# CHAPTER IX.

## "*LE FIN DU SIÈCLE.*"

The close of the nineteenth century and the commencement of the twentieth bring us to the end of one century of progress since the introduction of the modern steam-engine in the form of a "train of mechanism," as given shape substantially by Watt and his contemporaries. The marine steam-engine, the highest product of the genius of man in this field, has passed through a series of changes, with steam-pressures increasing to 2 atmospheres pressure at its middle, to 3 in 1860, to 5 in 1875, and to 12 and to 14 atmospheres at its close. The old, simple, cumbersome side-wheel engine of the earlier days has been supplanted, first by the compound engine of 1865, then by the triple-expansion of 1874, and finally by the quadruple-expansion machine of the close of the century. Screws have displaced the paddle-wheel, and twin and sometimes triple screws with separate and duplicated engines developing 20,000 and 30,000 horse-power drive the ship 20 knots and more an hour; while in the concentrated machinery of torpedo boats thousands of horse-power are compressed into craft of 100 to 200 feet in length, and these powerful and dangerous vessels have been brought up to speeds exceeding 30 knots (35 miles) an hour. Three hundred and five hundred tons of coal a day are required by the largest ships, and the equivalent of the maximum figures above could only be met, in the form of animal-power, by the employment of 80,000 to 120,000 horses with their no less inconceivable masses of supplies.

In the construction of the locomotive engine the same range of pressures has been traversed, and the compound engine is come to be the latest and most perfected form of this machine. High-pressure cylinders 15 and 16 or 17 inches in diameter, and low-pressure cylinders of 28 to 30 inches diameter are now common, and the weight of the engine has risen to 40 and 45 tons for passenger service and to 100 tons for heavy freight trains, the most powerful being rated to haul from 4,000 to 4,500 tons on a level track. The New York Central Railway engine No. 999 holds the record for short runs, its speed having exceeded 100 miles an hour, and this great engine has hauled 180 tons 436 miles at an average speed of over 64 miles an hour. The highest speed at present writing for long distances is held by a Brooks engine on the Lake Shore road, pulling its train at the rate of 73 miles an hour over a distance of 86 miles, and drawing 150 tons 33 miles at the rate of 81 miles an hour. A single establishment in the United States (the Baldwin Locomotive Works) has built a total of about 15,000 engines.

The stationary engine has reached its highest development in the form of the steam pumping engine, and has a record of consumption—in the case of the Allis engine at Milwaukee, designed by Reynolds—of 11.67 pounds of steam per horse-power per hour, a "duty" of about 150,000,000. The "high-speed engine" employed in the trying work of the electric railway station holds its speed to a perfection of regulation permitting no visible fluctuation, whatever the amount of variation in the work demanded of it or the suddenness with which change occurs.

Compound locomotives are less common than compound stationary engines. They are, however, gradually becoming used where fuel is expensive, and give, when well designed, very marked economical advantages. The usual system places a high-pressure cylinder on one side and a low-pressure cylinder on the other, the latter being commonly arranged to take steam direct from the boiler when starting, or whenever for any reason it is desirable.

Some of the more interesting and successful designs of compound locomotive engines are those of which outline

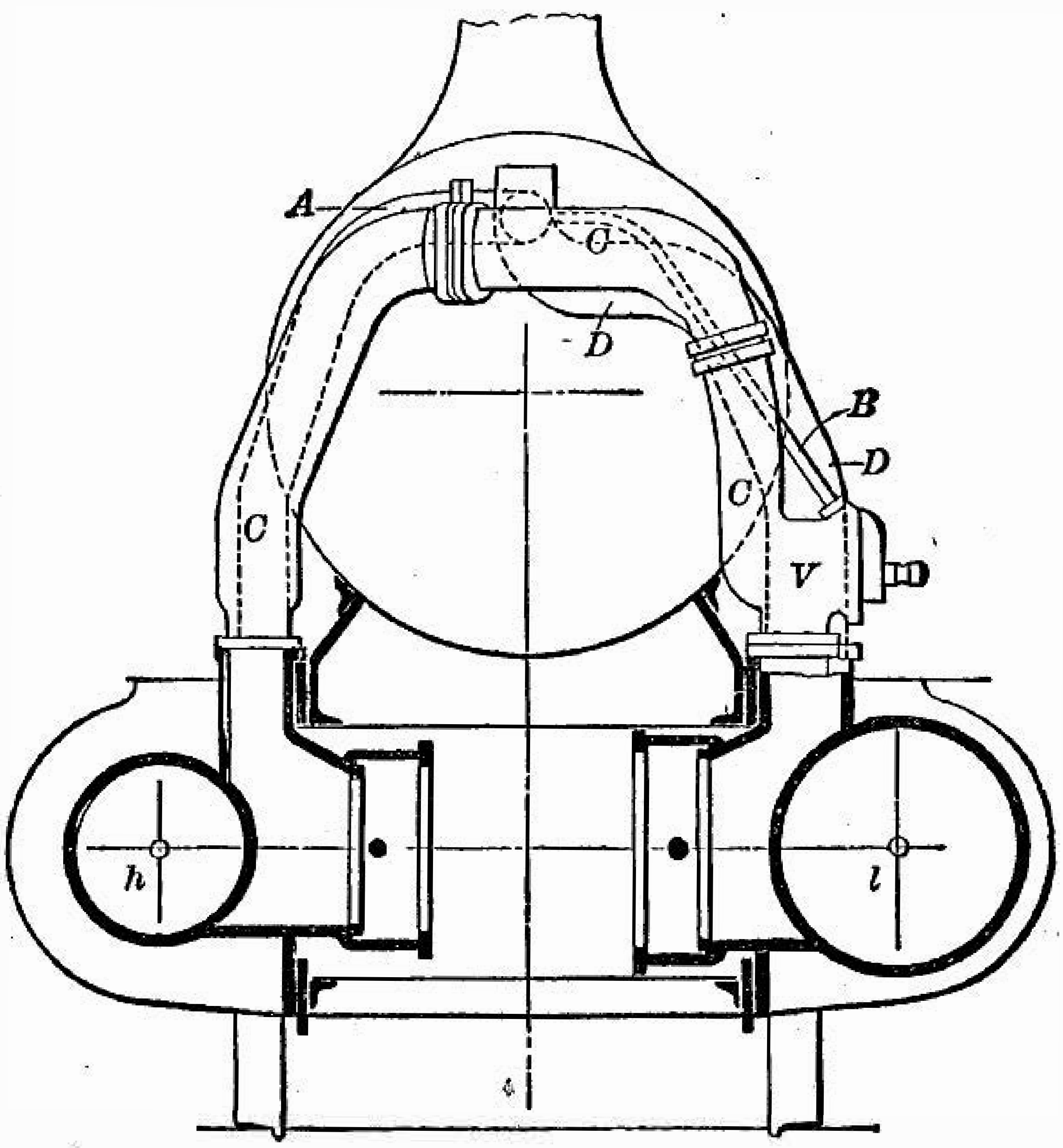


FIG. 148.—Compound Locomotive Engine.

illustrations follow, selected from Professor Woods's monograph.[1] That of Von Borries is exemplified by Figs. 148 and 149; the one exhibiting the arrangement adopted in

[1] "Compound Locomotives"; A. T. Woods, M. M. E. New York, Van Arsdale, 1891. The following matter is largely abstracted from the latest edition of the author's "Manual of the Steam-Engine." New York, J. Wiley & Sons, 1896.

an engine on the Prussian State Railways,[1] the other a common engine of less power.

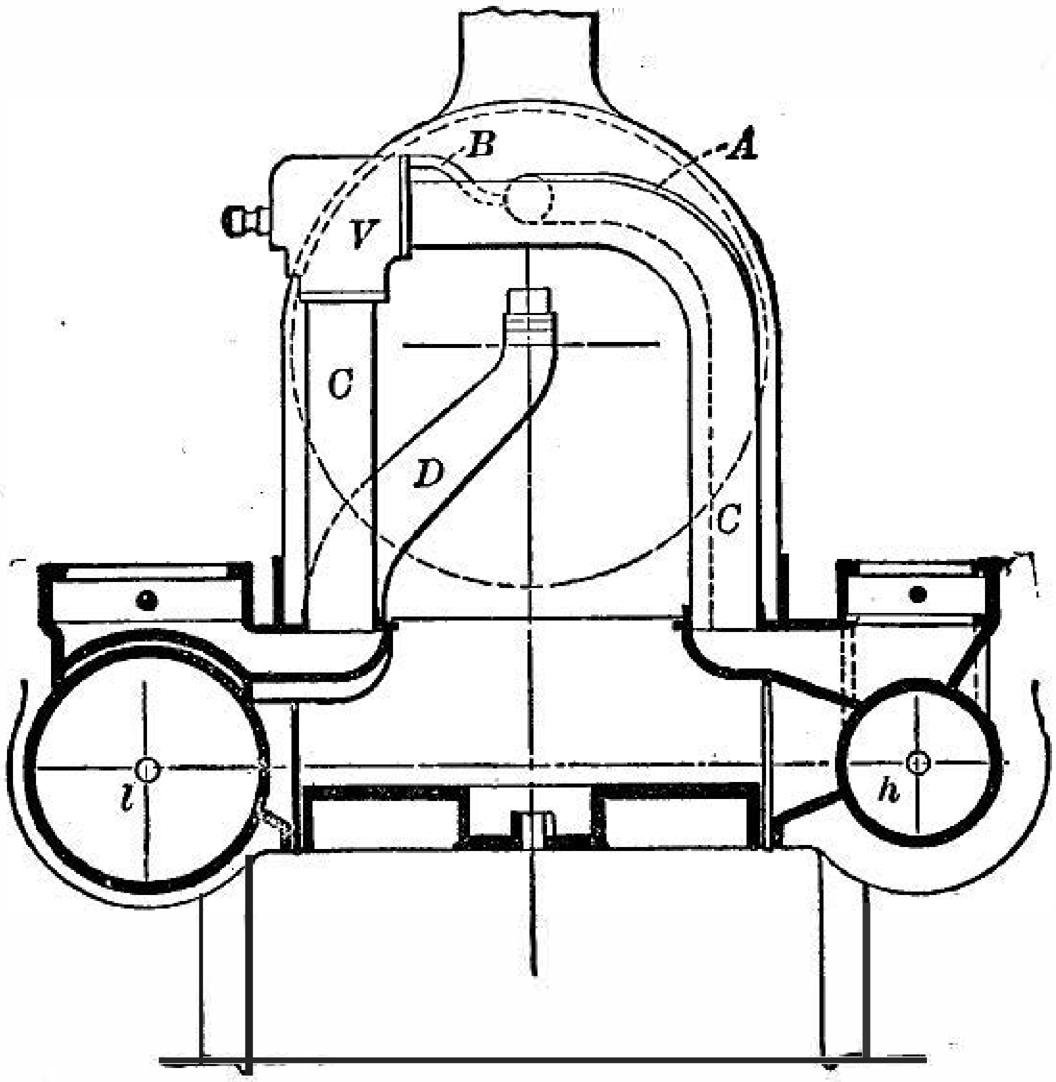


FIG. 149.—Compound Engine.

The former has cylinders 18.1 and 25.6 inches diameter, 24.8 inches stroke, weighs 88,250 pounds, and has 1,420 square feet of heating-surface and 16 feet grate-surface.

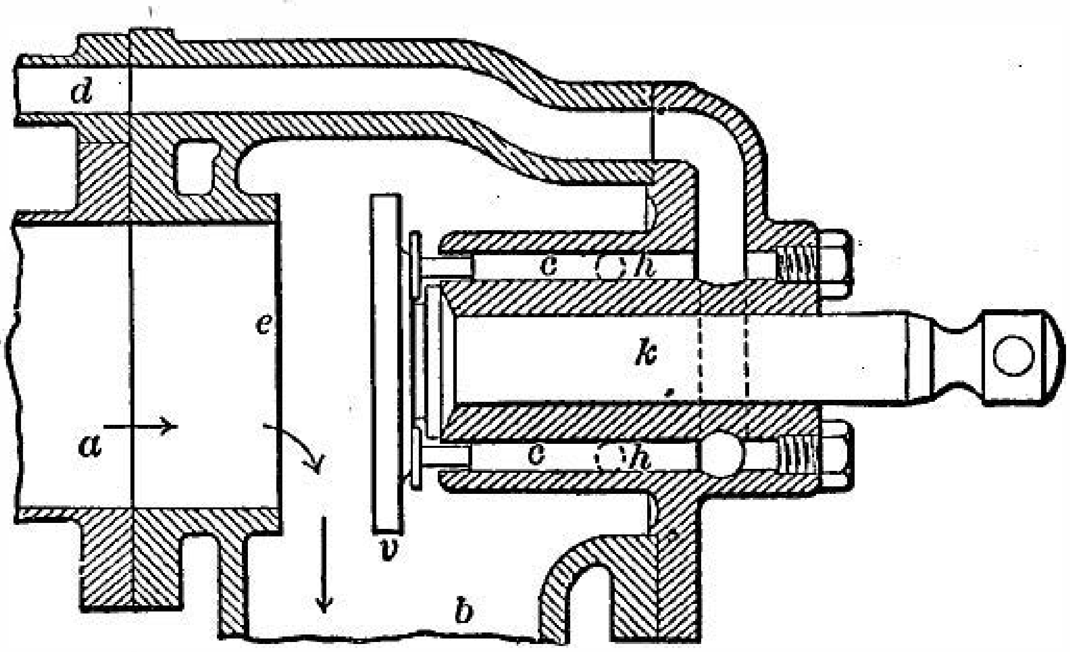


FIG. 150.—"Intercepting Valve."

[1] "Engineering," February 1, 1889.

The driving-wheels are 52.4 inches diameter, and the steam-pressure 175 pounds by gauge.

The second engine is of 86,200 pounds weight, with 16- and 23-inch cylinders, 24 inches stroke of pistons, $5\frac{1}{2}$ feet diameter of drivers, the pressure 170 pounds.

The arrangement of both engines involves the peculiar form of starting-valve devised by Von Borries, which is

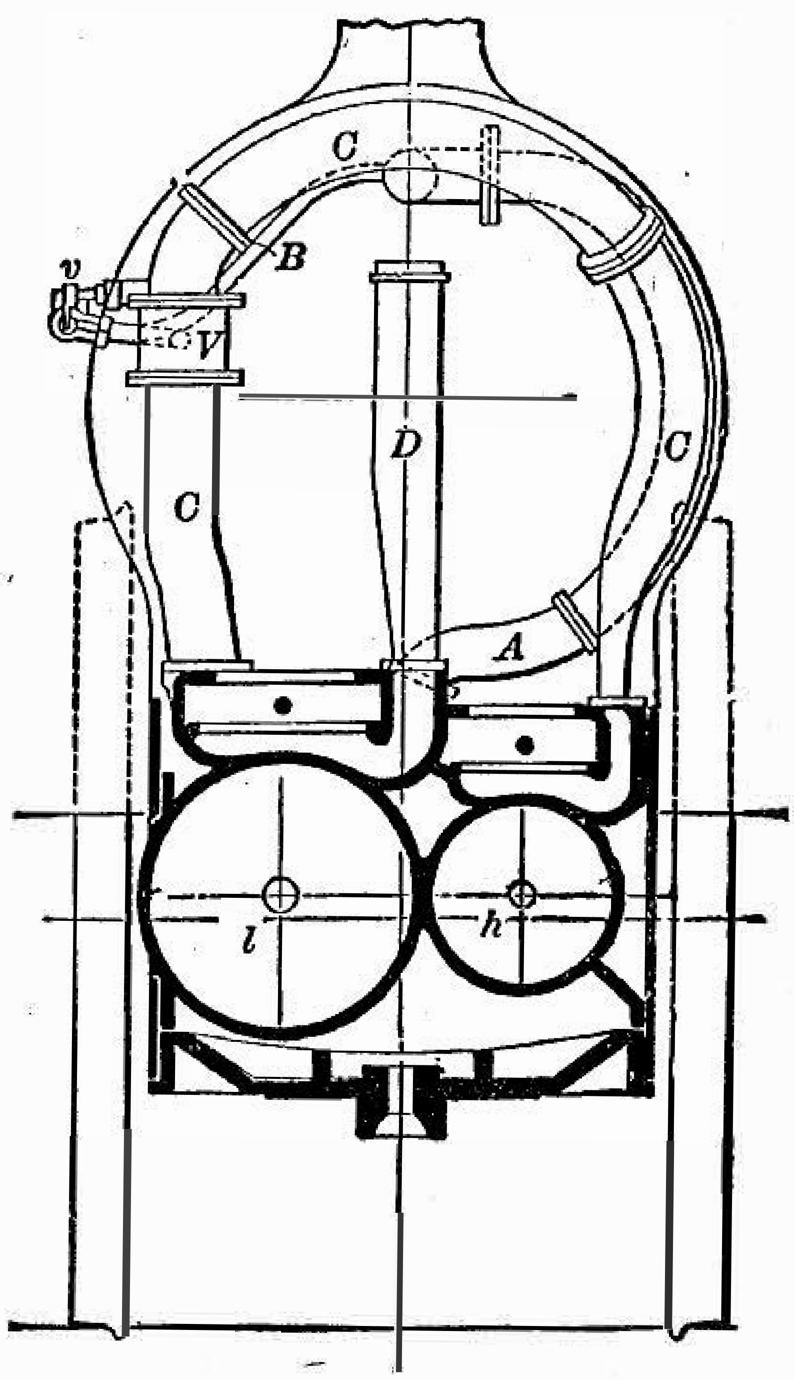


FIG. 151.—The Worsdell Engine.

seen in the next figure. In the sketch, *a* is the receiver-pipe to the high-pressure, *b* that to the low-pressure cylinder. The valve, *v*, is seen as in ordinary working when "under way," and the arrows show the course of the steam, Attached to the back of this valve are two plungers, *c c*, constituting the starting-valve. When the throttle-valve is opened steam enters the pipe *d*, passing back of the plungers, forcing the valve to its seat, *e*, at the same time opening the ports *h h*, through which and the passage *b* it goes on to the large cylinder.

