PUMPS & PUMPING MACHINERY 1500 BC-1960

Historical Development-3

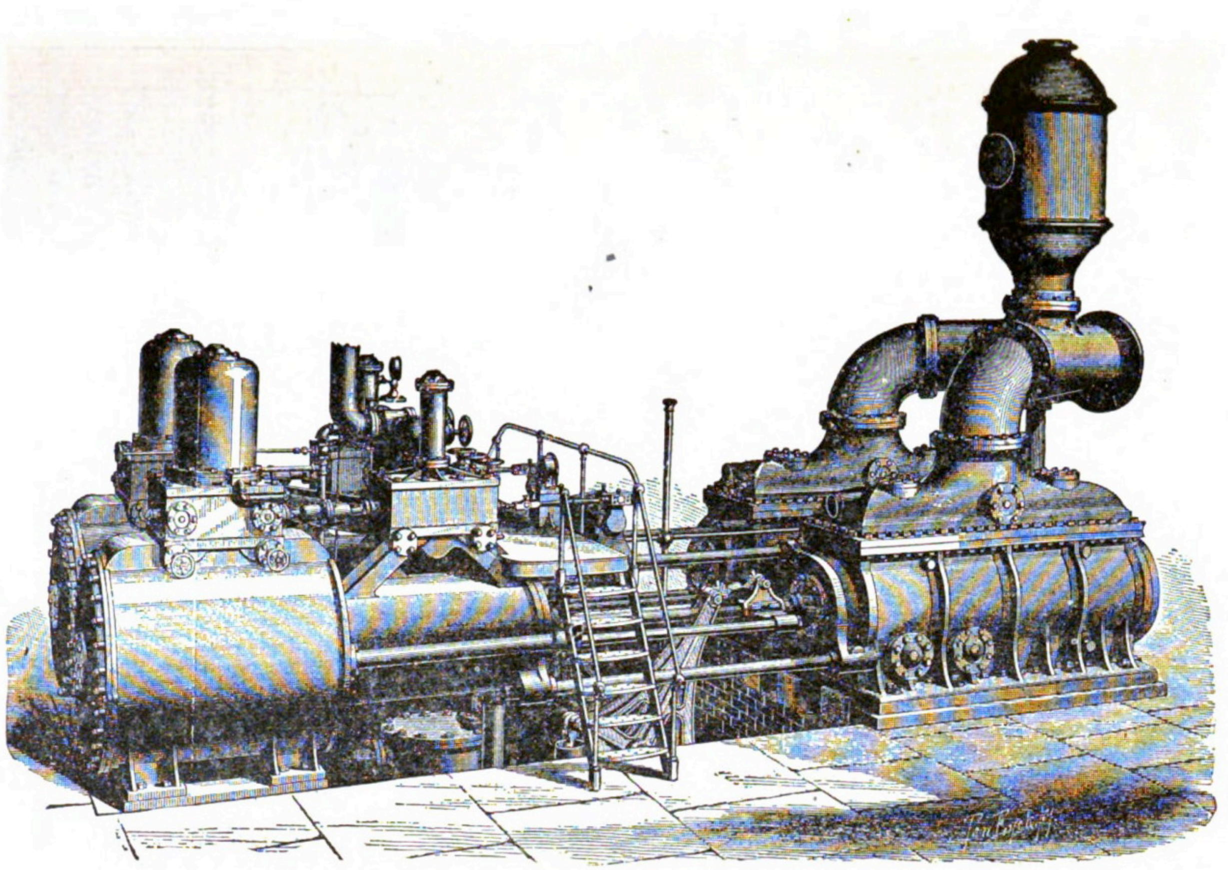

FIG. 72.—Worthington Water Works Pump of 1873.

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PUMPING MACHINERY

A TREATISE ON THE

HISTORY, DESIGN, CONSTRUCTION AND OPERATION OF VARIOUS FORMS OF PUMPS

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CHAPTER II

RECENT HISTORY

THE year 1840 marks an era in the history of pumping machinery, for it was in that year that Henry R. Worthington began his brilliant inventions, which have led to most of the modern forms of steam pumps.

Before this time the boiler-feed pump was usually driven by the main engine through some extension from the piston or pump rod or by an auxiliary rod from the walking beam. Worthington was concerned in the design of a steamboat for canal navigation. It happened that when the boat was stopped at locks or by obstructions the attendants had to resort to the use of hand pumps to keep the boiler properly filled. An independent steam pump was thought necessary, and on September 7, 1841, the pump shown in Fig. 55 was patented.

In the illustration this pump is mounted on a base for exhibition purposes, although it was originally bolted to the side of the boiler setting at the front. Steam enters the cylinder *A* through the pipe *B*, the steam being directed to either end by a valve in the steam chest *C*. In the position shown, the valve has just been moved so as to admit steam to the right-hand end of the cylinder. This drives the piston, piston rod, and plunger to the left. The plunger *D* drives the water from the cylinder *G* through an ordinary conical valve in the valve box *E* to the feed pipe *F* and from there to the boiler. As the rod moves to the left the arm *H*, attached to the rod, moves the tappet rod *I* to the left. Finally near the end of the stroke the right tappet *J* strikes the lever *K*, pivoted at its center, and forces it against the sloping top of the rod *M*. This forces the rod *M* down against the pressure of a spring. After the lever *K* passes over the point, the spring pressure suddenly forces the lever *K* over to the left away from the tappet. This moves the arm *N* to the right, which controls the steam valve through the axis of the arm *N* so as to admit steam to the left-hand end of the cylinder *A*.

The piston, piston rod, and plunger now move to the right,

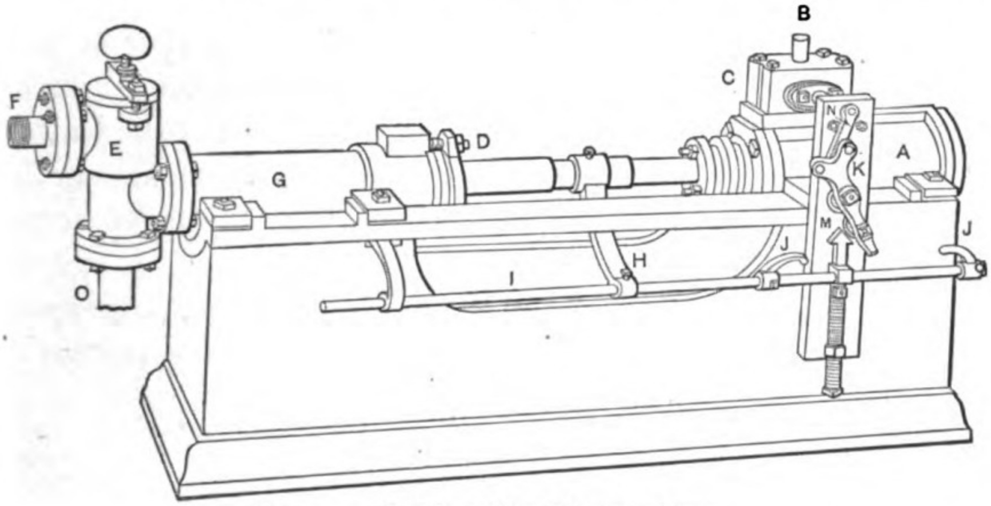


FIG. 55.—Original Worthington Pump.

