 24 feet 10 inches long, they are 1⅛ inch thick × 1 foot 9 inches deep, and 4 feet 1½ inch between each frame.

The boiler is 4 feet 4 inches diameter outside × 10 feet 4 inches long between the tube-plates; the shell is made of Yorkshire iron plates ½ inch thick, the rivets are $\frac{13}{16}$ inch diameter × 1$\frac{13}{16}$ inch pitch; the tube-plate at the smoke-box end is

$\frac{3}{4}$ inch. The tubes are $1\frac{3}{4}$ inch diameter outside, and 223 in number. The smoke-box is 2 feet $6\frac{5}{8}$ inches long inside; the internal fire-box is copper, $\frac{1}{2}$ inch thick, 5 feet 2 inches long inside at top; the stays are also copper and 1 inch diameter; the roof stays are cast steel. The external fire-box is 6 feet long outside, the front and back plates being $\frac{9}{16}$ inch thick, the sides and crown $\frac{1}{2}$ inch; the fire-bars are in two lengths, 2 feet $7\frac{1}{4}$ inches each. The steam dome is 1 foot 9 inches diameter × 1 foot $9\frac{1}{2}$ inches high; there are two safety valves 3 inches diameter; the main steam pipe is $4\frac{1}{4}$ inches diameter, and the exhaust pipe $4\frac{3}{4}$ inches at top of cone. The smoke funnel is 15 inches diameter at bottom and $17\frac{1}{2}$ inches at top, it stands 12 feet 11 inches from the top of the rails; the centre of the boiler is 6 feet 10 inches from the top of rails, and the buffers 3 feet $4\frac{1}{2}$ inches from rails and are 5 feet 8 inches centre to centre.

The springs are composed of thirteen plates, $\frac{1}{2}$ inch × 5 inches wide. The enclosure for the drivers is 5 feet 4 inches long over all. The brake cylinder is 7 inches diameter × 12 inches stroke. The boiler is fed by injectors of the usual kind.

The heating surface of the tubes	=	1055·13	square feet.
„ „ fire-box	=	105·5	„
Total ..	=	1160·63	„
Fire-grate area		17·9	square feet.

The Tender runs on six wheels; the tank holds 2755 gallons of water, and the space for coal is equal to 5 tons. The pressure of steam is 140 lbs. per square inch. The full load to draw = 35 loaded coal trucks. The average speed = 22 miles per hour; the average express speed 28 to 30 miles per hour. The average consumption of coal = 37·8 lbs. per mile. The weight of the engine in running order is 36 tons 10 cwt.

Up to the present time (1884) fifty-nine of these engines have been built, forty at the Stratford Works by Mr. T. W. Worsdell, and nineteen to the same drawings by Messrs. Sharp, Stewart & Co., of Manchester; they are principally employed between Doncaster and London.

Great Eastern Railway: Tank Engines for Suburban Traffic (*Drawing No.* 37).—These engines run upon eight wheels; the water tank is carried on each side of the frame and over the four main and trailing wheels; the front wheels are 3 feet 9 inches diameter × $5\frac{3}{8}$ inches wide, there are ten spokes; the axles run in a radial box, the diameter of the axle in the centre part is 6 inches and $6\frac{1}{2}$ inches diameter in the journal × 11 inches long, at the eye of the wheels it is 8 inches diameter × $6\frac{7}{8}$ inches long, the back collar is also $8\frac{1}{2}$ inches diameter × $1\frac{1}{4}$ wide.

The main driving wheels are 5 feet 4 inches diameter × $5\frac{3}{8}$ inches wide, having sixteen spokes; the main journals are 7 inches diameter × 9 inches wide, and at the eye of the wheel it is $8\frac{1}{2}$ inches diameter × $7\frac{3}{8}$ inches long; the diameter of the intermediate axle (and crank-axle) is $6\frac{3}{4}$ inches at the centre part; these wheels are coupled to two intermediate wheels, also 5 feet 4 inches diameter × $5\frac{3}{8}$ inches wide, the axle-bearings of these are the same dimensions as the last. The hind wheels are 3 feet 9 inches diameter × $5\frac{3}{8}$ inches wide, the axles are 6 inches diameter in the centre and $6\frac{1}{2}$ inches diameter at the journals × 11 inches long, the size at the eye of the wheels is 8 inches diameter × $6\frac{7}{8}$ inches long, these axles also run in a radial box. The wheel base is 23 feet long, the distance between the front wheels and the main driving wheels is 7 feet 6 inches, the main wheels are 8 feet centres and the back wheels 7 feet 6 inches centre to centre; they are hung on springs made of thirteen plates 5 inches × $\frac{1}{2}$ inch, the length of the springs is 3 feet 6 inches, the back large wheels are hung upon springs made of twelve plates 5 inches × $\frac{1}{2}$ inch, they are also 3 feet 6 inches long, the springs are placed *below* the axles in each case; the front and hind wheels are carried on springs made of twelve plates 4 inches × $\frac{1}{2}$ inch, these are placed *above* the axles; each radial box is fitted with a horizontal double spring, each made of five plates 4 inches × $\frac{1}{2}$ inch and 2 feet 6 inches long. The main frame is 1 inch thick and 1 foot 6 and 1 foot 9 inches deep, the distance between the frames is 4 feet. The water tanks are each 13 feet long × 1 foot $7\frac{1}{4}$ inches wide × 3 feet 5 inches deep × $\frac{3}{16}$ inch thick.

The steam cylinders are placed inside the frames and are inclined at an angle of 1 in 14, they are 18 inches diameter × 24 inches stroke; the pistons are solid discs $4\frac{1}{4}$ inches deep and are each fitted with two cast-iron rings. The steam chests are cast on the cylinders, the steam ports are $1\frac{3}{4}$ inch × $11\frac{3}{4}$ inches, the exhaust ports are $4\frac{1}{8}$ inches × $11\frac{3}{4}$ inches, the slide-valves are gun-metal; the valve-spindles are $1\frac{7}{8}$ inch diameter, they are attached to the slide-valves by a rectangular frame; the spindles are continued at the back end of the steam chests and connected to the valve-rod in the usual way. The piston-rods are 3 inches diameter; they are made conical where they pass through the pistons, and are attached to them by screwed ends and nuts, these are cross-pinned. There are four slide-bars to each cylinder, they are $2\frac{1}{8}$ inches thick × $3\frac{1}{4}$ inches wide, they are bolted to the cylinder covers at one end and to an open transverse frame fixed to the main side frames; there are four lubricators to each set of slide-bars. The cross-heads are wrought iron, the slide-blocks are $4\frac{3}{4}$ inches wide × 1 foot 3 inches long, and are made of cast iron; the cross-head pins are 3 inches diameter, they are secured at one end by screws and nuts, which are cross-pinned. The connecting rods are wrought iron 2 inches wide × $3\frac{3}{4}$ inches at the cross-head end and $4\frac{3}{4}$ inches × 2 inches at the crank-shaft end. The crank-pins are $7\frac{1}{4}$ inches diameter × $4\frac{1}{2}$ inches long; the crank-shaft has two throws, the crank-pins are 24 inches centre to centre. The outside coupling rods are $4\frac{1}{2}$ inches × $2\frac{1}{4}$ inches, and the crank-pins on which they work are $3\frac{3}{4}$ inches diameter × $4\frac{1}{16}$ inches long. The distance from the centre of the cylinders to centre of the crank-shaft is 9 feet 10 inches. The motion for working the slide-valves is Joy's patent, no eccentrics or link motion are therefore used.

The boiler is 4 feet 2 inches diameter outside and 10 feet $2\frac{1}{2}$ inches long between the tube-plates, the shell-plates are $\frac{7}{16}$ inch thick, the tube-plate at the smoke-box end is $\frac{3}{4}$ inch thick. The tubes are 198 in number, and $1\frac{3}{4}$ inch diameter outside. The smoke-box is 2 feet $7\frac{1}{2}$ inches long, the exterior fire-box is 5 feet 5 inches long × 3 feet 11 inches wide × $\frac{1}{2}$ inch thick, the internal fire-box is copper, 3 feet 4 inches wide × 4 feet 10 inches long outside and 5 feet $8\frac{1}{2}$ inches high inside; the thickness of the tube-plate is 1 inch, and the back plate $\frac{3}{4}$ inch at the top tapering to $\frac{1}{2}$ inch, the crown is $\frac{1}{2}$ inch, the back and front part of the box are $\frac{1}{2}$ inch at the lower part. The stays of the fire-box are copper, 1 inch diameter, screwed in, and placed at 4 inches centre to centre; the fire-bars are in two lengths, each 2 feet $3\frac{7}{8}$ inches long × 4 inches deep at the centre; they are sixty-eight in number; the internal longitudinal stays are $1\frac{1}{4}$ inch diameter. The steam dome is 1 foot 9 inches diameter × 1 foot 9 inches high × $\frac{1}{2}$ inch thick, and the top $\frac{7}{8}$ inch thick; there are two safety valves 3 inches diameter; the steam pipe is $4\frac{1}{4}$ inches diameter inside, and the blast-pipe is $4\frac{3}{4}$ inches diameter. The smoke funnel is 1 foot 4 inches diameter at the top × 12 feet 11 inches above top of the rails, the height from the top of rails to the centre of boiler is 7 feet $3\frac{1}{2}$ inches; the buffers are 3 feet $4\frac{1}{2}$ inches above the rails, and 5 feet 8 inches centre to centre. The extreme width over the platforms is 8 feet 4 inches, the width between the inside of the frames is 4 feet, the total length being 31 feet 9 inches. The cab or cover for the driver is 8 feet $2\frac{1}{4}$ inches long inside × 7 feet 6 inches high, the top is of wood $\frac{3}{4}$ inch thick, covered with canvas. The enclosure for coal and water is 5 feet 2 inches long × 7 feet 8 inches wide × 4 feet deep.

The capacity of the tanks	=	1200 gallons.
The fuel space	=	95 cubic feet, about $2\frac{1}{4}$ tons.
Heating surface of tubes	=	955·7 square feet.
„ „ fire-box	=	98·4 „
Total ..	=	1054·1 „
Grate surface	=	15·43 square feet.
The working pressure of steam ..	=	140 lbs. per square inch.

These engines are used to run a heavy suburban traffic, the trains are composed of fifteen to twenty carriages. In a distance of $10\frac{3}{4}$ miles there are fifteen stopping stations, the time allowed for the journey is 41 minutes = $1\frac{1}{2}$ minute per stop and start, and is equal to about 35 miles per hour between the stations.

The weight of the engine in running order :—

	tons.	cwt.	qrs.
Leading wheels	12	16	1
Driving wheels	15	13	0
Intermediate wheels	13	9	3
Trailing wheels	9	19	1
Total	51	18	1

The weight when empty :—

	tons.	cwt.	qrs.
Leading wheels	11	4	0
Driving wheels	13	6	3
Intermediate wheels	11	5	2
Trailing wheels	5	17	2
Total	41	13	3

These engines are a new class, designed by Mr. T. W. Worsdell, M.Inst.C.E., for this particular traffic; they have been in use for some time and have been very successful in working; the traffic is a very severe kind, as the start has to be made at a good speed, and while the engines are in full running, they are rapidly pulled up as they enter the platform of the stations; this would not be possible without the aid of the powerful Westinghouse brakes. It will be noticed that the engines are very compact and all parts well balanced, only construction of the highest class could stand the work they have to perform, the service is not only rapid but constant, the engines have but short spells of rest; the time is kept very exactly, otherwise the frequent trains during each hour, if not punctual, would soon throw the entire system out, and considerable time might be lost before the trains could be got into regular running again.

The author is much indebted to Mr. T. W. Worsdell for the valuable drawings he has so generously placed at his disposal, as well as the data of working details and other particulars; many improvements have been introduced in these engines, not in previous use in other locomotives, they have proved very suitable for the service they have to perform.

London and Brighton and South Coast Railway Light Tank Engines for short local traffic.—These engines only weigh 24 tons; the average weight of the trains is 59 tons. Coal consumed per mile = 21·63 lbs. The average speed is about 15 miles per hour. There are six coupled wheels 4 feet diameter, the length of the wheel base = 12 feet. Steam cylinders 13 inches diameter × 20 inches stroke. The pressure of steam = 140 lbs. per square inch. The heating surface of boiler is about 500 square feet.

The above engines are designed for local traffic for trains stopping at each one or two miles; it has been found that the wear of the engines and rails is less with these light engines than with those previously in use. The water tank is carried at each side of the boiler, and the coke or coal in a small bunker at the foot-plate. They were designed by Mr. Stroudley, M.Inst.C.E., the locomotive engineer of the above railway.

Metropolitan Railway Locomotives.—The author has been favoured by the engineer of the line, Mr. Joseph Tomlinson, Jun., M.Inst.C.E., with particulars of the engines used on this railway.

The steam cylinders are placed outside the frame, and at an angle of 1 in 9, they are 17 inches diameter × 24 inches stroke; the steam pressure is 130 lbs. per square inch, the pistons are solid discs, they are each fitted with two cast-iron rings $\frac{3}{4}$ inch × $\frac{7}{16}$ inch; the piston-rods are steel $2\frac{3}{4}$ inches diameter; the steam ports are $1\frac{3}{8}$ inch wide × 13 inches long, and the exhaust port $2\frac{3}{4}$ inches wide × 13 inches long. The slide-rods are steel, the travel of the slide-valves is 4 inches, they are worked with Allan's straight link motion by a pair of eccentrics to each cylinder; the sheaves of the eccentrics are cast iron, with cast-iron liners fitted with wrought-iron straps forged solid to the eccentric rods. It has been found by experience on this line that they wear very well. The guide-bars are four in number to each cylinder, each $3\frac{1}{4}$ inches wide × 2 inches thick at the middle and $1\frac{1}{2}$ inch at the ends; the cross-heads are wrought iron and the guide-blocks cast iron. The driving and trailing axles are $6\frac{1}{2}$ inches diameter, they are made of steel; the main bearings are 7 inches diameter × 8 inches long; the driving axle-boxes are made $\frac{1}{4}$ inch wider than the trailing axle-boxes, this enables them to be planed down when worn and used for the trailing axles, and so saves any lining up. The steam pipe is $3\frac{1}{2}$ inches diameter, and the exhaust pipe $5\frac{1}{2}$ inches diameter; they are both made of copper; for condensing the steam in the tunnels, a valve with double ports is provided, this is actuated by a lever and a set of rods from the foot-plate of the engine, it enables the driver either to turn the exhaust steam into the side water-tanks, or into the smoke funnel direct for discharge into the atmosphere. The crank-pins are steel $4\frac{1}{2}$ inches diameter × 4 inches long; the pins are shouldered down at the outside to receive the coupling rods, these are made flat in shape with gun-metal bearings and cottars. The engine runs upon eight wheels; the water tanks are carried at each side; there are four coupled driving wheels 5 feet 9 inches diameter, and an Adams' bogie frame in front with four wheels 3 feet diameter.

The pin of the bogie is cast upon the top bearer, and which is bolted between the side frames.

The wheel base is:—

		ft.	in.
Driving to trailing wheels	=	8	1
Driving wheel to centre of bogie	=	9	11
Bogie frame centre to centre frame of axles	=	4	0

The frame of the engine is wrought iron 1 inch thick and 1 foot 7½ inches deep; the horns for the axle-boxes are forged solid.

The boiler shell is 4 feet diameter × 10 feet 3½ inches long; the plates are $\frac{7}{16}$ inch thick, lap-jointed, and single-riveted; the fire-box is copper 3 feet wide × 6 feet long; the stays are copper, they are 4½ inches centre to centre; the top bridge stays are wrought iron, they are eight in number, and are placed longitudinally at 4½ inches centre to centre, the tubes are brass, 160 in number, 2 inches diameter × 10 feet 9 inches long. The steam dome is 1 foot 9 inches diameter × 2 feet 6 inches high; the chimney is 16½ inches diameter at the base and 14½ inches diameter at the top; the height of the chimney above the rails is 12 feet 6 inches; the centre of the boiler is 6 feet 7 inches above the rails. The total length of the engine over the buffers is 31 feet 10 inches. The coal-boxes hold 32 cwt.; the water tanks contain 1100 gallons, they are only filled to 900 gallons, to leave room for condensing the steam. The boilers are supplied with water by two 4-inch diameter × 5-inch stroke force-pumps, the valve-boxes are fitted with solid ball-valves 1¾ inch diameter; the water can be drawn from the side water-tanks at 212°; no pet-cocks or pipes are used for the pumps, a small hole is left in each barrel above the bottom valve, it is $\frac{1}{16}$ inch in diameter; each of the pumps is worked by an eccentric on the driving axle. One Giffard's patent injector is also supplied for use in case of emergency; owing to the darkness in the tunnels, as the driver cannot conveniently see to work an injector, the pumps are always used unless they are out of order; there is a great advantage in using the pumps, as water of a much higher temperature can be put into the boiler than by the injector. The brake is Smith's patent vacuum, it is worked by a double ejector 1½ inch diameter, with an annular steam space of $\frac{1}{16}$ inch full; two collapsable indiarubber cylinders are fixed under the foot-plate, and are connected to the brake cross-shaft by chains worked over rollers.

The consumption of coal is about 32 lbs. per train mile run.

The weight of the engine in running order is—

	tons.	cwt.	qrs.
Bogie wheels	10	7	3
Driving wheels	17	15	0
Trailing wheels	17	2	3
Total	45	5	2

The weight of the trains is—

Engine	=	45 tons.
Carriages	=	90 „
Passengers (430)	=	25 „
Total ..	=	160 „

The distance run by each engine without repairs is 40,000 miles. The gradients and curves on this line are very heavy, and the constant stopping at such short distances requires a heavy class of engine to do the work in an efficient manner. The length of the Inner Circle Railway is thirteen miles; there are twenty-seven stops; the time of running is eighty minutes.

It is astonishing, considering the heavy and almost unceasing work done by these engines and the heavy shocks they are exposed to, that the repairs and renewals are so small. When the author paid a visit to the locomotive shops at Neasden a short time since, he was surprised to see so few engines under repair. Everything has to be in perfect running order, as the stoppage at the stations is so short there is no time for adjustment. The author wishes to call particular attention to the details of these engines, and advises the student to carefully study them, as they afford the best example of well-proportioned engines admirably suited for the peculiar traffic of underground railways.

Locomotives for Local Traffic.—Much lighter engines than any previously described are used for this purpose, they usually run upon six wheels, including the driving wheels; the tenders are small, the water tank is carried at each side of the boiler on the main frame.

The dimensions of an average engine of this class are :—

	ft. in.		ft. in.
Cylinder	0 10 diam.	×	0 10 stroke.
Crank-pin	0 5 „		
Boiler	3 0 „	×	8 6 long.
Tubes of boiler			88 in number.
Area of fire-box surface			45 square feet.
Area of tube surface			364 „
Total heating surface			409 „
Area of fire-grate			7½ „
Diameter of chimney			12 inches.

The dimensions of these engines will of course vary according to particular circumstances, viz. gauge of rails, weight to be drawn, &c. The above particulars are given as a fair average to enable the reader to form an idea of the size and power of this class of engine.

A smaller engine is sometimes used for shunting purposes at the large London termini, the tender and water tank being of smaller capacity than the class above described; these engines are principally used for making up trains at the termini and for shunting wagons at the goods depôt. Private firms also use this kind of engine for goods traffic on their own lines of railway; they are largely used in Burton-on-Trent at the breweries there, and in the colliery and mining districts and at large ironworks.

There is a great variety as to design in locomotive engines, but the general principles of construction do not much differ; the kind of traffic will decide which particular class of engine is the most suitable; this is however a matter for the skilled locomotive engineer to determine. The leading features of locomotive engines having been described, any one wishing for further detail of a more advanced kind should consult the good works that have been written on the subject.

Some of the leading types of locomotive engines upon the chief English railways have been described, many of the foreign engines are also of a very good type, and have much to recommend them for the particular work they have to do ; the author however thinks that the student cannot do better than follow the English engines herein described, examples being given both for heavy and light traffic. As above hinted, the locomotive engine treated in detail suitable for advanced students would require a book for the subject; in this work, the object is to give an outline of the leading kinds of engines illustrated by some of the best examples of modern practice. A careful examination of the drawings, with the description in the text, will enable the student to understand the subject, and may lead him to further study in more advanced books. The author believes that England is still in advance of all other countries in the improvements made in the locomotive, and also in the design, perfection, and finish of the work.

CHAPTER XII.

MARINE ENGINES.

THE history of the introduction of vessels propelled by steam power is too extensive a subject to be entered into in much detail in this book, a slight sketch only will be given which the author thinks may prove interesting to the reader.

In 1802 W. Symington constructed a steamboat for use on canals; it had a paddle-wheel at the stern and was driven by a double-acting horizontal engine, the cylinder being 22 inches diameter × 48 inches stroke; it was able to tow two vessels of 70 tons each, at the rate of about 20 miles in six hours. The vessel was only in use a short time, as it was feared the canal banks would be destroyed by the wash of the water.

In 1807 Robert Fulton (in America), after having seen Symington's boat in this country, built a vessel and put an engine into her made by J. Watt & Co., of Birmingham; the cylinder was 24 inches diameter × 48 inches stroke; she attained a speed of 150 miles in thirty-two hours. The vessel was 133 feet long × 18 feet wide × 9 feet deep at the hold.

In 1812 the steamer "Comet" was built by J. and C. Wood at Glasgow for Henry Bell; she was 40 feet long × 10 feet 6 inches beam, and 25 tons burden. The boat was driven by a table vertical condensing engine of about 4 horse-power; she was used on the Clyde and attained a speed of five miles per hour. Several boats were subsequently put on the Clyde; but on the Thames, owing to the opposition of the watermen, no steamboat was used until 1815, when the "Margery" ran between London and Gravesend. This was the first steamer for passenger service seen upon the Thames; she was built at Glasgow by the firm named above; the burden was 70 tons; she was fitted with *one* engine of 14 horse-power nominal. Between the years 1815 and 1821 many steamers were built and used, between Greenock and Belfast, Dover and Calais, between Holyhead and Dublin, and also on other short services.

In 1825 the first steamer ran to Calcutta, she was named the "Falcon," and was 84 feet long × 22 feet beam, 11 feet 6 inches deep at the hold, and 176 tons burden. The vessel was propelled by paddle-wheels, the steam power being used as an auxiliary to the sail power.

Steam vessels were first built for the Royal Navy in 1825, they were propelled by paddle-wheels, the hulls were built of wood; the first vessel was the "African," 90 horse-power and 295 tons burden. The first steamer to cross the Atlantic was built in 1835, and sailed between Bristol and New York in 1838; she was named the "Great Western," and was of the following dimensions:—236 feet long × 35 feet 4 inches wide, and 23 feet 3 inches deep at the hold, and 1340 tons burden. She was fitted with side-lever engines of 400 horse-power nominal, they were made by Messrs. Maudslay, Sons, & Field. The maximum speed attained was 12·88 miles per hour; the average of sixty-four passages was 10½ miles per hour; this speed at that date was considered very rapid. She was in use until 1858, when she was broken up.

It may be noted that the speed of the fastest merchant marine boats at the present time is 17¾ knots per hour = 20·4 miles.

The dates of the formation of the chief large steamboat companies are:—1839, Cunard Line; 1840, Royal Mail Company; 1837 to 1841, Peninsular and Oriental Company; 1843, Pacific Mail Company; 1850, Collins' Line of American Vessels; 1850, Inman Line; 1851, African Mail Company; 1854, Allan Line.

Rivxr Boats.—The Woolwich Packet Company's boats were commenced in 1835, they were chiefly built by Thompson, of Rotherhithe.

In 1838 the "Diamond Steamboat Company" commenced running between London and Gravesend. In 1841 the "Watermen's Steam Packet Company" commenced running between London and Woolwich; these vessels were of iron, and chiefly built by Ditchburn.

Steamers commenced running between London Bridge and Westminster and also to Nine Elms and Chelsea as follows:—1838, the "Iron Steamboat Company"; 1846, the "Citizen Company"; 1846, the "Halfpenny Steamers," these latter steamers ran from Dyer's Hall Wharf to the Adelphi, Strand; they were named the "Ant," "Bee," and "Cricket."

The first steamboat running from Hungerford Bridge to Richmond was built in 1829by Maudslay, Sons, & Field, who also fitted the boat with oscillating engines; she was called the "Endeavour."

Iron Steamers were first built in 1820 by Aaron Manby, of Tipton, followed in 1837 by John Laird, of Birkenhead, who built the "Rainbow"; she was 582 tons burden and 180 horse-power nominal; she ran between London and Antwerp or Rotterdam; the engines were built by G. Forrester & Co., of Liverpool; they were "steeple engines"; the cylinders were 50 inches diameter × 4 feet 6 inches stroke. The paddle-wheels were 21 feet 6 inches diameter, and the float-boards 10 feet long.

The above short sketch will give the reader some idea of the early history of the engines applied to propel steam vessels: the author is indebted to Mr. Henry

Sandham for many of the dates and facts named, who has liberally placed at his disposal the result of his long and patient researches.

It would be impossible in the limits of this book to enter into much detail, owing to the extent of the subject, especially as it would be beyond the purpose of the book.