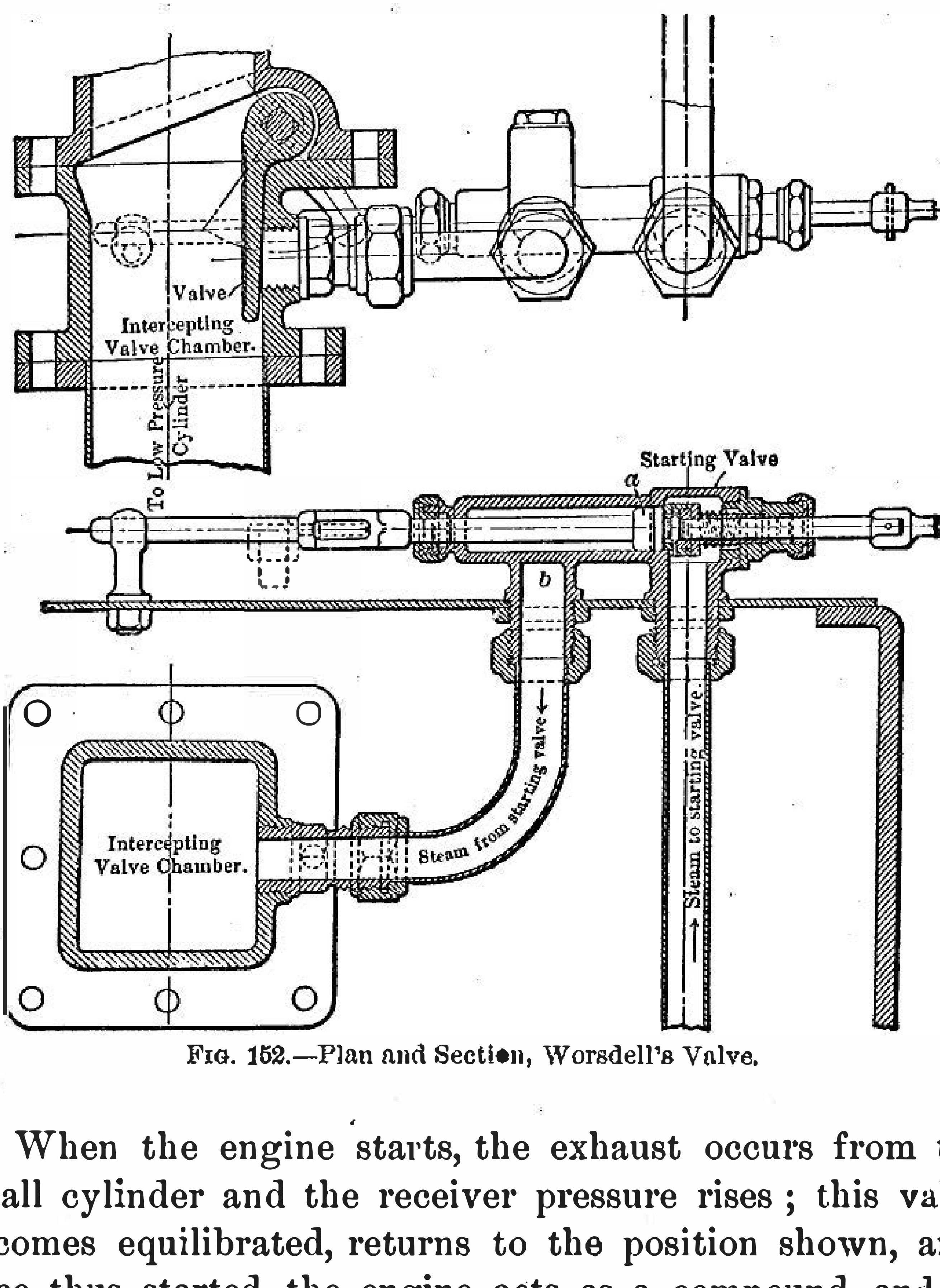


FIG. 152.—Plan and Section, Worsdell's Valve.

When the engine starts, the exhaust occurs from the small cylinder and the receiver pressure rises ; this valve becomes equilibrated, returns to the position shown, and, once thus started, the engine acts as a compound, and so continues until, after shutting off steam, this equilibrium is lost and the engine starts again, later, as a simple machine. This device is in extensive use.

In the Worsdell form of engine, Fig. 151, the construction is as seen in the sketch.[1] *A* is the steam-pipe, *B* the starting-valve connection, *C* the receiver, *D* the exhaust-pipe, and *v* and *V* are the starting and the intercepting valves. The engine here taken for illustration is an English passenger locomotive, having 16- and 20-inch cylinders, 24 inches stroke, drivers 80¼ inches in diameter. The steam-pressure the same as the preceding, and the weight of engine 97,000 pounds, of which 68,000 rests on the driving-wheels. The areas of heating and grate surface are, respectively, 1,323⅛ and 17⅛ square feet. Joy's valve-gear is employed.

The construction of the valves is seen in the next figure. The flap-valve is the intercepting valve, seen as in regular working. Its spindle is connected with the small piston at *a*, as shown. The starting-valve is set in a pipe or casing connected with the former, as seen in the sketch. A valve held in place by a spring connects the pipes *b* with the piston *a*. The starting-valve is worked by the engine-driver, the same motion closing the intercepting valve, and the locomotive starts as a simple engine. The rise of pressure in the receiver presently restores the valves to the position shown, and the engine at once becomes compound.

Steam-pressures have risen, since the improvement of the steam-engine by Watt was begun, somewhat as follows, at sea and in condensing engines:

| Year. A. D. | Steam-Pressures. Lbs. | Steam-Pressures. Atmos. |
|---|---|---|
| 1800 | 0 to 5 | 0 to ⅛ |
| 1810 | 5 " 7 | ⅛ " ½ |
| 1820 | 5 " 10 | ⅛ " ⅜ |
| 1830 | 10 " 20 | ⅜ " 1⅛ |
| 1840 | 15 " 20 | 1 " 1⅛ |
| 1850 | 15 " 25 | 1 " 1⅜ |
| 1860 | 20 " 30 | 1⅓ " 2 |
| 1870 | 30 " 60 | 2 " 4 |
| 1880 | 60 " 90 | 4 " 6 |
| 1885 | 75 " 120 | 5 " 8 |
| 1890 | 100 " 200 | 8 " 20 |

[1] "Engineering," March 30, 1888.

In many cases considerable variations from these figures have been observed, but they may be taken as representative.

The following have been considered fair average figures as representing what was good and standard practice at the dates given, and as illustrating the progress effected in marine engineering in the period 1870–1900:

| TYPE. | Date. | Pressure of steam. | Coal per I. H. P. per hour. | Piston-speed. | Weight per I. H. P. |
|---|---|---|---|---|---|
| Simple | 1870 | 50 | 2.1 | 375 | 500 |
| Compound | 1880 | 75 | 1.8 | 480 | 480 |
| Triple | 1890 | 180 | 1.3 | 800 | 400 |
| Quadruple | 1900 | 225 | 1.1 | 1,000 | 350 |

The Clermont, the first successful steam-vessel of Robert Fulton, has now for its lineal descendants vessels like, for example, the steamer New York, built eighty years later, for the same route, by the Harlan & Hollingsworth Company, and "engined" by the W. & A. Fletcher Company (Fig. 152). The dimensions of hull are as follows:

| | | |
|---|---|---|
| Length on the water-line | 301 feet. | |
| " over all | 311 " | |
| Breadth of beam, moulded | 40 " | |
| " " over guards | 74 " | |
| Depth, moulded | 12 " | 3 in. |
| Draught of water | 6 " | |
| Tonnage (net, 1,091.89) | 1,552.52 | |

The wheels are aft of the centre of length, instead of forward—a great improvement in the appearance of the boat.

The engine is a beam-engine, with a cylinder 75 inches diameter and 12-feet stroke of piston, provided with Stevens's cut-off. The use of a surface-condenser instead of a jet-condenser in this river-steamer is a change made to overcome the evil of using mixed salt and fresh water in the boilers, as the tides extend to Albany and the water changes from salt to fresh *en route.*

Another change is the return to the use of Stevens's feathering wheels. These are 30 feet 2 inches diameter

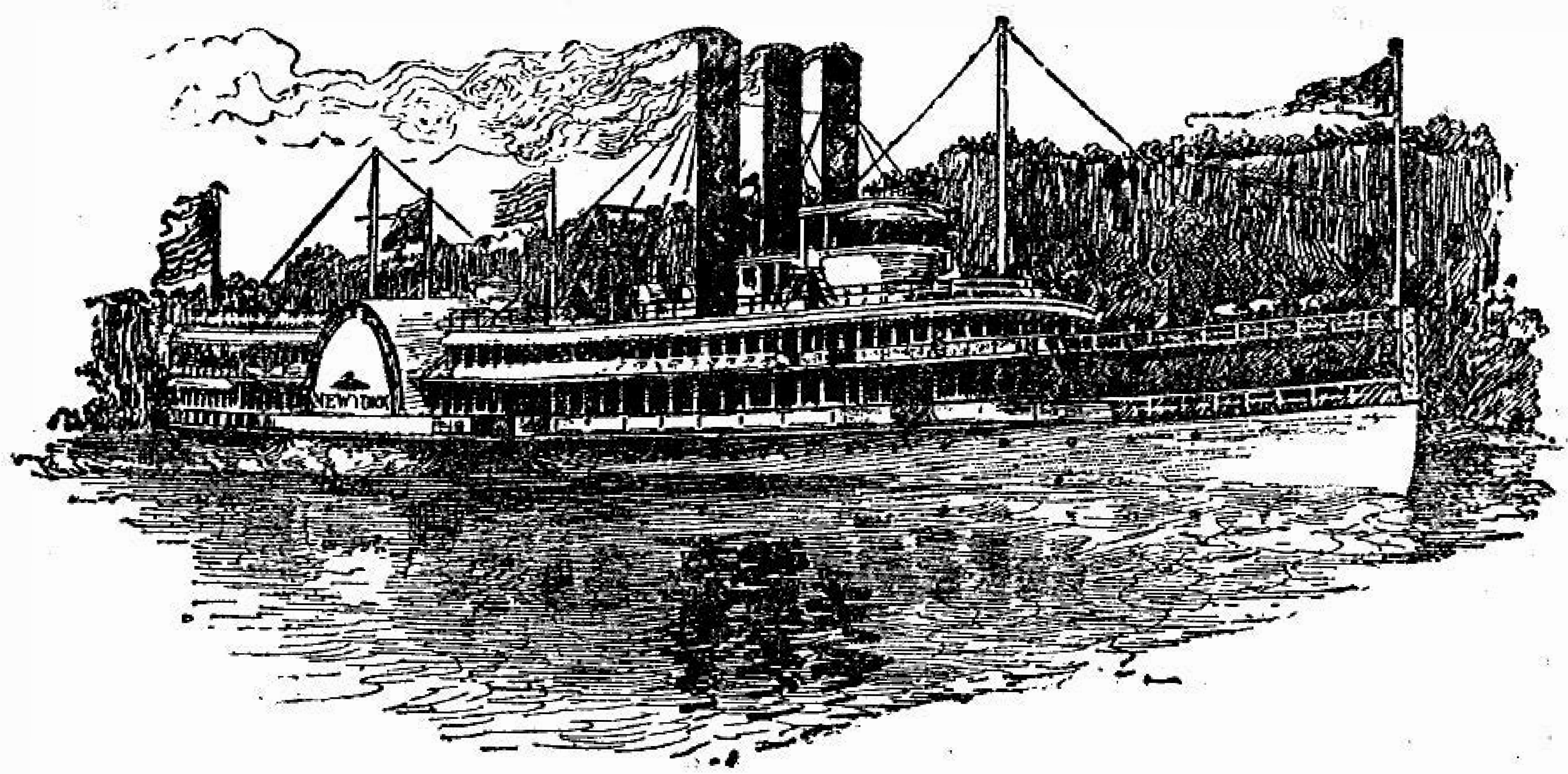

FIG. 153.—The "New York."

outside of buckets. There are 12 curved steel buckets to each wheel. Each bucket is 3 feet 9 inches wide and 12 feet 6 inches long. The wheels are overhung, and they have a bearing on the hull only. The feathering is effected in the usual manner by driving and radius bars, operated by a centre placed eccentric to the shaft and held by the "A-frame" on the guard. These wheels were introduced in the New York for the purpose of gaining speed, and the trial-trip shows that the builders' expectations were completely fulfilled. Absence of jar is another gain obtained by the use of these wheels, and the comparatively thin buckets enter the water so cleanly and smoothly that one notices none of the shake so common on boats with the ordinary wheels.

Steam is supplied to the engine by three return-flue boilers, each 9¼ feet diameter of shell, 11 feet width of front, and 33 feet long, constructed for a working pressure of 50 pounds per square inch. Each boiler has a grate-surface of 76 square feet or 228 square feet in all, and with the forced draught produce 3,850 horse-power.

The exterior is of pine, painted white, relieved with tints and gold. The interior is finished in cabinet-work, and is all bard wood, ash being used forward of the shaft on the main deck, and mahogany aft and in the dining-cabin. Ash is also used in the "grand saloons" on the promenade deck. The saloon-sides are almost entirely of glass, and the windows so low that persons seated inside have an opportunity to view the scenery.

The Puritan (Fig. 154) illustrates the adaptation of this type of steamer, so nearly perfected by Robert L. Stevens, to that kind of navigation intermediate between river or still-water and oceanic, which permits the retention of some features of the former, while modifying the shape of hull and type of engine to meet the demands of "outside" navigation.

The plans of this steamer are by Mr. Pierce, the details of hull-construction by Mr. Faron, and the machinery by the W. & A. Fletcher Company. The principal dimensions are as follows: Length over all, 420 feet; length on the water-line, 404 feet; width of hull, 52 feet; extreme breadth over guards, 91 feet; depth of hull amidships, 21 feet 6 inches; height of dome from base-line, 63 feet; whole depth, from base-line to top of house over the engine, 70 feet. Her total displacement, ready for a trip, is 4,150 tons, and her gross tonnage 4,650 tons.

The ship is fire-proof and unsinkable, having a double hull divided into 59 water-tight compartments, 52 between the hulls and 7 made by athwartship bulkheads. In the fastenings of hull and compartments there were used 700,000 rivets and upward of 30 miles of steel angle-bar. Her decks are of steel, wood-covered. Her masts are of steel, and hollow, to serve as ventilators, and are 22 inches in diameter. Her paddle-wheels are encased in steel.