and water is sucked into the cylinder *G* through a conical valve at the bottom of *E* and the suction pipe *O*. The left-hand tappet drives the lever *K* to the right and finally the spring forces it over, suddenly reversing the motion. The spring action was necessary to properly reverse the steam valve, as a tappet

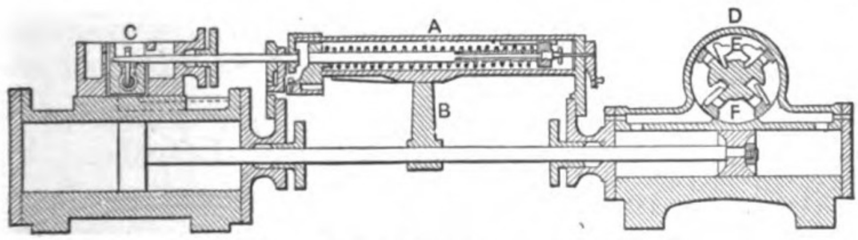


FIG. 56.—Spring-Thrown Valve.

alone would permit the valve to cut off steam from each end when the motion was slow. It is necessary to have the valve reversed positively while the pump has positive motion, however slow.

The admission of steam to this particular pump was controlled by a float in the boiler so that when the water became low the pump would start automatically and continue until the float would again cut off the supply of steam. The pump shown in the figure was in service for twenty-five years and was finally bought back by the Worthingtons as a cherished relic.

In 1844 Worthington used a helical spring in a casing *A*, Fig. 56. The arm *B* pressed against a helical feather or projection on the casing, turning the casing against the action of the spring. When the arm went beyond the end of the feather the spring forced the casing over suddenly, thus moving the valve at *C* by turning the valve rod, moving the valve across the cylinder, perpendicular to the piston motion.

The water valves at *D*, in which *E* is the discharge space and *F* the suction, are of the forms used in many pumps of

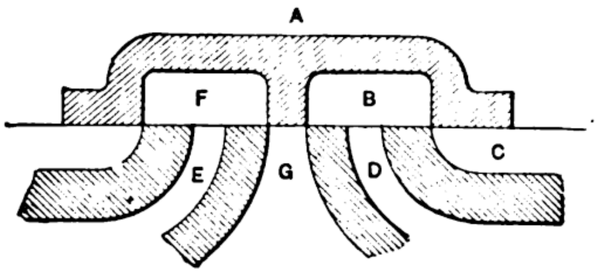


FIG. 57.—*B* Valve.

that day. The pistons, stuffing boxes and cylindrical parts are quite similar to those of the present.

The *B* valve, Fig. 57, was invented for the purpose of admitting steam to the right-hand end of the cylinder by a motion to the right when steam is above the valve. In the figure it is seen that when the valve is moved to the right, the steam above the valve at *A* will enter the space *B* through the space *C* and thus pass to the right-hand end of the cylinder through *D*. At the same time the left-hand end *E* is connected to the exhaust port *G* through the cavity *F*. This is necessary when a slide valve is moved directly by the motion of the piston, since the motion to the right moves the valve to the right and with this movement steam is admitted to the right-hand end, reversing the pump.

The next improvement was a steam-thrown valve, Fig. 58. This was in 1849. In this arrangement an auxiliary valve rod not shown moved an auxiliary valve, admitting steam to the right or left of the piston *A*, which forced the small cylinder to the right or left, thus moving the main valve, which was

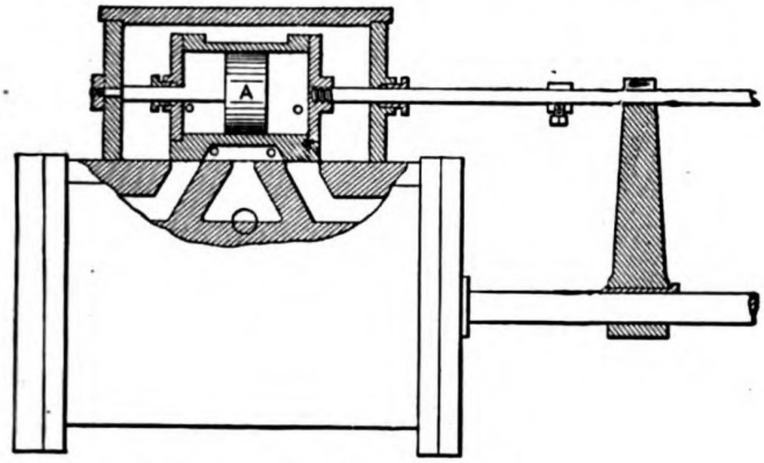


FIG. 58.—Steam-Thrown Valve.

part of the small cylinder. The excessive friction from the steam on top of the auxiliary piston led to the design of a balanced valve which took steam in through the ordinary exhaust passage and used the so-called steam chest as an exhaust chest.

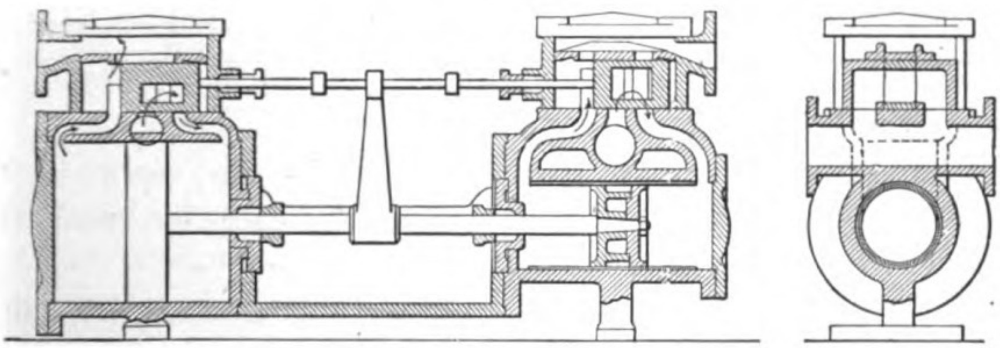


FIG. 59.—Positive Water and Steam Valve.

Fig. 59 shows a pump built about 1850 in which both the water and steam valves were controlled by the movement of the valve rod. This was in a measure a water dash pot for the purpose of stopping the motion of the pistons. Worthington used this in some cases, but he did not advocate its general use.

In 1849 Worthington, with his partner, Wm. H. Baker, patented a relief-valve motion. This scheme is shown in Fig. 60, where radial water valves or clack valves are used. The invention consisted of the use of two water passages *AA* at each end of the water cylinder, so that when the water piston uncovered the inner of these ports the pressure in front of the piston was relieved suddenly and the steam in the steam cylinder drove the piston to the extreme end, moving the main slide valve *B* over by means of the arm *C* and the tappets on the valve rod *D*. This same scheme was applied by cutting grooves in the water-cylinder bore at each end.