The main principles of the construction of engines of the marine kind is much the same as in land Condensing and Compound engines, the manner in which they work is also the same; steam acting on one side of the piston in the cylinder is assisted by the vacuum made by the condenser and air-pump acting on the other side of the piston. There are many forms of engines both for river and sea purposes, for passengers and goods, and also for war purposes; they are made to drive paddle-wheels or screw-propellers. The particular service for which the steamers are intended decides whether paddle-wheels or screw-propellers are to be used, and also the type or form of the engines best adapted to the boats.

The original steamboats were all propelled by paddle-wheels, most of those of the present day for sea-going purposes are propelled by screws; all war ships are fitted with screws; the use of the screw permits the engines being placed *below* the water-line, which is very important in war vessels, as they are beyond the range of shot. The paddle-wheels were not only exposed to shot and shell, but were much in the way when working the guns; added to this, especially in large vessels, the screws are not much affected by the rolling of the ship in rough weather, whereas with paddle-wheels, great strains are thrown on parts of the machinery when one wheel is fully submerged and the other out of the water.

The screw-propeller was first used in 1840; the Admiralty used screw boats in 1843. In the original steam vessels, the pressure of steam did not exceed 3 to 7 lbs. per square inch, subsequently 20 lbs. per square inch was used, and later on it was increased to 30 lbs. per square inch, in the box or rectangular boilers used; at the present time the usual pressure is 60 to 90 lbs. per square inch; the use of high-pressure steam in marine engines has effected a large saving in coal. Some of the modern war ships have been fitted with twin screws; this is of great advantage, as it allows the vessel to be divided into water-tight compartments.

PRINCIPAL TYPES OF MARINE ENGINES.

The chief kinds of engines in former and present use, with makers' names and dates of introduction, are the following:—

"*Side Lever Engines*" in 1816, by Maudslay, Sons, & Field, R. Napier, James Watt & Co., Miller & Ravenhill, and others of the first makers of marine engines.

"*Oscillating Engines*" in 1828, by Maudslay, Sons, & Field.

"*Direct-acting Engines*" in 1840, by R. Napier, Maudslay, Sons, & Field, G. Forrester & Co., Liverpool.

"*Return Connecting-rod Engines*" in 1846, by Maudslay, Sons, & Field, four-cylinder engines; and in 1851 two-cylinder engines.

"*Trunk Engines*" in 1835, by Francis Humphreys, and in 1847, by John Penn & Sons; these may be looked upon as the first successful engines of this class.

"*Compound Engines*" in 1858, by John Elder & Co., shortly after also by Humphreys, and in 1867, by Maudslay, Sons, & Field.

Most of the above engines will be presently described and the dates and designers named again, so as to make the matter more clear.

The steam pressures first used were about 3 lbs. per square inch, and have risen about in the order named below:—

1820 = 3 lbs.	per square inch.	1865 = 30 lbs.	per square inch.
1842 = 7 lbs.	"	1867 = 50 lbs.	"
1843 = 10 lbs.	"	1870 = 70 lbs.	"
1844 = 15 lbs.	"	1882 to 1884 = 90 lbs.	"
1850 = 20 lbs.	"		

"*Side Lever*" *or* "*Beam*" *Engines* were made at an early date, they were somewhat like a land or mill beam engine with the beam inverted, they worked very steadily, all the parts being in balance, the long connecting rods also add to their steady motion, and for this reason they were great favourites in certain classes of vessels.

"*Direct-acting Engines.*"—There are several types of these, viz.:—"Steeple engines," with vertical cylinders, these are much used in America, and also on the river Clyde; "Horizontal engines with return connecting rods"; "Horizontal direct-acting engines," with connecting rod between the cylinders and crank-shaft. "Oscillating engines" are very generally used for ordinary passenger vessels when propelled by paddle-wheels, and also in some instances for sea-going vessels.

For vessels propelled by screws, horizontal fixed engines and also "trunk" engines are principally used; all of the engines named have two cylinders, and in the case of the screw engines, three and four cylinders are sometimes employed; the speed of the screws being from 50 to 150 revolutions per minute, the motion is more even and regular and the strain is more divided. The main crank-shaft of large engines was geared to the propeller-shaft, and the speed increased by tooth-wheel gear in the early vessels; the wheels were divided at the teeth and made very wide; the present practice is to drive direct from the crank-shaft.

An outline will now be given of each principal type of engine named above;

sufficient information can only be given to enable the reader to form a good general idea, as the subject if treated in detail would form a book of itself; in most instances the engines described are by the best makers, the proportions and sizes may be looked upon as the highest examples to follow.

Side Lever (Beam) Engines.

These, as before stated, were the first kind of engines used for steam vessels, they were made by Maudslay, Sons, & Field in 1820. *Drawing No.* 38 shows a pair of engines 80 horse-power collective, the cylinders were 36 inches diameter × 42 inches stroke, pressure of steam about 3 lbs. per square inch, they were fitted to the "Harlequin" steamship in 1824; the following is a general description of this class of engines:—The steam cylinders are two in number, fixed vertically to a bed-plate which is bolted to the lower part of the ship; the pistons are made in much the same way as for land condensing engines, they consist of an upper and lower flange with a metallic ring between, this is either held close to the inside of the cylinders by its own elasticity or by means of several steel springs pressing between the bosses or centres of the pistons and the inside of the rings; the top and bottom of the pistons are turned, and the centre bosses bored out to receive the piston-rods, these are made of wrought iron, they work through glands and stuffing-boxes, which are made rather longer than in land engines; the covers of the cylinders are cast hollow to form a jacket to keep the cylinders hot. The piston-rods are keyed to strong wrought-iron cross-heads, they are kept vertical by parallel motions of much the same kind as in land beam engines. The slide-jackets are placed at the back of the cylinders and are worked by eccentrics on the main shaft by means of connecting rods and rocking shafts; the slides are D shape; for running the engines backward or forward the eccentrics are loose upon the shaft, working against either of two lugs, according to the position in which the starting lever is placed; the steam is thus admitted on either the top or the bottom of the piston, and the engines run in either direction as required. Connecting rods are attached at their upper ends to the overhanging pins of the cross-heads, and at the lower ends to beams or side levers, they are made of cast iron. The main centre bearings on which the beams vibrate are on the bed-plate and are close to the bottom of the ship. At the reverse end of the side levers a long wrought-iron connecting rod, fitted with gun-metal bearings at each end, is attached; the top end of the rods works on to the crank-pins of the double cranks on the main shaft, to this the paddle-wheels are keyed on each side.

The main bearings for the shaft are carried on strong frames, bolted at the bottom to the bed-plate, and at the top are well framed, stayed, and braced together, they are also steadied at the sides by a cast-iron frame or stay bolted to the side frames and the side of the steam cylinders; the main bearing blocks are made very strong, they are lined with gun-metal, and fitted with caps, bolted on by four bolts, provided with check-nuts and cross-pinned, to prevent the nuts becoming loose from the vibration of the engines; the bearings are made wide, and ample means for lubrication are provided. The air-pumps are worked off the beam, the condenser is placed between the pump and the steam cylinders. The air-pump is made with a top cover, stuffing-box and gland for the rod to work through, it is fitted with a bucket and metal valves on much the same plan as for land engines; the pump-rod is made of gun-metal, and is fitted to a cross-head of wrought iron, having cast-iron guide-blocks working between guide-bars fixed on the pump.

The paddle-wheels are made of wrought iron with cast-iron bosses at the centres; they are bored out and keyed to the main crank-shaft; at the outside of each wheel, the wood framing of the paddle-boxes is carried round, and on these frames very strong bearing blocks are fixed; the bearings are lined with gun-metal, and in them the paddle-shaft revolves at each end. The wheels are each formed of wrought-iron outside rings, with flat wrought-iron arms bolted to them and to the centre bosses, they are diagonally stayed at the arms, the paddle-boards are secured to the exterior rings; the diameter and width of the wheels vary considerably with the speed and size of the boat.

The coal bunkers are placed on each side of the vessel near the boilers; the contents vary according to the distance the boat has to run without a stoppage to take in fuel. The bunkers are made of wrought-iron plates, and are fitted with sliding doors at the bottom, at which points the necessary supply is taken to feed the boiler furnaces; the capacity of the bunkers is about 48 cubic feet per ton of coals to be carried. In large vessels the stowage of coals requires very serious attention to ensure that the proper quantity required for the distance to be run is carried, and also that as little *space* as possible is taken up in the ship; the bunkers are made to fit the sides of the vessel, and are placed as near the boilers as possible; the coals are put in through holes in the deck, which are covered with iron plates.

Direct-acting Vertical Engines.

The steam cylinders in this case are bolted to a bed-plate fixed to the bottom of the vessel, six cast-iron columns or three strong A frames are bolted to the bed-plate, on the top of these a frame or entablature is bolted, this carries the bearings of the main shaft.

The cylinders, pistons, slides, and other parts, are the same as in the last engines, the piston-rod is guided by guide-blocks on each side of the cross-head, working in open cast-iron guide-bars fixed on the cylinders. The connecting rods are attached to the cross-heads of the piston-rods, and at the other end to the crank-pins of the double cranks on the main or paddle-wheel shaft. The slide-valves of the cylinders are worked by eccentrics in the same way as before described. The air-pump is either worked directly under the main shaft by a double crank forged on it, in this case it is fixed between the two steam cylinders, or it may be worked by a lever or beam, and the pump placed in front of the steam cylinders. The condenser in both cases is placed between the air-pump and the steam cylinders. The cold-water pump and bilge-pump are worked off the main shaft. Unless the cylinders are made with rather short strokes, the main paddle-shaft is thrown rather high above the level of the deck; they do not work quite so steadily when this is the case. The paddle-wheels and other details are the same as before described.

Steeple Engines.

These were first used by David Napier in 1840 for paddle-wheel steamers; as the engines are so little used in this country, they do not require much description. The cylinders are fixed vertically to a bed-plate as before, the piston-rods are keyed to a "bow" cross-head and are connected by two wrought-iron links to sliding blocks of cast iron, these work in open guides formed in strong A frames bolted to a frame about level with the top of the cylinder; connecting rods are attached to the cross-heads of the guide-blocks, and motion is given to the cranks which are keyed on to the main or paddle shaft at the deck level, the main bearings are the same as before described. The air-pump is worked by a lever or beam from the "bow" cross-heads fixed on the piston-rods; the construction of the pump is the same as before; the condenser is placed between the pump and the cylinders. The cold-water pump and bilge-pump are worked off the main shaft as before. On account of the height these engines are above the deck, they do not work very steadily, and for sea-going vessels are seldom used; they are however, still favourite engines in America for river purposes.

Trunk Engines.

These engines were first introduced by Francis Humphreys, in 1835, and were used by him in a paddle steamship named the "Dartford." John Penn & Sons, of Greenwich, improved upon the original plan, and applied them to screw vessels in 1847 in H.M.S. the "Encounter" and "Arrogant"; they are fixed vertical for paddle-wheel ships, and for ships propelled by "screws," they are made horizontal; they are very compact engines, and do not require guide-blocks and guide-bars or parallel motion to keep the piston-rods (according to the way they are fixed) in a vertical or horizontal line; the piston-rods are also dispensed with; the trunks are hollow and of sufficient internal diameter to permit the connecting rods, which are attached inside them at the piston, to vibrate clear of the inner side of the trunk. These engines work with rather increased friction, which is the one objection to their use, but for war purposes they are very suitable for driving screw-propellers. The screw revolves under the surface of the water, the engines may be placed 6 to 7 feet under the water-line; as a rule, shots will not penetrate the sides of a vessel at more than 2 or 3 feet below the water-line. These engines are sometimes made with four cylinders, two on each side of the ship; the crank-shafts in screw engines are placed in a line with the "keel," all paddle engines are placed transversely. When used with compound engines, they are provided with surface condensers; these are chambers fitted with a large number of small tubes presenting an extensive surface to the cold water for the purpose of condensing the steam from the cylinders. The steam cylinders are jacketed both at the sides and covers; steam from the boiler is admitted to keep the cylinders warm. A short detailed description will now be given of this class of engine, which will explain the general design and method of working.

Trunk engines, as before stated, are usually fixed horizontal, and are now used only for screw vessels; the steam cylinders are made in much the same way as in ordinary marine engines, except that trunks are used instead of piston-rods; the pistons have hollow cast-iron pipes or trunks attached at each end, they are turned on the outside and work through stuffing-boxes and glands provided in the cylinder covers at the top and bottom, these are made in the usual way. Piston-rods, cross-heads, guide-blocks and guide-bars are dispensed with, the slide-jackets and slides are placed on the side of each cylinder; a cover is fitted at the slides to examine and adjust them when required. One end of the wrought-iron connecting rods is attached to the pistons by strong pins fixed *inside* the trunk at this point; the end part of the trunks only serves as a guide in the cylinders and helps to bear the weight of the piston. The internal diameter of the trunks is settled by the vibration of the connecting rods; only enough room is left to allow proper clearance between the trunks and the exterior of the rods; the other ends of the connecting rods work on to the crank-pins of the crank-shaft.

There are two sets of eccentrics to each cylinder, with link motions to enable the engines to run either way as required. The air-pumps and cold-water pumps are placed at the other side of the crank-shaft, the surface condensers are fixed over them. The cylinders, crank-shaft bearings, and air-pumps are connected to side frames and bed-plates to which all the parts are bolted.

The surface condensers consist of cast-iron chambers formed over the air and cold-water circulating pumps, they are fitted with a large number of small brass tubes which present a large surface to the steam in its passage from the cylinders, and the steam is thus rapidly condensed. The air and cold-water pumps are worked by rods keyed on to the pistons of the steam cylinders; they pass through stuffing-boxes and glands in the cover, in the same way as the main piston-rods. The force and also the bilge pumps are worked off the same rods; the pumps are made double-acting, they are either fitted with gun-metal or indiarubber valves, these are of ample capacity so as to afford the quantity of water required. The plunger barrels and valves are made of gun-metal, with covers over the valves to give access in case of any stoppage or for doing necessary repairs. Safety valves are fitted on the delivery side of the pipes to give relief in case of any stoppage.

Drawing No. 39 shows Compound Horizontal Trunk Engines by Messrs. John Penn & Sons, Greenwich; the engines are fitted to H.M.S. "Daring," and are 955 indicated horse-power; the cylinders are placed side by side; the high-pressure cylinder is $45\frac{1}{2}$ inches diameter, and the low-pressure cylinder $70\frac{3}{4}$ inches; both are 24 inches stroke. The pressure of steam is 60 lbs. per square inch. The slides of each cylinder are worked by eccentrics and link motions. The air-pump and condenser are placed in front of the low-pressure cylinders. The screw-shaft is worked direct off the crank-shaft. The diameters of the trunks are 25 inches for the high-pressure cylinder, and 25 inches for low-pressure. The connecting rods are $5\frac{3}{4}$ inches diameter × 4 feet 10 inches centres. The diameter of crank-shaft is $9\frac{1}{2}$ inches, and the length of the bearings is 22 inches. The air-pump is 16 inches diameter × 24 inches stroke, it is double-acting. The feed-pump is $2\frac{3}{4}$ inches diameter × 24 inches stroke, it is single-acting. The propeller is 11 feet diameter × 13 feet 6 inches pitch, it has two blades. The surface condensers have tubes $\frac{3}{4}$ inch diameter × 5 feet $6\frac{1}{2}$ inches; the number of tubes is 1375. The number of revolutions of the engines is 107 per minute. The speed of the ship on trial was 10·85 knots per hour. The boilers are three in number, each 7 feet 8 inches diameter × 15 feet long, the tubes in each are 498 in number, 3 inches diameter × 5 feet long. There are six furnaces to each boiler, these are 3 feet wide × 5 feet long at the bars.

The general method of working in these engines is the same as in other *compound* engines, they are compact in form, direct in their action, and can be placed low down in the ship, out of the way of shot or other projectiles.

Trunk Engines of 500 *Horse-power Nominal.*—These engines are constructed by Messrs. John Penn & Sons; the following will give an idea of the proportions:—

The diameter of the two steam cylinders is 7 feet $2\frac{1}{2}$ inches; the diameter of the trunks, 2 feet 9 inches; the stroke of cylinders is 3 feet 6 inches; the length of the connecting rods is 10 feet 3 inches; the pistons are $7\frac{3}{4}$ inches deep; the crank-shaft bearing is $14\frac{1}{2}$ inches diameter × 2 feet $7\frac{1}{2}$ inches long. The surface condensers have 4832 tubes, they are 1 inch diameter × 6 feet 10 inches long. The feed-pumps are 5 inches diameter × 3 feet 6 inches stroke. The propeller is 18 feet diameter, it has two blades, the pitch is 23 feet. The number of revolutions of the screw-shaft per minute is 70. Steam pressure, 20 lbs. per square inch. The average speed of the ship is 12·69 knots per hour. The boilers are four in number, the tubes are 3 inches diameter × 7 feet long and 1216 in number; there are sixteen furnaces, each 2 feet 10 inches × 7 feet. The diameter of the chimney is 6 feet 8 inches.

The details of an engine of this kind are of a very complex character, and in the limits of this work cannot be further entered into, the above particulars are only given to enable the reader to understand the large sizes this class of engines are made.

Oscillating Engines.

For river and short sea-passage boats oscillating engines are generally used. They were first used by Messrs. Maudslay, Sons, & Field in 1828, in the "Endeavour." The engines were 20 horse-power collective, the cylinders were 20 inches diameter × 24 inches stroke. In 1832, four sets of 60 horse-power engines, with 36-inch cylinders × 36 inches stroke, were made by the same firm, they were not at this time much used in this country, but were principally sent abroad; Messrs. John Penn & Sons much improved the oscillating engine, and have built a large number of them. The engines consist of two vertical oscillating steam cylinders, each hung on centre trunnions cast on the cylinders, and turning in bearing blocks cast on a bed-plate, which is bolted to the lower part of the vessel. A top frame of a box section is fixed above the cylinders, and is supported by six or eight cast or wrought iron columns fixed in the bed-plate; on this top frame the main bearing blocks are bolted; these are fitted with gun-metal bearings and strong caps. The pistons, covers, and slides do not differ from other kinds of marine engines. The slide-jackets are placed on the front of the cylinders, and the slides are worked by rocking shafts; each cylinder slide is worked by two eccentrics and link motion of the locomotive type on the same plan as those described for other marine engines. The eccentrics are keyed on the crank-shaft; the rods of each set are connected to opposite ends of the links; a lever and rod is used to work the slides, and by its means the steam is admitted into the top or bottom of the piston, and the engines run forward or backward. The piston-rods are made large in diameter, they are either keyed to gun-metal cross-heads fitted with caps bolted on, or the rods have the cross-heads forged on, and are then lined with gun-metal bearings; the cross-heads work direct on the crank-pins of the crank-shaft. The cranks are either forged on the crank and paddle shaft, or they are separate cranks and keyed on to the shaft; the crank-shaft is made of wrought iron or steel, it has three cranks, two for the cylinders and one for the air-pump; the shaft turns in four bearings, these are cast on the top frame as before described. The paddle-wheels are keyed on at each side at the end of the shaft.

The air-pump is fixed on the bed-plate in the centre between the two cylinders, it is made in the same form as the air-pumps for land engines, the condenser is placed near it; the pump is worked by a double crank in the centre of the crank-shaft by means of a connecting rod, which is attached to a cross-head with guide-blocks at each end; these work between guide-bars fixed to the top frame at one end and to the air-pump at the other. A cold-water pump is also worked off the crank-shaft to supply the condenser; a force-pump for the boilers is also sometimes worked in the same way, also a bilge-pump for the purpose of keeping the lower part of the vessel clear of water.

The method of working in these engines does not differ from ordinary land engines of the same type. It will be seen from the above that the cylinders act direct upon the shaft carrying the paddle-wheels, these wheels are made with a strong cast-iron centre boss, the rims and the arms connecting the rims and the bosses are wrought iron; these wheels are now generally made upon the feathering principle; the paddles in this case are hung on centres worked by levers and radial rods fixed to the centre bosses, by this means the boards are made to feather, and so leave the water easily and without much friction. The wheels are covered by the wood paddle-boxes, these are fitted with doors at the top, to allow of examination and repairs to the wheels.

Drawing No. 40 shows engines of this kind, and will give a good general idea of their form; the details differ according to the purpose for which the engines are to be used, and whether for river or sea purposes.

The engines were made for the Royal Mail Packet "Mersey," they are 250 horse-power nominal. The cylinders are 60 inches diameter × 5 feet stroke. The air-pumps are 36 inches diameter × 27 inches stroke. The pressure of steam used = 20 lbs. per square inch. The *indicated* horse-power at a trial, April 21st, 1859, was 1117 horse-power, and the speed 13·215 knots per hour. The boilers are placed at each end of the engines and at either side of the ship; there are two smoke funnels. The bed-plate of the engines is bolted to four powerful wrought-iron box girders, which are riveted to the shell of the vessel; the top frame is bolted to wrought-iron box girders, which reach from side to side of the vessel; there are two air-pumps worked off one central crank, they are placed in an inclined position. The paddle-shaft outer bearings are supported on wrought-iron brackets; the paddle-wheels have wood floats with gear to feather; the paddle-boxes are wood. Many modifications have been made in this class of engine since the date above named (1859) when these were built, the general design, however, is much the same.

This class of engine is also used for large vessels for the merchant service, in these cases they drive screw-propellers, as paddle-wheels, except for river and short-passage ships, are now seldom used.

The following are the principal dimensions of a pair of engines for war ships of 500 horse-power nominal:—The steam cylinders are each $82\frac{1}{4}$ inches diameter × 6 feet stroke, making $18\frac{1}{2}$ strokes per minute. The diameter of the paddle-wheels is 27 feet, and the width 9 feet. The paddle-shaft at the necks is $16\frac{1}{4}$ inches diameter. The weight of the machinery per horse-power is 11·97 tons. The weight of the engines is about 117 tons. The weight of the boilers is 70 tons; the extra weight of the water in the boilers is 28 tons. The weight of the coal-boxes is 16 tons, they contain 340 tons, say about 9 days' consumption. The paddle-wheels weigh 38 tons. The total weight is about 292 tons.

Return Connecting-Rod Condensing Engines.

Drawing No. 41 shows the engines made by Messrs. Maudslay, Sons, & Field in 1846, for H.M. ships "Ajax" and "Edinburgh," they were for driving screw-propellers, and were 550 horse-power collective; there were four cylinders, 55 inches diameter × 30 inches stroke. In 1851 the same firm fitted Return Connecting-rod Engines to H.M.S. "Tribune," a screw vessel; there were two cylinders, 55 inches diameter × 2 feet 6 inches stroke, and they were 300 horse-power collective. Low-pressure steam of about 20 lbs. per square inch was used. The screw was 14 feet diameter × 19 feet 6 inches pitch. The engines of the "Tribune" were not made in the same form as those for the "Ajax" and "Edinburgh."

The engines of the "Ajax" and "Edinburgh" are horizontal; their arrangement enables the crank-shaft and cylinder to be placed very close, thus economising much space; there are four cylinders to the engine; the pistons of each cylinder are fitted with two piston-rods, one of these rods passes *under* and one *over* the crank-shaft. They are attached to cross-heads of wrought iron, having planed bases working in guide-bars. The connecting rods are attached to the cross-head pins and are turned *back*, and attached to the crank-pins of the main shaft; the rods are made of wrought iron, and have solid ends fitted with gun-metal bearings. The air and circulating pumps are worked off the cross-heads in front of the guides;

the condensers are fixed over the pumps. The eduction pipes from the cylinders are of copper, and pass from the cylinders over the crank-shaft to the condensers fixed at the other side of the vessel; the discharge pipe from the air-pump and condenser passes through the side of the vessel. The engines are fixed across the ship. It will be noticed this kind of engine allows a longer stroke than in the case of direct-acting engines, where the connecting rod works *between* the cylinders and the crank-shaft. The details of the cylinders, cranks, connecting rods, and other parts, do not differ from the other kinds of marine engines already described. These engines are somewhat complicated, only the leading points can be touched upon sufficient to give a good general idea of the particular type and the general arrangement of the parts; the student is recommended to carefully study the drawing and master the details of the engine.

Compound Engines.

These engines were first introduced by Messrs. J. Elder & Co. in 1858, there are several forms of this class for marine purposes, both vertical and horizontal, one or two kinds will be described to give a leading idea of their construction and dimensions.