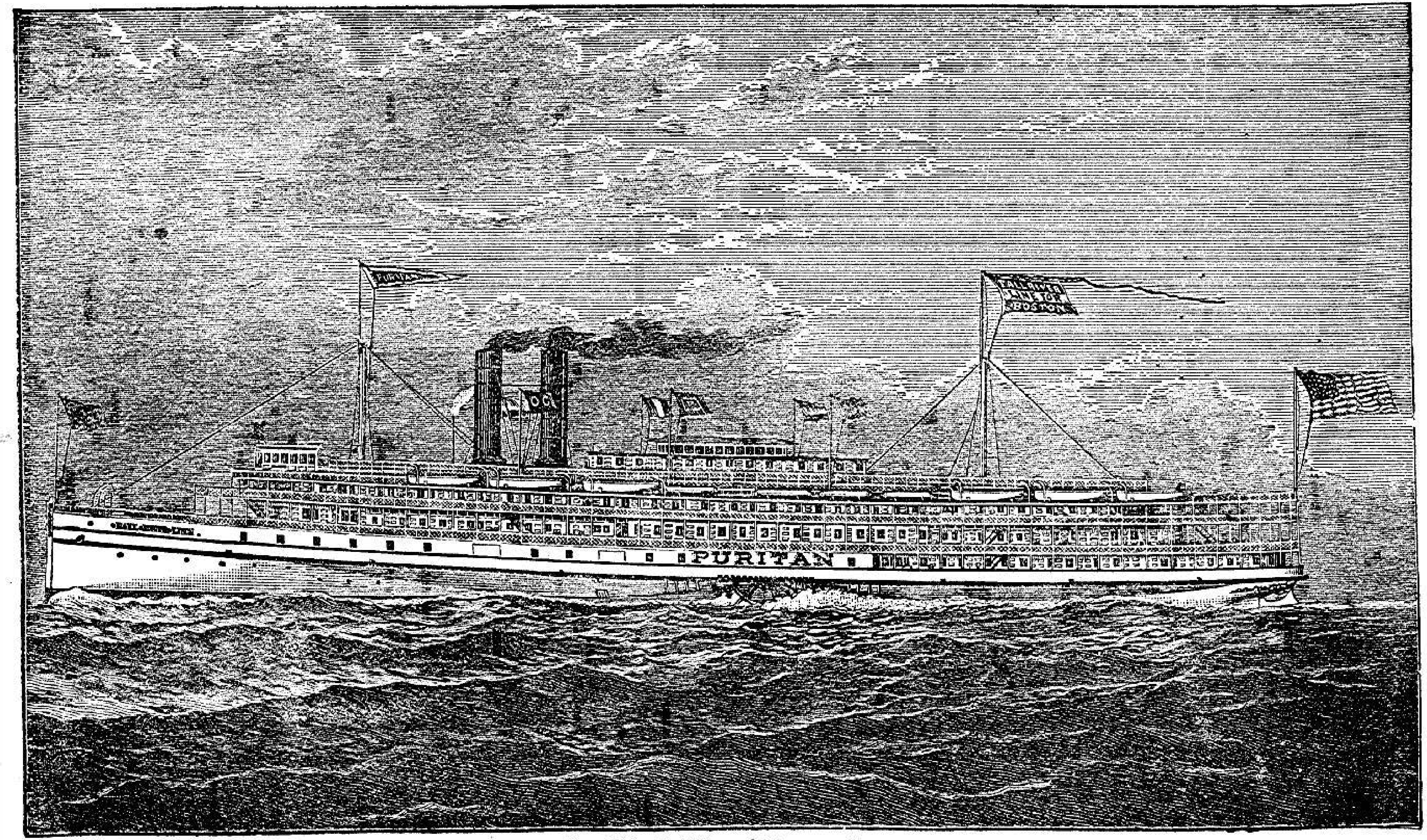


FIG. 154.—A "Sound Steamer."

The hull is of "mild steel," 20 per cent. stronger than iron. The wheels are of steel, and are 35 feet in diameter outside the buckets. The buckets are 14 feet long and 5 feet wide, each bucket of steel seven eighths inch thick, and weighing 2,800 pounds without rocking arms and brackets attached. The totals weight of each wheel is 100 tons. The wheels are "feathering," and turn at the rate of 24 revolutions a minute.

The boat has a compound, vertical, beam, surface-condensing engine of 7,500 horse-power. The high-pressure cylinder is 75 inches in diameter, and 9 feet stroke of piston. The low-pressure cylinder is 110 inches in diameter, and 14 feet stroke of piston. The surface-condenser has 15,000 square feet of cooling surface and weighs 53 tons. Of condenser-tubes of brass there are 14½ miles. Her working-beam is 34 feet in length from centre to centre, 17 feet wide, and weighs 42 tons. The section of beam-strap measures 9½ × 11¼ inches. The main centre of the beam is 19 inches in diameter in its bearings. The shafts are 27 inches in diameter in main bearings, and 30 inches in gunwale bearings; they weigh 40 tons each. The cranks weigh 9 tons each. The crank-pin is 19 inches in diameter and 22 inches long.

The boilers contain 850 square feet of grate-surface and 26,000 square feet of heating surface. The products of combustion passed through two super-heaters, 8 feet 10 inches inside diameter and 12 feet 4 inches outside diameter, by 12 feet high; thence into two smoke-stacks, the top of each being 101 feet 1 inch from the keel.

The dining-saloon is 108 feet 4 inches in length by 30 feet in width, and 12 feet in height. There are 12 miles of electric-lighting wire, and, including annunciators, fire-alarm, etc., there are 20 miles of wire and 12,000 feet of steam-pipe. There are capacious gangways and staircases, lofty cornices, and ceilings supported by tasteful pilasters, the tapering columns of which, insrelief, flank exquisitely tinted panelling throughout the length of her saloons. Every convenience known to civilization, and which can contribute to the ease and comfort of the traveller on land or when afloat, is included in the internal arrangements of this floating caravansary.

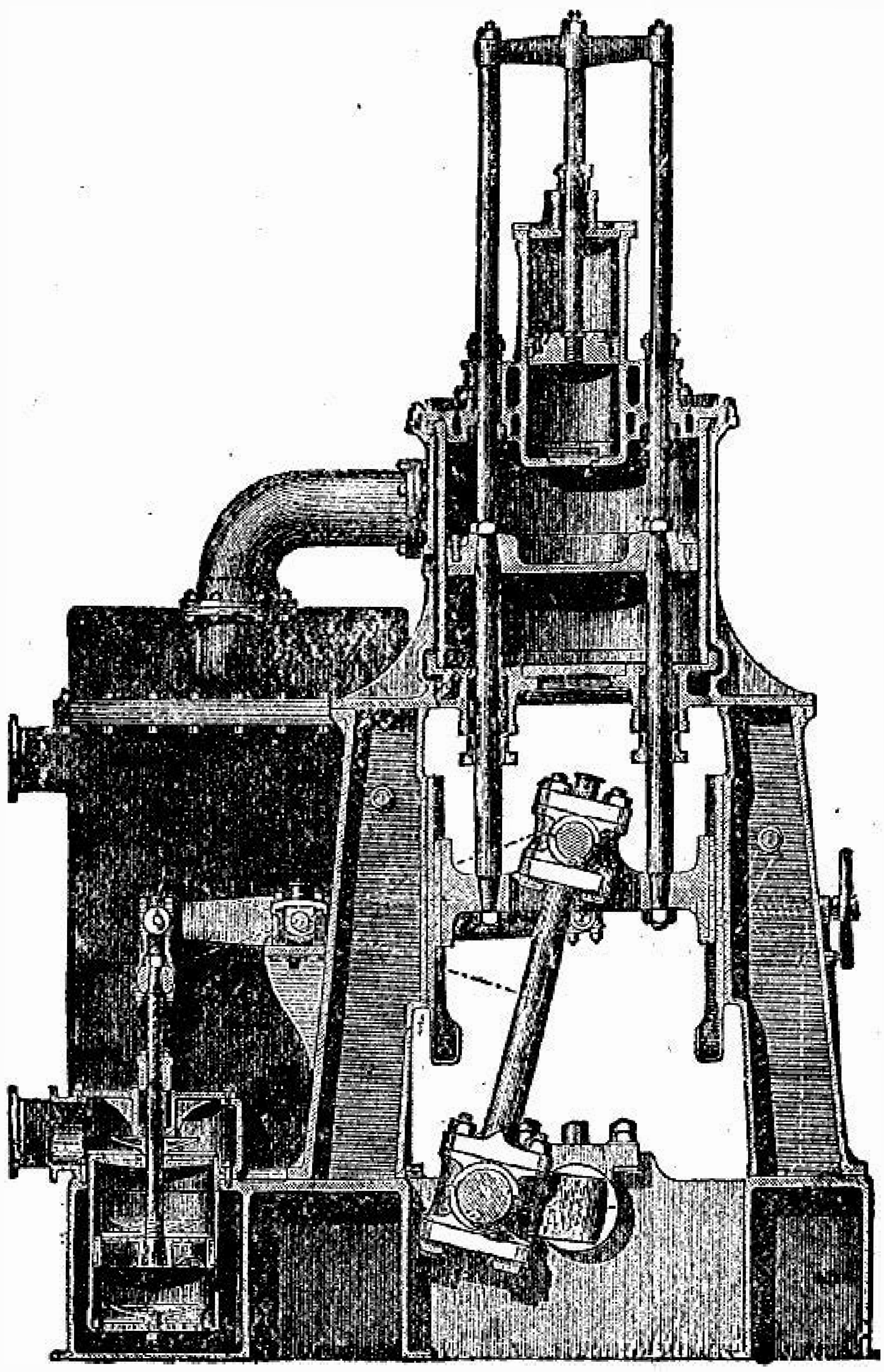

FIG. 155.—Tandem Compound Engine. (Scale $\frac{1}{36}$.)

The latest types of marine engine are those compounded engines in which the number of engines in series is three, or even more, usually driving three equidistant cranks, and those which are designed to drive two, or even three, screws independently. In the extension of the principle of compounding in multiple-cylinder engines, it is probably desirable to restrict the number of cranks to three, even with a pair of low-pressure cylinders, or in the quadruple-expansion engine; both as a matter of economy and

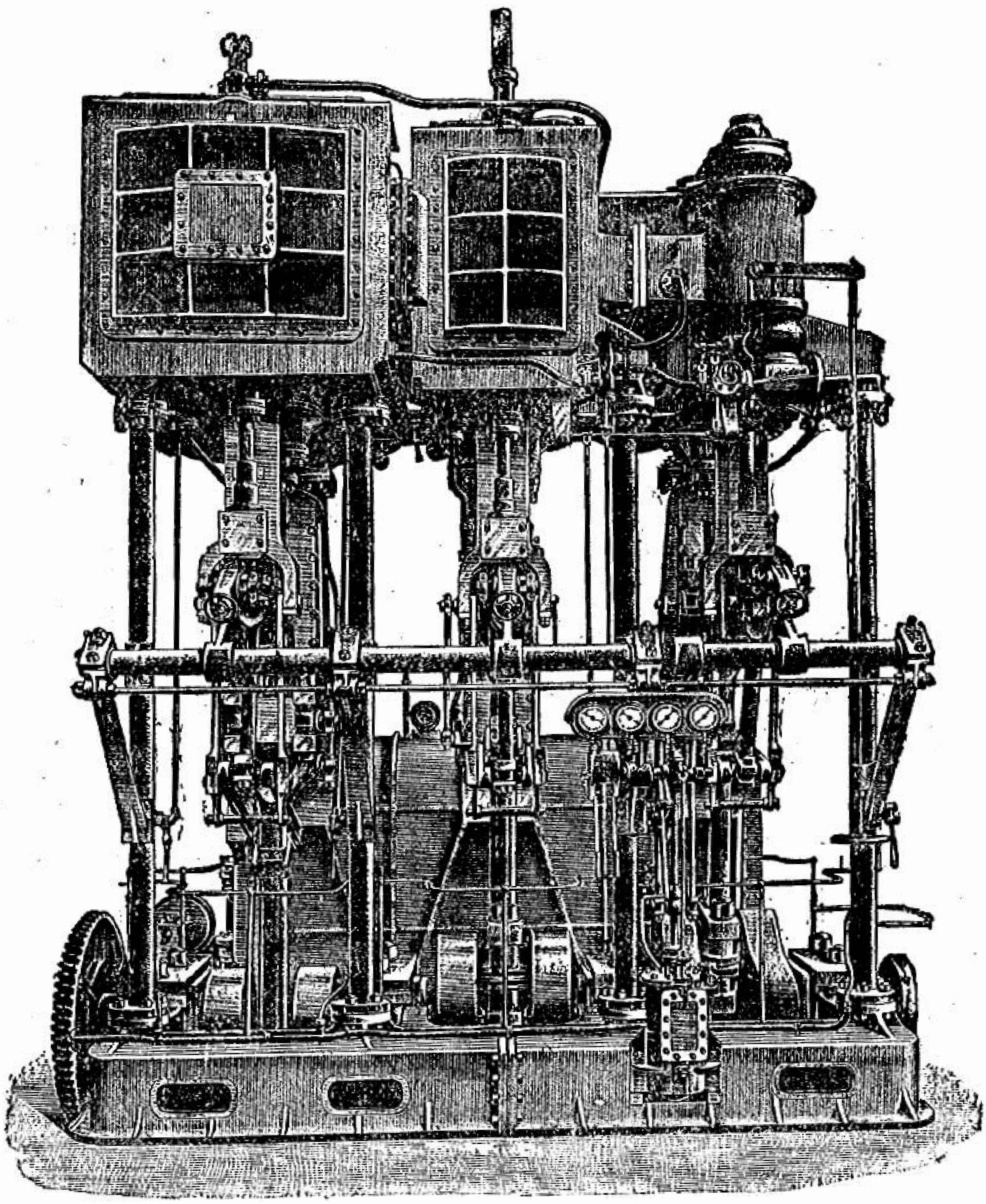

FIG. 156.—Triple-expansion Engine.

to secure smooth working with minimum friction. The balance is usually practically perfect and the full advantage of compounding is attained.

In these cases the construction of all the engines which constitute an element of the compounded machine is com-

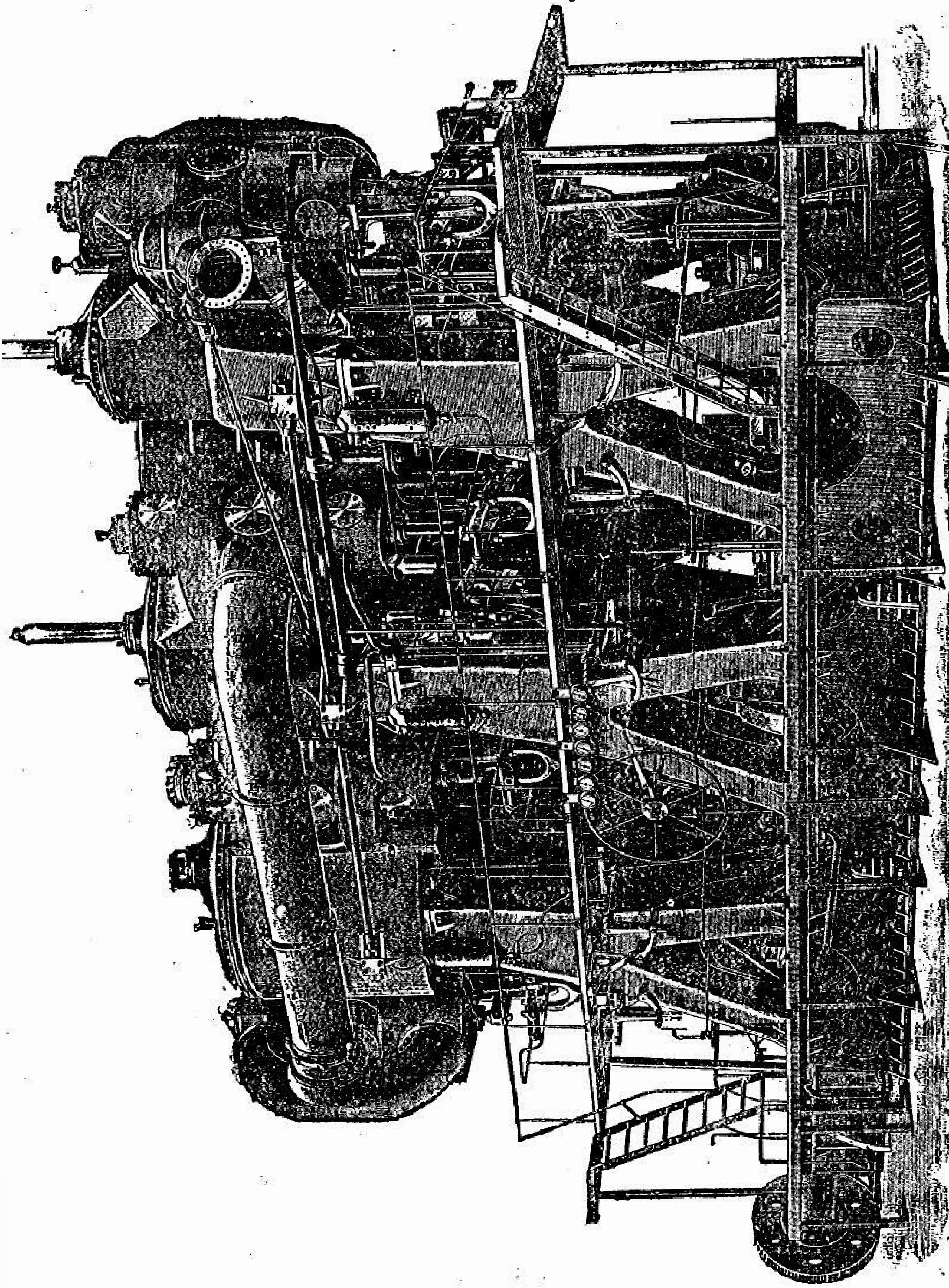

Fig. 157.—Engines of "Paris" and "New York."

monly substantially the same in general, the differences being principally in the proportions of the steam-cylinder and its accessories. The triple-expansion engine thus usually consists, as a whole, of three similar simple engines, side by side, so arranged, as to size of cylinder and disposition of pipes and valves, that they work as a series in taking and exhausting steam. There are, however, a number of successful arrangements of three- and of four-cylinder engines driving but two cranks and in which the "tandem" disposition of cylinders is adopted with good results.