The aim in all of these later pumps was to simplify the

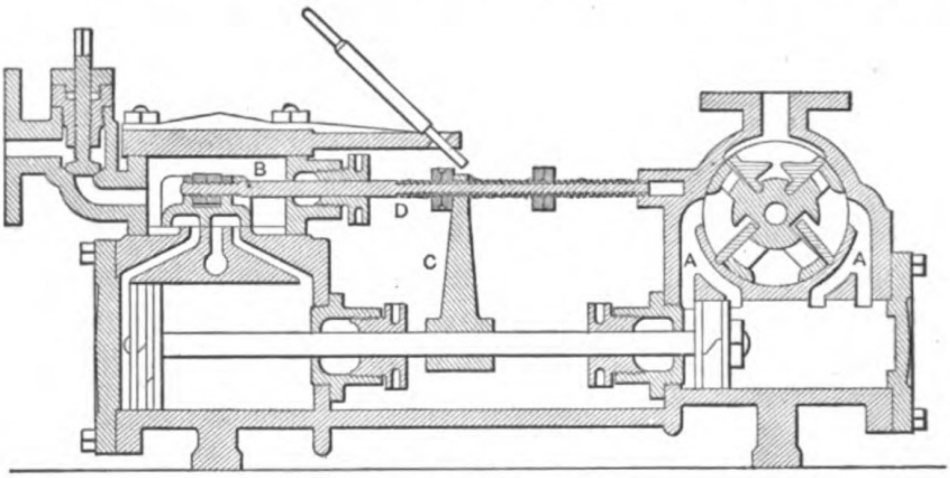


FIG. 60.—Relief Valve Motion.

mechanism so that the pump would do the work in a positive manner and still be simple to care for and to operate.

In 1850 Worthington made another improvement by substituting a number of small valves for the four large valves used on pumps heretofore, and also employed a plunger and ring in place of the piston of former pumps. The pump, Fig. 61, was used on the steamer "Washington." There were thirty-six of these small valves arranged on valve decks as indicated in the figure. The large number of small valves gave the requisite amount of opening with a small lift and hence the amount of leakage passing the valves when the pump was

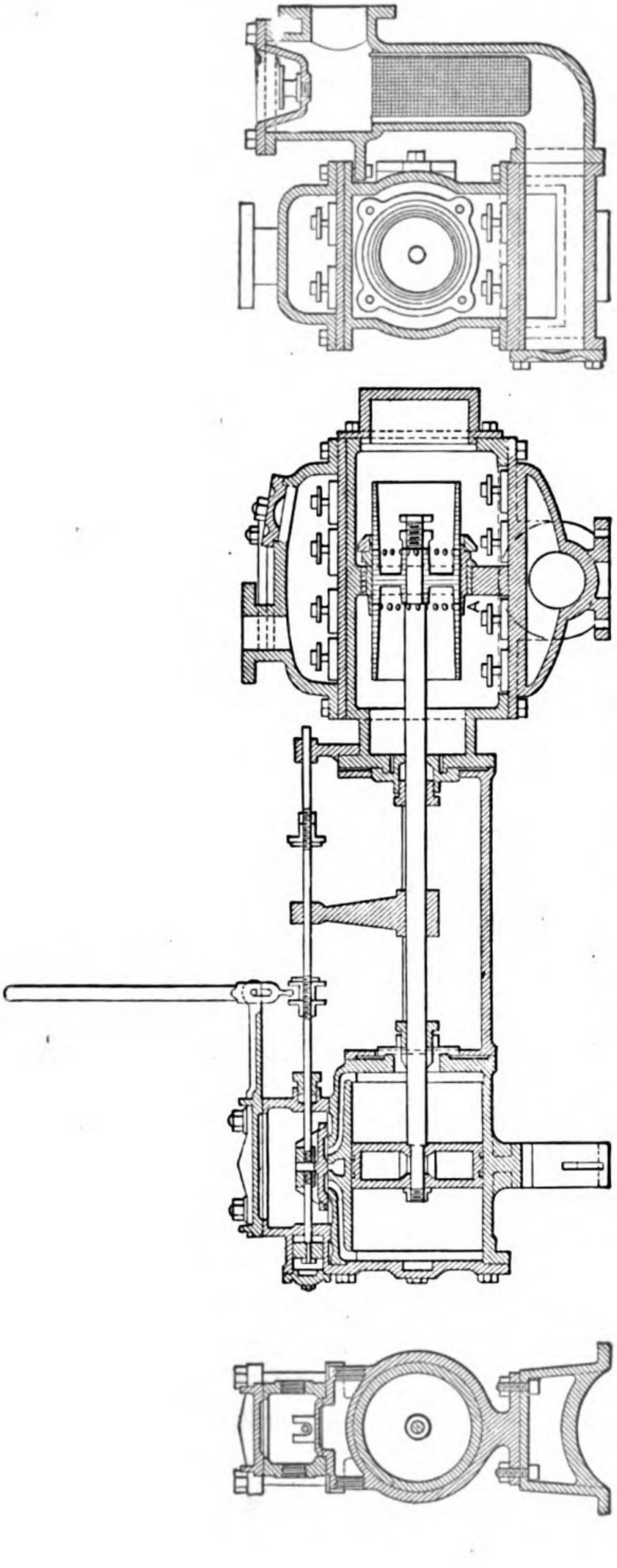


FIG. 61.—Pump for the S. S. Washington.

reversed was greatly reduced. The valves were of rubber, one-half inch thick.

The arrangement of the plunger and ring of Fig. 61 is markedly different from the pistons of the former figures, and Worthington adopted it for several reasons:

1st. It gives ample space above and below for the valves.

2d. The ample space around the plunger forms a subsiding chamber where harmful materials may settle out of the way of the plunger packing.

3d. The constant protrusion of the plunger tends to carry foreign matter away from the packed joint.

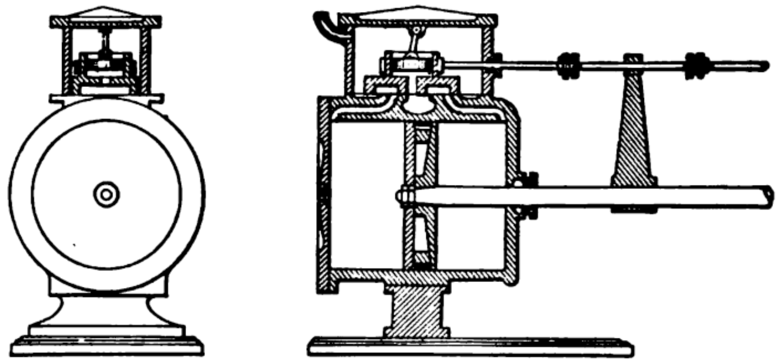


FIG. 62.—Steam End of Savannah Pump.

4th. The construction makes the removal or renovation of the parts an easy matter.

5th. The deflection of the water currents is less than in ordinary arrangements. The friction is very small.