Drawing-No. 42 shows Messrs. Maudslay, Sons, & Field's patent compound engines as fitted to H.M.S. "Sirius" in 1867; the pressure of steam used was 50 lbs. per square inch. The high-pressure cylinders are sunk in and partly enclosed in the low-pressure cylinders. The slide-jackets and valves of the high-pressure cylinders are placed on the top of the cylinders, and those of the low-pressure cylinder are at the sides. The slides are worked by eccentrics and link motions, to allow the engines to be run either way as desired; the piston-rods pass from the high-pressure to the low-pressure cylinders, the pistons of the latter are sunk in the middle to clear the bottom of the high-pressure cylinders. Two extra piston-rods are attached to the low-pressure pistons, the rods pass through stuffing-boxes and glands in the covers, and communicate motion to the wrought-iron cross-heads, these have arms forged on them, with eyes bored out to receive the ends of the piston-rods, they are secured by nuts, and are cross-pinned; the cross-heads work in slipper-guide bars fixed on the bed-plate. The air and the cold-water pumps are also worked by means of piston-rods direct from the low-pressure pistons. The connecting rods are returned and work backwards on to the crank-pins of the double cranks on the crank-shaft; the shaft is placed midway between the steam cylinders, the condensers, and air-pumps. The air-pumps are placed under the surface condensers and near the bed-plate, they are double-acting; the condenser consists of a casing of cast iron, fitted with a large number of small tubes in order to effect the rapid condensation of the steam from the low-pressure cylinders, cold water is pumped through the tubes by the circulating force-pumps, the exhaust steam is on the outside in the casing, the steam from the cylinder is thus quickly condensed and is drawn away by means of the air-pumps; the water is pumped from the hot wells to the boilers. The force-pumps are worked off the cross-heads, and are fitted with valve-boxes of the usual kind.

All the parts of the engines are connected by strong side frames, to which they are bolted; the main bearing blocks are cast upon the frames and are lined with gun-metal bearings; powerful caps are fitted on, these are held down by four bolts each, secured by check nuts and steady plates. The horse-power of the engines is 350 nominal collective.

The following leading dimensions will give an idea of the proportions of these engines:—High-pressure cylinder, 2 feet 10 inches diameter × 2 feet 9 inches stroke; low-pressure cylinder, 6 feet 3 inches diameter × 2 feet 9 inches stroke (steam jacket 3 inches annular space). Piston-rods of the low-pressure cylinder are 5½ inches diameter, and the piston-rods of the high-pressure cylinder are 4¾ inches diameter. The connecting rods are 6½ inches diameter × 5 feet 9 inches long. The crank-shaft bearing is 11 inches diameter × 18 inches long. The steam-pipe is 12 inches diameter. The pipe to condenser is 21½ inches diameter. The diameter of the air-pumps is 15 inches; the diameter of the feed-pumps is 4 inches. The number of tubes in each condenser is 1833, they are 6 feet 3 inches long; the total surface is 4200 square feet. The propeller is 15 feet diameter × 15 feet 6 inches pitch, it has two blades. There are four boilers, the total number of tubes is 1248; the total heating surface is 5500 square feet; there are twelve furnaces; the funnel is 6 feet 10 inches × 4 feet 10 inches, it is oval in shape. The steam pressure is 55 lbs. in the boilers. The revolutions of the engines at full power are 96 per minute. The average indicated horse-power at full power is 2325.

Vertical Compound Marine Engines.

These engines are made with inverted cylinders, they are supported on A frames, the low-pressure and high-pressure cylinders being fixed side by side. The general construction is somewhat like land engines of the same class, the crank-shaft is near the bottom of the vessel; the air-pumps are worked off the cross-heads by means of rocking beams. Surface condensers are placed close to the pumps.

The steam cylinders are jacketed, the slides are worked by eccentrics and link-gear; expansion gear is also provided for the high-pressure cylinder. These engines are made 500 to 600 horse-power nominal; they are very compact, from their vertical position they require less floor space in the engine-room than horizontal engines.

Drawing No. 43 shows a pair of vertical compound marine engines by Messrs. Maudslay, Sons, & Field, made in 1871 for the steamships "Britannic" and "Germanic." The horse-power is 760 nominal. There are two high-pressure cylinders, 48 inches diameter × 5 feet stroke, and two low-pressure cylinders, 83 inches diameter × 5 feet stroke; the high-pressure cylinders are placed *above* the low-pressure cylinders; the latter are bolted to powerful A frames. There are two air-pumps worked off the cross-head pins by means of links and wrought-iron double rocking beams. The feed and circulating pumps are also worked off these beams. The condenser is fixed horizontally, and is placed between the two air-pumps. The bed-plate to which the A frames are attached is carried on powerful wrought-iron girders bolted to the shell of the ship. The slide-valves are worked by two eccentrics each, and link motion of the usual kind. The steam passes first into the high-pressure cylinders, it is then discharged into the low-pressure cylinders, and afterwards to the central condenser. The connecting rods are wrought iron, 12 inches diameter and 10 feet long from centre to centre; the ends of the rods have T-pieces forged on, and are fitted with gun-metal bearings and wrought-iron caps; two large bolts secure each bearing in position. The lower parts of the piston-rods are 9 inches diameter. The main crank-shaft is 18 inches diameter. There are four vertical donkey engines. The main engines are very compact as to the floor space, which is about 25 feet × 24 feet; the total height is about 33 feet. The low-pressure cylinders are stayed together with powerful framing.

The main steam pipes are 15 inches diameter, and the exhaust pipes to the low-pressure cylinders 16 inches. The pipes from low-pressure cylinders to condenser are 24 inches diameter. The pressure of steam 70 lbs. per square inch. The indicated horse-power = 5500. Speed, average $15\frac{1}{2}$ knots per hour. Propeller, diameter 23 feet 6 inches, pitch 30 feet 6 inches, and four blades.

The leading dimensions of a pair of engines of this class of 100 horse-power nominal are:—The high-pressure cylinder is $30\frac{1}{2}$ inches diameter × 27 inches stroke, the low-pressure cylinder is $43\frac{1}{2}$ inches diameter × 27 inches stroke; the piston-rods are $4\frac{1}{2}$ inches diameter; the cross-head pins are $4\frac{3}{4}$ inches diameter. The connecting rods are 4 inches to 5 inches diameter × 4 feet 6 inches centres. The air-pump is 21 inches diameter; the crank-shaft bearings are 8 inches diameter, and the pins $8\frac{3}{4}$ inches diameter.

There are several modifications of this class of engine, but the general principle is the same in all. The great consideration in all marine engines is lightness combined with the necessary strength, compactness, and freedom from complication of the various parts. This class of engines is sometimes made with four cylinders, smaller in their proportionate diameter, and are run at a higher rate of speed, being made shorter in stroke; the height to the top of the cylinders is much less in this case. Compound vertical engines, with inverted cylinders, are only used for driving screw-propellers.

Details of Marine Engines.—The following details, remarks, and particulars apply to all the engines described above:—

Steam Pipes are usually made of copper, they are taken as direct as possible to the cylinders; they should have full area, the bends are made as large a radius as possible, and when there is any long length of pipe without a bend, an expansion joint is used, this permits the pipe to expand and contract without injury to the joints. The pipes are either covered with several thicknesses of felt, and sewn up in canvas, or they are covered with non-conducting composition well painted on the outside. The pipes are made in convenient lengths, they are fitted with flanges of copper, and bolted together with copper or gun-metal bolts.

Blow-through Valves are used to expel the air from the cylinders, air-pump, &c., the place being supplied by steam, vacuum is obtained by condensation. The condenser is provided with a "snifting valve," the steam passes out of this valve; the valves are closed directly the engine is set to work. The passage of the steam through all parts of the cylinder warms it up, and prevents loss from condensation in the cylinders when the engine is working. These valves are only fitted when low-pressure steam is used; they are not a necessity for high pressures.

Self-acting Escape Valves are fixed at the cylinder covers to allow the condense water to escape, these are essential in marine engines on account of the boilers priming; serious strains on the machinery are thus prevented. The valves are usually made conical, and are kept on their seat by spiral springs, of sufficient power to prevent any escape of steam below the working pressure on the cylinders; the valves are fitted with a guard at the top to prevent accidents from scalding by the sudden discharge of condensed water.

Relief Cocks are fitted to the cylinders at each side of the piston; they are connected by levers, and are opened at the starting of the engines to clear the cylinders; the water is usually discharged into the condenser.

Donkey Engines are provided to feed the boilers; these can be worked separate from the large engines, they are an essential in all classes of steamships. They are fixed vertically and horizontally, and work direct-acting from the steam cylinders to the pumps; they are sometimes fitted with a fly-wheel to equalise the motion and work the slides, or they are worked by "tappets." The details of these engines have been more fully entered into for land engines at p. 22; they do not differ from them in any essential particular.

Bilge Engines.—These are for the purpose of keeping the vessel clear of water, engines and pumps of the above kind are used, they are worked independently of the donkey feed-pumps; they are also used as fire pumps, for washing decks, &c.

Superheaters are placed in the main flue to the funnel; the steam passes from the boiler into the superheater before it enters the cylinders; dampers are placed in the flues to allow the hot gases to pass through or to go direct to the funnel; when steam of high pressure of say 60 lbs. per square inch is used, this apparatus is not much employed, as the extra economy does not pay for wear and tear.

Kingston's Valves are used for the blow-off from the boilers, or for any opening of like kind in the vessel under the water-line; they are conical valves, and so made that the pressure of the external water keeps them tight at the seatings.

Engine-Room Signals.—These are made in several forms, either as pneumatic, electric, or ordinary spring bells; in some cases a telegraph message is sent direct from the deck or bridge of the steamer by the captain; a regular code is adopted to prevent any error; speaking-tubes are now seldom used.

Counters are always provided to record the number of revolutions of the engines in a given time, by this means the speed of the vessel is ascertained.

Marine Boilers.

Low-Pressure Boilers of from 30 to 40 lbs. pressure per square inch, are usually made rectangular in shape; the furnaces and flues are placed inside the boiler, and are always surrounded by water; there are several forms of these boilers, but those most used are multitubular. Each boiler has three or four furnaces, the grate-bars are set inclined from the fire-doors, a bridge is built up at the end of the furnace; some of the heat is expended on the top plates of the flue over the furnaces, and the rest passes over the bridges at the end of the furnaces; it rises at the back of the boiler, and then passes through a large number of tubes, from 2½ inches to 3 inches diameter, to the front part of the boiler where a smoke-box is formed, from this chamber it is connected with a main flue and passes into the smoke funnel. The outside casing of the boilers and the flues are strongly stayed together, the small tubes pass through plates and are riveted to them in the same way as in the locomotive boilers. The method of jointing and riveting the plates of the boilers and other details of manufacture do not much differ from land boilers. The furnaces should not exceed 6 feet in length, the thickness of the bars, the air spaces between them, and their depth, depend upon the kind of coal to be used; dead-plates are provided at the fire-door frames for the purpose of coking the coal before it is pushed into the fire. The top furnace plates should be covered with about 14 inches of water, and the tubes with about 3 inches; in sea-going vessels allowance is made for the disturbance of the water-line during heavy rolling of the vessel. At the front of the boiler where the smoke-boxes are placed, doors are provided to clean out the tubes, also man-holes and mud-holes to give access to the parts of the boiler when necessary for cleaning and examination; all parts are designed to permit of proper and efficient examination. Owing to the use of sea-water, scale forms very rapidly in the boilers, every care is used to prevent this, not only on account of the extra amount of fuel consumed when the boilers are foul, but also because of the loss sustained when laid up for repairs for any period. The boilers are usually bedded on iron girders, which are of sufficient height to permit of examination of the bottom plates, and also to ensure the plates being free of bilge-water.

The boiler fittings do not much differ from those used for land boilers, the following are provided for each boiler: Two glass water-gauges, two sets of gauge-cocks, one scum-cock, one blow-off cock, one feed-valve, safety and steam valves; steam whistles for giving notice if the level of the water falls too low, and one or two steam whistles are also supplied for signalling and giving warning when moving near other vessels. The smoke funnels are encased at the lower part with a jacket to keep the heat away from the vessel, and for war ships they are made telescopic to lower by means of chains in time of action. Marine boilers have to be blown off at stated periods to prevent the salt in the water forming on the inside of the plates; this is a great difficulty in all boilers of this kind; scum pipes and several kinds of apparatus are used to prevent the deposit from forming and settling on the plates.

Water should be tested by the hydrometer every one or two hours, to ascertain the density, when it rises beyond a certain amount, the blow-off cocks are opened; if this has not careful attention the interior of the boilers will soon be coated with scale. Small surface or brine cocks are fitted to the boilers at the surface of the water, these are opened occasionally, and the brine is blown out before it has time to deposit.

Drawing No. 44 gives a general idea of the form of these Low-pressure Boilers, they differ in sizes and shape to suit each particular case.

High-pressure Boilers are made either cylindrical or oval in shape, they have two or three tubes, in these the furnaces are placed; the boilers are fitted with a number of small tubes through which the heated gases pass to the uptake box, this is fitted at the front of the boiler and is provided with proper doors for cleaning out the tubes. Boilers of the locomotive type are sometimes used in fast torpedo and other boats; the working pressure on these is sometimes as high as 130 lbs. per square inch; the fire-boxes are made very deep; in general details these boilers do not much differ from boilers used for locomotive engines; for small fast boats the boilers are usually made of steel plates.

Drawing No. 45 shows a high-pressure boiler as used in H.M. ships, and made by Messrs. Maudslay, Sons, & Field; the shape is oval, it is 12 feet 4 inches wide × 14 feet 1 inch high × 9 feet 11 inches long; the shell is $\frac{13}{16}$ inch thick; the end plates $\frac{3}{4}$ inch thick. The furnace tubes are 3 feet 2 inches diameter × $\frac{1}{2}$ inch thick; the tubes are 221 in number and made of Yorkshire iron, they are $2\frac{3}{4}$ inches diameter outside, and weigh $4\frac{3}{4}$ lbs. per foot run; the length of the tubes is 7 feet. The stays of the tube-plate at the lower part are $1\frac{1}{2}$ inch diameter, and at the upper part they are steel, $2\frac{1}{4}$ inches diameter; the small stays at the smoke-box are $1\frac{1}{2}$ inch diameter; the transverse stays are also of steel, $2\frac{1}{4}$ inches diameter. The rivets for the shells are 1 inch diameter and 3·9 inches to 4·4 inches pitch. The man-hole is 11 inches × 16 inches. The furnace bars are wrought iron, and 7 feet long × $3\frac{1}{2}$ inches deep. The working pressure of the boiler is 90 lbs. per square inch, and proved to 180 lbs. per square inch.

The drawing is in full detail, and shows the exact construction of this kind of boiler, and may be taken as a good example of its class; a careful study of it will enable the reader to understand it more clearly than any further detail in description.

Drawing No. 46 shows a cylindrical high-pressure boiler by the same makers; the shell is of Siemens-Martin steel, it is 13 feet 4 inches diameter × 9 feet $1\frac{1}{4}$ inch long outside; the thickness of plates is $\frac{15}{16}$ inch, and the end plates $\frac{5}{8}$ inch thick. There are three tubes in which the furnaces are placed, these are 3 feet 2 inches diameter × $\frac{1}{2}$ inch thick; the tubes are jointed, with solid flanges. The furnace bars are in two lengths, and are 6 feet 6 inches long. The tubes are iron, $2\frac{3}{8}$ inches diameter, they are No. 9 gauge, and are 6 feet 3 inches long between the tube-plates; the total number of tubes is 287. The steam chamber is 3 feet $4\frac{1}{2}$ inches diameter × 5 feet high. The stays between the front and back plates are Siemens-Martin steel, 2 inches diameter, and eighteen in number; the lower stays are $1\frac{5}{8}$ inch diameter; the stays between the outer and inner shell are $1\frac{1}{4}$ inch diameter. The furnaces and fire-boxes are made of Yorkshire iron. The rivets for the shell are 1 inch diameter × $3\frac{1}{4}$ inches pitch; the rivets for the tubes are $\frac{7}{8}$ inch diameter × $2\frac{1}{4}$ inch pitch. There are five man-holes at the lower part of the boiler, and one at the steam chamber. Each internal box is stayed by five bridge stays at the combustion chamber. The front and back plates are solid flanged, and double riveted to the shell plates; these are made in three lengths. The drawing is in full detail, and shows the general construction very clearly.

Engines for Steam Launches and Yachts.

These are made in various forms for small boats; the most usual kind are those made in the form of inverted cylinder engines and fitted to side frames, the screw-shaft is geared direct or worked by spur gear according to the size of the vessel. These engines have two cylinders, and are worked with high-pressure steam; the pressure of steam used is about 50 to 60 lbs. per square inch; they run at a high speed; the slide-valves are worked by two eccentrics to each cylinder, they are fitted with link motions to run the engines either way as desired. The method of construction will be understood by reference to p. 57, where a description is given of land engines of the same kind; they do not very materially differ from these engines. All the moving parts are well balanced and are made of steel or gun-metal, the bearings are made long. The engines have to be stowed in a small compass; so are made as compact as possible, and the parts much lighter compared with their power than in land engines. Horizontal engines fitted with oscillating cylinders are sometimes used; link motion is provided to work the slide-valves; the piston-rod cross-heads work direct on to the screw-shaft; the engines are run at a high speed, and the pressure of steam is generally not less than 60 to 70 lbs. per square inch. Engines for Steam Launches are sometimes made upon the Compound system.

Boilers for Steam Yachts.

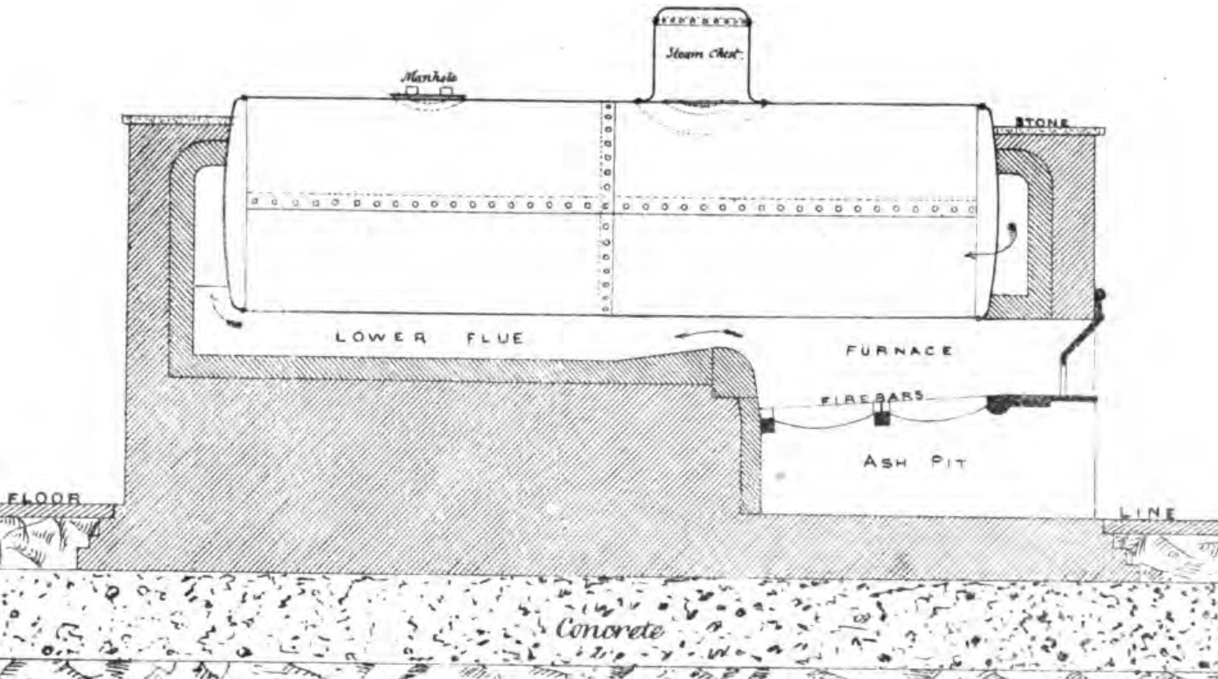
These are made either in the vertical or horizontal forms, and either in the multitubular form or with cross tubes, in the same way as described at pp. 18 and 19. For small boats the boilers are nearly always made vertical, and in many instances the engine frames are bolted on to them. The plates of the boilers are either made of steel or Lowmoor iron of the best quality; the funnel is fixed direct on the top of the smoke-box; the exhaust steam is passed into it for the purpose of creating a good draught at the furnace. The exterior of the boiler is covered with felt and wood lagging, and all the steam pipes, cylinders, and other parts through which steam passes are also covered with felt or other non-conducting materials. The fittings of the boilers do not differ from land and locomotive boilers. The fuel burned is either coal or coke, the latter is the most suitable because no smoke is produced. The engine and boiler are generally placed mid-ship and the steering wheel near them to enable those who drive the engines to steer the boat at the same time. Some of these small boats obtain a considerable speed, they are easy in movement in the water, and when well proportioned are economical in working. Very high results have been obtained in the small torpedo boats, as far as lightness and speed are concerned, this is the chief object, the consumption of fuel is not so closely considered in such cases; these are, however, a very special class of boat, the engines and boilers are constructed on a special plan.

In this section of the book upon marine engines and boilers, the intention has been to give sufficient information to indicate the general forms in modern use; the subject is too large to treat in more full detail; the student is recommended to consult the many good books that have been written on the subject, and then to see the various types of engines and carefully study the details while at work.

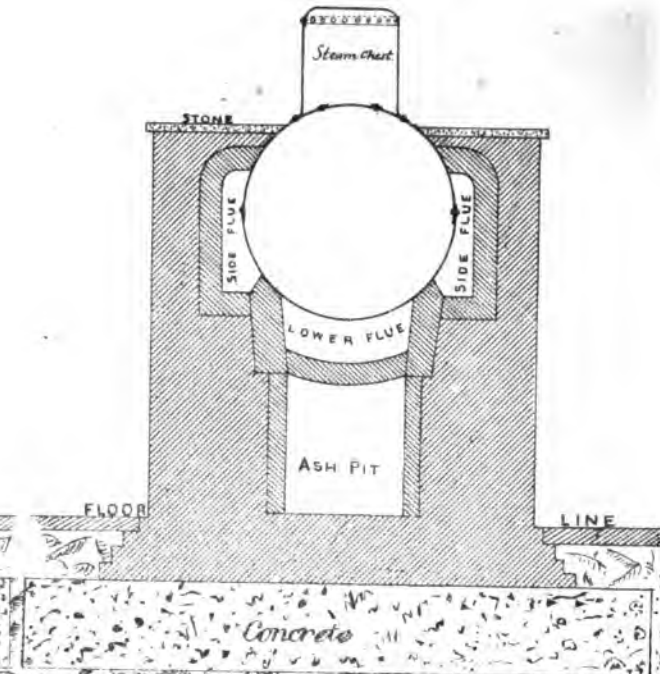
INDEX.

LONDON: PRINTED BY WILLIAM CLOWES AND SONS, LIMITED, STAMFORD STREET AND CHARING CROSS.

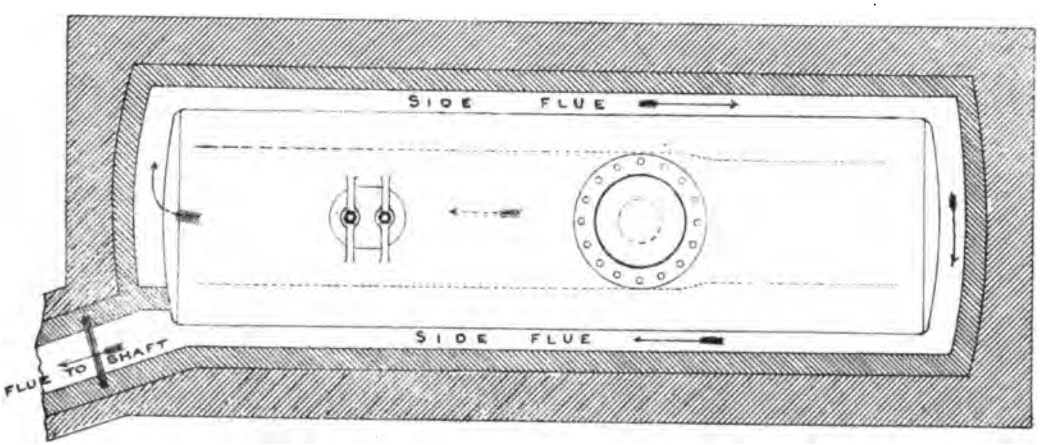
SETTING FOR 3.6 × 13.0 BOILER.