The engraving represents one set of the triple-expansion engines of the twin-screw sister-ships, the City of Paris and the City of New York. Their general arrangement is well shown. Each set drives one screw. The magnitude of these great engines is indicated by the altitude of the working platforms and the reversing wheel. This may be taken to represent a standard and very satisfactory disposition of parts and general proportion of engines.

A good sample set of figures for the proportions and performance of these engines are:

| | |
|---|---|
| Steam-cylinders, diameter, inches | 45, 71, 113 |
| Stroke of pistons, feet | 5 |
| Ratios of volumes | 1; 2.489; 6.304 or 0.402; 1; 2.53 |
| Steam-pressure, per gauge, lbs | 148 |
| Revolutions per minute | 87 |
| Vacuum, inches | 26 |
| Mean pressures, lbs | 64; 32; 14 |
| Indicated power, H. P. | 19,175 |
| Temperature feed-water, Fahr. | 119° |
| " sea-water, " | 54° |
| Area H. S., square feet | 50,250 |
| " G. S., " | 1,294 |
| " condensed surface | 33,000 |
| I. H. P. per square foot G. S. | 14.8 |
| " " " H. S. | $\frac{1}{2.62} = 0.38$ |
| " " " condensed surface | $\frac{1}{1.72} = 0.58$ |
| Ratio H. S. to G. S. | 38.8 |
| " " " C. S. | 1.52 |

These figures are given by the engineer officers of the ship for a passage across the Atlantic made in 5 days, 19 hours, 34 minutes.

The triple-expansion engine has now displaced the ordinary two-cylinder compound machine in regular work of the merchant navy for long routes, and is also adopted for stationary engines where the cost of fuel is such as will justify the somewhat increased cost of construction. By its use it is found practicable to raise the steam-pressure to above ten atmospheres (150 pounds and upward) and to increase the ratio of expansion to 15 or more, with good results. The great cost of fuel and the value of tonnage space on shipboard have hastened this advance in marine-engine design. Mr. A. E. Seaton, comparing sister-ships fitted with the two types of engine, found this change to produce a saving of about 20 per cent. over the two-cylinder compound engine.

These engines were introduced in 1874 by Mr. A. C. Kirk in the steamship Propontis, the steam being supplied at 160 pounds pressure by water-tube boilers.

This type of engine in the long voyage between London and Australia (1880) has given great economy, saving 500 tons in the voyage and permitting the carrying of 500 tons additional freight.

Quadruple expansion in engines carrying 175 to 200 pounds steam has been introduced (1885), and promises still further advantage should it prove practicable to construct satisfactory boilers.

These engines thus permit the economical employment, often, of twice the pressure, or more, customary in ordinary compound engines, and a third, or more, higher than with triple expansion, and the best ratios of expansion are correspondingly increased, 20 and 25 being not unusual values. In the arrangement of this engine the cylinders are variously grouped by the different designers; all of whom, however, endeavor to secure a combination of lightness, compactness, small clearance-spaces, and good steam-distribution, with uniform rotatory action on the crank-shaft. A common design mounts two cylinders on the upper ends of the other two, thus in effect producing a pair of "tandem" engines, with the two cranks at right angles and with properly proportioned receivers; in other designs, three cranks are employed in order to secure more uniform turning moments, and in such examples one crank is acted upon by two cylinders, while the others are connected to a single piston each. A less compact and more weighty and costly design applies each of the four pistons to each of four cranks, giving admirably good rotative effect, but sacrificing something of the advantages of the other types. For boiler-pressures exceeding 15 atmospheres (above about 225 pounds per square inch) the quadruple-expansion engine is unquestionably an economical form, and for marine purposes, or where fuel is very costly, it is likely to supersede the triple-expansion engine.

Among recent forms of pumping-engines worthy of special notice is the modified "high-duty" engine of Mr. C. C. Worthington (Fig. 158). In the figure the "high-duty attachments" performs an exceedingly important office in a very ingenious yet simple manner. It consists of a pair of plungers working in oscillating barrels, seen at the right, attached to a cross-head on each piston-rod common to engine and pump. Water under high pressure from the "rising main" is introduced behind these plungers and retained as nearly uniform as practicable as the engine makes its stroke. It is seen that this pressure resists the motion of the engine from the beginning to the middle of its stroke. At mid-stroke the centre-lines of the plungers are perpendicular to the line of the rod; they counterbalance each other, and the action of the pair is neutral as respects the engine. Beyond half-stroke this pressure aids the steam, and the more as the end of stroke is approached. The irregular action of the expanding steam is thus met by a correspondingly variable and precisely opposite action of "equalizers," and it is easy, with high ratios of expansion, even, to thus secure a very uniform pressure in excess of the resistance of the water-column, by careful proportioning of parts and of pressures.

This engine is thus brought into the class known as "high-duty engines." This attachment does the duty of the fly-wheel, often in other engines of enormous weight, and thus increases effectively the efficiency of the engine as a machine. It is also at times a safety-attachment, stopping the engine in case of a breakage in the mains.

Under similarly favorable conditions we may also, with equal likelihood, anticipate a probability that we may obtain economy with multiple-cylinder engines in somewhere about the following proportions:

| ENGINE. | Consumption. | Steam-pressure. | Gain, total. | Gain, difference. |
|---|---|---|---|---|
| | Lbs. | Lbs. | Per cent. | Per cent. |
| Simple, one cylinder | 2.0 | 75 | .. | .. |
| Compound (double-expansion) | 1.6 | 125 | 20 | 20 |
| Triple-expansion | 1.4 | 175 | 30 | 10 |
| Quadruple expansion | 1.25 | 225 | 40 | 10 |
| Quintuple-expansion | 1.1 | 450 | 50 | 10 |

The figures in the first three cases are based upon what is probably ample experience; the others are obtained by inference from the rate of progression thus established, and upon the principle, above enunciated, that the waste is reduced.

The stationary multiple-cylinder engine is rarely given the same form as the marine engine. The necessity of having a pair of cranks, and the objection to the employment of the fly-wheel, do not here exist; nor does either the volume or the weight of the machine become so vitally important a matter as at sea. The design adopted is, for these reasons, one which will be of minimum first cost, irrespective of these considerations.

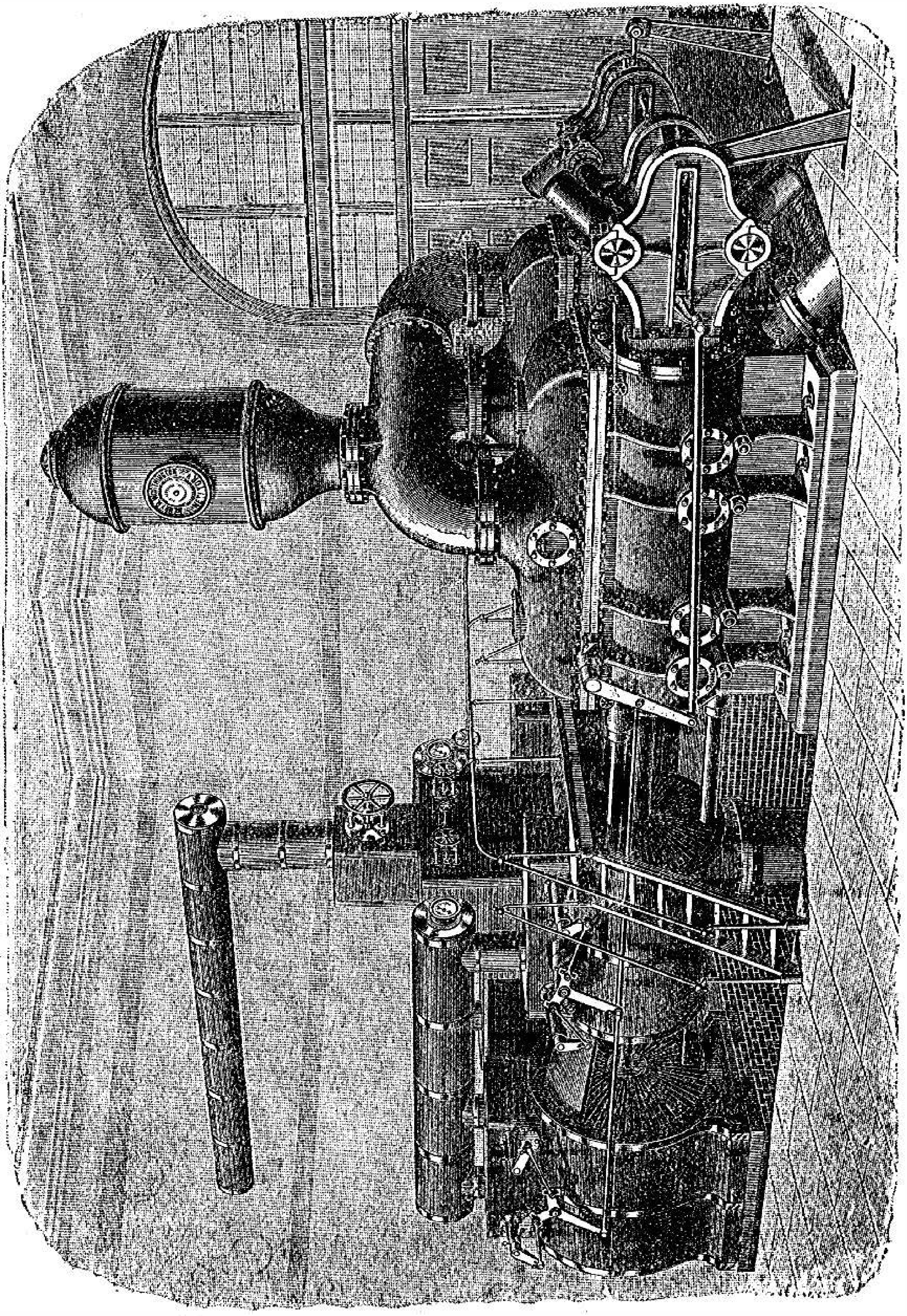

FIG. 158.—The Worthington High-duty Pumping-Engine.

The "tandem" engine is perhaps the most common form of stationary compound engine. In this type, as shown in the next illustration, the two cylinders are set in line, have a common piston-rod, and drive the same crank. The high-pressure cylinder is commonly placed behind the low-pressure, and the latter is directly attached to the frame of the engine. The exhaust of the smaller cylinder is carried in any convenient manner to the large engine ; but the more direct and the larger the conduits employed, the better. In some cases the two cylinders are set directly in contact. This plan involves a difficulty usually in packing the rod between them, but it has the advantage of great compactness.

The compound Corliss engine was first introduced by other builders ; but no one was more successful in the economical working of the machine than was its great originator, the late George H. Corliss. The usual method of compounding this engine for stationary purposes is that known as the "tandem" system, in which the high-pressure cylinder is set behind the low-pressure, both pistons having a common rod and driving a common set of reciprocating parts and having valve-gearing actuated by the same eccentric and rod. The plan is simple, inexpensive, convenient, and compact, and is found to be very satisfactory in operation, the economy attained by it being about as high as that of any other arrangement yet devised. This method is illustrated by Fig. 159, which exhibits a form of the engine designed by Mr. Edwin Reynolds. It is readily seen that it would probably be impossible to find a better method of combining maximum efficiency with minimum cost.

High and low speed engines are already described. Classified with reference to their method of driving machinery, we may thus designate the two classes :

(1) Engines which may be used in driving by belt, and which are not adapted for direct connection.

(2) Engines especially designed and constructed to be coupled directly to the "dynamo."

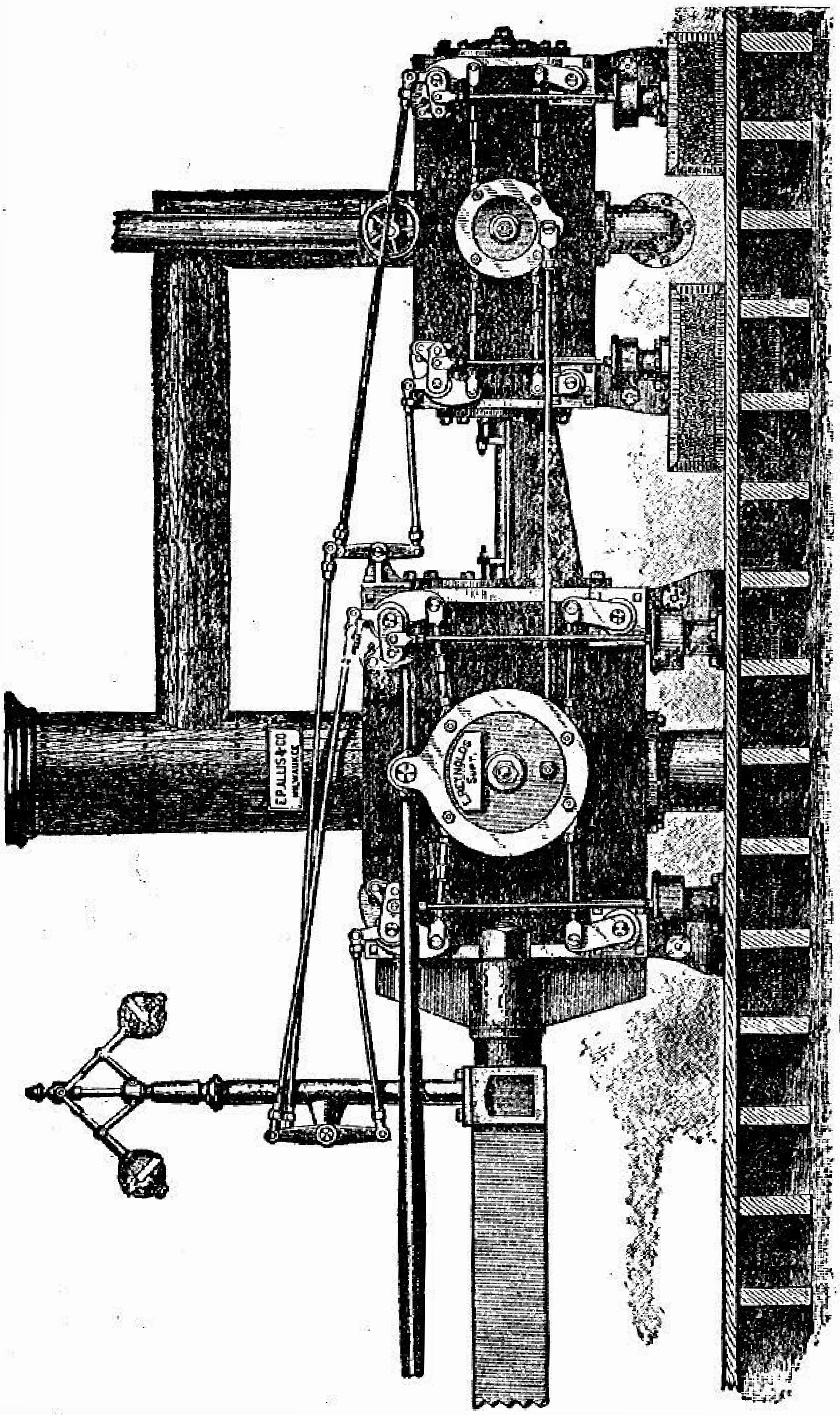

Fig. 159.—"Tandem" Compound Engine. (Scale $\frac{1}{24}$.)

The first class of engines is by many of the more conservative engineers still preferred to the second. The latter constitute the so-called modern "high-speed" type of engine, and are coming into general use for high-speed machinery, especially in electric light and power stations.