It is to be noted in passing that this design simplified the construction of the water end of the pump as far as the foundry-work and the machine-shop work were concerned. The use of a solid metal packing around the plunger as seen at *A* was an innovation, but it has proved a success. It was made long and with clear water the wear was not sufficient to cause excessive leakage for some time. A steam-thrown valve was used in this case. Worthington was not satisfied with this method of valve operation and after his invention of the duplex pump in 1859 he rarely used it, although inventors such as Knowles, Blake, and others continued to use it.

In 1854 Worthington erected his first water-works pump for the city of Savannah. It was a compound pump of peculiar design, in that the high-pressure cylinder was at the center of the annular low-pressure cylinder. Another new feature of the pump was the balancing of the steam valve by carrying part of the pressure on the back of the valve by a piston supported from the steam-chest cover as shown in Fig. 62. This figure illustrates the use of this balancing method on an ordinary cylinder. The Savannah engine was a success and a duplicate of it was built for Cambridge, Mass., in 1856. This engine, and a companion engine, built soon after, were of the following dimensions:

High-pressure cylinder	12 inches diameter
Low-pressure cylinder	25 "
Plunger	14 "
Length of stroke	25 inches
Capacity	300,000 gals. per 24 hrs.

This engine was the best of its day, as was shown by tests made for the Brooklyn Water Works in 1857 and 1859, when that city was about to install new pumping engines. The results of these tests as shown in the report of Mr. James P. Kirkwood, chief engineer of the Brooklyn Water Works, were as follows:

Date of Test.	Name of Engine.	Duty in ft. lbs. per lb. of Coal.
April, 1857	Worthington engine, at Cambridge	669,411
June, 1857	" "	675,746
Jan., 1857	Cornish engine, at Jersey City	628,233
July, 1857	Hartford crank engine	646,994
July, 1857	" "	614,426
Jan., 1860	Brooklyn new rotative engine	601,407
June, 1856	Cornish engine, Philadelphia	589,903

As a result of this the Worthington pump was selected and a modification of the Cambridge pump design, known as the duplex pump, was accepted; this was, however, abandoned on account of trouble with the contractor and it was not until 1863 at Charlestown, Mass., that this important type was installed in a water works. It will be remembered that the term duty as used by Moreland and Watt meant the useful

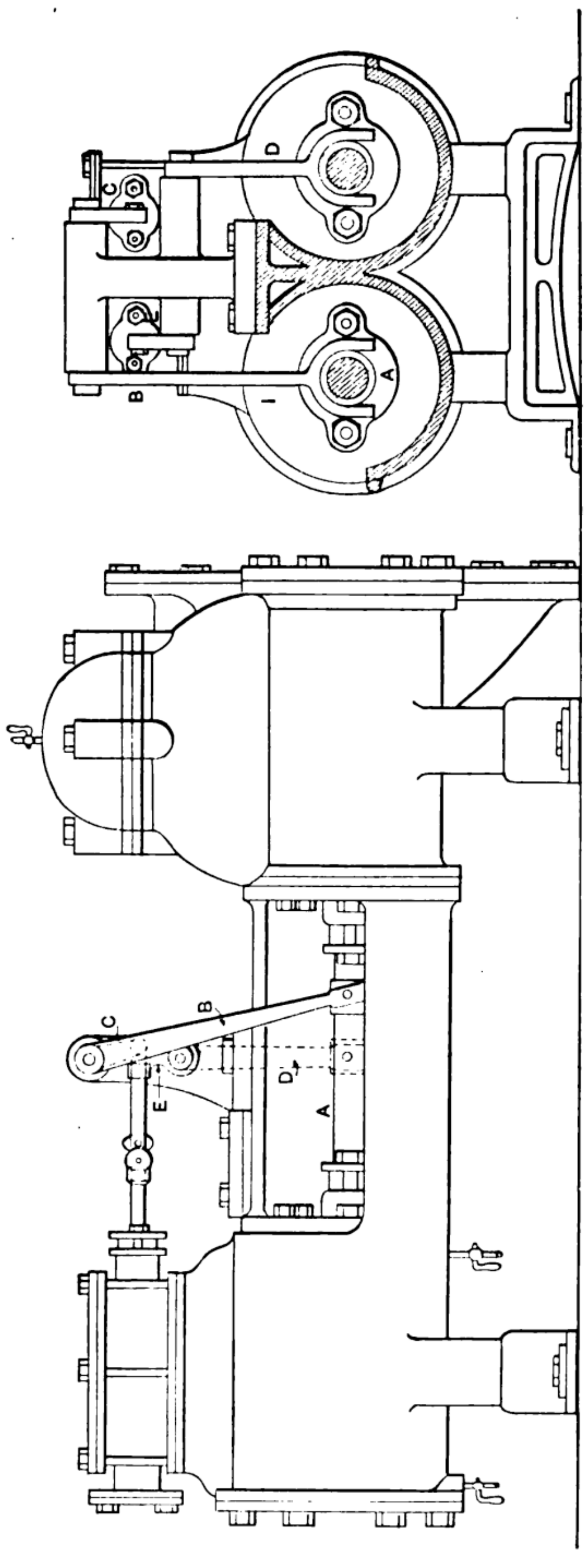


FIG. 63.—Duplex Pump.

work per bushel or hundred weight of coal, but in later years the duty was figured as the useful work per 1000 pounds of steam or per 1,000,000 British thermal units.

The date of 1859 is that of the invention of the duplex pump, one of the simplest contrivances for operating the valves of a pump, doing away with the complex arrangements used heretofore for this work. This then became for many years the standard type of pumping engine, as the Corliss engine became the standard mill engine.

To make clear the operation of the duplex pump a modern form of boiler-feed pump, Fig. 63, is illustrated. This consists really of two pumps placed side by side. In this figure the piston rod *A* of the front pump has just reached the right-hand end of its stroke, and the bell-crank lever *BC*, which extends from the front piston rod to the back valve rod has moved the *D* slide valve of the back pump to the right, uncovering the steam port of the left-hand end of the rear pump, causing that pump to move to the right. This motion is transmitted to the front valve stem through the reverse lever *DE*, which connects the back piston rod to the front valve rod. The *D* slide valve of the front pump is moved to the left, admitting steam to the right-hand side of the cylinder and thus the piston of the front pump moves to the left. This motion, in turn, causes the back pump to move to the left and this then moves the front valve so that the piston moves to the right, when the operation is repeated.

The action of the pump may be represented by the diagram, Fig. 64, in which vertical distance represents time and horizontal distance represents motion of the pump. The solid line represents the front pump and the dotted one the rear pump. At the end of each stroke there is a period of rest while the other pump follows the stroke of the first one. This is accomplished, as will be explained later, by the method of moving the valve by the valve rod or its equivalent.

Not only is the claim for a simpler valve gearing made or this pump, but there should also be a steadier discharge of water, because as one pump nears the end of its stroke the other one discharges water to keep up the flow while the first reverses.