LONGITUDINAL SECTION



TRANSVERSE SECTION



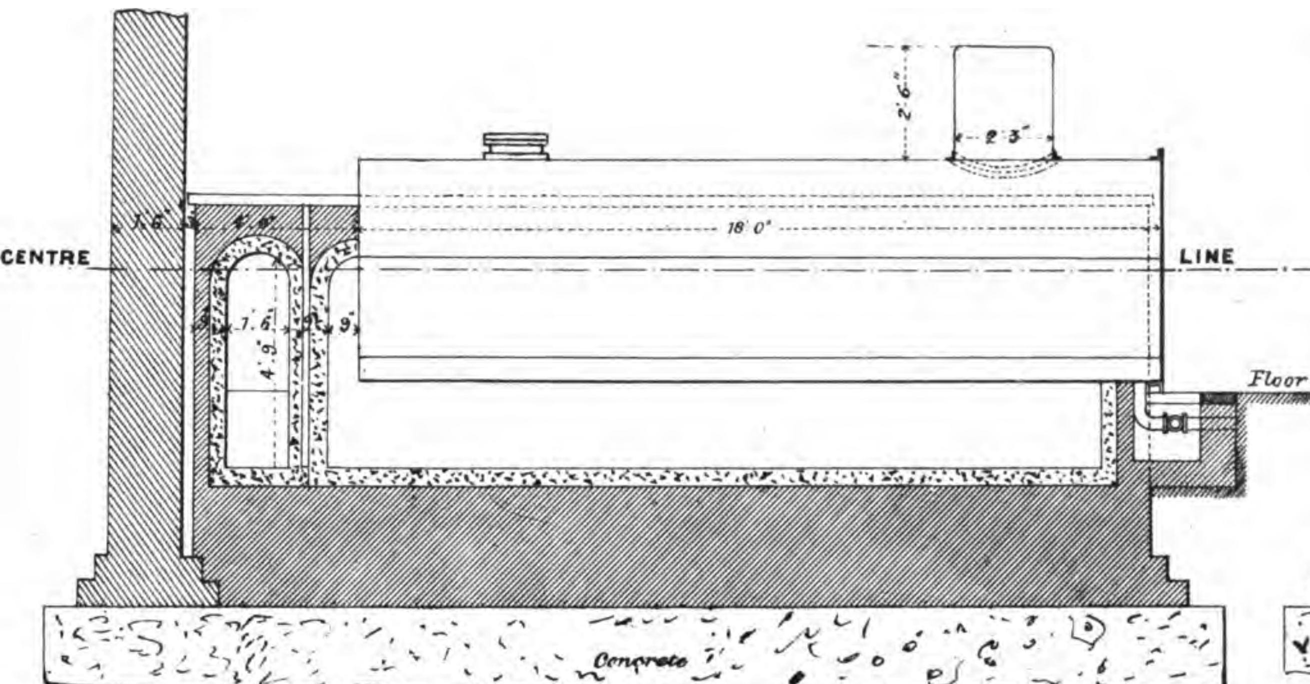
PLAN

F. Colyer: M. Inst. C.E.

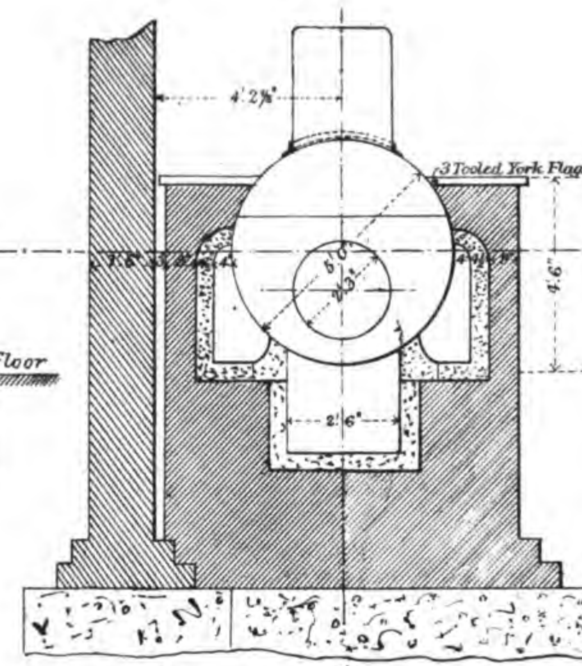
Spon, London & New York

PHOTO-LITHO. SPRAGUE & Co LONDON

CORNISH BOILER.



LONGITUDINAL SECTION.



TRANSVERSE SECTION AT A.B.

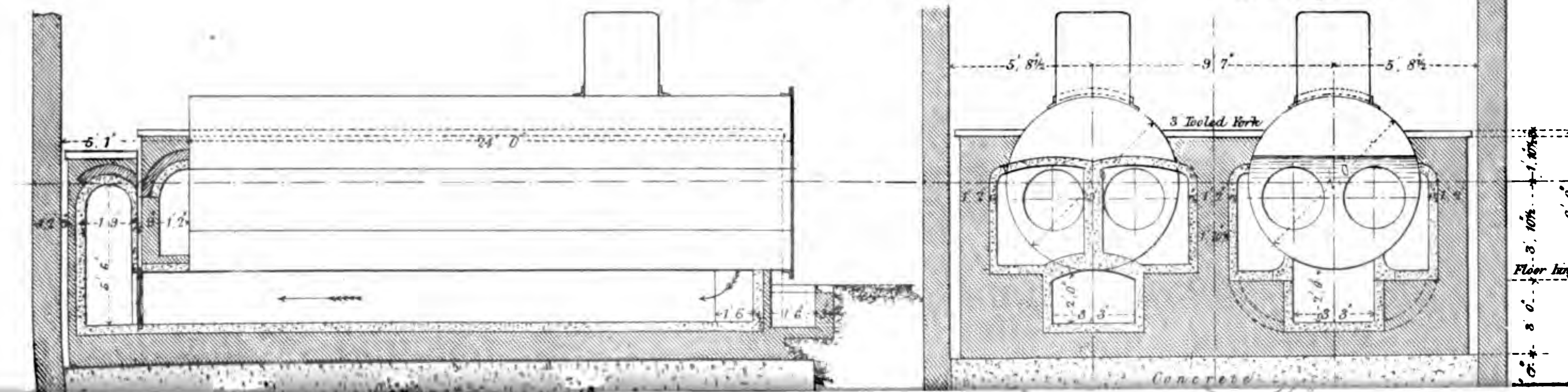
F. Colyer. M. Inst. C.E.

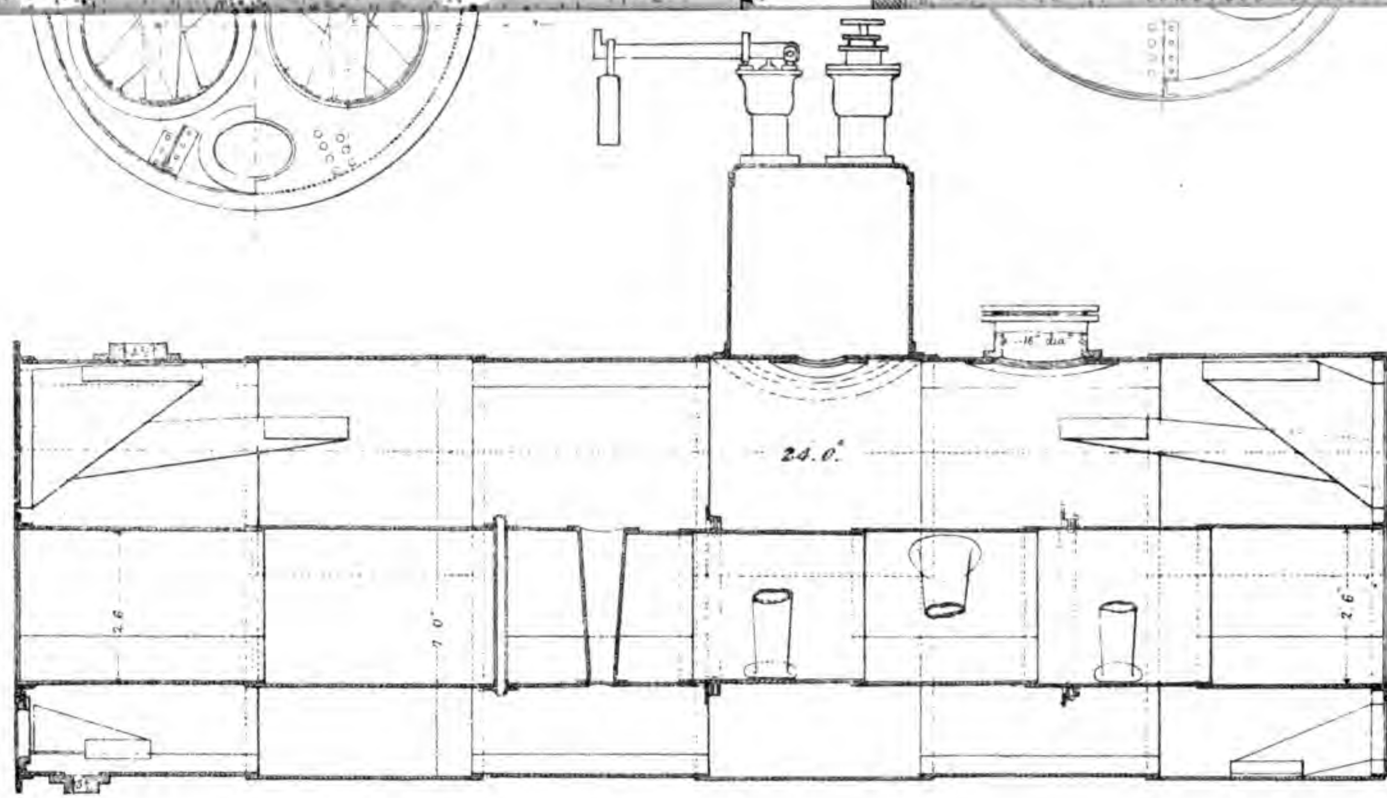
E. & F. N. Spon, London & New York

PHOTO-LITHO. SPRAGUE & Co. LONDON.

LANCASHIRE BOILERS.

Drawing No. 3.



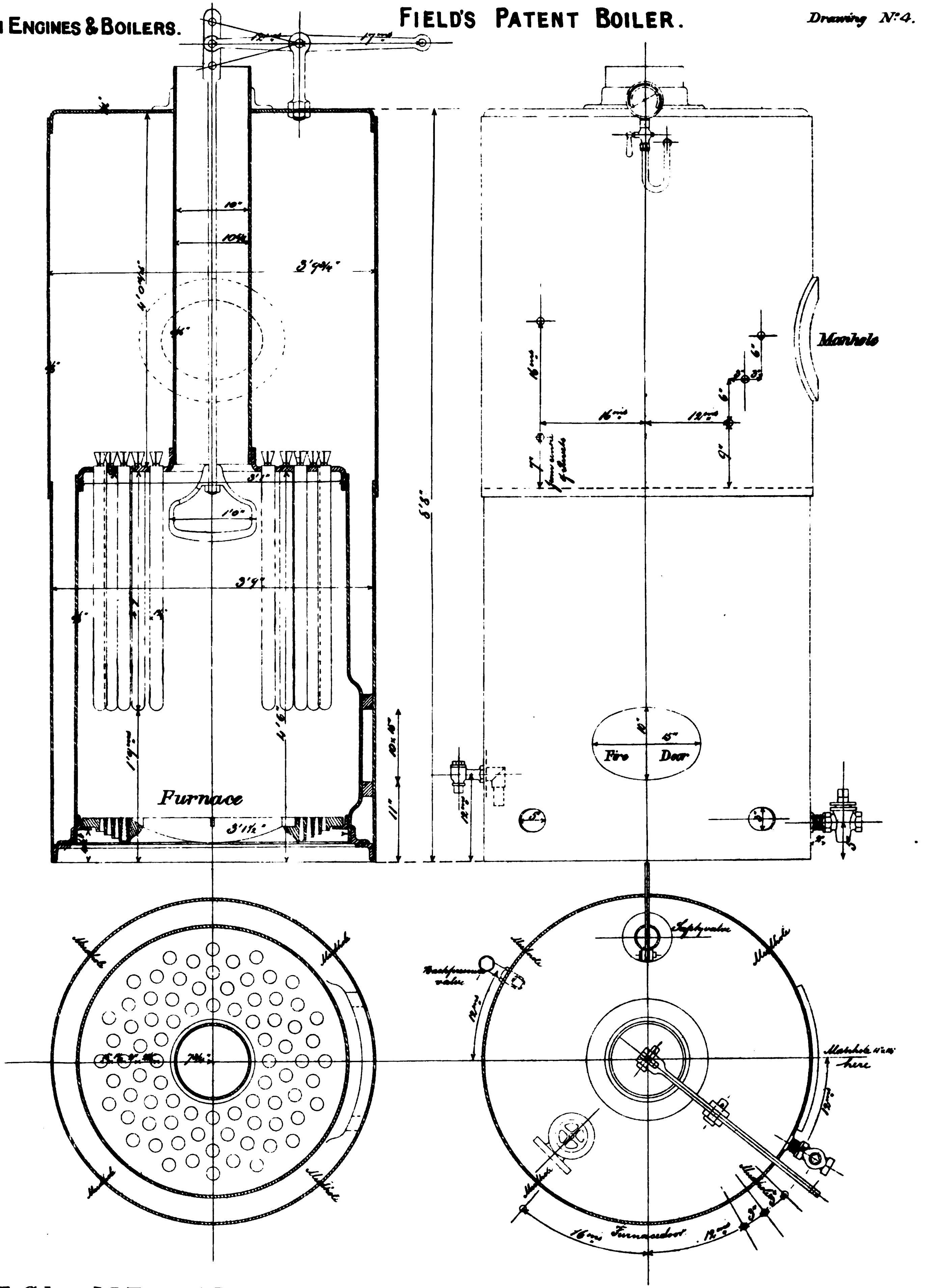


LANCASHIRE BOILER. 7' 0" DIA. × 24. 0

F. Colyer M. Inst. C. E.

FIELD'S PATENT BOILER.

Drawing N° 4.

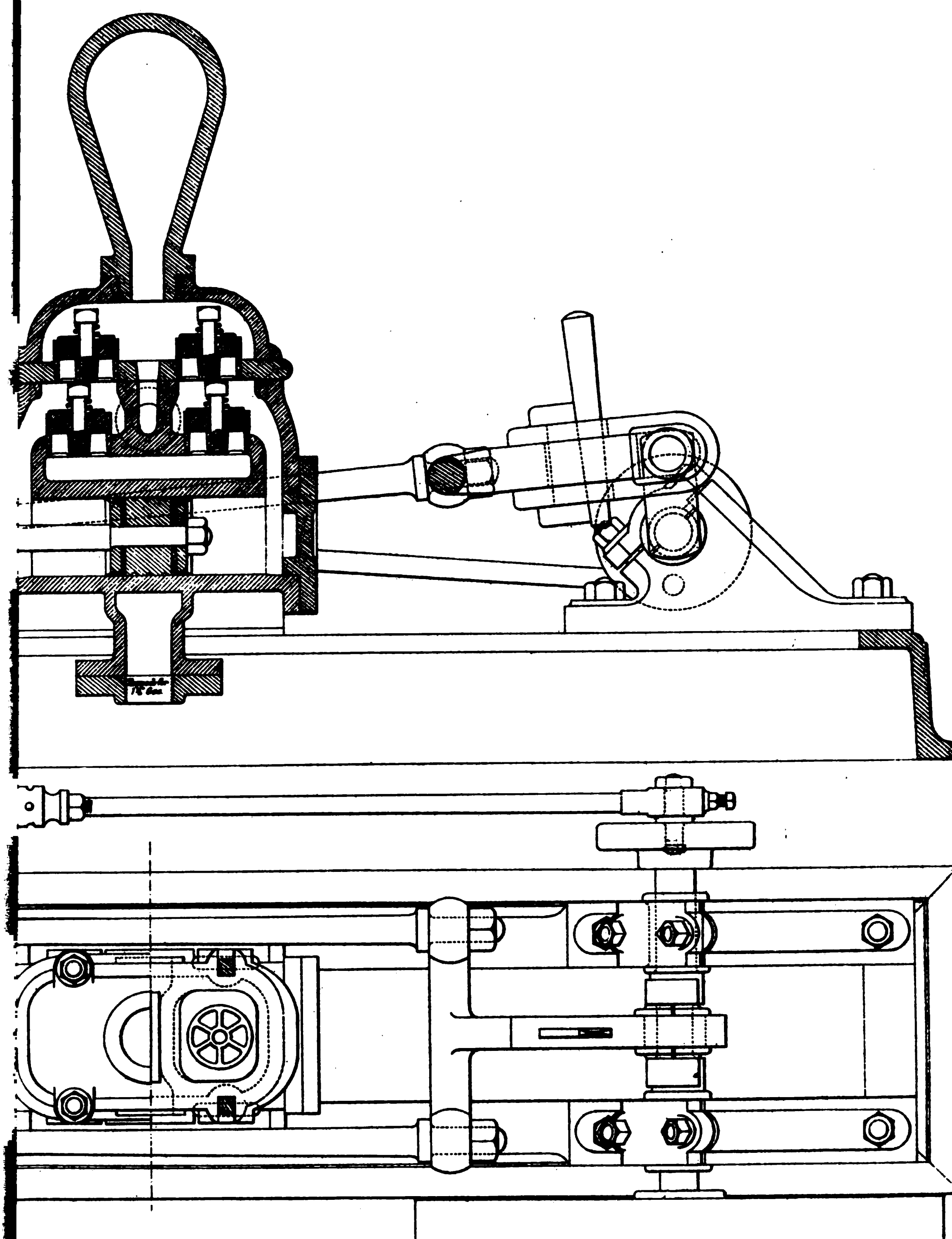


Drawing Nº 5.

STEAM PUMP.

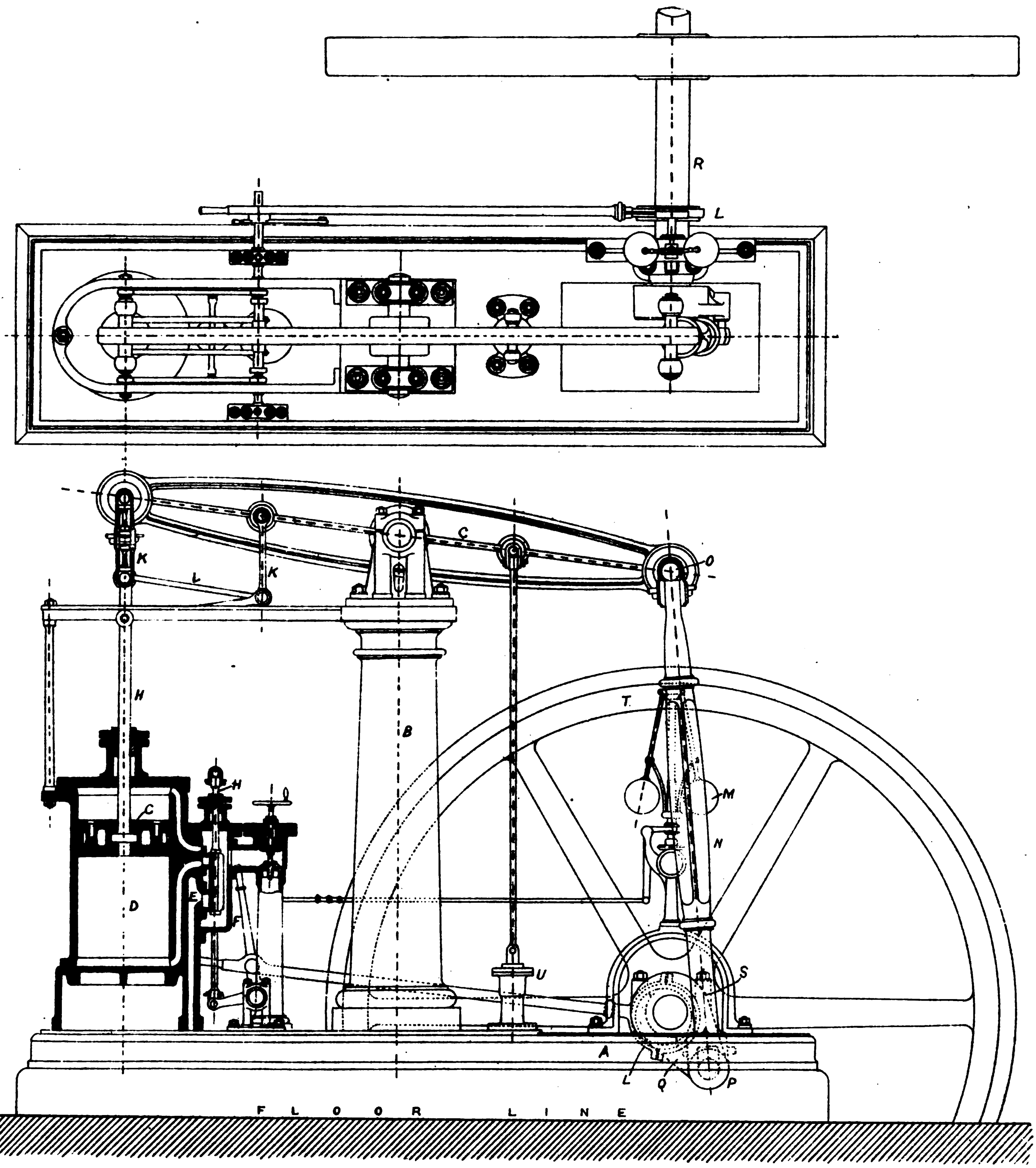
THORNEWILL & WARHAM.

URTON ON TRENT.



HIGH PRESSURE BEAM ENGINE.

BY MESSRS GEORGE WALLER & Co
LONDON.

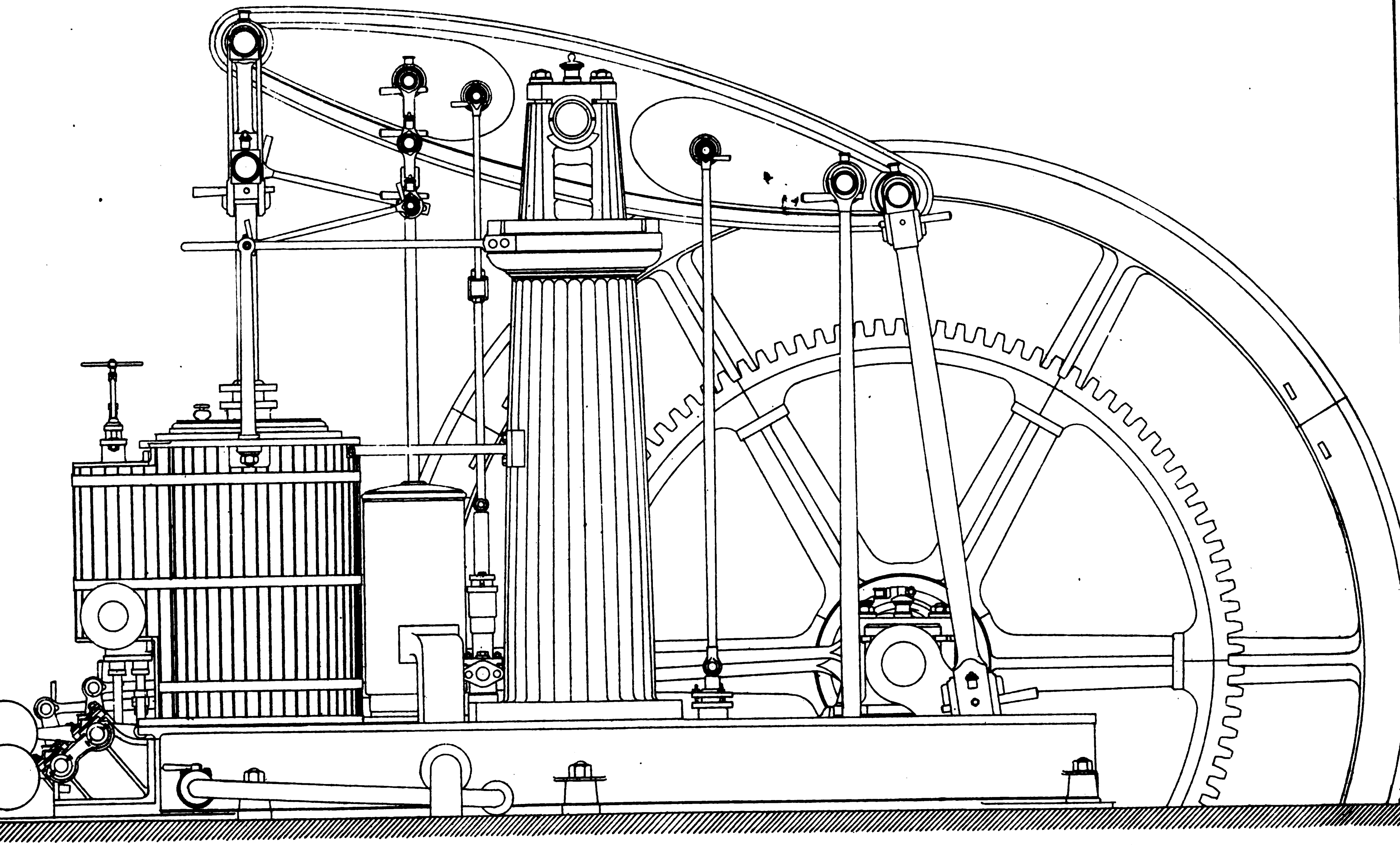


F. Colyer M. Inst. C.E.

CONDENSING BEAM ENGINE. By Mess^rs. Simpson & C^o.

Cylinder 2.6 diam Stroke 3.6.

Scale ½ - 1 Foot.