One of the methods of securing economy in the working of steam has been stated, when describing the Porter-Allen engine, to be the driving of the engine up to the highest safe velocity of piston and giving it maximum speed of rotation. The time allowed for "initial" condensation of each charge, and for the necessary change of temperature preceding such condensation, is thus reduced, the amount of steam condensed within the cylinder being thus made a minimum in any given time. This fact, and their wonderfully perfect regulation and safety against "running away," constitute their peculiar advantages.

The governor is of a type that has not been seen in the engines previously described. In the common "fly-ball governor" the two balls revolve about a vertical spindle, to which they are attached by a pair of arms in such a manner that they may take any position that the resultant action of gravity, centrifugal force, and the pull on the supporting arms may give them. A defect common to all governors of this class is, that the force tending to pull the balls downward is perfectly uniform. The position taken by the balls, at any fixed speed of engine, is always the same; the connection of the balls with the regulating mechanism is one which always preserves a fixed relation between the position of the governor-balls and the position of the regulating apparatus. Thus it happens that the engine can never be kept precisely at speed, unless the speed is such as will give the governor exactly its normal position, and at the same time such that the valves shall supply just the normal quantity of steam to the engine. If we can substitute for the action of gravity a force which can be made to vary with change in the position of the balls, in such a way that the variation in the opening of the throttle, or in position of the point of cut-off, shall go on until the engine comes to speed, irrespective of all other conditions, we shall have what is known as an "isochronous" governor, and shall be able to secure the right speed, whatever changes occur in steam-pressure or in load, provided that there is steam enough to drive the load at that speed with the least expansion for which the engine is designed. Such a result can be reached by substituting the tension of a spring, properly set, for the action of gravity. The form of governor here illustrated is, or can be made to be, of this class. It simply requires that the spring tension shall be given a certain easily determined relation to the effort of centrifugal force.

A governor of this character, when well made and adjusted, will open the throttle-valve, or will increase the ratio of expansion, as the steam-pressure diminishes or as the load is increased, and will continue to move in the proper direction indefinitely, or until the machine comes to speed, or until the engine is doing all that it can do. In this governor (Fig. 160) two levers are set on either side the crank-shaft, in a frame or a pulley to which they are pivoted at *b b*. These rods carry weights, *A A*, which may be adjusted to any desired position by means of the bolts seen in the cut. The outer end of each rod is linked to the loose eccentric, *C C*, by the rods, *B B*, and is controlled by the springs, *F F*, which resist the effort of centrifugal force tending to throw the weights outward. As the weights swing outward or inward as the one or the other of the two opposing forces predominates, the eccentric is turned on the shaft in such a manner as to give the valves that motion which is necessary to produce the proper distribution of steam to bring the engine to its speed. The adjustment of this regulator to its work is easily obtained by the shifting of the weights along the levers, or by increasing or diminishing their amount, as is found necessary.

The general arrangement of this system and the appearance of an engine of this class are illustrated in the accompanying engraving.

A dash-pot has sometimes been used on the governor

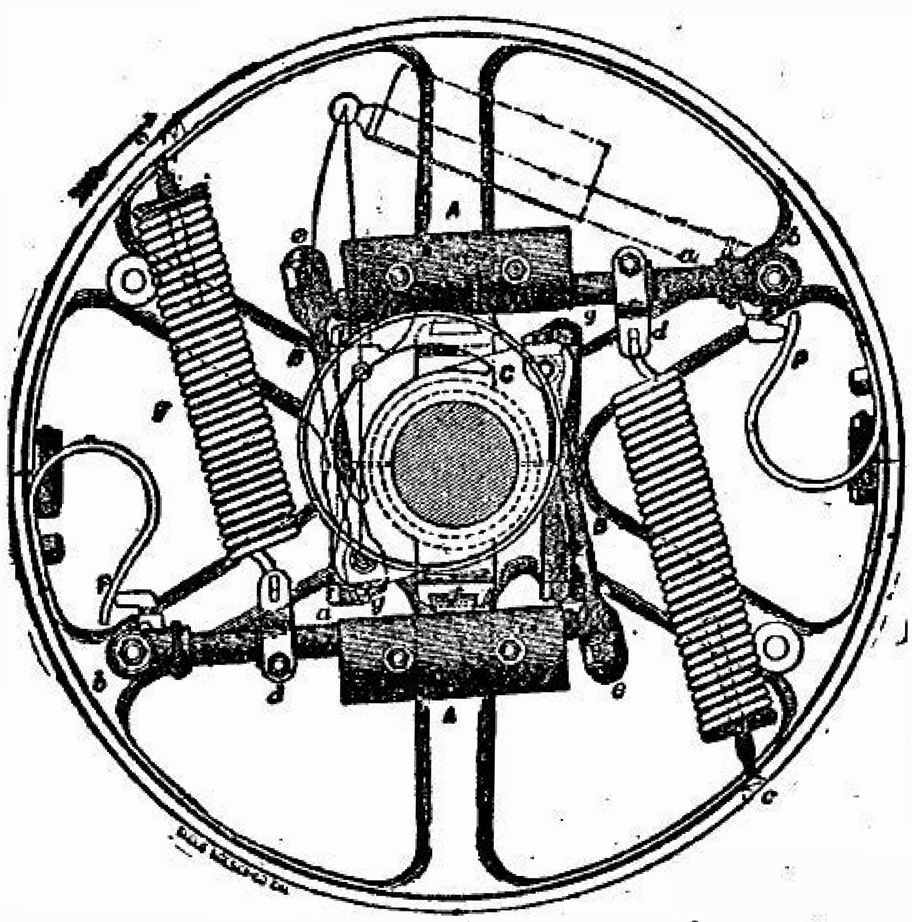

FIG. 160.—Shaft-Governor.

to correct the tendency to violent fluctuation when nearly isochronous.

Among the first of these automatic engines to find a place in electric-lighting was the Armington & Sims engine, which was also one of the earliest to be built as a compound engine. An experimental engine was built about 1880; but the engine was not constructed as a multiple-cylinder engine regularly and as a standard type until some years later. The form given this engine is seen in the accompanying illustration, which represents the machine as constructed to give 100 horse-power at high speed. The regulation and the general construction of each of the two elements of the compound engine are similar to those already described in the simple engine. The two cranks are placed opposite, and this gives that perfection of balance which cannot be secured by any other device. It is also the best method of obtaining transfer of steam from the one engine to the other with minimum loss of pressure. The attainment of a speed of 800 revolutions a minute is not impracticable. In the more common type next shown

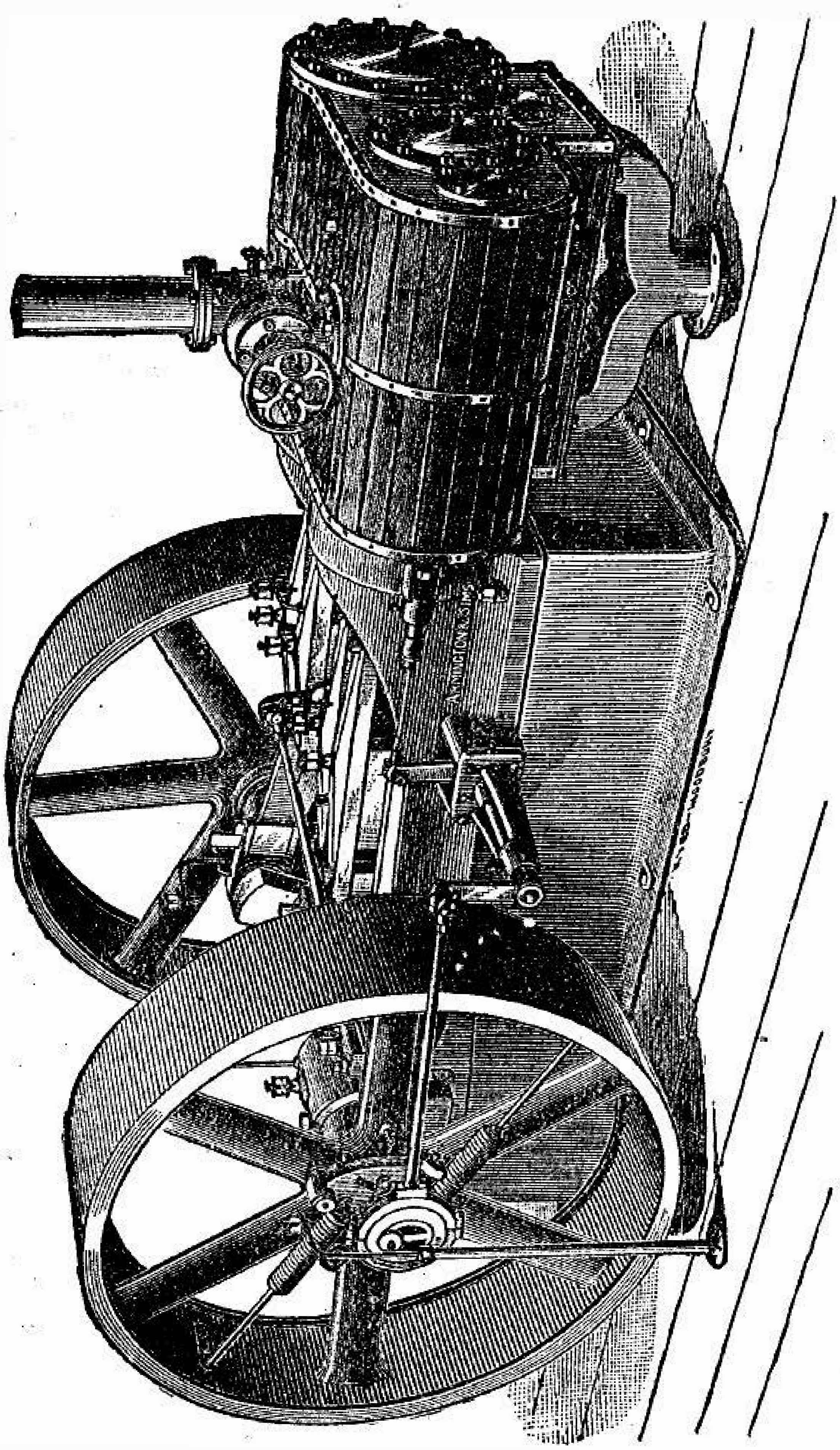

FIG. 161.—Compound Engine.

the peculiar form of the valve provides for quick admission of steam, and the large wearing surfaces insure it more or less fully against leakage; the pistons and stuffing-boxes used are more easily got at than ordinarily with engines of the "tandem" type.

Piston-valves are used, and in this engine the steam-chest is bored out and fitted with bushings which have supporting bars to prevent the valve catching upon the ports. When worn they can be withdrawn and new ones inserted, and a new valve introduced, without delay.

Fig. 162 represents an automatic compound enginesdesigned by Mr. F. H. Ball, especially for use in driving dynamo-electric machinery.

The illustration represents engines using steam at 125 pounds pressure, and of 250 horse-power each.

It was thought best to build these engines in the form of a double engine rather than the "tandems" type of compound, because it was believed that higher rotative speed could be successfully used where the work was distributed over two sets of crank-pins and journals of smaller sizes, rather than with the use of a single set of bearings of larger size, as in the case of a tandem engine developing the combined power of the double compound.

An engine designed by Mr. Ide (Fig. 163) illustrates both the "tandems" form of compound high-speed engine, and some features of design of peculiar interest. This engine has its running parts covered in, to insure that the oil, which is freely supplied, may not be wasted or spattered about, to the injury of surrounding objects, while thus also obtaining thoroughness of lubrication approximating that of the "oil-bath." This gives, when fully effected, very great decrease in the wasted energy of internal friction of engine and corresponding increase of efficiency. The design is simple, inexpensive of construction, and embodies details of construction coming to be generally recognized as essential to high efficiency. The engine has a shaft-governor, controlled by a dash-pot, and thus enabled to regulate more closely. Its running parts are usually of steel.

One of the dangers to which fast-running engines are peculiarly exposed is that of injury by the entrapping of water in the cylinder and the plunging of the piston against the mass of incompressible fluid which then fills the clear-

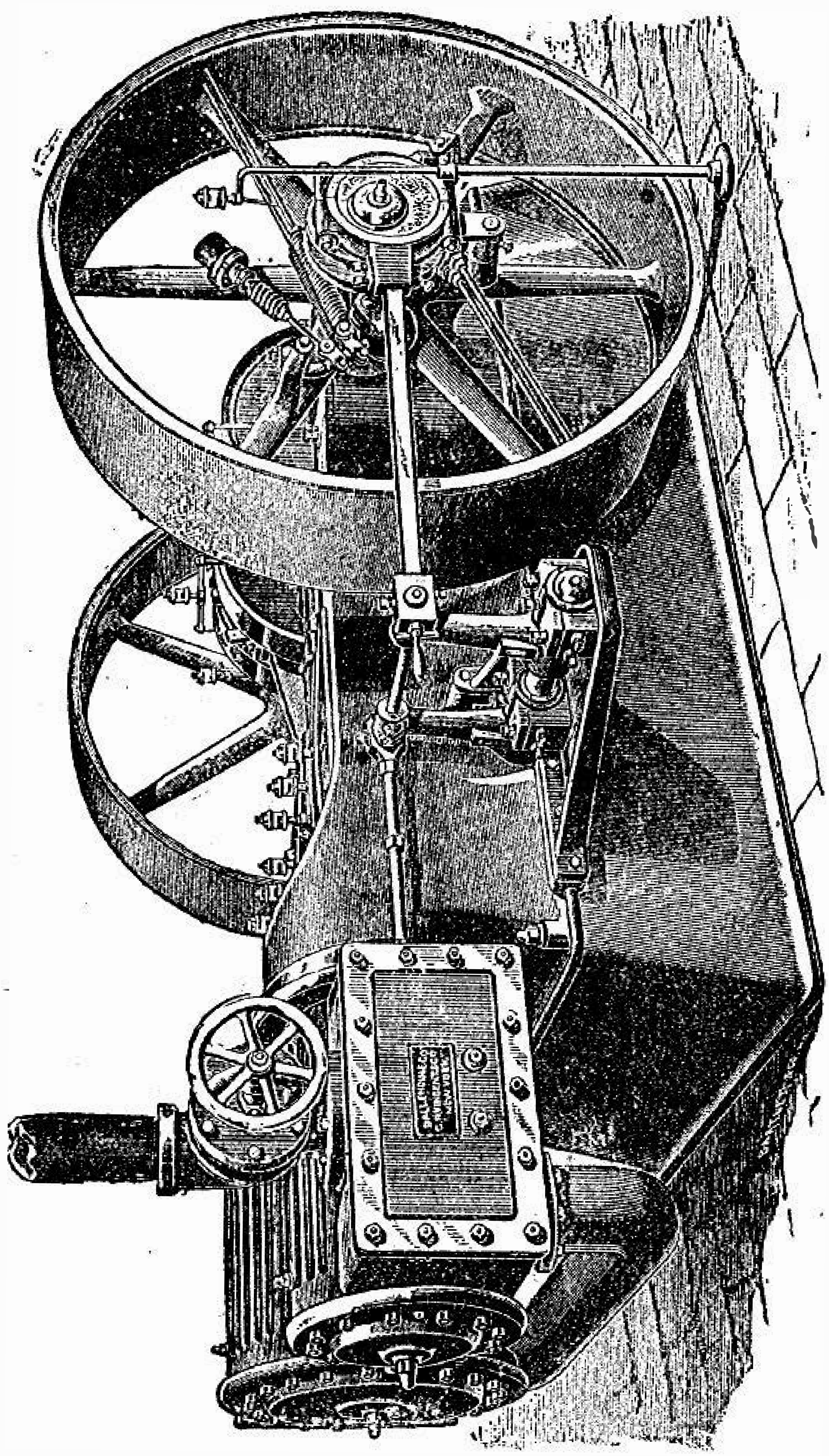

FIG. 162.—"Cross" Compound Engine.

ance-spaces. In this engine, in addition to the relief-cocks or valves which are always fitted to such engines, a safeguard is introduced in the form of what engineers are ac-