This duplex pump was one in which, by the use of an additional unit, a simple form of valve gear was obtained. While Worthington was inventing steam-thrown valves of various forms previous to his invention of the duplex pump the same

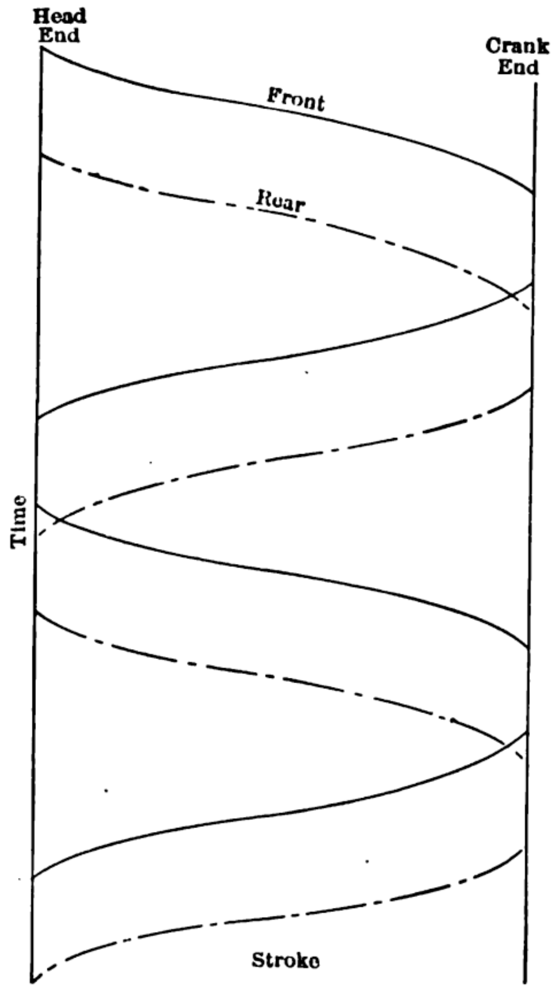


Fig. 64.—Action of Duplex Pump.

problems were being investigated by others in this country as well as abroad. It is not the intention of this book to follow all of the different forms of simplex pumps invented from the time of Worthington to the present, as his inventions mark the era. Later a number of modern simplex mechanisms will be examined in detail to illustrate what had been done and what forms have survived. It is necessary at this point, however, to mention such names as Blake, Cameron, Knowles, Earle, Cope, Maxwell, Marsh, Silver, Dean, Davison, and Gordon in America; and Moreland, Thompson, Baummans, Tyler, Clarkson, and Davies in Europe, as some of those who had been working on this problem. Their work is of interest in comparing the complicated manner of the earlier forms with the simpler forms of to-day.

The introduction of the duplex pump, at least while the patent lasted, caused considerable argument as to the relative merits of the simplex and duplex forms, the simplex manufacturers claiming a lack of positive length of stroke for the duplex against a full stroke of the simplex to offset the greater complication. The proper adjustment of each pump, however, will give a proper stroke.

Pumps of the duplex type were introduced into water works in 1860, and in 1863 one of 5,000,000 gallons per twenty-four hours was installed by Worthington at Charlestown, Mass., and in 1871 a larger one for 19,000,000 gallons was built for the city of Philadelphia. The earlier engines were single expansion on the steam end.

The pumping engine of Mr. George Shields for the city of Cincinnati, which was built in 1861, was one of the largest of its day; it was to lift 9,600,000 gallons per twenty-four hours against a head of 170 feet. It was direct acting and had no balance beam. The steam cylinder was 100 inches in diameter and had a stroke of 12 feet. The pump cylinder was 45 inches in diameter. This engine was one of the unfortunate structures of American engineering in that it cost the municipality many times its original estimated figure; but to its credit it may be said that twice it was the means of saving the city from a water famine, when the other pumps gave out. The use of vertical engines in which the steam and water cylinders were placed over each other was quite common, as, for example, in the Bull Cornish engines, but when it was desired to eliminate the inertia bob weight to cut down the weight of the engine, fly wheels were introduced. The fly wheels were driven from a beam in most cases, but in 1868 Richard Moreland, Jr., and David Thompson invented the direct-acting engine shown in Fig. 65. In this the cross-head was connected to the pump plunger by two or four rods which spanned the crank shaft. The cylinder was supported by A frames. The pump barrel was bolted to the base of the engine. The pump was single acting and the general arrangement was excellent and simple.

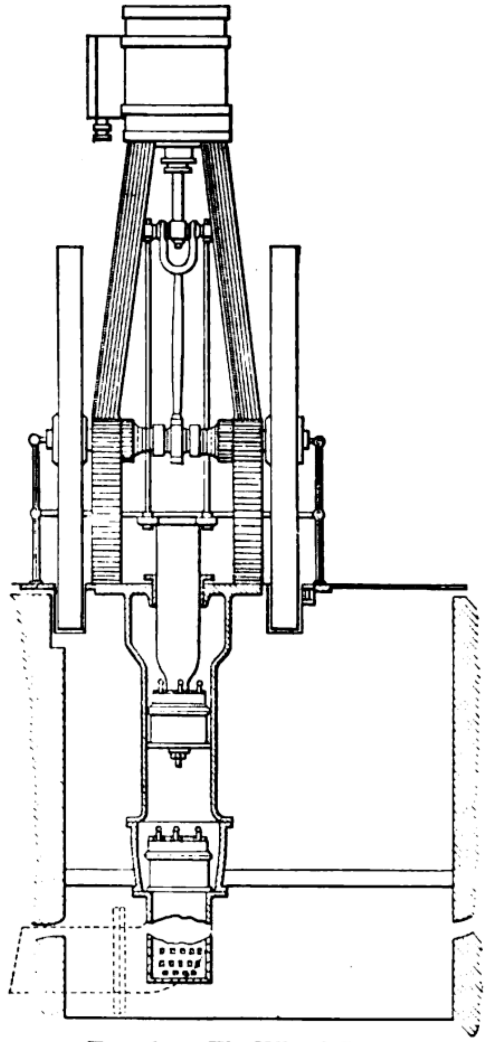


FIG. 65.—Fly Wheel Pump.

This type o. engine was installed in 1868 and 1876 at the Eastbourne Water Works in England. It proved to be so successful in operation and needed so little repairing after being in service until 1881 that new engines for that plant were made of the same type.

The general arrangement of steam end and pump for this machine will be seen to be quite similar to the modern American pumps. The design was good and one of the simplest for the application of the fly wheel to the pump.