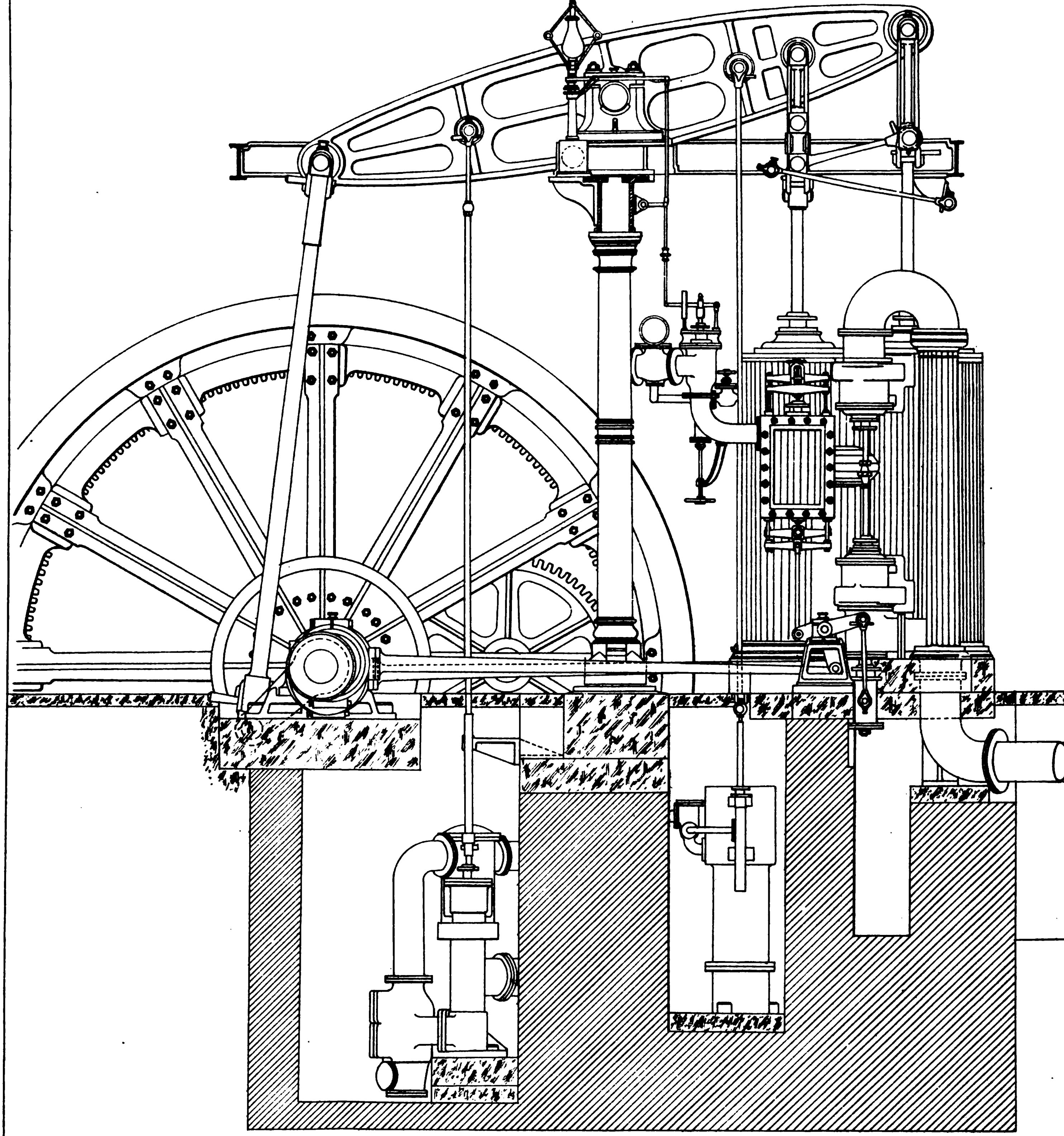


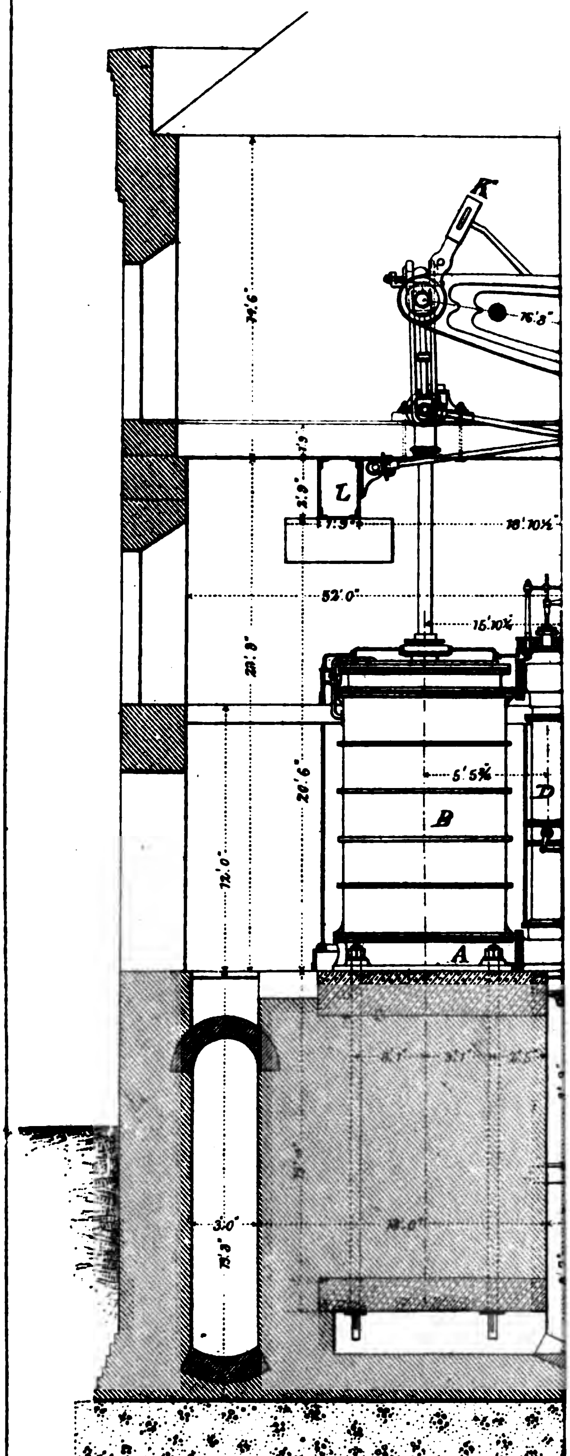
F. Colyer. M. Inst. C.E.

COMPOUND BEAM MILL ENGINE.

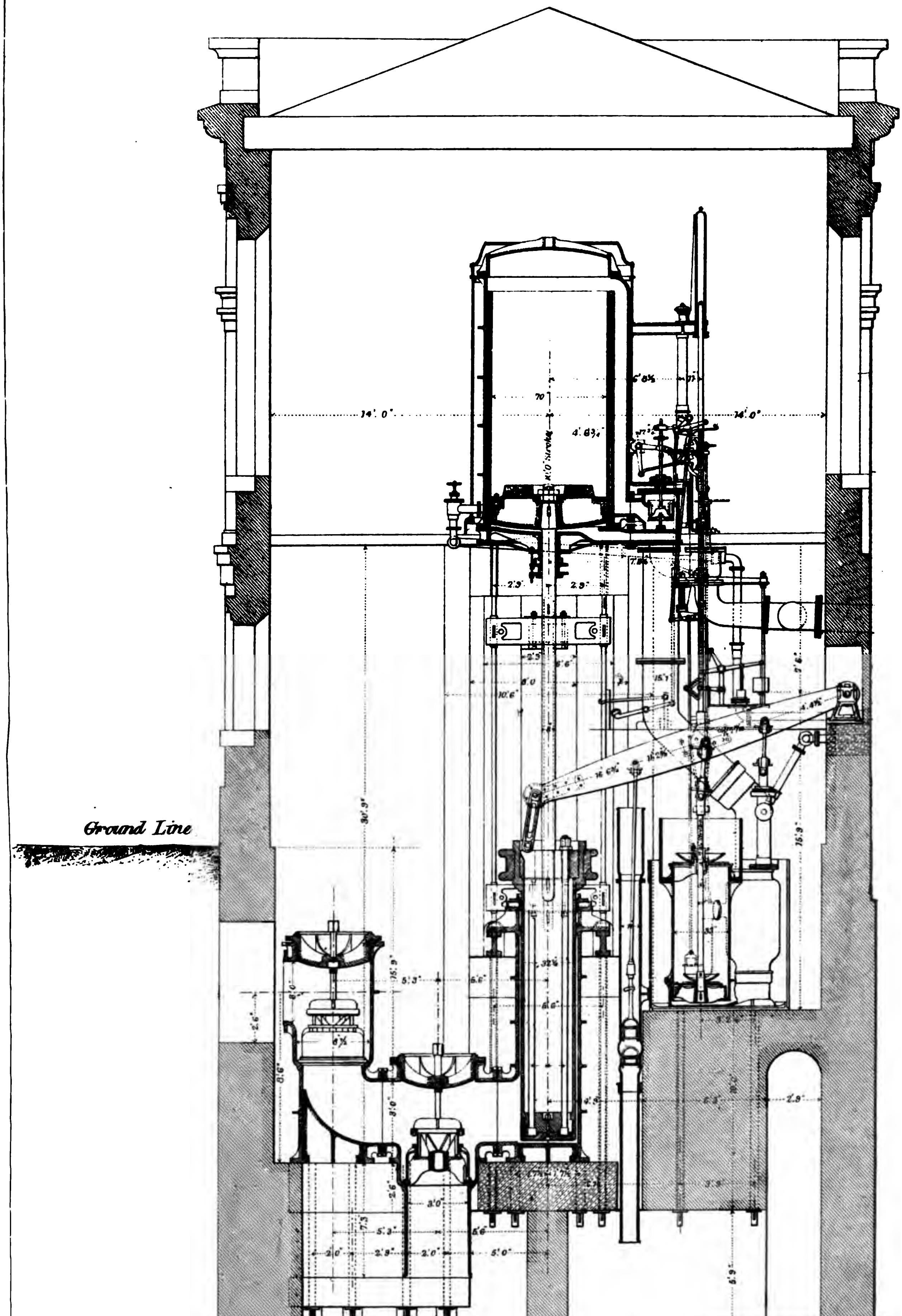
Drawing No. 8.

BY MESSRS. SIMPSON & Co. LONDON.




K
G
L
B
D
A
5' 5⅝"
52' 0"
15' 10¼"
18' 10½"
20' 6"
72' 0"
3' 0"

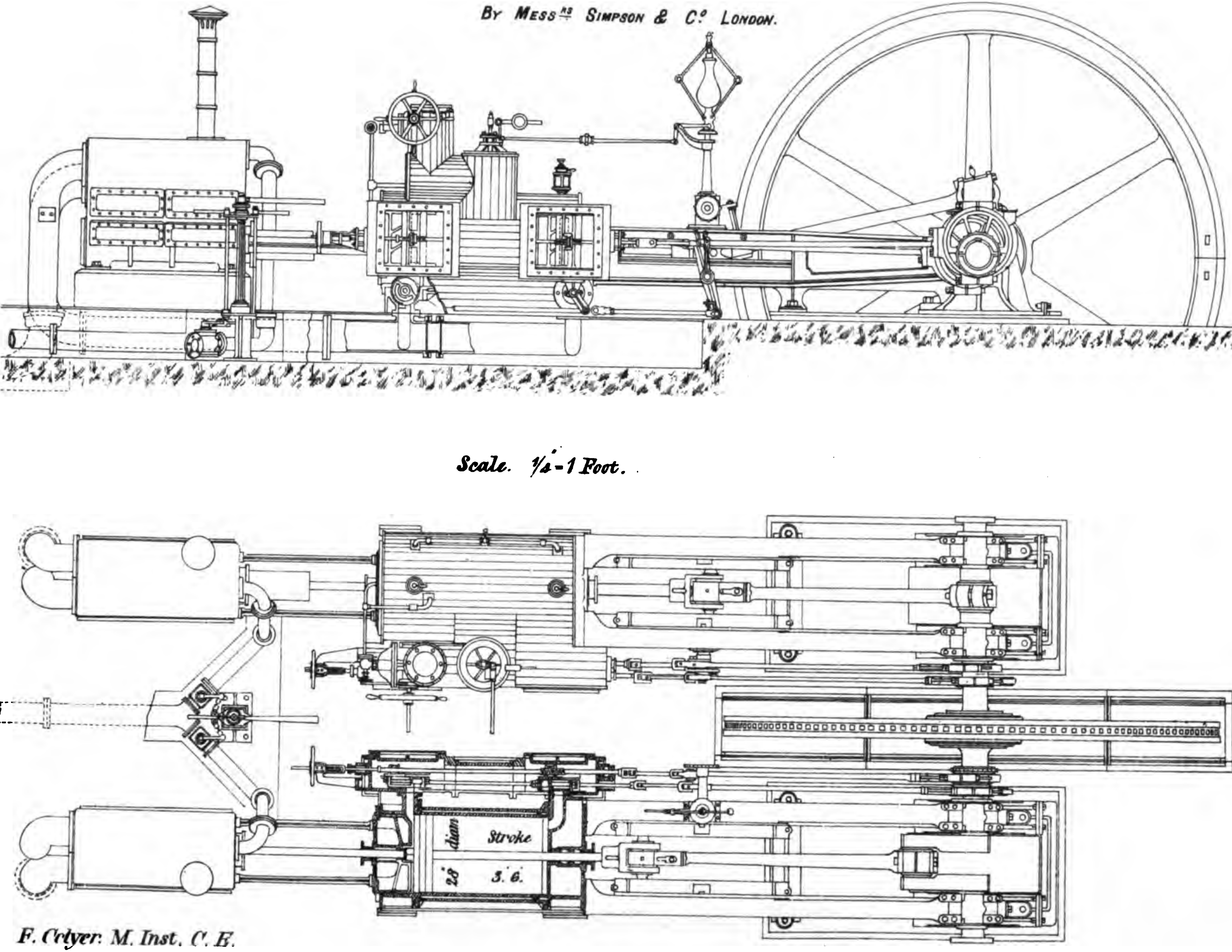
CORNISH BULL ENGINES.



HIGH PRESSURE CONDENSING ENGINES.

Drawing No. 12.

BY MESS^RS SIMPSON & C^O LONDON.

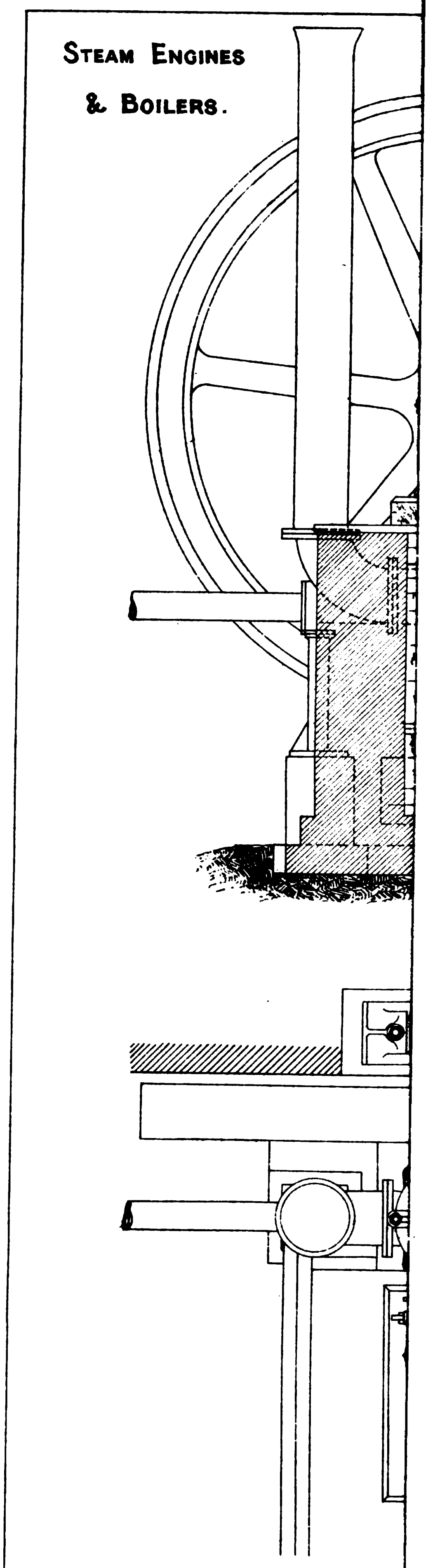


Scale. 1/2" - 1 Foot.

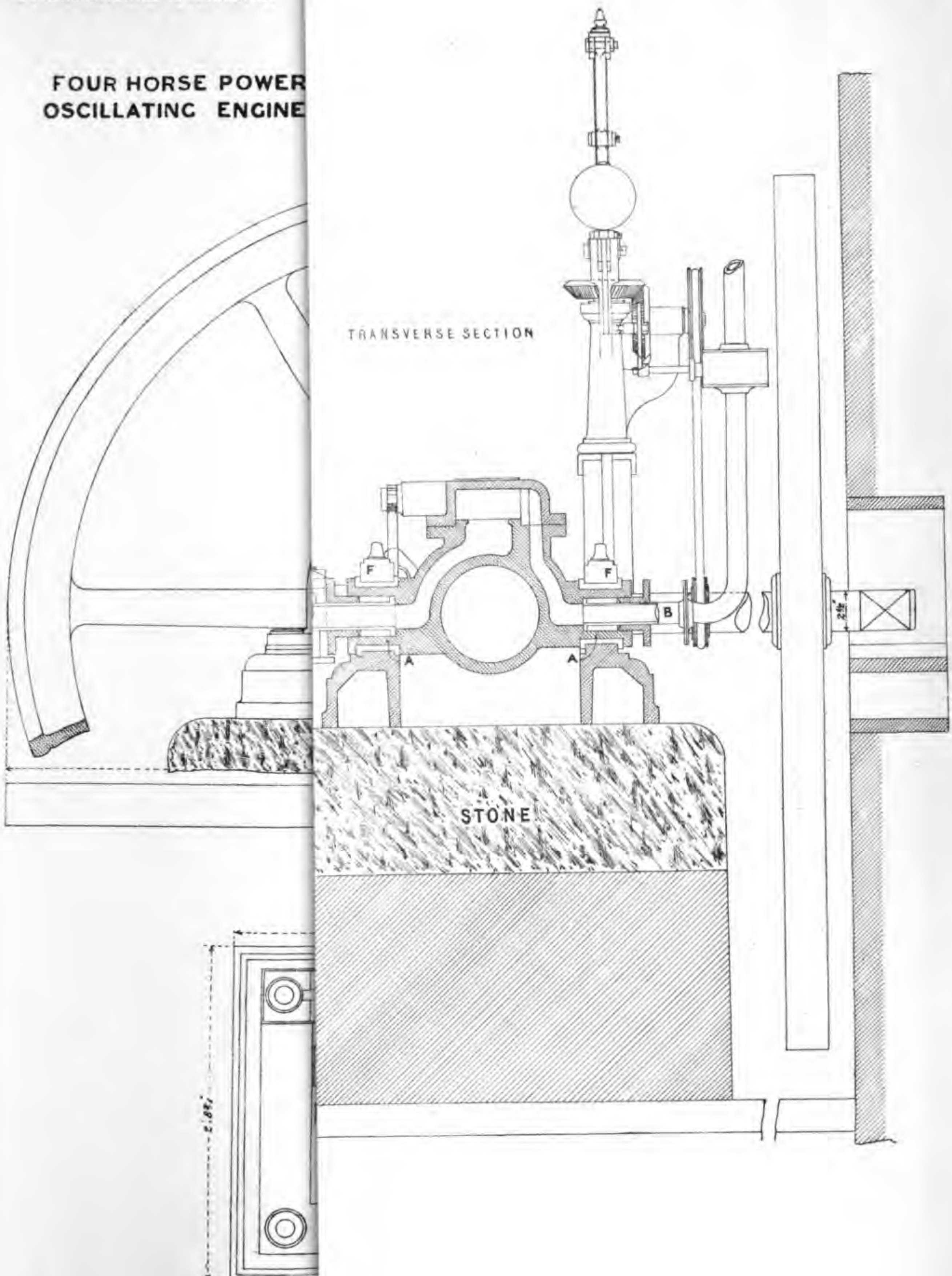
F. Colyer. M. Inst. C. E.

Spon, London & New York

Sprague & C^o Photo-litho. London


Steam Engines
& Boilers.

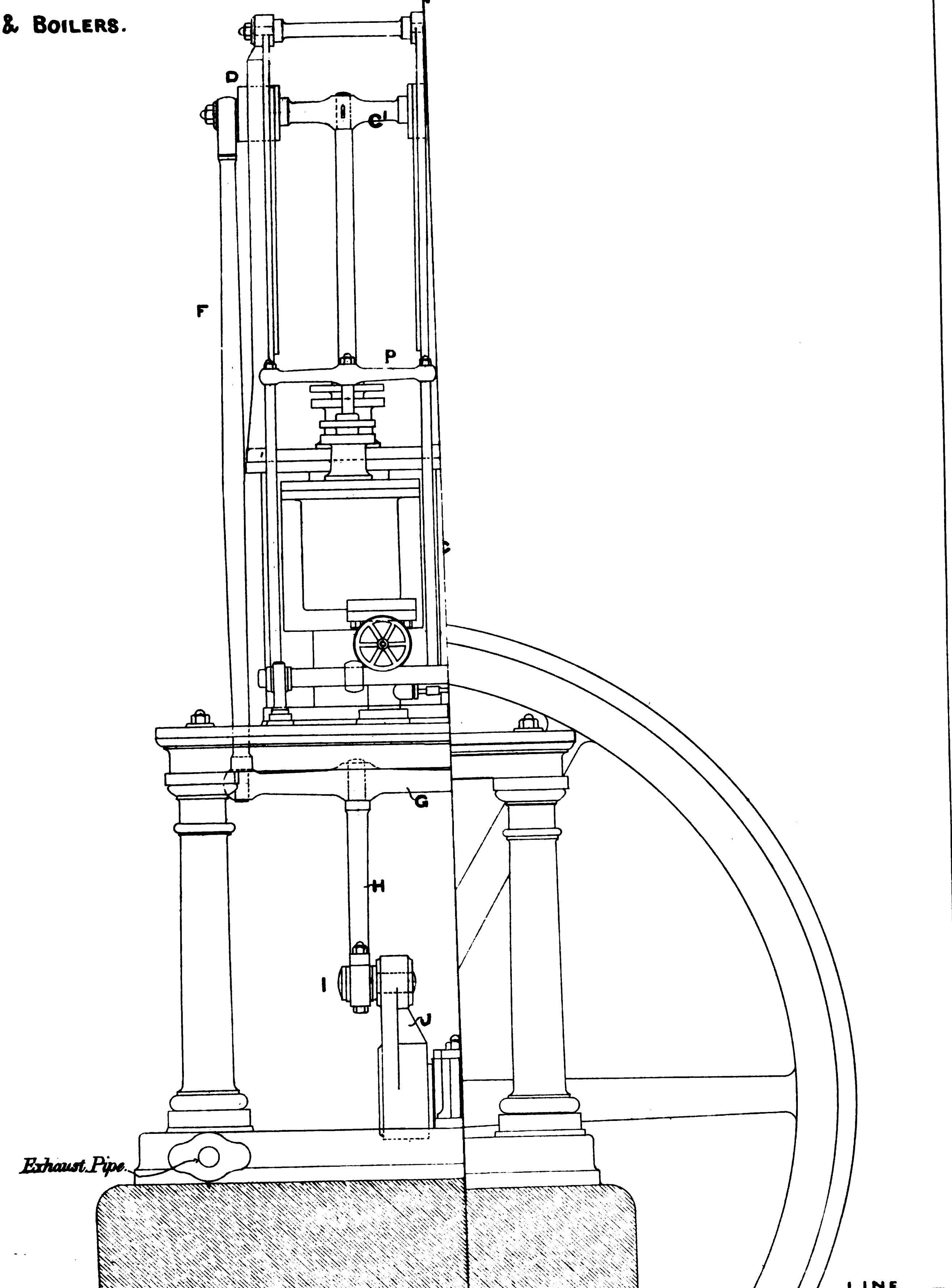
FOUR HORSE POWER OSCILLATING ENGINE



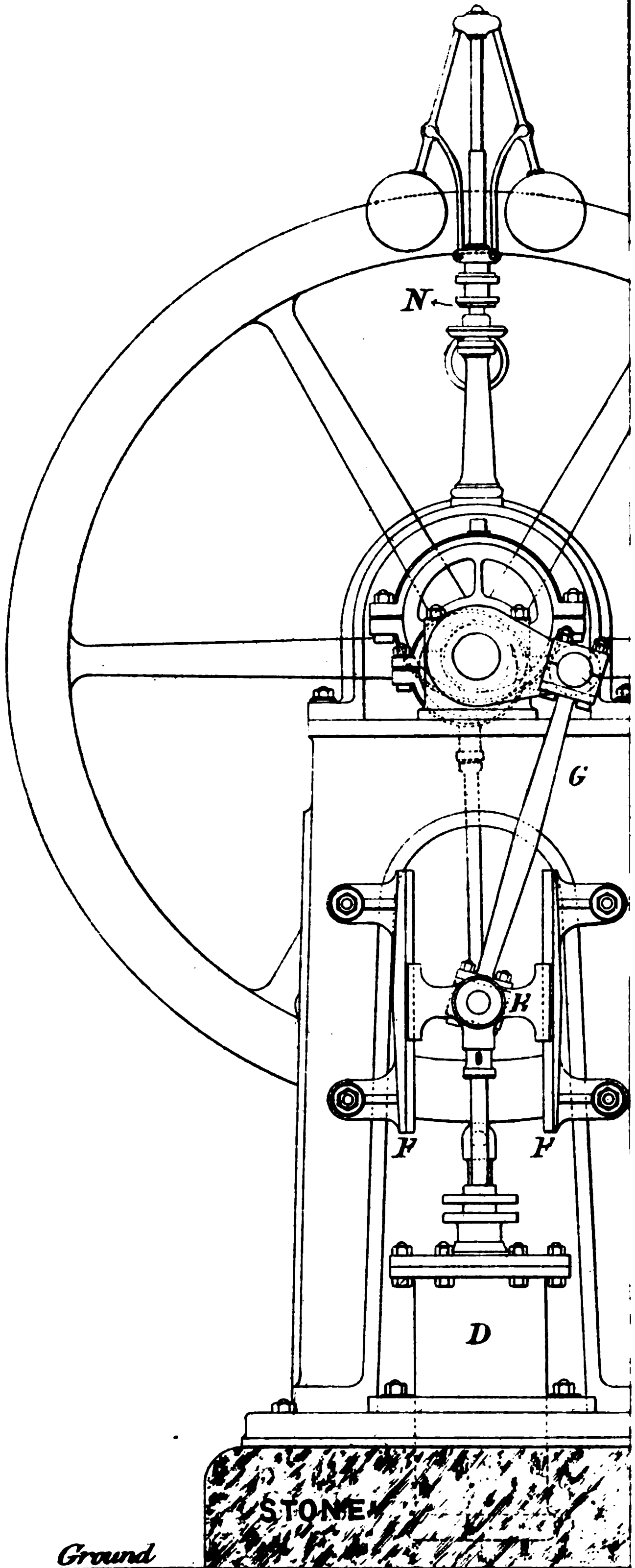
STEAM ENGINES & BOILERS.