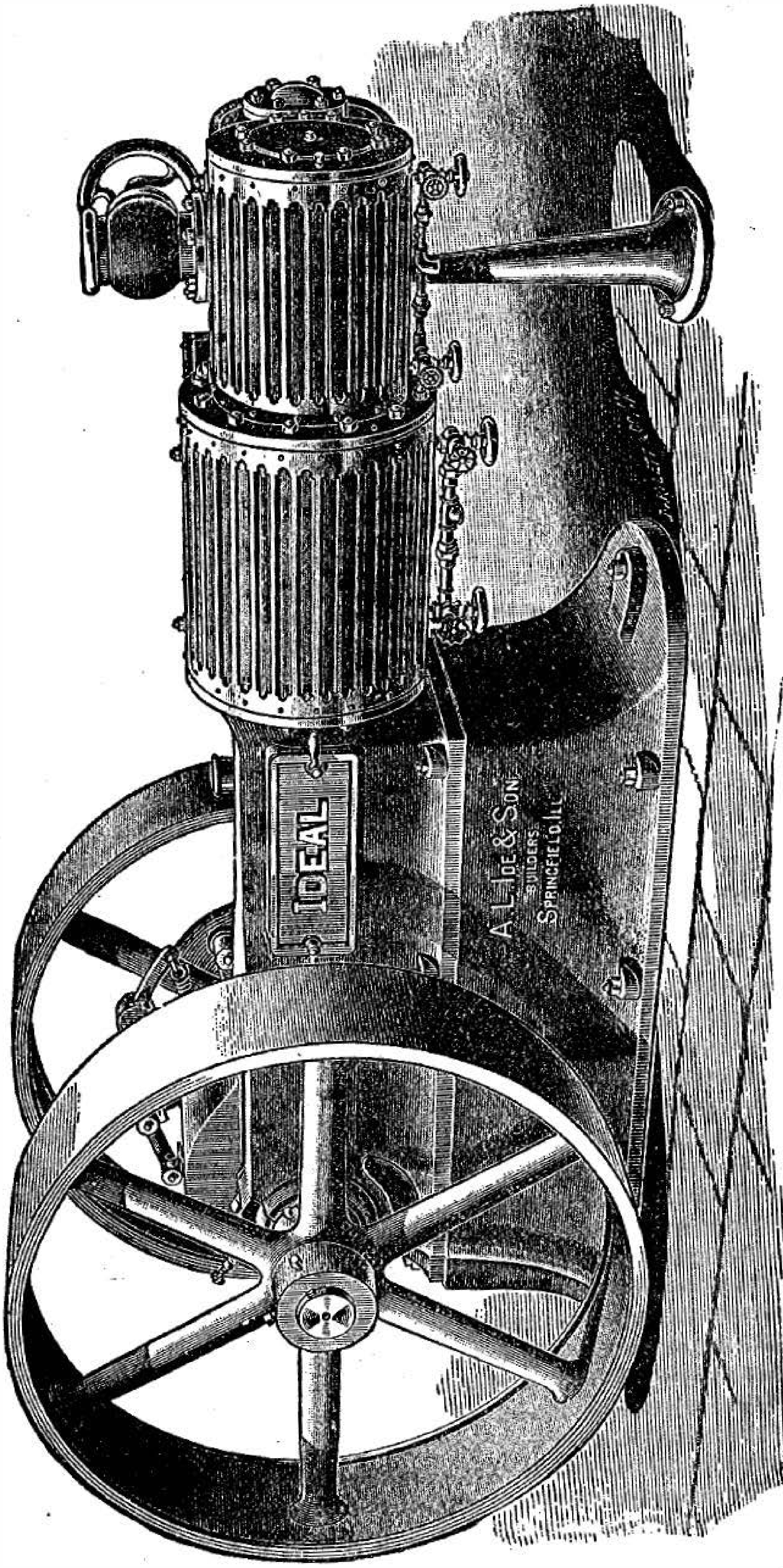


FIG. 163.—"Tandem" Compound Engine.

customed to call the "breaking-piece," a part which is made purposely weaker than other portions of the machine, exposed to a common danger, so that this piece may go when danger arises. This piece is always one the replacement of which will give little trouble and make but little expense. Such a breaking-piece is made to form a part of the cylinder-head. This may be knocked out without injury to any important or costly part of the structure.[1]

The single-acting multi-cylinder engine of Westinghouse, illustrated in the engraving, is a good typical representative of this class, and is one of the simplest devices of its kind. A single piston-valve, set horizontally above the two cylinders, distributes the steam and is regulated by a shaft-governor which properly varies its throw. The cranks are set opposite each othera; the motions of the pistons are synchronous in opposite directions, and no receiver is needed. Both engines are single-acting, and high compression does away largely with the wastes due to considerable clearance.a The cut-off in the high-pressure cylinder is effected by the lap of the valve. It has been found possible by this arrangement to bring down the consumption of steam to less than 20 pounds (9 kilos) per horse-power per hour when condensing, and below 25 pounds (11 kilos) when working non-condensing.

In such single-acting engines it is usually intended that the rod shall never leave the crank-pin, in order that pounding may not occur. It is therefore evidently necessary that they should be so proportioned and speeded that the action of the inertia of their reciprocating parts shall not produce stresses, on turning the centre, in excess of the sum of weights and steam pressure.

[1] The author planned an engine, about the year 1860, in which the whole cylinder-head was made a safety-valve which could lift and discharge the water into the chamber behind it, the cover of the latter being bolted on, while the cylinder-head was only held in place against a faced joint by steam-pressure.

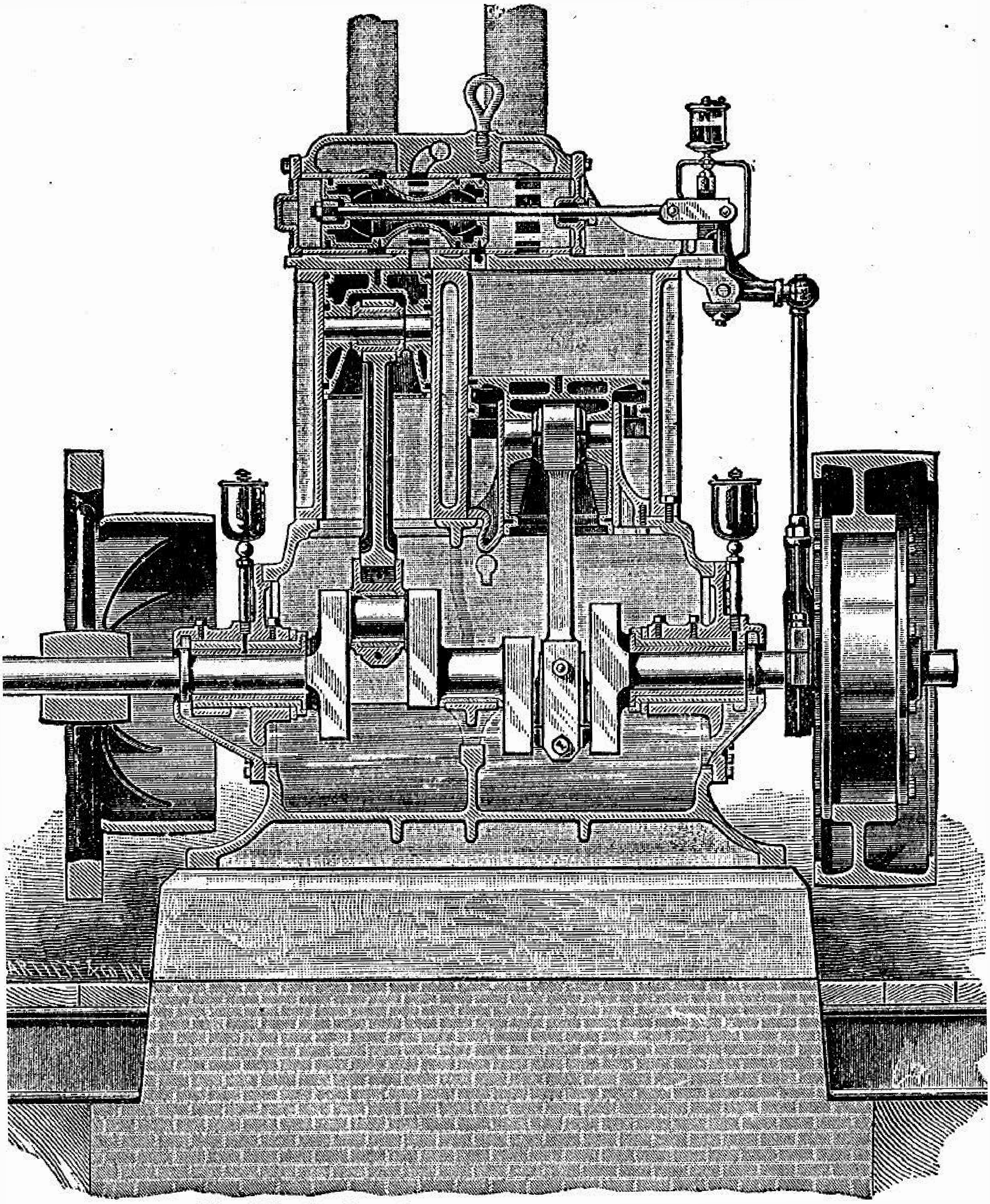

FIG. 164.—Single-acting Compound Engine. (Scale $\frac{1}{12}$.)

An ingenious modification of the enclosed single-acting compound type of engine, the "central-valve engine" of

Mr. Willans—which is also interesting as having been the subject of exceptionally complete scientific investigation—is seen in Fig. 165. It was studied as a simple, a compound, and a triple-expansion engine, being easily adapted to either system.[1]

As here shown, its three cylinders are placed in series and "tandem." The valves are on one rod, driven by a single eccentric on the crank-pin, the rod being in the axis of the engine and the valvesa within the hollow piston-rod. Cut-off is effected by the passage of the ports into metallic rings in the ends of the cylinders, and is adjustable by hand or by the governor. Compression is effected in the separate cushion-chamber.[2]

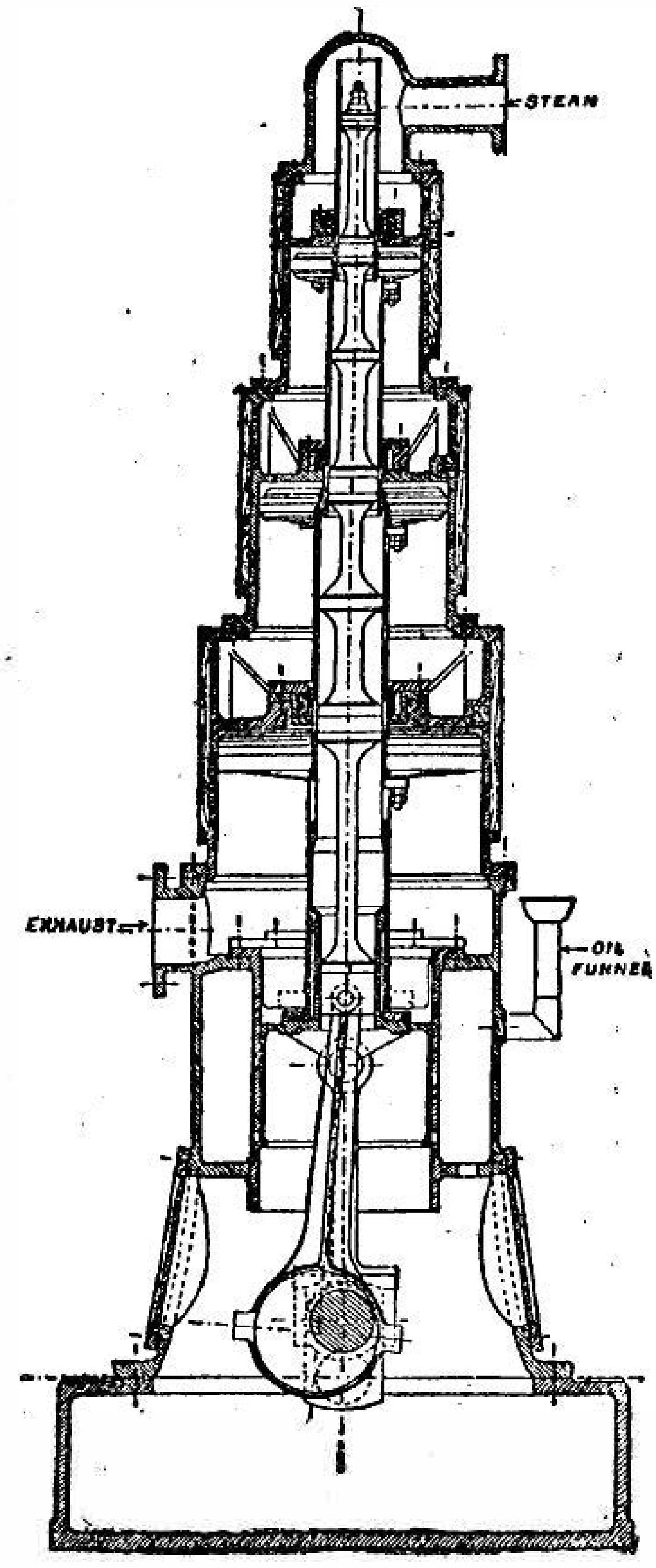

Fig. 165.—Central-Valve Engine.

These engines are usually grouped in pairs, with cranks at right angles.

In some cases the arrangement of a pair of complete engines, of properly selected sizes,a in such manner that either the exhaust of one may be used in the other, or steam may be taken direct from the boiler to either, is

[1] The discussion of this paper is remarkably interesting:—"Transactions of the British Institute of Civil Engineers," March, 1888; 1887–1889; No. 2,306, vol. xciii.

[2] Ibid., vol. lxxxi, p. 166.

found advantageous. When less power is demanded, or when one is disabled, the available engine may then be used alone. Economy has been attained by this plan even when the two engines are placed at considerable distances apart, the precaution being taken to carefully guard against loss of heat between them.

The "cross-compound" type of Corliss engine is illustrated by the accompanying sketch of a pair designed by Mr. Reynolds and built by Allis & Company for the Nam-quit Mills. The cranks are set at right angles, and the receiver is placed beneath the floor. This is a less common variety than the "tandem" form, but is still often adopted.

The general arrangement and disposition of the parts of a triple-expansion engine as built by the Corliss Company is seen in Fig. 166. Here the low-pressure cylinder is divided, one of its two elements being coupled with the high-pressure cylinder on the right, and the twin with the intermediate cylinder on the left. The cranks are set at 90°. These engines have cylinders 20, 34, 36, and 36 inches diameter and 5 feet stroke of piston. All cylinders are completely steam-jacketed, heads included, and the steam is somewhat superheated. Jet-condensers are used. The capacity of the engine is 1,000 I. H. P. or more, and its "duty" is about 135,000,000 pounds; the fuel used, when of good quality, amounting on test to 1.44 pounds per horse-power per hour.

"Compounding" simple engines is often a very economical and profitable plan. The method depends mainly upon the design of the engine to be so altered. The common forms of stationary beam-engine are frequently improved by what is called "McNaughting," placing a new high-pressure cylinder beside the old and low-pressure cylinder and connecting it to the same beam.