About this time a unique pump was introduced by Birdsill Holly to care for his direct-pressure system, which dispensed with a reservoir or standpipe, obtaining pressure direct from the engine. He introduced the system in 1866 in Lockport, N. Y., using a pump driven by a water wheel, but in 1871 he used his quadruplex engine at Dunkirk, N. Y. The four pumps, Fig. 66, were placed in tandem with the steam cylinders, which were arranged in pairs, each acting on a crank. The two

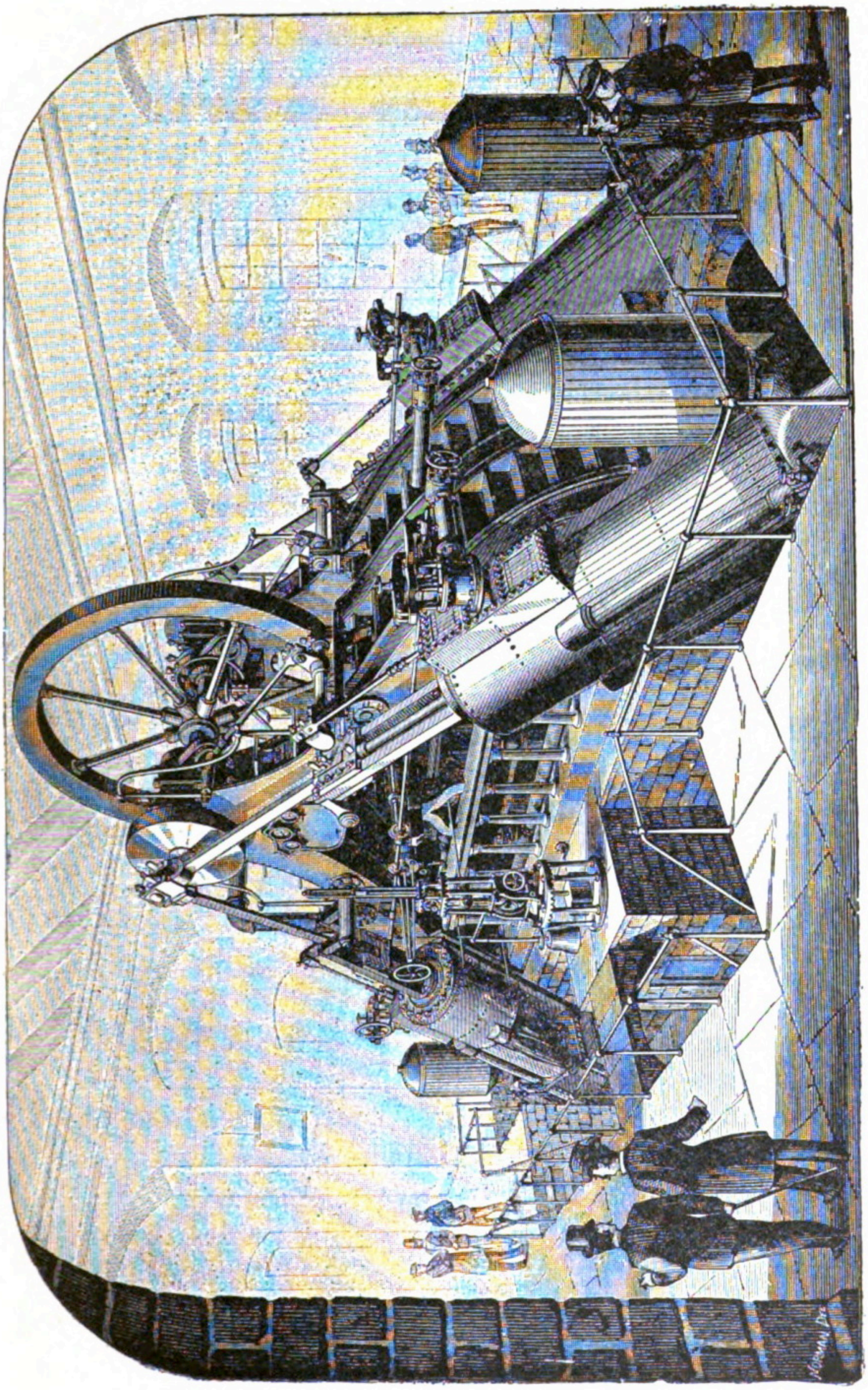


Fig. 66.—Quadruplex Pump.

cranks were arranged at 135° and the frame of the engine was such that the center lines of the engines intersected at 90°. The figure shows the construction of the engine.

Such an engine was necessary for this system, as the engine had to start from any position as soon as the drop in pressure in the mains moved the governor. This system saved the expense of a reservoir, but the necessity of keeping the engine under steam continually made the steam use and the labor

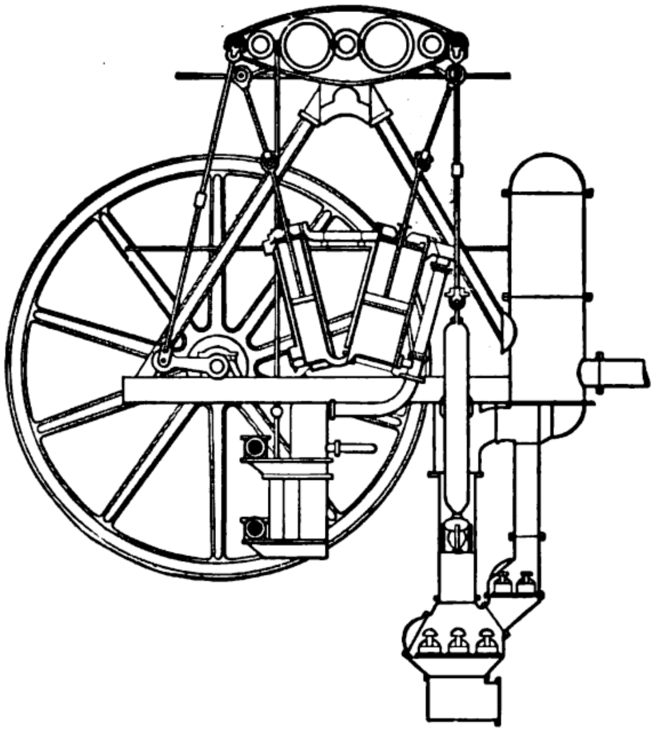


FIG. 67.—Leavitt's Lynn Pump.

expense very high. The engine could be run with any number of steam or water cylinders, and the engines could be used as single-expansion cylinders or by exhausting from one to the other three, as was done in 1874 at Rochester, the advantages of compounding could be had. On account of the intermittent action of these engines their duty was not better than that of other pumps. A duty of 86,176,315 foot-pounds was obtained on the 6,000,000 gallon pump at Buffalo, N. Y., in 1879.

The first important compound steam end for water works in America was designed in 1872 by Frederick Graff, chief engineer of the water department of the city of Philadelphia. Compound pumps were built by Simpson & Co. of England, in 1848, although most of the pumping engines were of single-cylinder type.

This Graff engine was followed in 1873 by an engine designed by Mr. E. D. Leavitt, jr., which was quite similar to the Graff engine in its theoretical operation, although different in its arrangement. It was intended for the water works of Lynn, Mass.

As shown in Fig. 67, this had two inclined steam cylinders and a pump which was arranged to discharge on each stroke, although it was single acting on the suction side. This was accomplished by the plunger attached above the pump bucket. The supplementary pipe and valves connecting the two ends of the pump cylinder were for the purpose of reducing the friction. The valves were of large diameter and double beat, that is, each valve had two discharging edges. This type of pump end was first built in 1848 and was known as a Thames-Ditton pump. The figure also shows the application of the fly wheel to the pump for the purpose of using steam expansively. The cylinders were steam jacketed and the steam valves were of the gridiron type, driven by cams. The double-acting air pump was driven from the beam.