END ELEVATION

Drawing Nº 15.

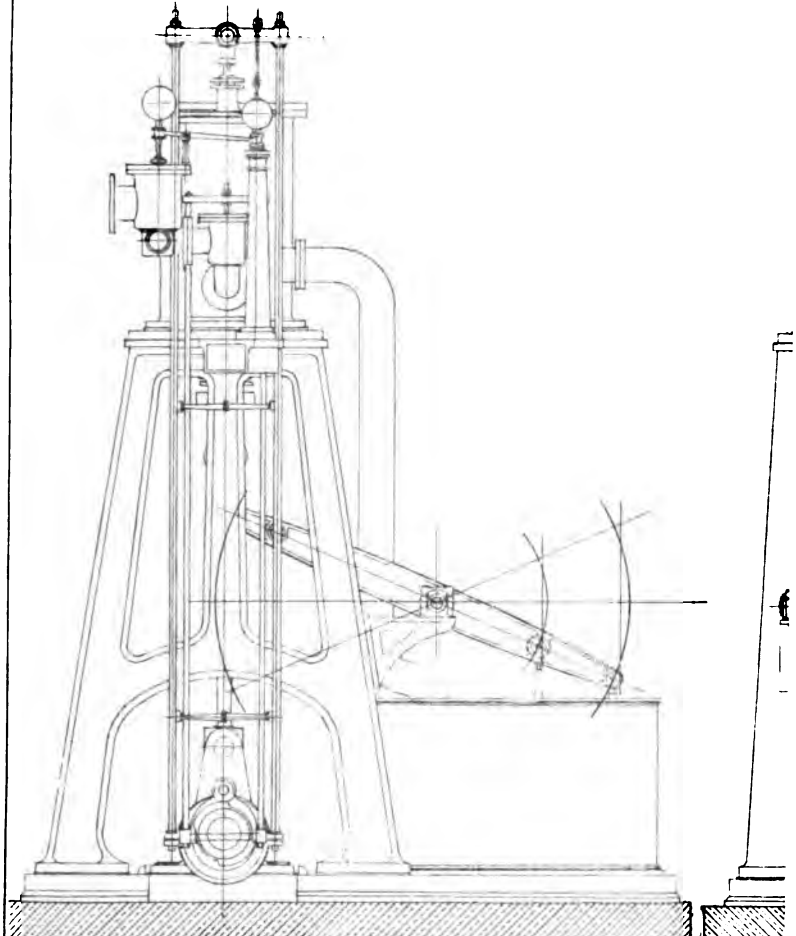


8 H

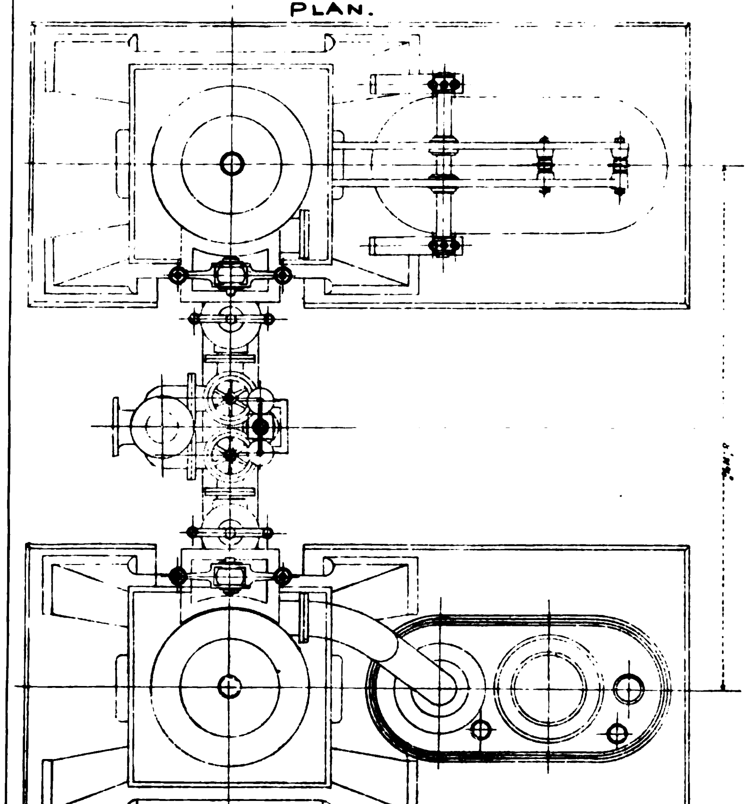


STEAM ENGINES & BOILERS.

FRONT ELEVATION

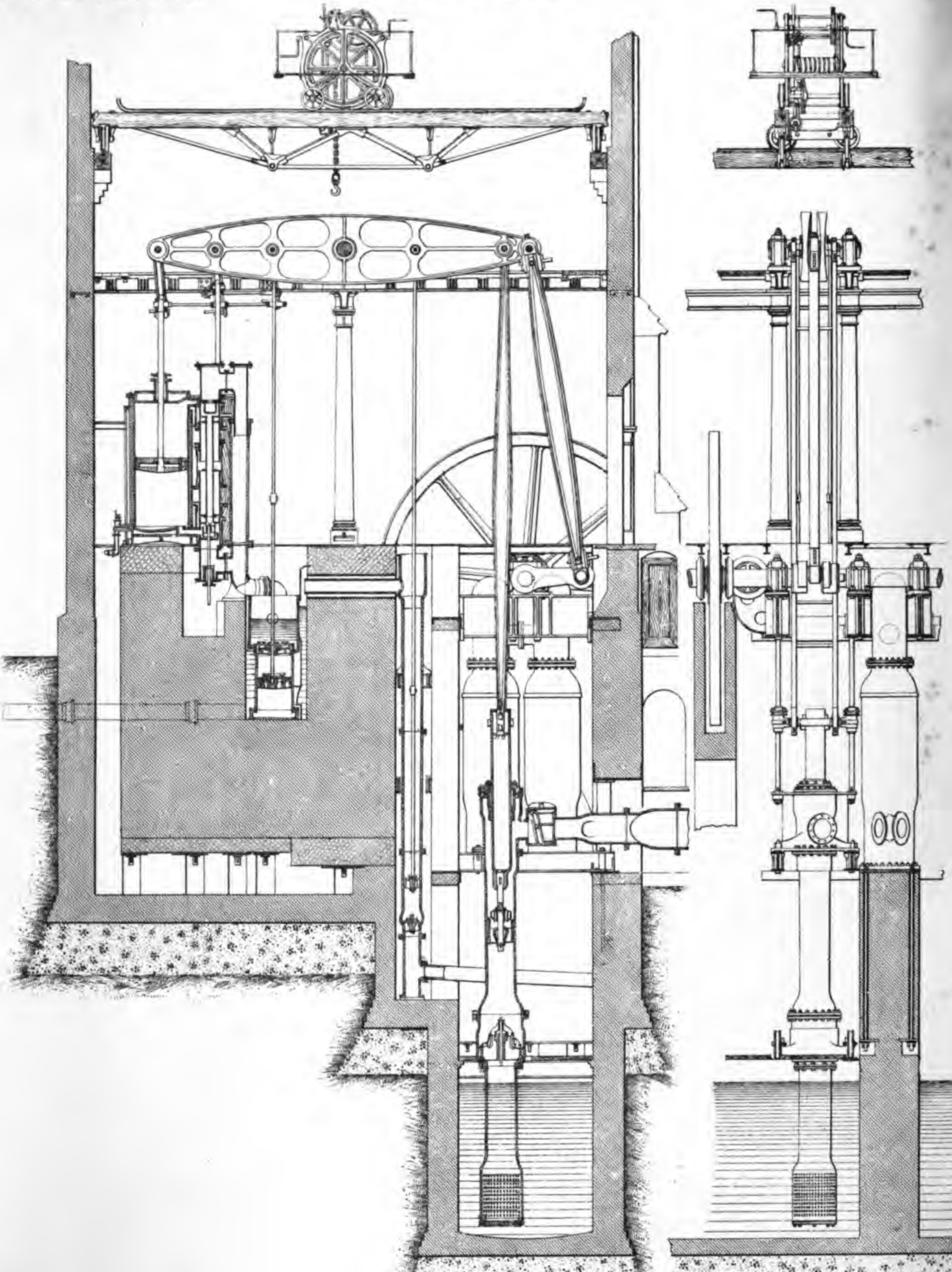


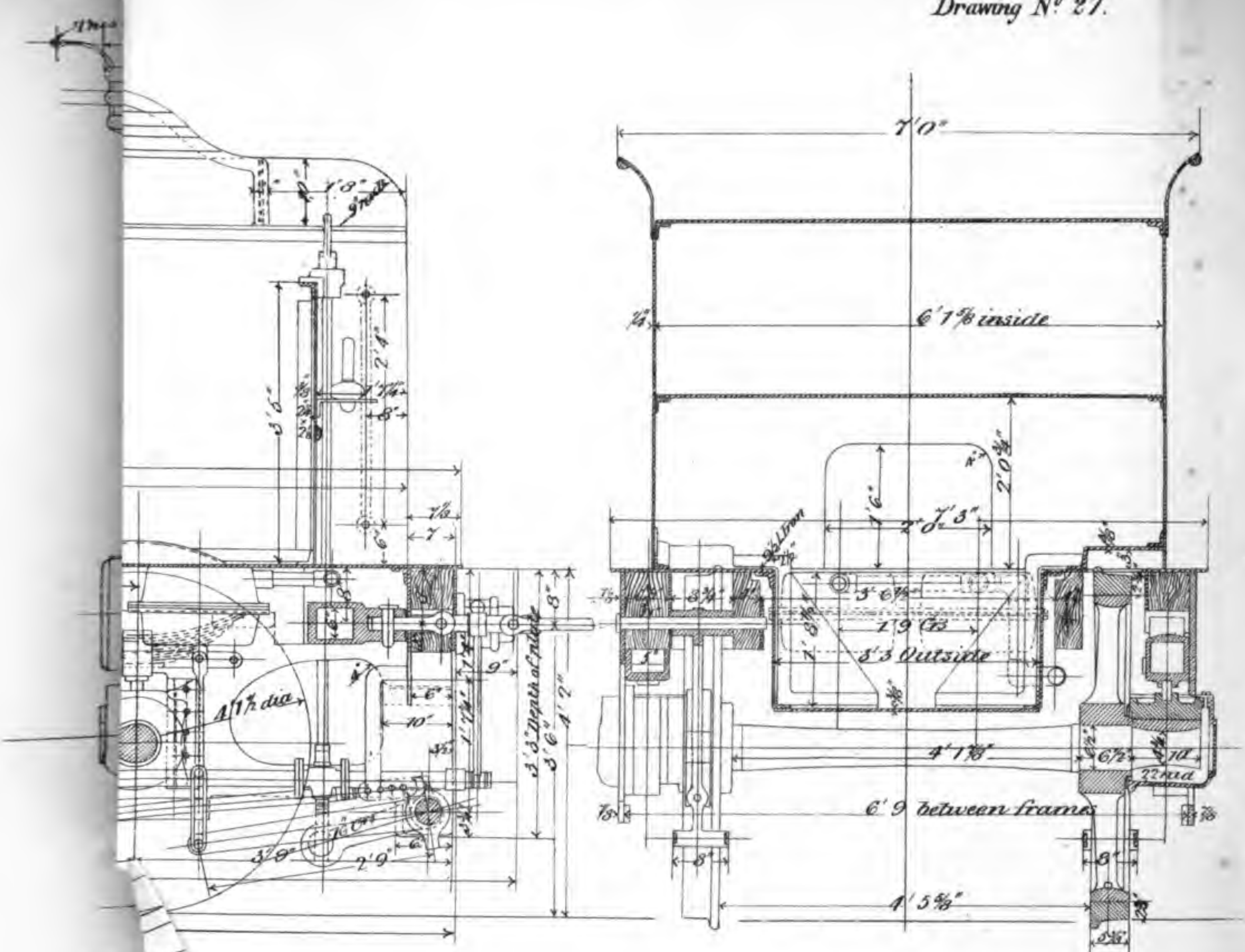
PLAN.

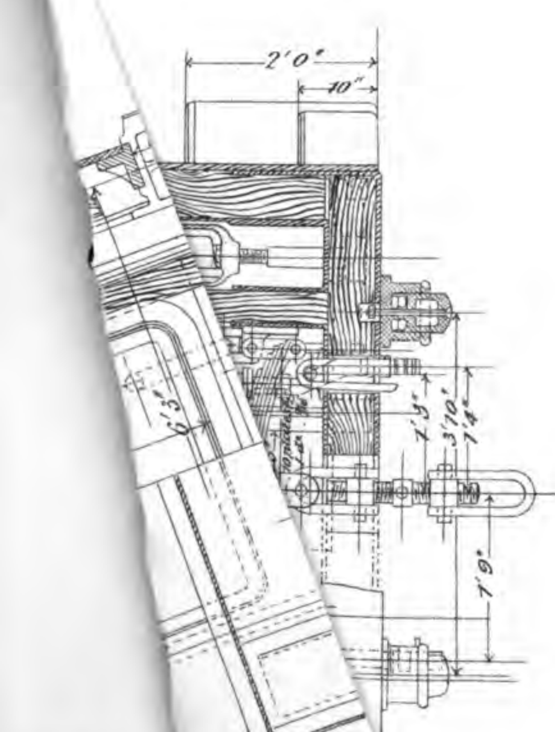


HIGH & LOW PRESSURE BEAM ENGINES.

BY MESS^RS SIMPSON & C^O

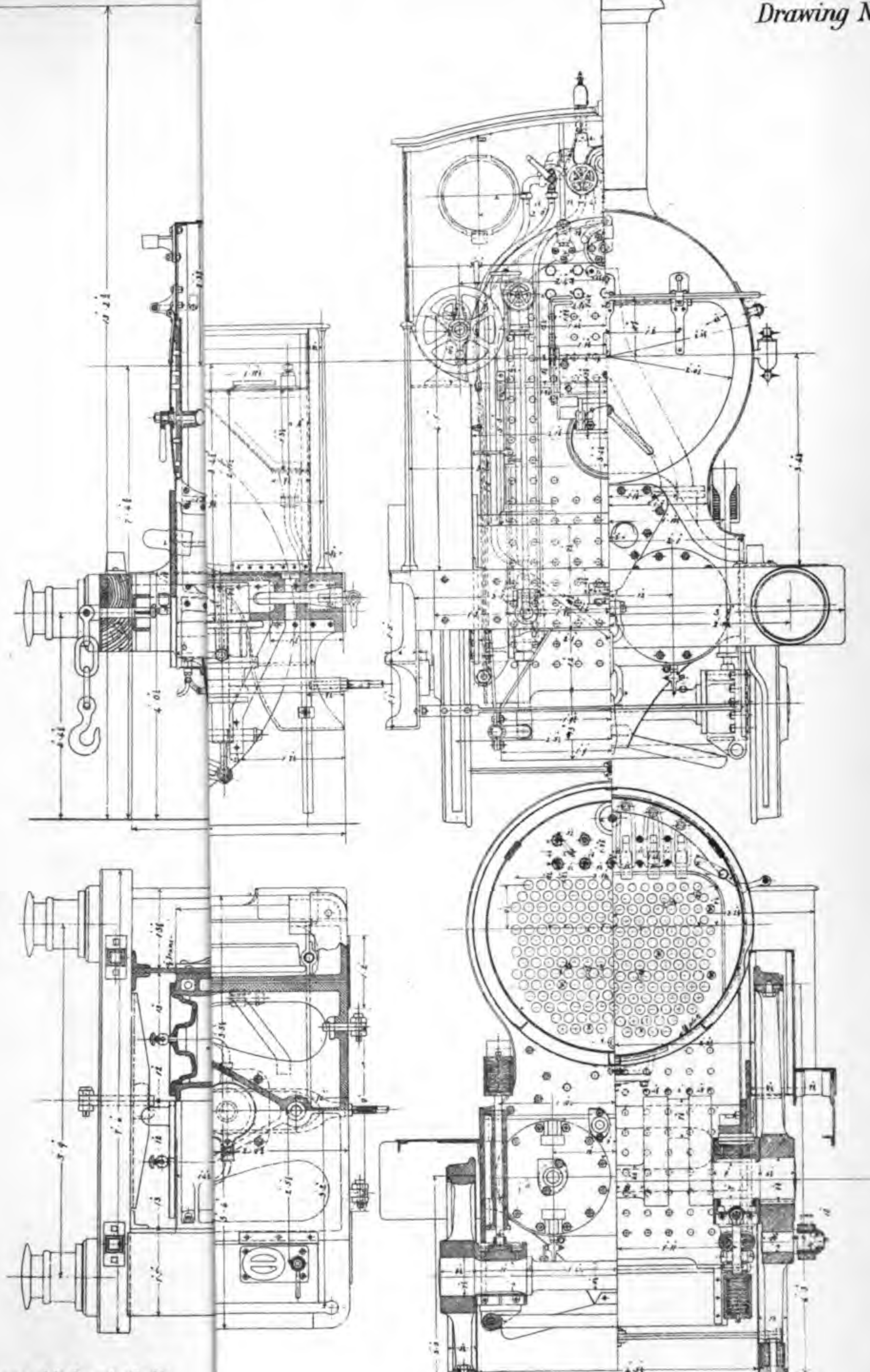


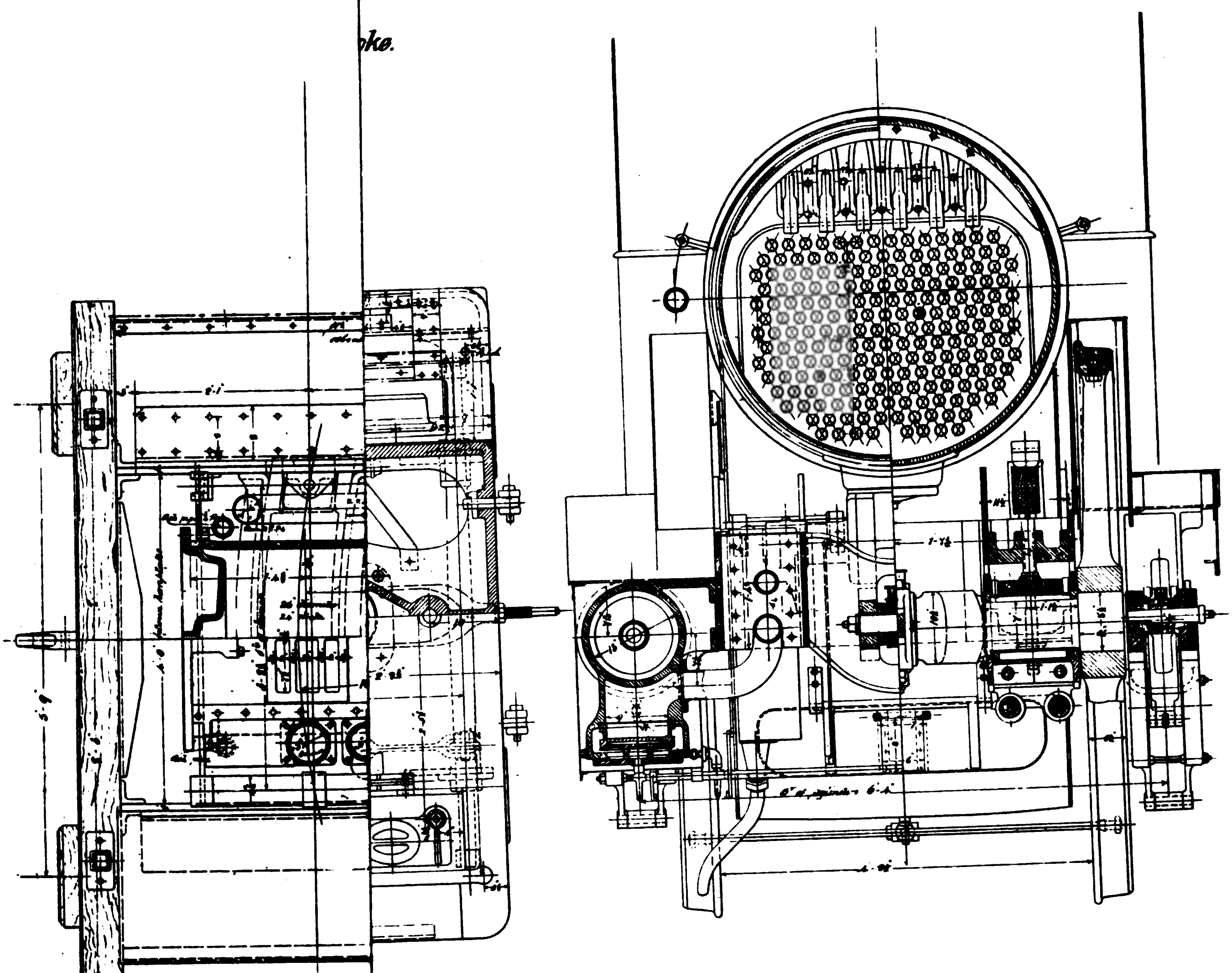




Scale. ½" = 1 Foot.

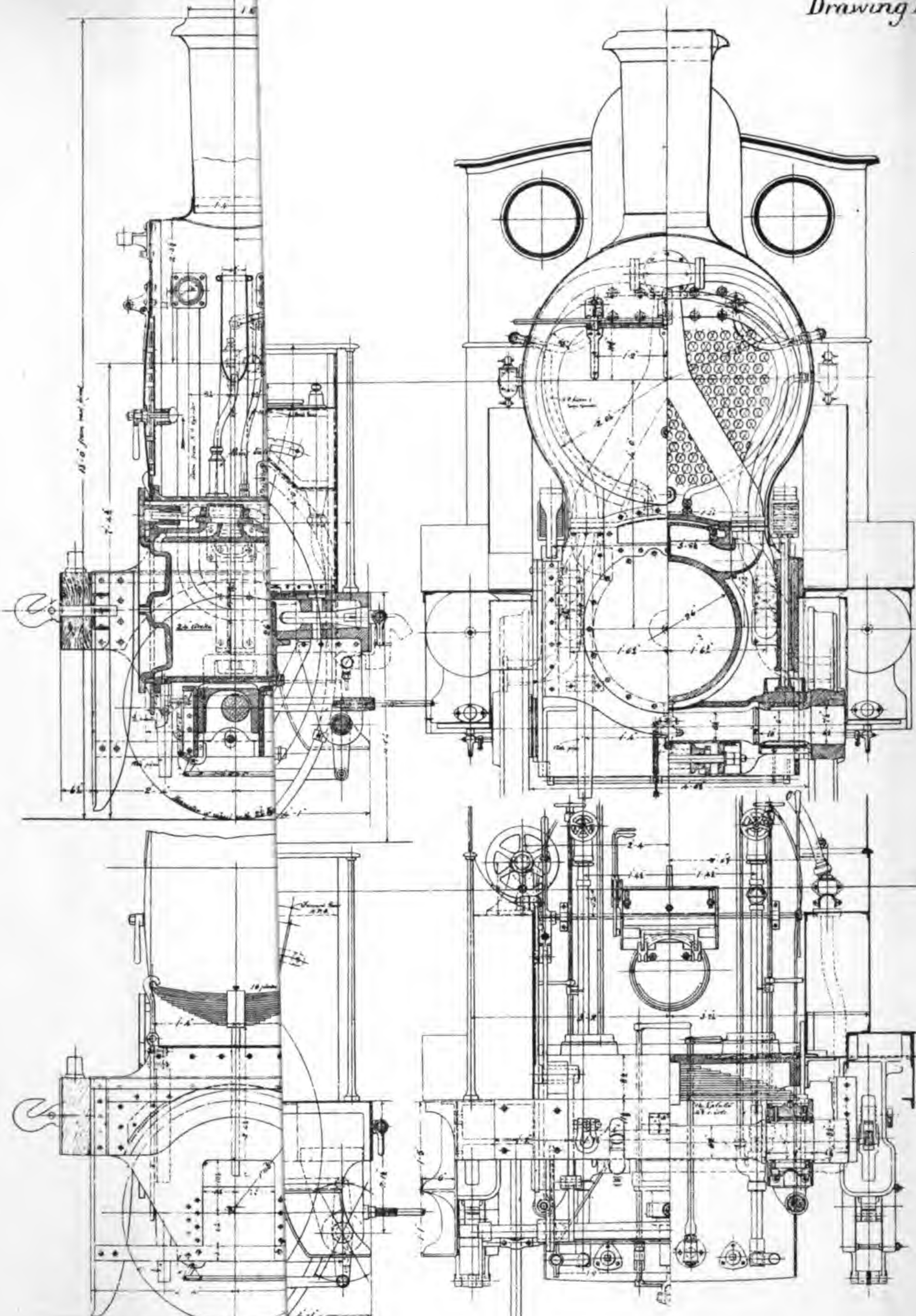
Drawing No. 28.