*The Steam-Turbine* constitutes a class of steam-engine which, although the first invented, and familiar as a type to all engineers from the days of Hero the Younger, and

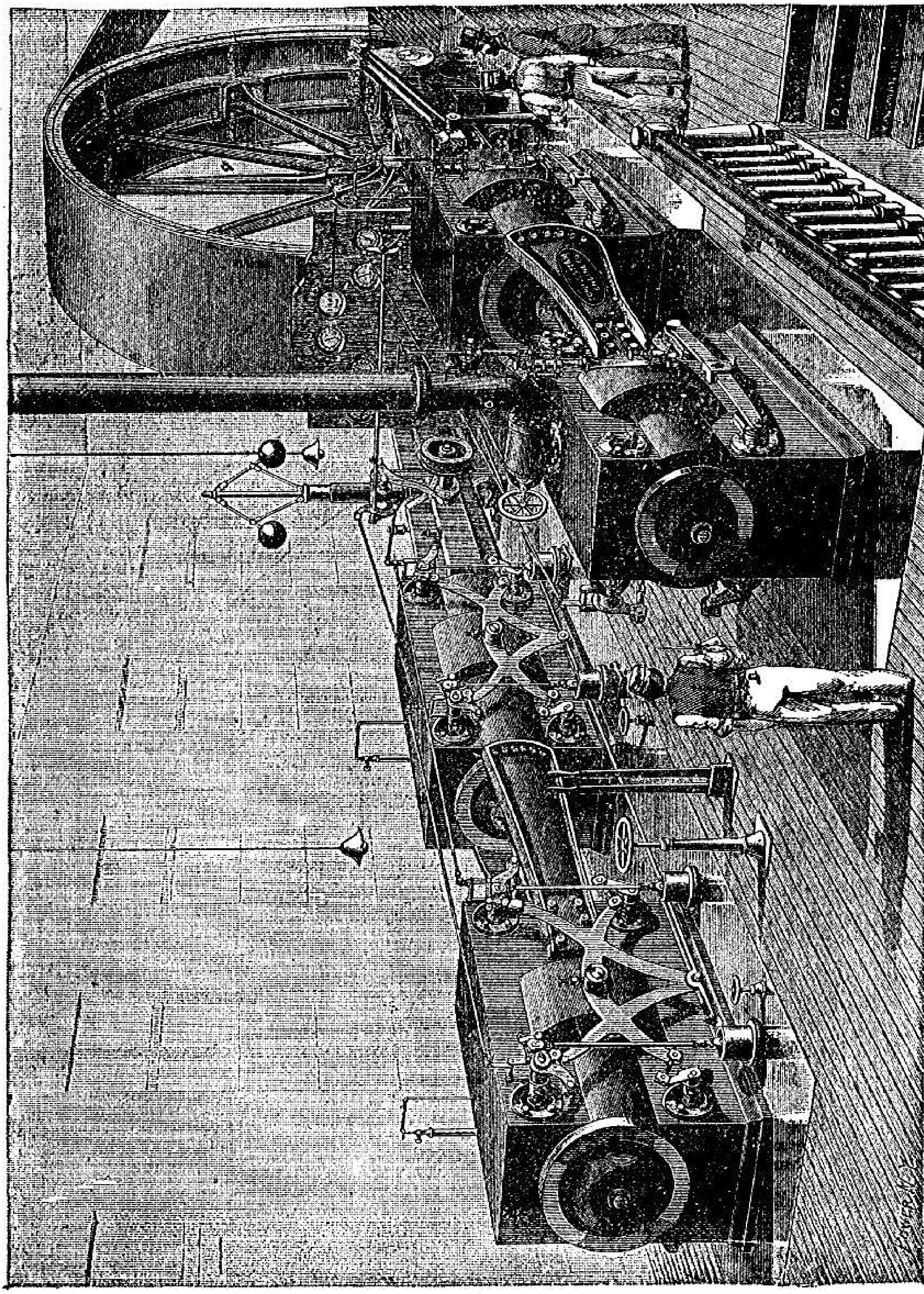

Fig. 166.—Triple-expansion Corliss Engine.

known to have a high theoretical and moderately high actual efficiency, has been only experimentally used until a very recent date. That of Hero has been illustrated in Fig. 3. Branca's engine (Fig. 6) was the first exemplar of another now common form of "steam-turbine," although the name is not precisely correct. This is illustrated in the recent device of La Val. The Atwater engine of about 1840 was of this type, and was said to be as economical as the engines of the time of equal power. Steam-turbines of the inward-flow type have been used by Gorman and others.[1]

The later "compounds" steam-turbine has recently been somewhat extensively employed in the operation of dynamo-electric machinery. It consists of two sets of parallel-flow turbines set in twin series on one shaft on either side the induction-pipe, thus balancing. The passages are gradually enlarged as the volume of the steam increases with its progressive expansion.

The turbines thus alternate with their guide-blades, and both the vanes and the blades are carefully proportioned and set to secure maximum attainable efficiency at the proposed speed of rotation, their pitches and depths being suitably varied.

The actual consumption of steam is found to be 75 to 25 pounds per electrical horse-power produced, and per hour, as steam-pressures rise from 60 to 150 pounds by gauge. The speed of rotation ranges from 5,000 or 10,000 revolutions per minute upward, according to size and steam-pressures, 18,000 and 20,000 being common speeds for the smaller sizes.

Dow's turbine is an inward-flow wheel with concentric sets of guides and vanes in series, and is said to have attained 35,000 revolutions per minute, working regularly at 25,000, consuming 55 pounds of steam per horse-power per hour.

[1] Rankine, p. 538.

The theory of this type of machine is that familiar to the hydraulic engineer, and the speeds of orifice for maximum efficiency are well known to be infinite in the Hero class of turbine and approximately one half the final velocity of flow in the guide-blade turbine. Since these speeds are impracticable in their use, a certain loss of energy is thus inevitable. In compensation for this loss, in the steam-turbine, is the fact that it is not subject to that fluctuation of temperature of parts exposed to contact with the steam which results in large wastes by cylinder-condensation in the common forms of steam-engine. A gain of from 25 to 50 per cent. in this item is to be counted upon.

The Dow turbine, as built for work in connection with the Howell torpedo, gives an average of about 11 horse-power in coming up to speed in regular working, at 60 pounds steam-pressure, and weighs from 100 to 150 pounds, or not far from 13 pounds per horse-power.[1] Its fly-wheel rim attains a speed of nearly 7 miles an hour at 10,000 revolutions per minute. The designer estimates its power at 150 pounds steam-pressure and the same speed at 40 horse-power, or 1 horse-power to 3.75 pounds weight, and states that this may be still further reduced to the extraordinary minimum of 2½ pounds weight per horse-power, a figure well within the estimated allowable maximum for use in aëronautic work.

The steam-turbine of Parsons (Fig. 167) is an engine consisting of a series of turbines, the different pairs of guides and wheels being so placed that the fluid passes successively from one pair to the next. Of the two forms, radial and axial flow, only the latter have been used here. Two series of cylindrical turbines are used, arranged symmetrically to the right and left of the central steam-inlet, the exhaust taking place from the two ends. In this manner a balance is obtained, and the bearings are relieved of end-pressure. Oil is forced through the bearings by a pump. The bear-

[1] *Electrical World*, April 18, 1891.

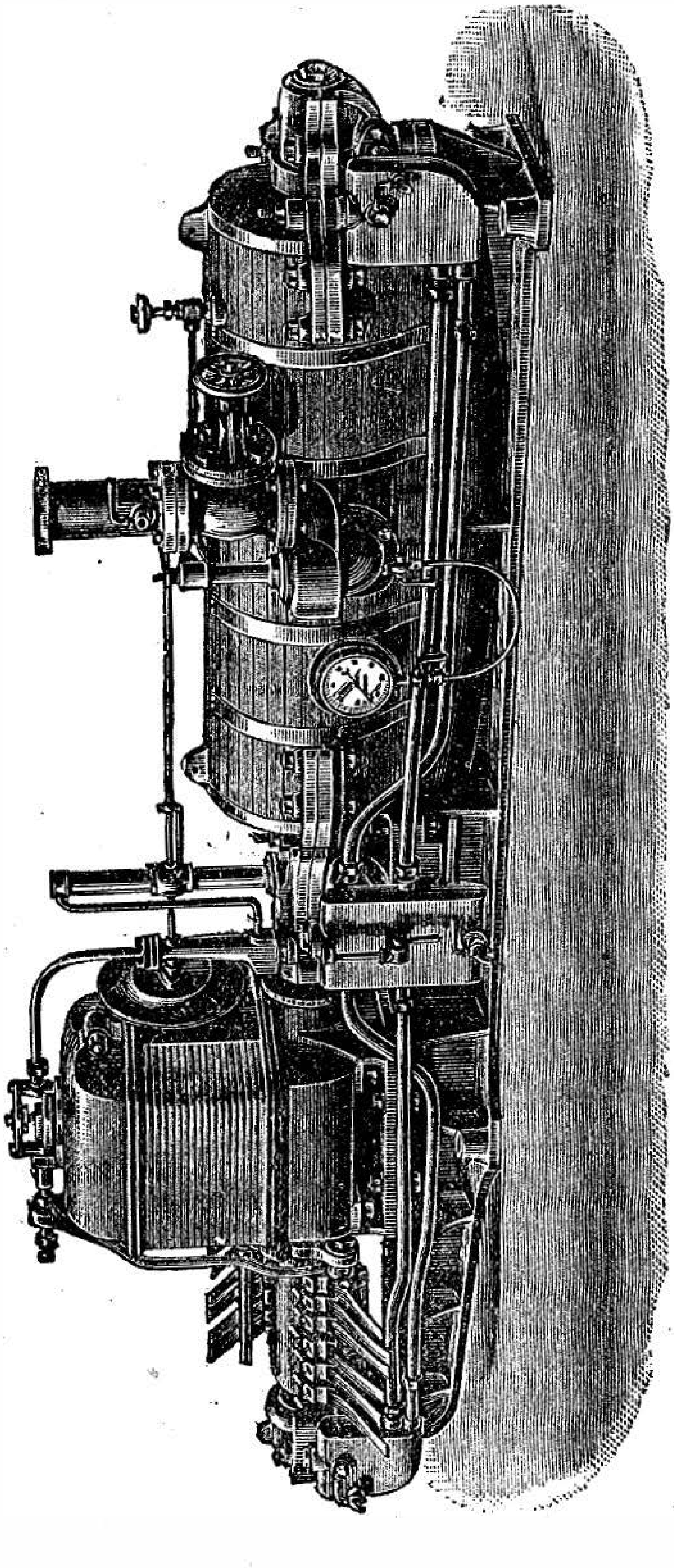

FIG. 167.—Steam-Turbine.

ings are thus forcibly deluged with oil, which returns to a reservoir. The governor is a suction fan mounted upon the spindle and connected with a diaphragm, which operates the throttle-valve against the power of a spring. Its action is found to be rapid and certain.

Such engines have been successfully employed in driving electric machinery and in "spinning" the "fly" of the Howell torpedo. For alternating electric currents, this system possesses the peculiar advantage of permitting a "dynamo" to be employed having but two poles. It may be readily driven continuously at speeds exceeding 20,000 revolutions per minute.

In conclusion of this review of the later developments of the close of the nineteenth century, we may abstract a few paragraphs from an article by the author on "The Trend of National Progress," and summing up the major points of interest in this connection:[1]

"Great movements, whether of mind or matter, of nations or of planets, of civilizations or of comets, of philosophy, of religion, or of wealth-production, are the results of the action of great natural forces, and have in all cases a definable route and rate of motion. As the writer has often put it, 'Nature never turns a sharp corner' in any such movement, and the mighty flux of material and of intellectual forces, and the grand resultant flow of the current of material, or of intangible progress, must always be as steady and as smooth as that of a great river flowing through a plain. It may deviate, and even turn upon itself at times, but it must have a smooth curve, if not a rectilinear course. Now and then some great moral or physical obstruction may impede or divert its stream, but only mighty forces, commensurate with the tremendous inertia of the mass affected, can produce immediate or marked effects upon either its magnitude or its direction.

[1] "Trend of National Progress, by Robert H. Thurston, Director of Sibley College, Cornell University," *North American Review*, 1896.

"It thus comes that, if we can trace the line of progress during the immediate past—if we are able to follow it during past centuries or bygone ages—we may lay down upon the chart the line of its earlier course to date, and can see at once what must inevitably be the direction, the rate, and the distance gained in any stated time in the immediate future, *provided* new and catastrophic phenomena do not, by their unexpected and unforeseeable action, invalidate all prophecy. Given the curve of human progress in any field as representing the immediate past, the immediate future becomes knowable with a degree of accuracy and certainty which is the greater as the forces and the masses affected by them are the greater. The terminal portion of our curve exhibits the tendency and the direction of movement at the moment; and if no great physical or moral force threatens to introduce a new deviating power, or to cause some catastrophe, the progress of to-day will be inevitably the outcome of the progress of yesterday and the introduction to the progress of to-morrow, with unchanged, or little changed, rectilinear or curvilinear advance. The rate of progress of education, or of wealth accumulation, in 1895, must be substantially correct as a gauge of that of 1896, or, with perhaps a little less exactness, of that of 1900. A great war, or a world-wide commercial depression, or a 'reformation,' may now and then, in the course of the centuries, affect these great social currents of progress; but, if nothing at the moment looms up, threatening the immediate future, the trend of human or of national progress may be considered as fully established."

. . . . . . . .

"The basis of all wealth and the measure of the power of accumulation of wealth is the aggregate working power of a people. The working power of a civilized people has come to be measured by the total of its steam-power. The growth in its total 'horse-power' *in steam-engines* of all kinds is the measure of its growth in all the material foundation of civilization and progress, and thus material progress underlies progress in all the arts and sciences, and every intellectual as well as material advance. The first of our diagrams (Fig. 168, *A*) exhibits the trend of our national progress in developing power of national advancement. Its smooth, steady curvature shows not only advance and constant gain, but a steady and continuous *gain in rate of gain*. A straight line would simulate gain by simple interest; our curves, *A* to *D*, simulate gain by compound interest with frequently recurring periods of payment. The century has seen great gain in power of doing work, of accumulating wealth, and great *gain in rapidity of gain* of power and wealth. All our subsequent deductions confirm this primary and essential, this fundamental, conclusion. The United States of North America constitutes not only the most powerful of nations, in the most literal and meaning sense, but it is all the time increasing its speed in the race and as constantly more and more rapidly distancing its competitors. As we shall see presently, its greater and growing intelligence ; its great inventive power, fostered by our exceptionally effective patent system; its industry, its education ; its conscientious acceptance of the correct principles of morals and of economics, as they are brought forward and generally discussed—all these, and other and concomitant qualities, give good reason for Mulhall's enthusiastic prediction, as well as for all the eloquence and pride and confidence of Carnegie.

"In Fig. 168 the line *A* is the expression of the fact and the law of the progress of the United States from 1820 to 1895; and the dotted portion shows clearly what is to be anticipated in the immediate future, if no catastrophic and unanticipated change in the conditions determining the fact and the law occurs. The smoothness of the curve and its regularity of curvature prove that natural causes have operated very steadily and continuously, in spite of occasional 'crises,' and that we may fairly assume the continuation of the curve in the same geometric relations to give us a prophecy of the coming years. Our total physical power for use in driving machinery, for wealth production,

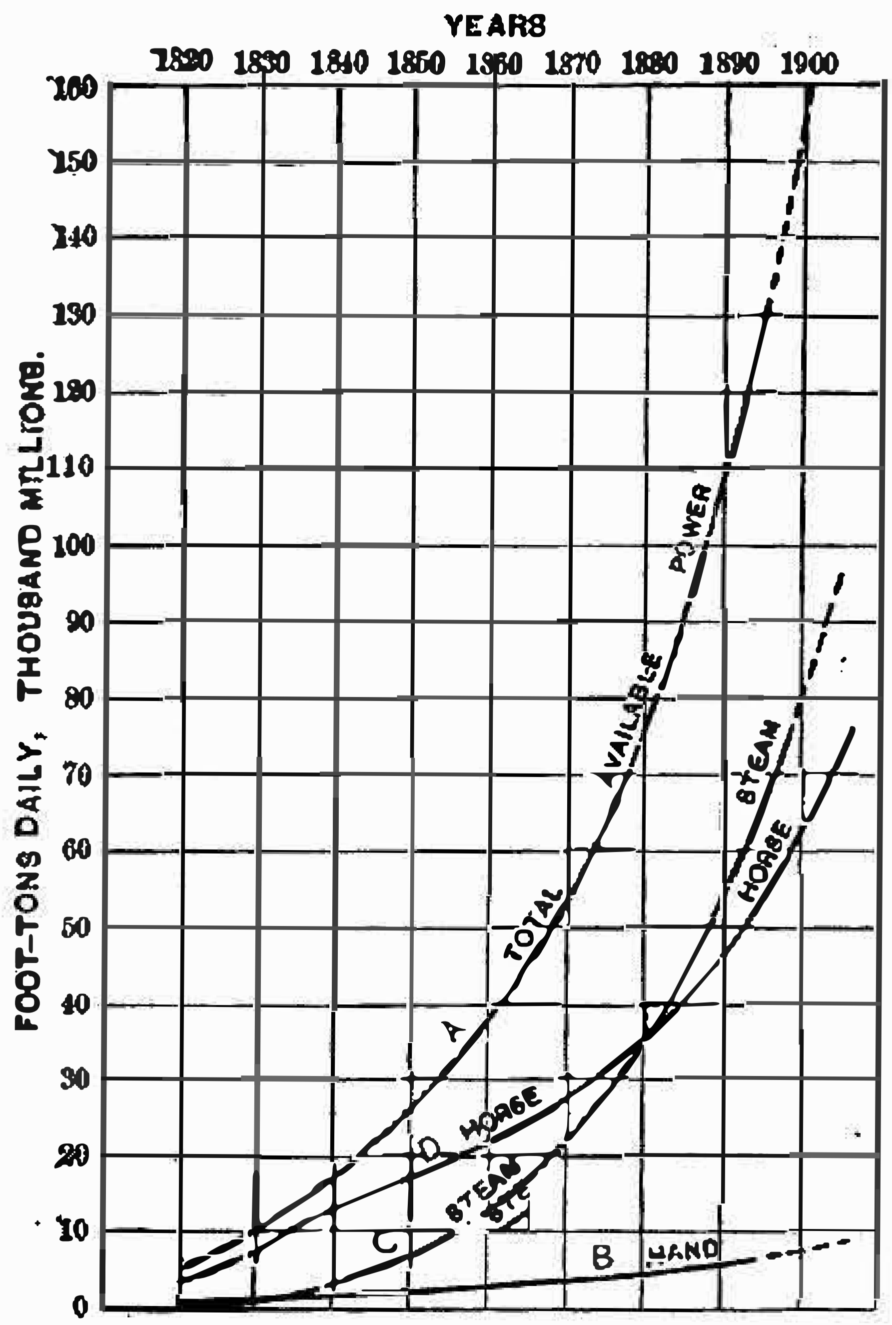


Fig. 168.—Available Steam-Power in United States.

has risen from about 4,300,000,000 foot-tons, daily, in 1820 —the equivalent of lifting a ton 800,000 miles—to nearly ten times that figure in 1860, and to thirty times that power in 1895. It is seen that it must become something like forty times as much—150,000,000,000—about 1900 or a little later. Human power is seen to be growing slowly—i. e., in proportion to population, simply; while steam-power, coming in with Watt's perfection of the engine, at the beginning of the century, will amount to one half the total this year, and aggregate 80,000,000 in 1900, and 110,-

000,000,000 in 1910. Horsepower, steadily growing at a moderate rate, though much faster than population, in the earlier half century, and greater by far than steam-power, finally is eclipsed about 1880 by the latter, and, though still rapidly and steadily growing, falls far behind at the end of the century. Steam-power measures most accurately, probably, the ability to accumulate all those comforts and luxuries which constitute modern civilization, and it is seen that the trend of the line is there most rapidly upward."