This pump gave a duty of almost 104,000,000 foot-pounds per 100 pounds of coal on a 52-hour test, when pumping about 5,000,000 gallons per day. The duty for its year's record was about 75,000,000. The dimensions of the pump are given below:

Diameter of high-pressure cylinder	17½ ins.
" low-pressure cylinder	36 "
" high-pressure piston rods	3 "
" low-pressure piston rods	3¾ "
" air pump	11¼ "
" pump barrel	26.1 ins.
" plunger	18½ "
Length of stroke of steam and water pistons	7 ft.
" " air pump	44½ ins.
Distances between end centers of the beam	11 ft.
Weight of fly wheel	10.7 tons
" beams	4.2 "
" moving parts connected with beams	5 "
Length from pump to top of vertical pipe reservoir	1904 ft.
Height of top of vertical pipe above bottom of well	163.34 ft.

This pump with its walking beam may be taken as an example of many of the pumping engines to be found in Europe and America, although the arrangement of the cylinders in an inclined position was novel. Practically all of these machines, with the exception of Graff's for the Philadelphia Water Works,

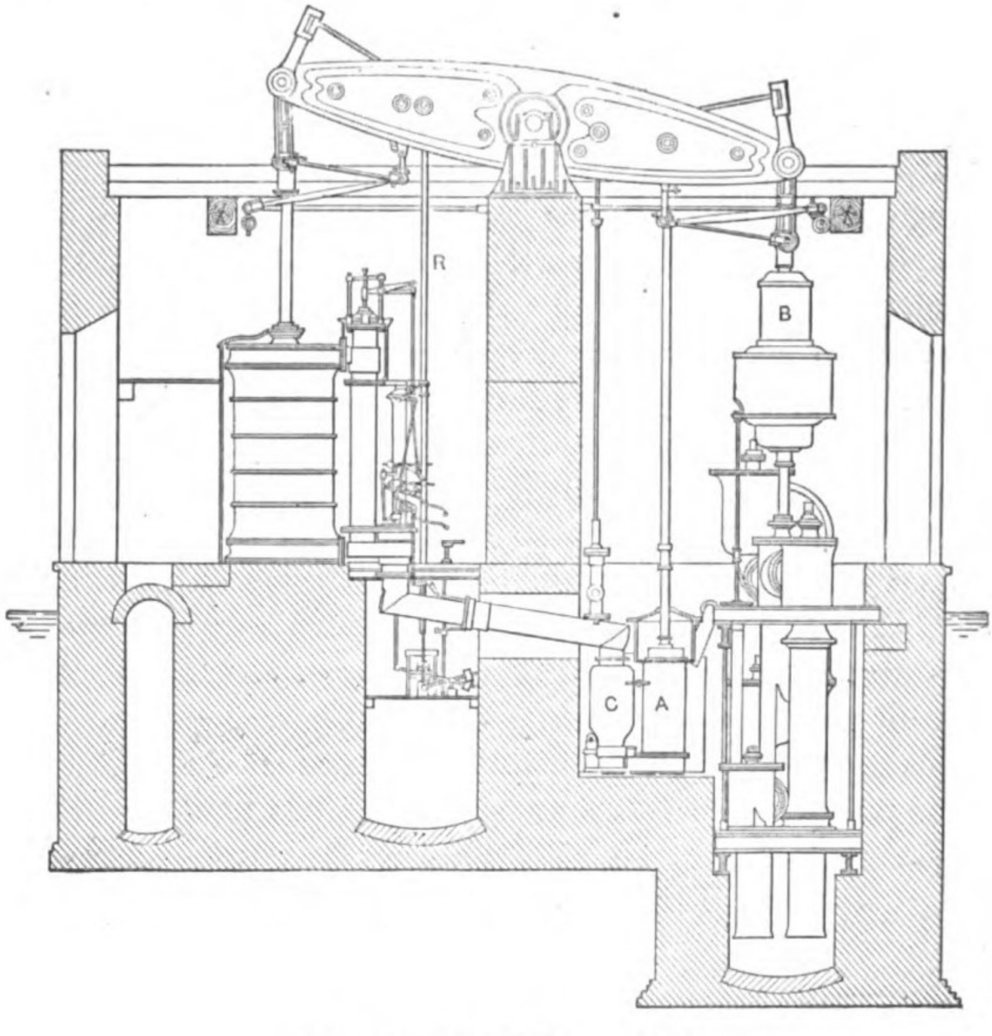


FIG. 68.—English Pump of 1866.

were with single cylinders, although compound engines had been known. To give an idea of one of the English pumps of this period the West Middlesex pump of 1866 is shown in Fig. 68, as this illustrates the general arrangement of such pumps. The steam cylinder was 80 × 120 inches, while the water cylinder was $24\frac{1}{8}$ × 120 inches. The pump was double acting, although the steam cylinder was single acting. The large acorn-shaped box

B on the pump rod directly beneath the parallel motion is the balance box, which was loaded so as to force the water from the pump against a head of 200 feet on the down stroke. During this stroke the two ends of the steam cylinder were connected through a 15-inch equilibrium pipe as in the old type of Watt engine. The weighted box pulled the piston up until the piston reached the top of the 10-foot stroke, when the plug rod *R* reversed the valves, bringing live steam on top of the piston and connecting the lower end of the cylinder to the condenser *C* through a 19-inch exhaust valve. The steam on the upper side then drove the piston downward, the air pump *A* driven from the main beam maintaining the vacuum in the condenser. This pump was provided with a safety device so that pressure would be held in the discharge chamber in case the discharge pipe should break. This pump is the equivalent of Watt's original pump, although it was worked with steam at 40 pounds pressure. The water pressure was 200 feet and the pump made 16½ strokes a minute.

Several important inventions of Worthington's should be mentioned here: the dash relief valve, the rotary pump valve, and the cross connection for compound pumps.

The dash relief valve was used on pumps to regulate the length of the stroke and prevent pounding. The motion of the piston could be stopped by cutting off the exhaust steam before the end of the stroke and compressing the steam in the space behind the pistons. This was done by having the piston ride beyond the port to the exhaust passage, but in order to introduce live steam into the cylinder in this cushion space it was necessary to use another passage beyond the one for the exhaust. This made five steam passages in the cylinder, Fig. 69, the two outer for steam and the three inner ones for exhaust. It is seen from the figure that when the piston reaches the position shown, the steam to the left of the piston, retained behind the piston after passing *B*, has been compressed into the clearance space and into the passage *A*. This acts as a cushion, and as soon as the valve moves to the right high-pressure steam enters and drives this piston to the right. If the piston is brought to rest too far from the end of its stroke, a valve *D* is opened slightly between the passages *A* and *B* and some of the steam compressed in *A* exhausts into *B* and then to *C*,