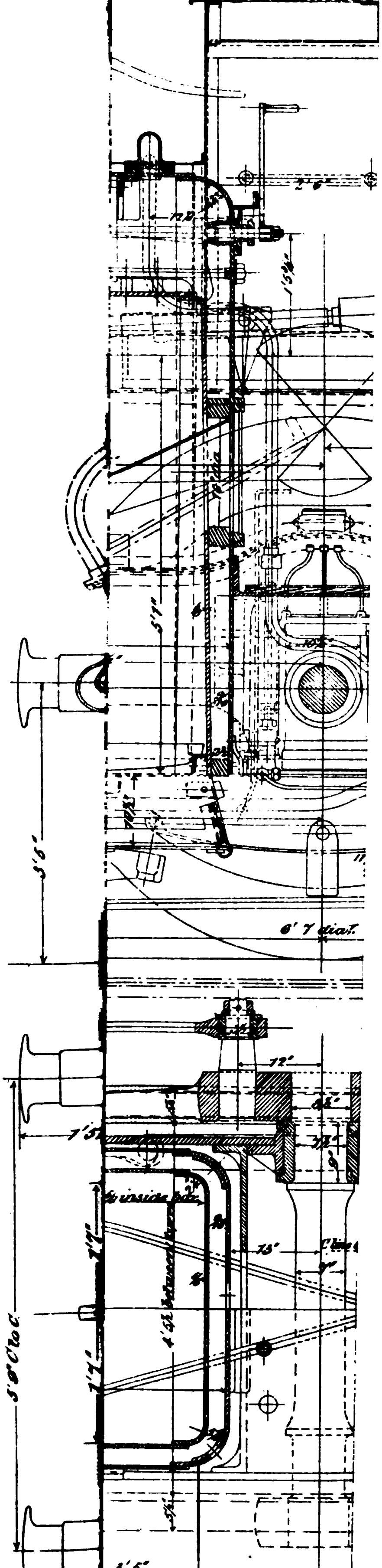


END ELEVATION

Drawing No. 30.



STEAM ENGINES



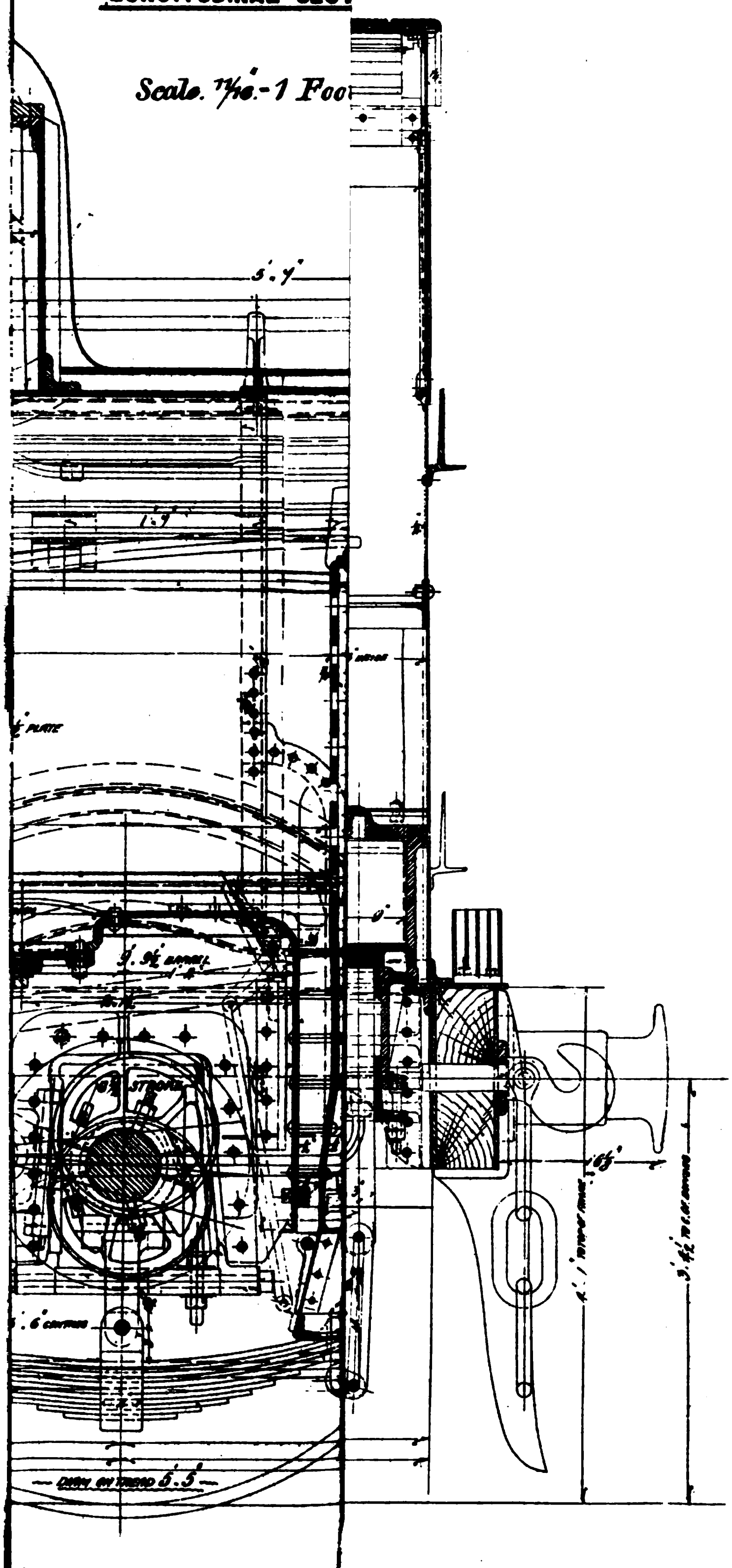
Drawing Nº 32.

STEAM ENGIN

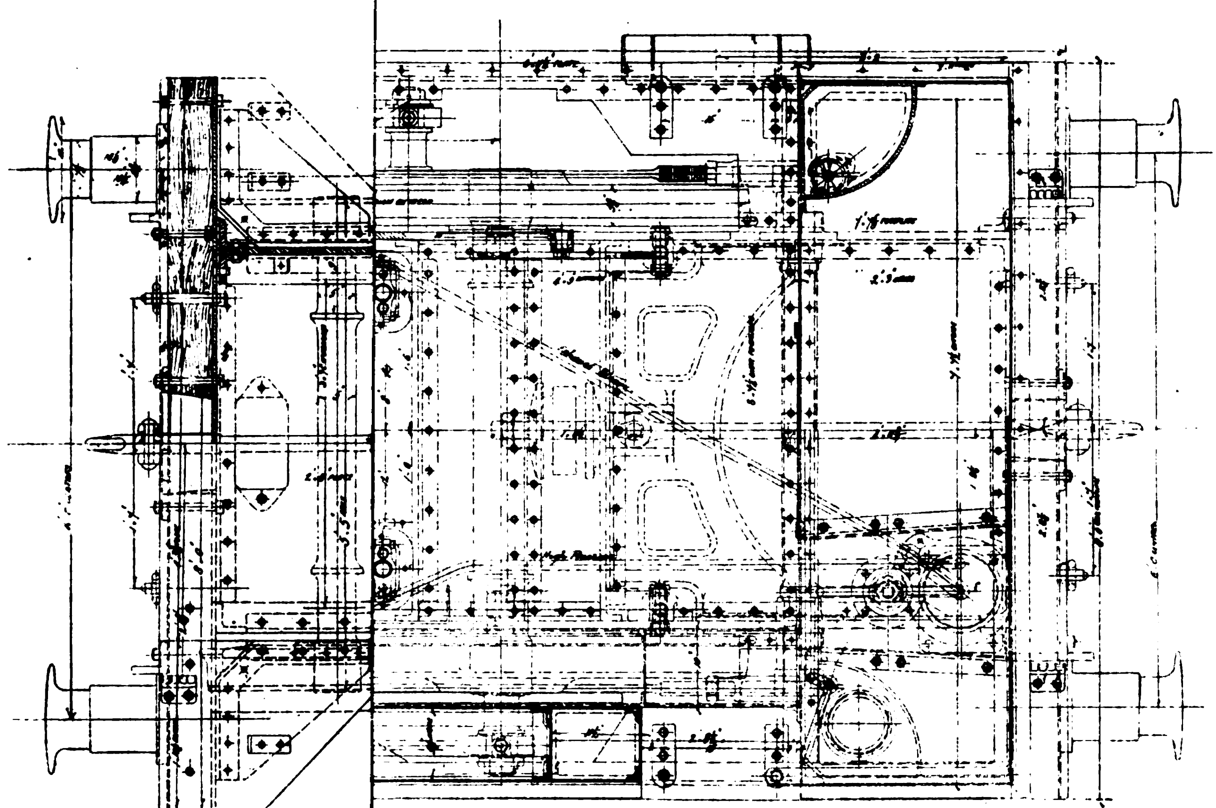
H LONDON RA
DE CYLINDER P

LONGITUDINAL SECT

Scale. 7/16"-1 Foo

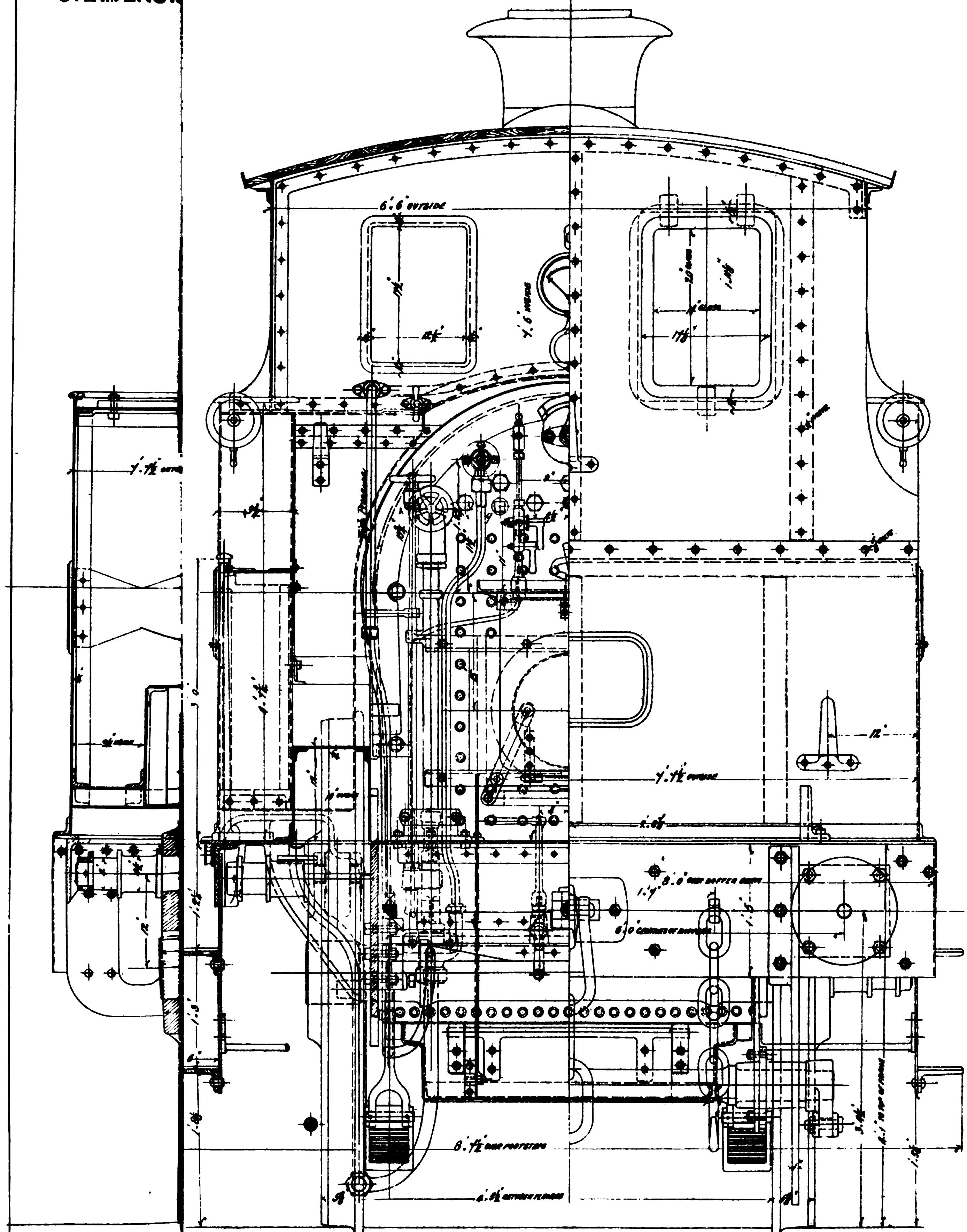


Drawing No. 33

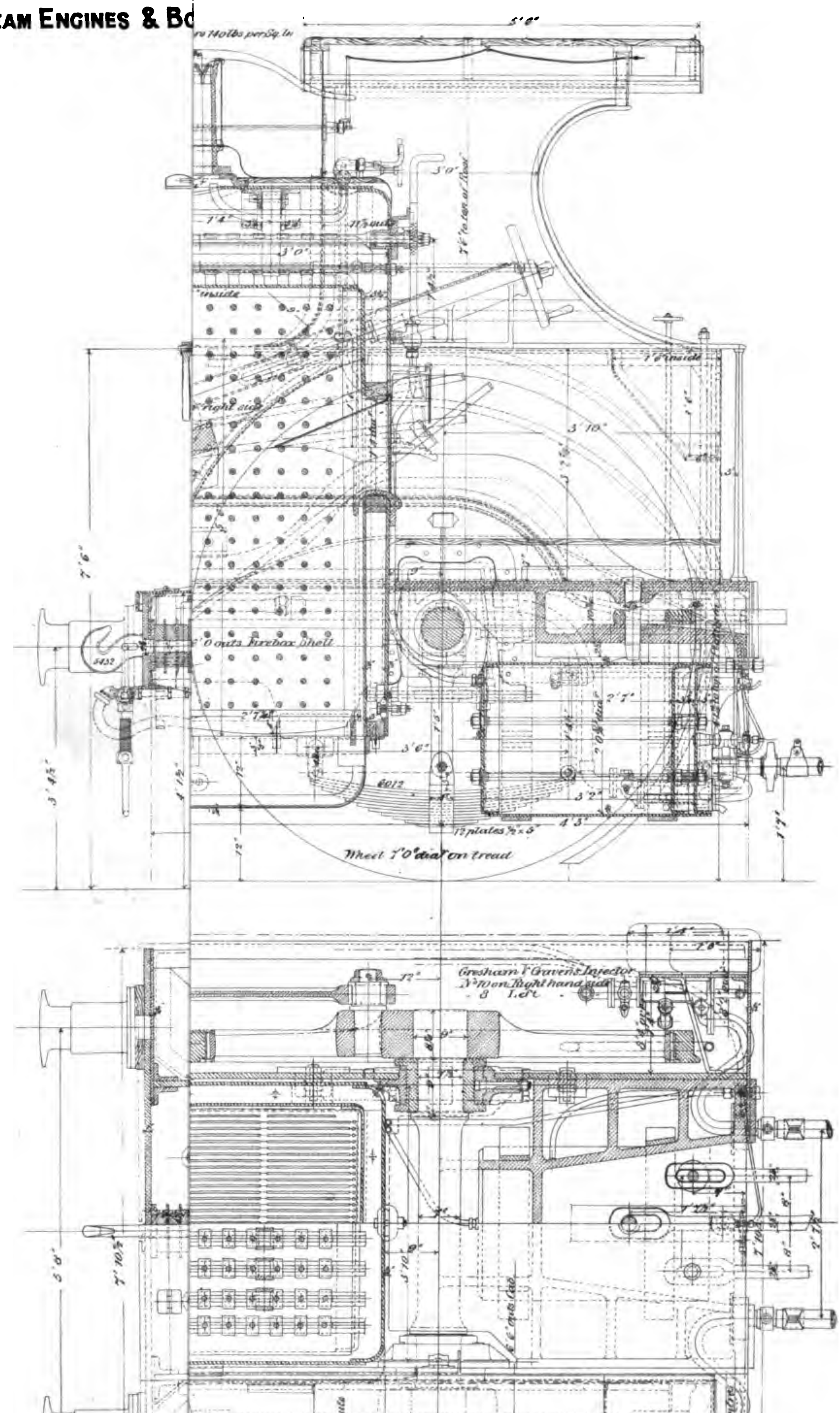


STEAM ENGI

Drawing No. 34.

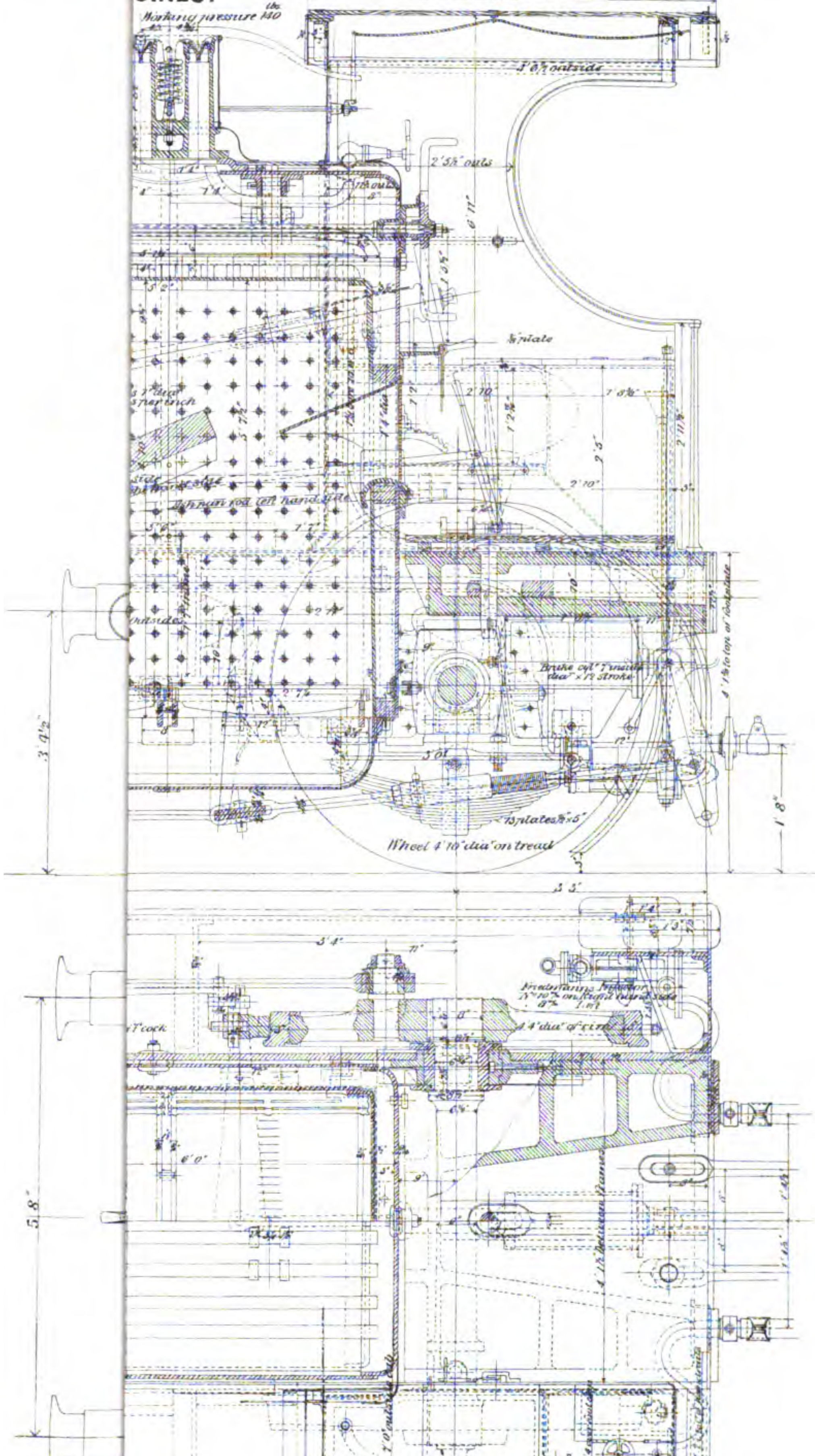


HALF SECTION THRO' FOOTPLATE. —— BACK END ELEVATION.


7'0" outs Firebox Shell
Wheel 7'0" dia on tread
12 plates
Gresham & Craven's Injector
No 10 on Right hand side

Drawing Nº 36.

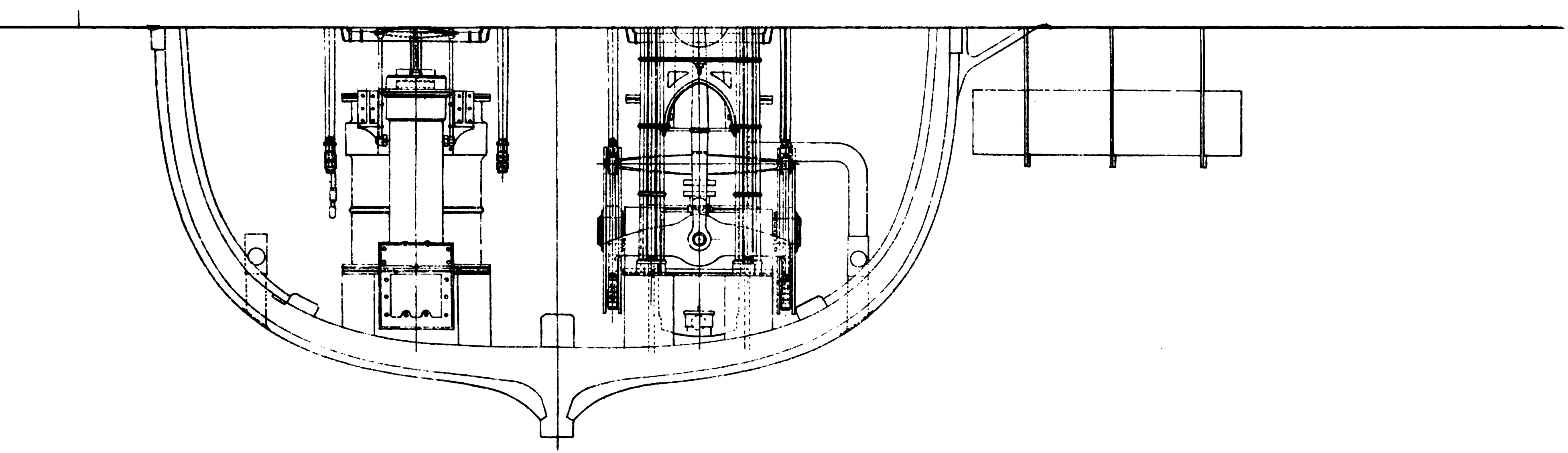
GINES.



SIDE LEVER MARINE ENGINE.

MESSRS MAUDSLAY SONS & FIELD.

1824.