. . . . . . . . .

"Fig. 169 simply classifies the forms of steam-power into marine, stationary, locomotive, and gives their aggregate. The mightiest gain is seen to be in locomotive-engines on our railroads. These curves show not only what are the figures for the past and the present, and for the next few years, but their uniformly steady curvature proves that we may fairly anticipate their continuation, with the

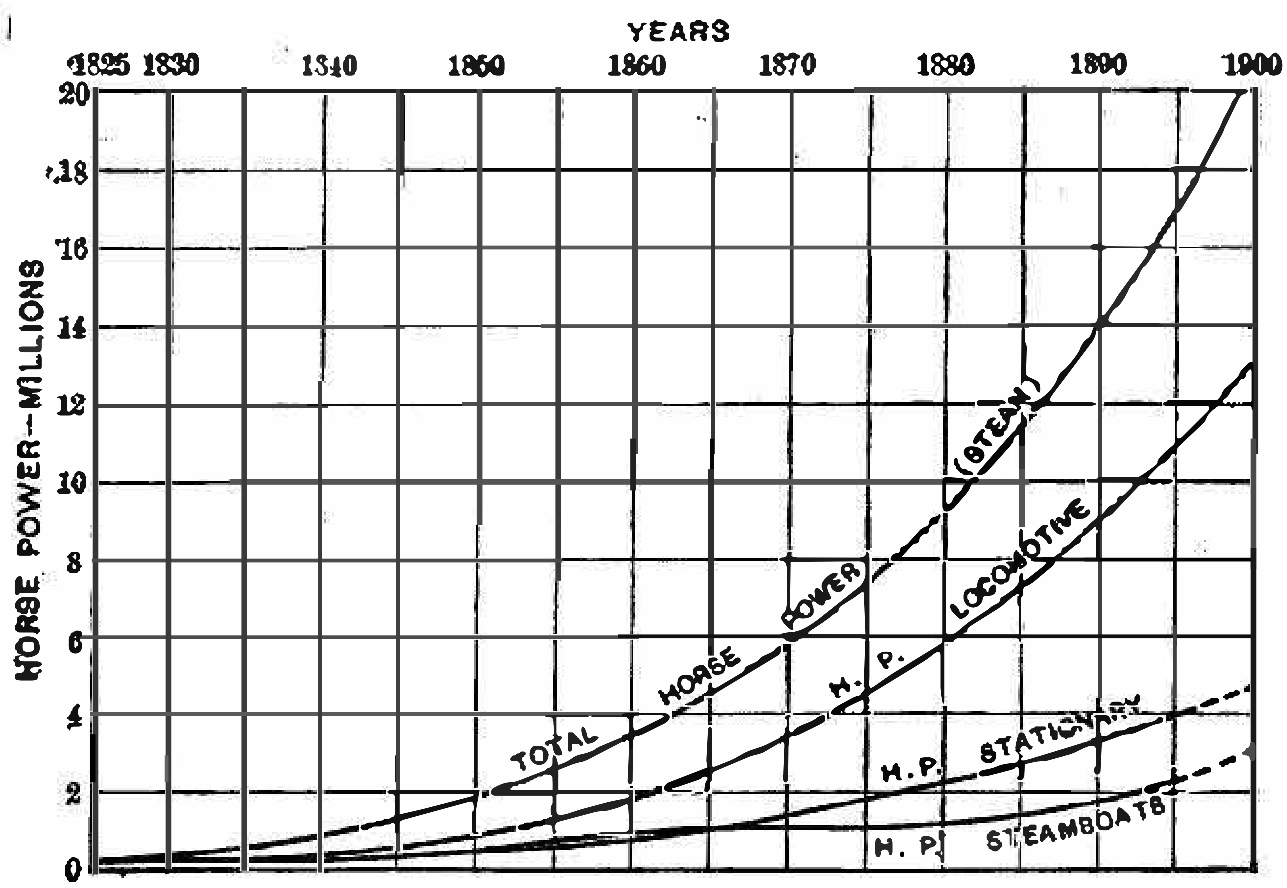


FIG. 169.—Available Steam-Power in United States.

same steady, smooth sweep, for a quarter or a half century to come, should no catastrophe or revolutionizing invention break up our industrial methods and radically change social conditions. The horse-power of all the steam-engines in the

United States to date has come to be about 17,000,000, will be nearly 25,000,000 in 1900, and double that figure in another quarter century. The striking fact, here, is the proportion in which transportation demands power, as shown by the sum of the figures for railroads and steamboats. The curve for stationary engines exhibits the proportion devoted to manufacturing the articles transported. In every case the trend of progress is onward and upward, and with an accelerating velocity.

"The next cluster of diagrams illustrates present momentary relations, as to numerical and comparative quantity, of the principal nations, as obtained by laying down Mulhall's data. Fig. 170 places side by side the figures for

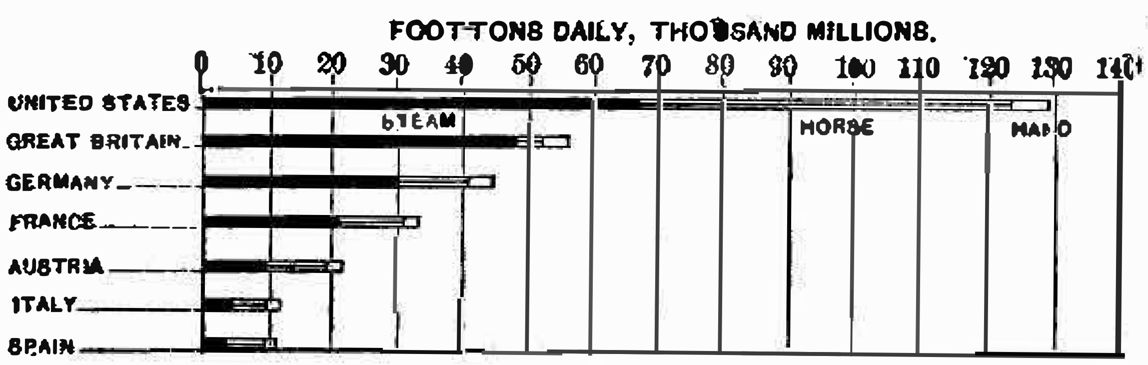


Fig. 170.—Available Working Power in United States.

available power of wealth production, and we find the United States leading all nations, and doubling the amount assigned even to the leader among European countries, Great Britain. Germany is third, France fourth, and the other nations fall far behind. Reducing these figures to the measure of the working power per inhabitant, as in Fig. 171, however, we get a more correct basis of comparison, as a gauge of the character of the nation and its civilization. Here we find that the United States is still in the van; but Great Britain is a close second, and the inhabitant of France or Germany has but about one half as much power of wealth production as the inhabitant of the United States."

. . . . . . . .

"*Important conclusions* are easily and positively deducible from the study of these curves. Those

"1. It is evident that great social and economic laws are in steady, unintermitted operation, covering with broad sweep, industrially as well as chronologically, the trend of modern progress, and controlling the development, in wealth, education, and all material and intellectual lines, of every civilized nation.

"2. These laws insure steady progress for decades, probably for centuries, and with steady acceleration as

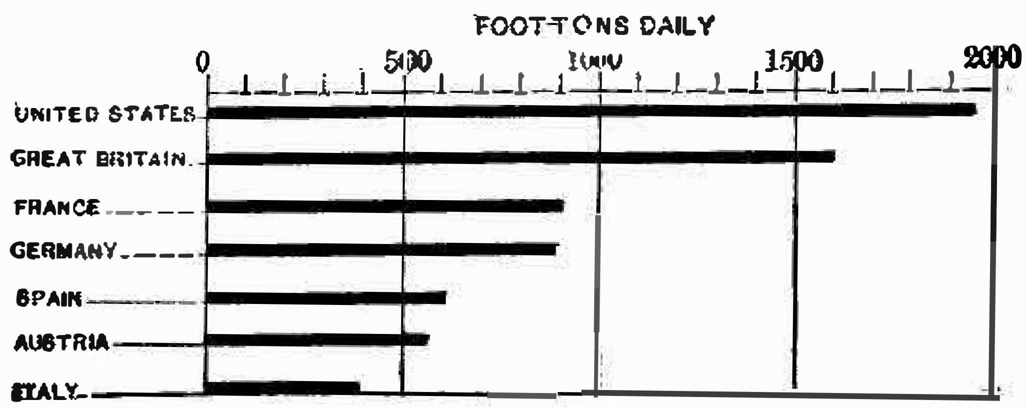


FIG. 171.—Total Available Working Power, per Inhabitant, 1895.

well, and without much regard to 'crises,' or to what are called good and bad times.

"3. The trend of progress during past decades, and its direction and acceleration at the moment, constitute the best guide in predicting a probable future for our industrial and social system.

"4. This guide indicates a constant gain in rate of progress, as well as in actual accumulation of wealth, in all industrial products, in intellectual capital, and in general improvement.

"5. A point has been reached at which the already enormous, and now rapidly growing power of the world is being mainly directed in civilized countries, and especially in the United States of North America, to the supply of comforts and luxuries to a people already on the average well cared for and insured against suffering and hardship.

"6. Very soon, and probably within another generation, the average citizen will possess comforts and luxuries, and enjoy the advantages of leisure for thought and study and intellectual growth, which are to-day the sole possession of those who are distinctively denominated rich. The nation may be expected to become a country of large and well-distributed wealth, and of, on the whole, well-to-do and contented people.

"7. The direct means and methods of progress are through the continual improvement of the arts and sciences, and the steady reduction of the proportion of working power applied to the manufacture of the more perishable forms of wealth, and through the steady gain in the productiveness of that power as a result of improvements in modern machinery and of the introduction of new inventions.

"8. Culture, and all that makes life worth living, will come to the nation, in constantly and rapidly increasing proportion, as the progress indicated by our diagrams, and by the smooth sweep of our curves, continues.

"9. Our own nation, through its free institutions, its wise encouragement of the arts and sciences and of invention, already leads, and will lead in still greater and greater degree as time goes on, through the immediate future, and until economic laws, or the follies of social leaders, break the curve which exhibits 'The Trend of Modern Progress.' Science thus reads us an oracle.

"The scientific principle which this article further illustrates is that of a truly logical and scientific form of prophecy. Science, and science only, often can, and frequently does, by a perfectly accurate and correct method, give us clairvoyant views of the immediate, if not often of the remote, future. Of the Trend of Modern Progress in direction and rate of movement there is no reasonable doubt."

An increasing number of scientific men and engineers, authorities relative to the development of applied thermodynamics, are coming to the conclusion that the steam-engine has nearly reached its limit of efficiency and economic valuet; their deductions being based upon the apparent fact that its pressures and temperatures seem to be nearly as high as is safe. The indications are considered to be, at the moment, that to secure further gain in thermo-dynamic conversion of energy, temperatures must be endured which are beyond the safe limit with the metals now available for controlling them, and that higher mechanical efficiency can also only be attained by increasing the mean pressures beyond the point at which initial pressure is controllable. How much truth these conjectures involve is as yet unknown; but it is possible that by superheating, by methods and to an extent now beyond conjecture, that combination of high thermal and mechanical efficiencies which must constitute maximum final total efficiency may be attained. No one can as yet say, however, where we may look for that limit. Meantime, also, many engineers are inclined to expect the steam-engine to be ultimately displaced by the gas-engine.

Some years ago the late Prof. Fleeming Jenkin made the following statement in a paper read before the British Institution of Civil Engineers, premising that experience shows the best contemporary gas-engine to have substantially equal efficiency with the best contemporary steam-engine, through its comparatively extended thermo-dynamic range of temperature:

"Since that is the case now, and since theory shows that it is possible to increase the efficiency of the actual gas-engine two or even threefold, thetconclusion seems to be irresistible that gas-engines will ultimately supersede the steam-engine. The steam-engine has been improved nearly as far as possible, but the internal-combustion gas-engine can undoubtedly be greatly improved, and must command a brilliant future."

It has been seen that the improvement of the steam-engine must probably involve the elevation of the superior limits of both temperature and pressure, the machine having already been given an efficiency within about 30 per cent. of the ideal case. The improvement of the gas-engine must take place by reducing its wastes by extra-thermo-dynamic action. Its limit of range has already been closely attained. Which of the two motors will finally take the lead no one can say. It is not at all beyond the range of reasonable probability, we may perhaps assert, that both these, as all other forms of thermo-dynamic machines, may yet be displaced by some new motor analogous to those employed by Nature in the animal-machine, which are known to depend upon some apparently direct conversion of chemical energy into the dynamic form, and to have much higher efficiencies than any thermo-dynamic machine to-day has or probably can ever have.

As remarked by the author, in concluding a study of the animal-machine:[1]

"We know that the vital machine is not thermo-dynamic in the sense of being a heat-engine of any known class. We find in electricity the apparently next most available form of energy for use in transformation into dynamic and thermal and other forms, and many accept this as a provisional, a working, hypothesis. This was long ago hinted at by the greatest scientific men, the greatest minds, it would perhaps be fair to say, that have illuminated the history of the race. A century ago, Benjamin Thompson (Count Rumford), a keen 'Yankee,' with uncontrollable inclinations toward scientific research, showed to his own satisfaction, and to the extent of proving to others its possibility, that the animal system constitutes a machine of higher efficiency than any steam-engine.[2] Joule, as long ago as 1846, working with Captain Scoresby, concluded that the animal motor 'more closely resembles an electro-magnetic engine than a heat-engine,' and this is re-

[1] "*Journal of the Franklin Institute*," January to March, 1895; "*Science*," June, 1895: "The Animal as a Prime Motor."

[2] "Rumford's Essays," 1800.

affirmed by Tait in our own day.[1] Sir William Thomson, now Lord Kelvin, in his papers of about 1850, adopts the idea of Joule and introduces the principle of Carnot, and says explicitly: 'When an animal works against a resisting force, there is not a conversion of heat into mechanical effect, but the full thermal equivalent of the chemical forces is never produced; in other words, the animal body does not act as a thermo-dynamic engine, and very probably the chemical forces produce the external mechanical effects through electrical means.'

"We have now seen how all investigations made before and since that date, so far as interpretable, point to the same conclusion:[2] that the machine is not a heat-engine.

"The possibilities of improvement by simulating or paralleling Nature are seemingly stupendous. Could the chemical energy of fuel oxidation be directly transformed into dynamic energy; could it even be changed by double or by indirect transformation, as through the intermediary of electricity, and in such manner as to insure a full equivalence of utilizable energy, it is evident that we might anticipate a conversion as economical as we now attain in the transformation of mechanical into electrical energy, and, consequently, many times as large a return for outgo as we at present realize, and thus gain correspondingly lengthened time of exhaustion of our stores of primary energy."

. . . . . . . .

"Similarly, could chemical energy be directly and fully transformed into light, where needed, and as effectively as Nature performs these operations of energy-transformation in the vital apparatus, the enormous expenditure, the fearful wastes now going on even in our production of out-of-door light by the use of the electric arc, would be reduced to a fraction of their present amounts, and to an insignificant fraction of total costs. Could vital energy be identi-

[1] "Tait's History of Thermo-dynamics."

[2] "Mathematical Papers," vol. i., lviii., p. 505.

fied and brought under control, or could that mysterious energy which is its servant in directing and producing animal power, be securely gained and its processes understood and controlled, it would seem possible that direct transformations of energy—which probably means by influencing molecular and atomic rather than molar motion—might be made possible to man, and all this impressive and wonderful chain of consequences caused to follow."

And thus it is seen how clearly these studies bring into view "*Le Fin du Siècle*" at "*La Fin du Siècle.*"

(1)

THE END.