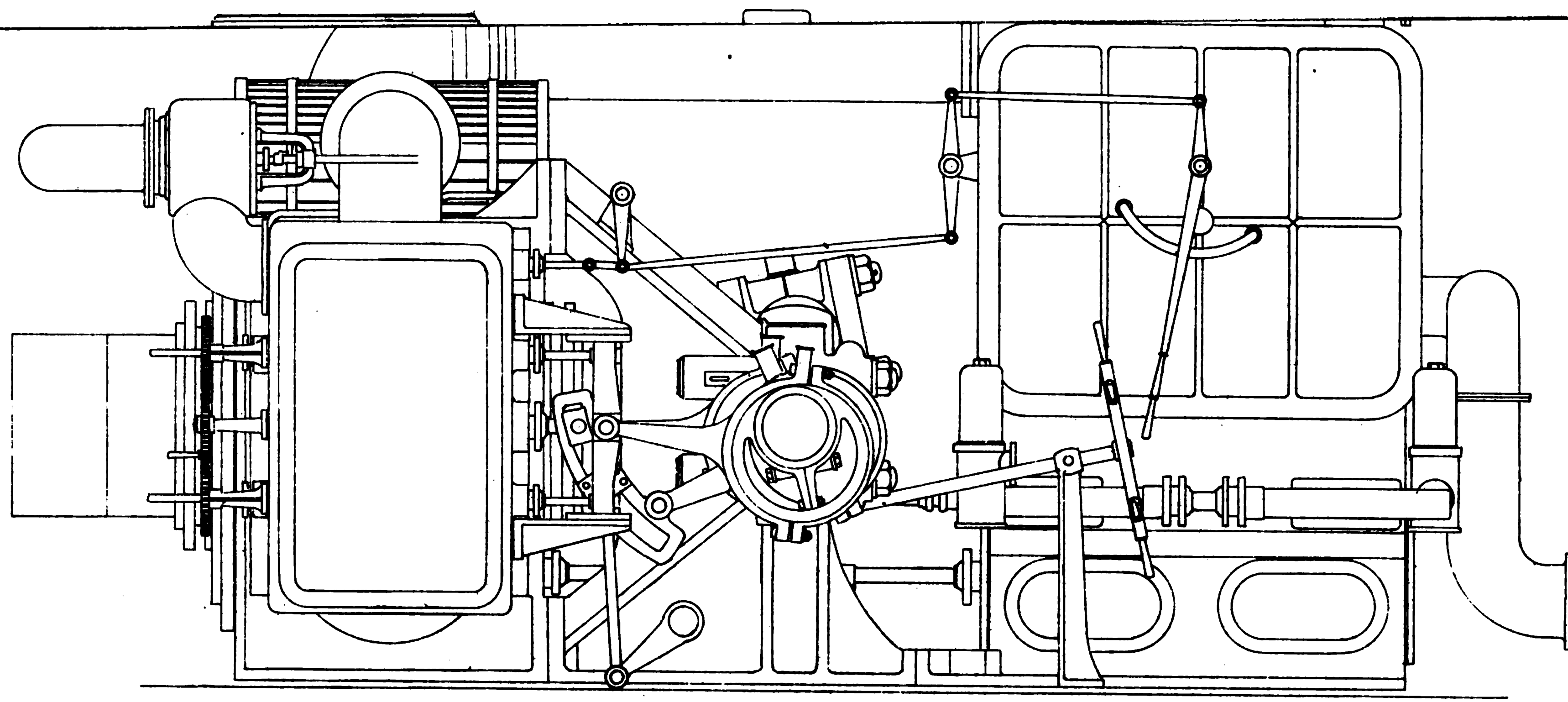
F. Colyer. M. Inst. C.E.

PHOTO LITHO SPRAGUE & Co LONDON

Drawing Nº 39.

COMPOUND TRUNK ENGINES. 955 I.H.P.

BY MESS^RS J. PENN & SONS. LONDON.

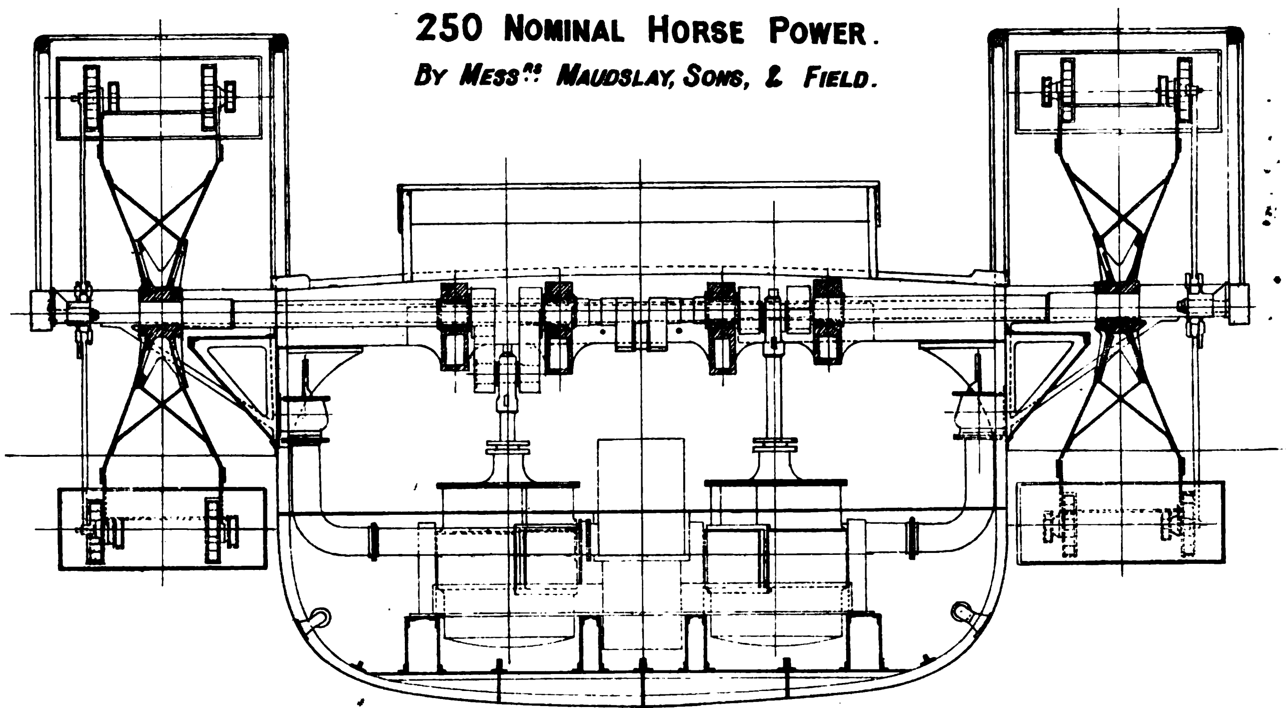


Colyer. M.Inst.C.E.

OSCILLATING MARINE ENGINES.

250 NOMINAL HORSE POWER.

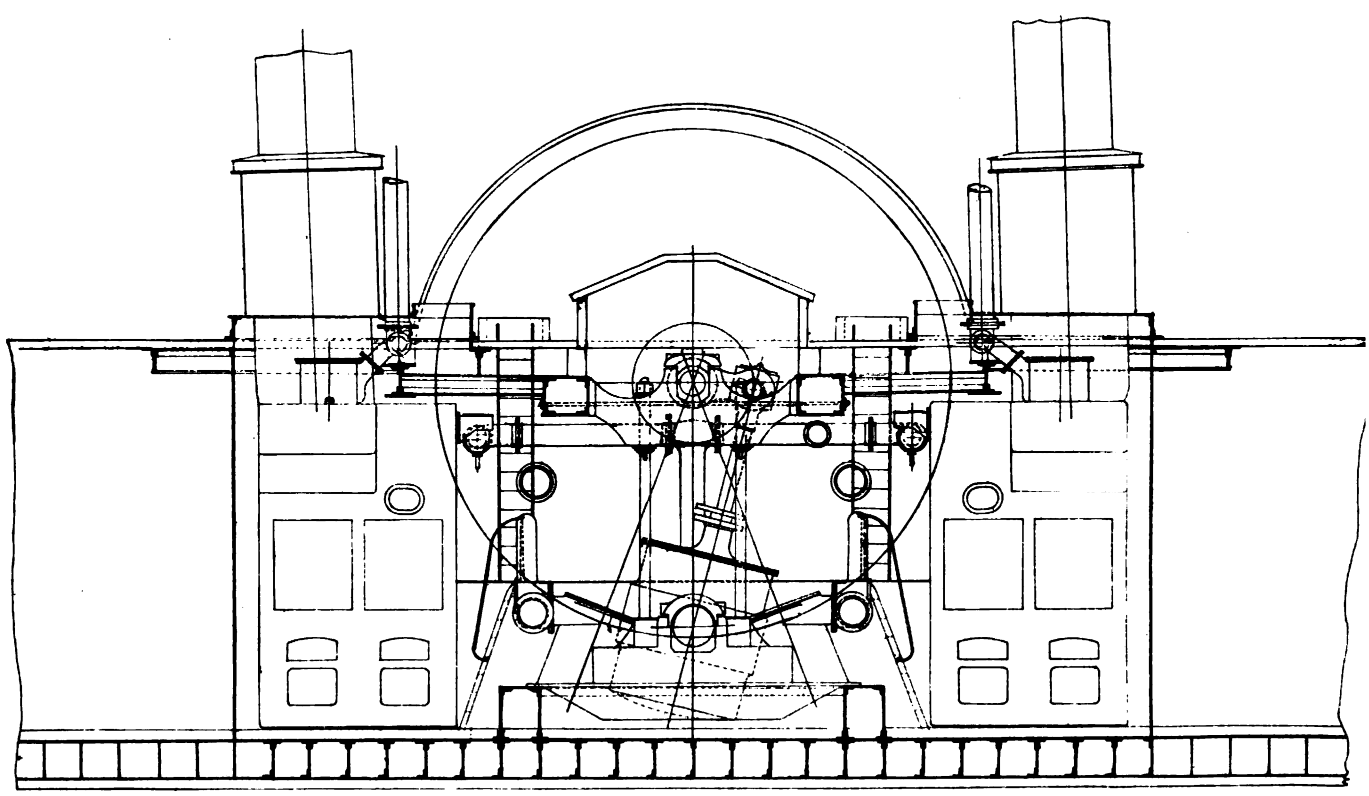
BY MESSRS. MAUDSLAY, SONS, & FIELD.



Trial. 21st April 1859.
Steam. 20 lbs.
Revol.ns 30¾. I.H.P. 1177
Speed 13·275 Knots.
Cylinders 60ins diam. 5.0' stroke.
Air Pumps. 36ins diam. 2.3' stroke

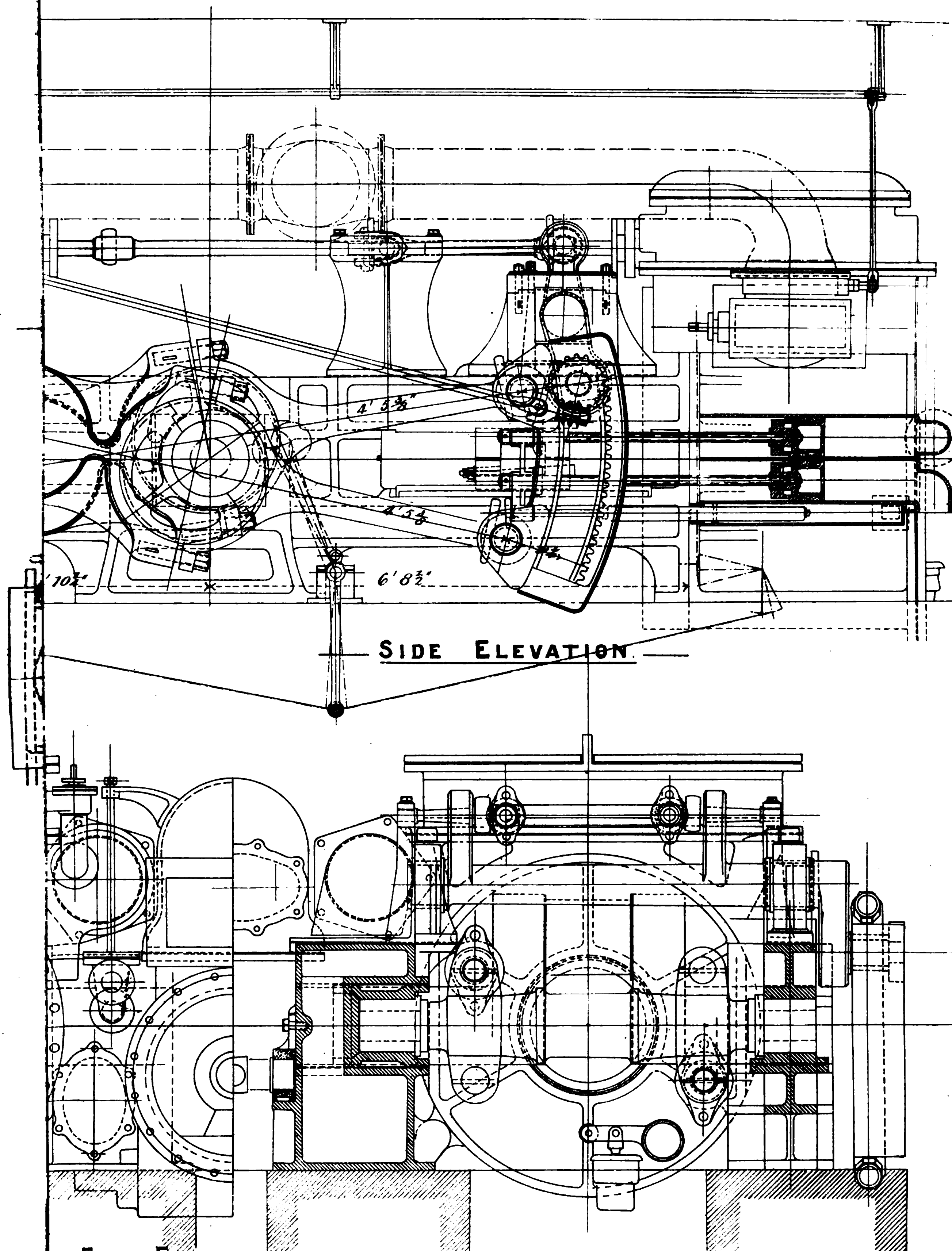
ELEVATION & SECTION

Scale. ⅛" = 1 Foot.



SIDE ELEVATION

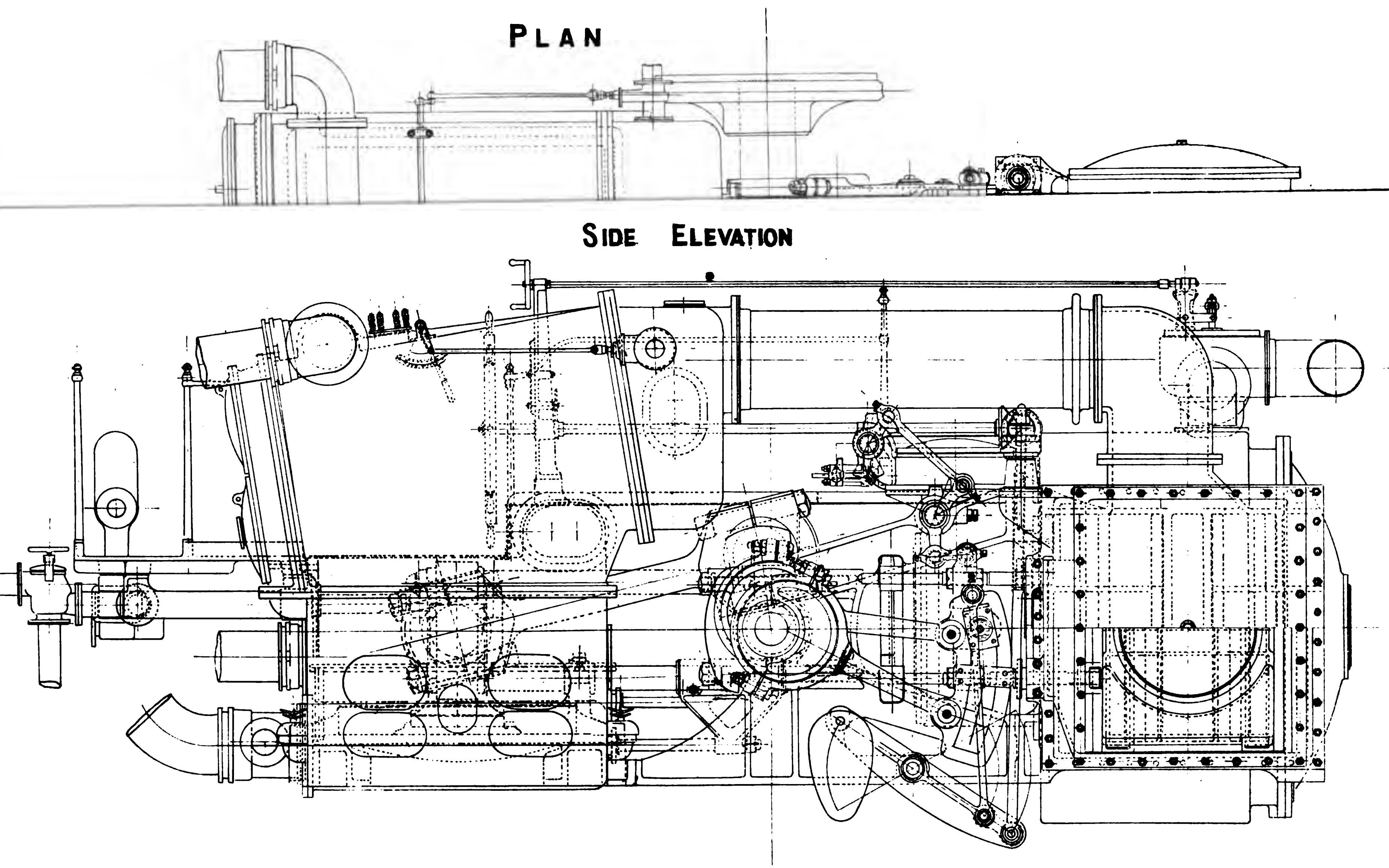
Drawing No. 41.



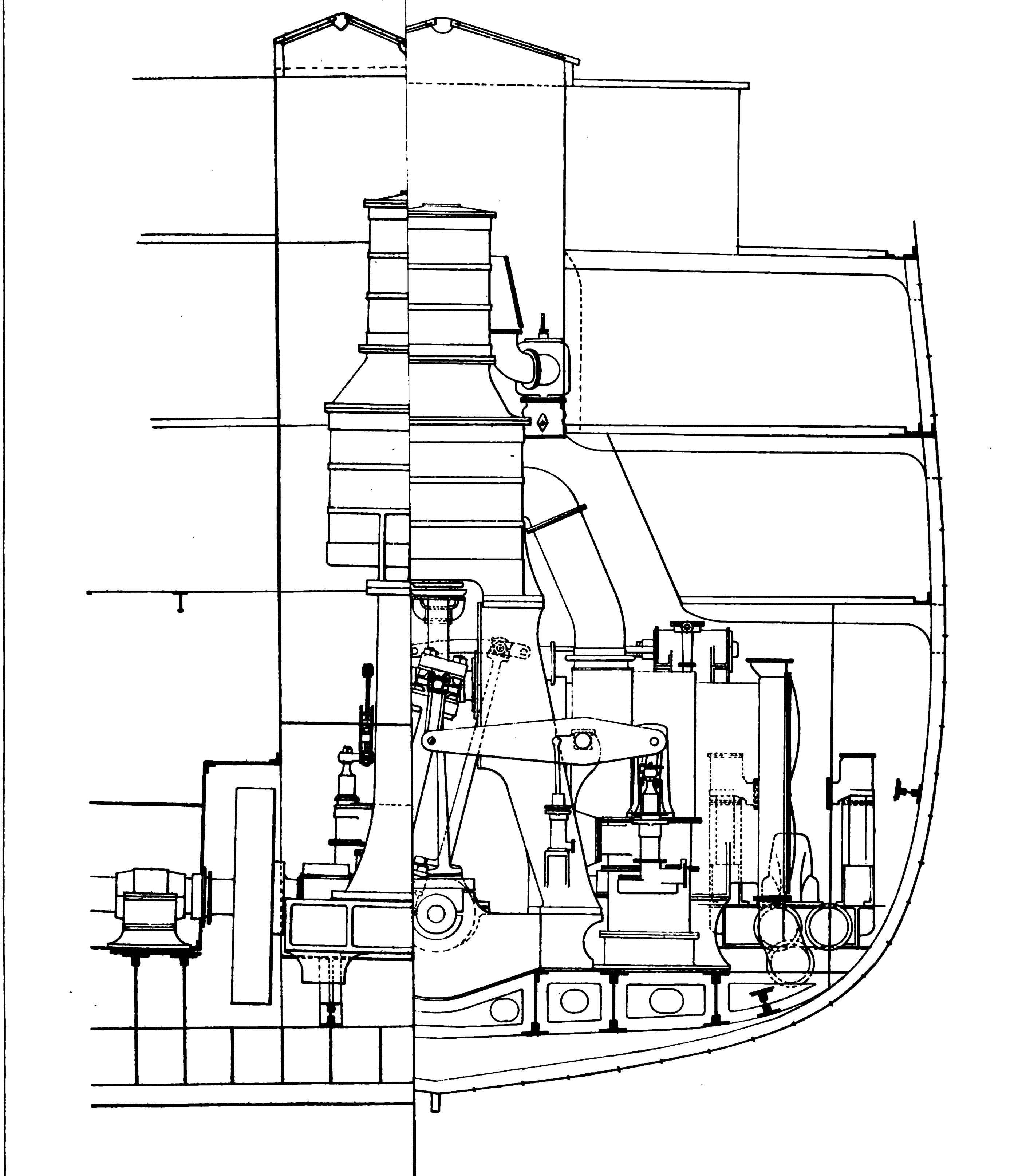
SIDE ELEVATION

END ELEVATION

Drawing Nº 42.

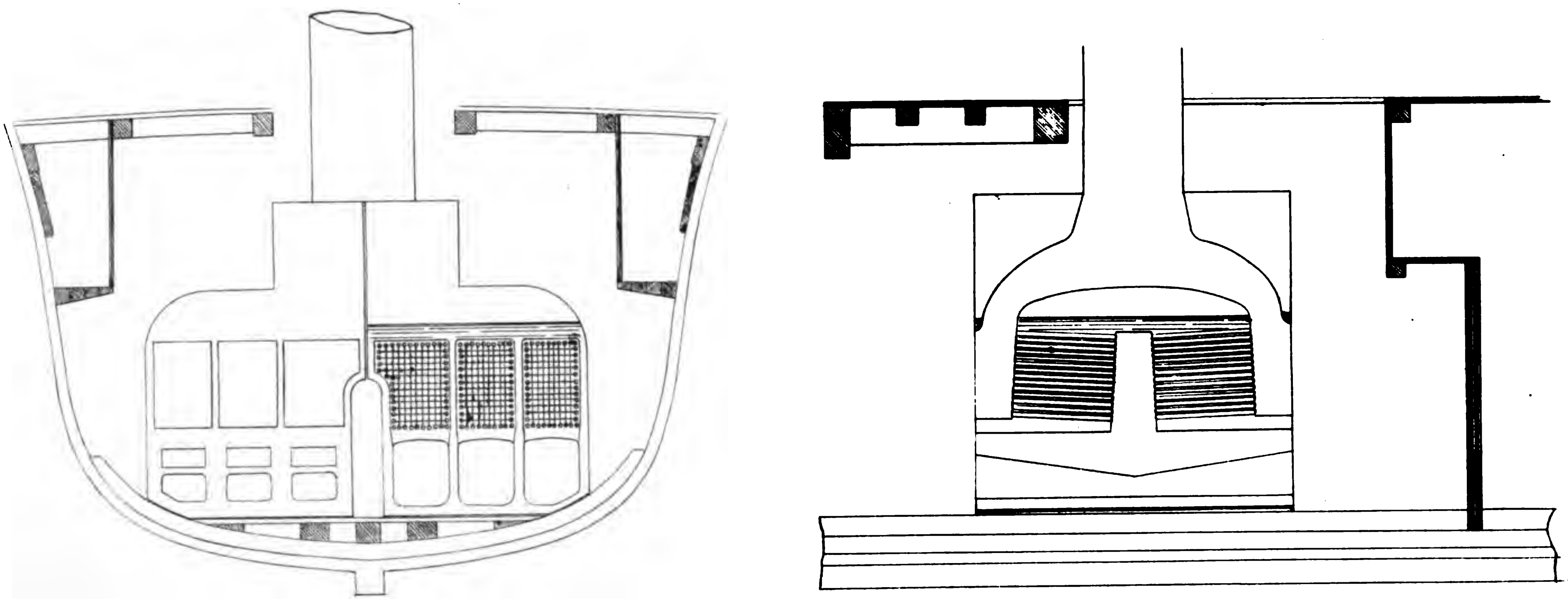


… Colyer. M. Inst. C.E.



Drawing No. 44.

LOW PRESSURE MARINE BOILERS.



F. Colyer. M.Inst. C.E

PHOTO-LITHO. SPRAGUE & Co. LONDON.

STEAM B

Drawing No. 46.