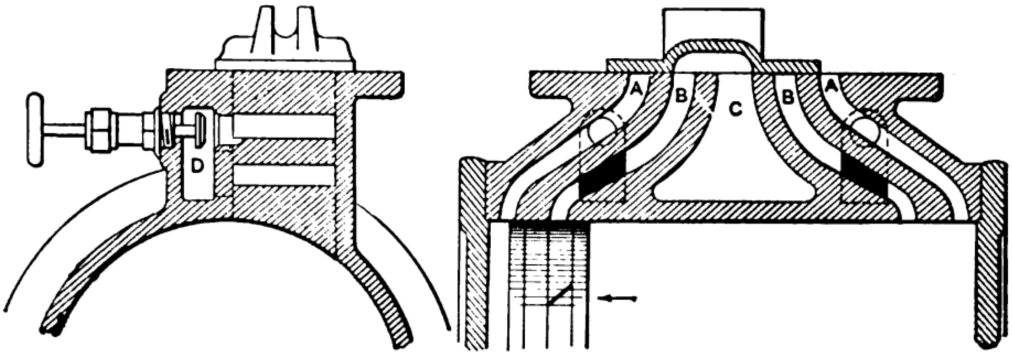
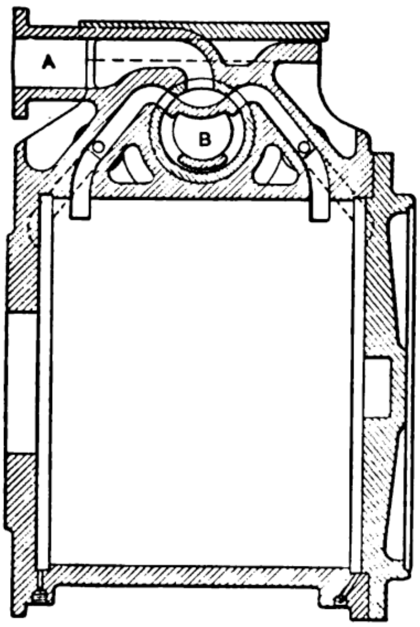


FIG. 69.—Dash Relief Valve.

thus allowing the piston to travel farther. If *D* is opened too much the piston will strike the cylinder head, causing pounding, and it is then necessary to close the valve *D* slightly. The



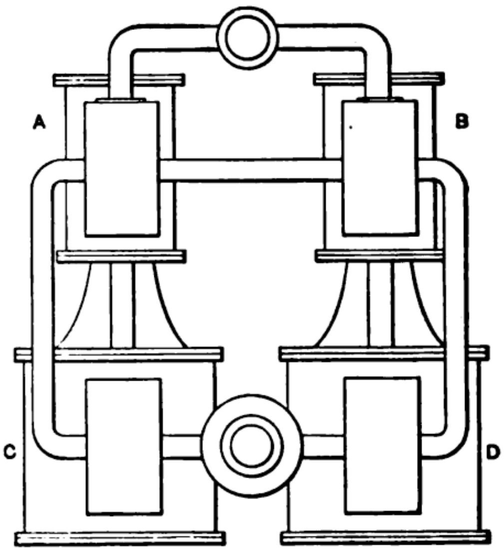


FIG. 70.—Rotary Steam Valve.

FIG. 71.—Cross Connections.

application of the rotating valve was the application of the common valve used by Corliss to the steam cylinder of the pump, Fig. 70. This valve operates in the same manner as a slide

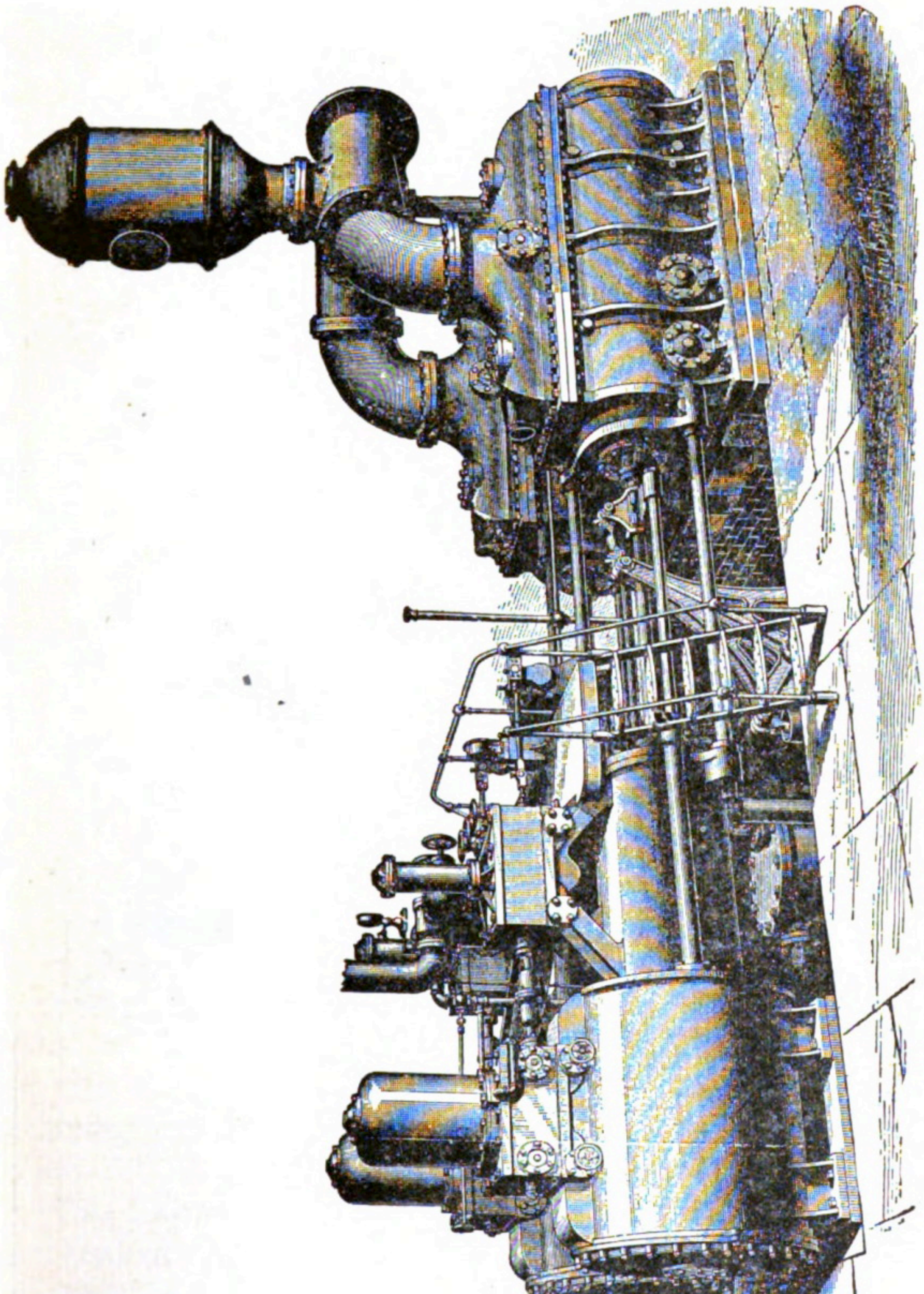


FIG. 72.—Worthington Water Works Pump of 1873.

valve, the steam or exhaust being conducted by the passage *A* or the center of the valve casting *B*. The dotted passage leading to the end controlled by a dash relief valve acts as the

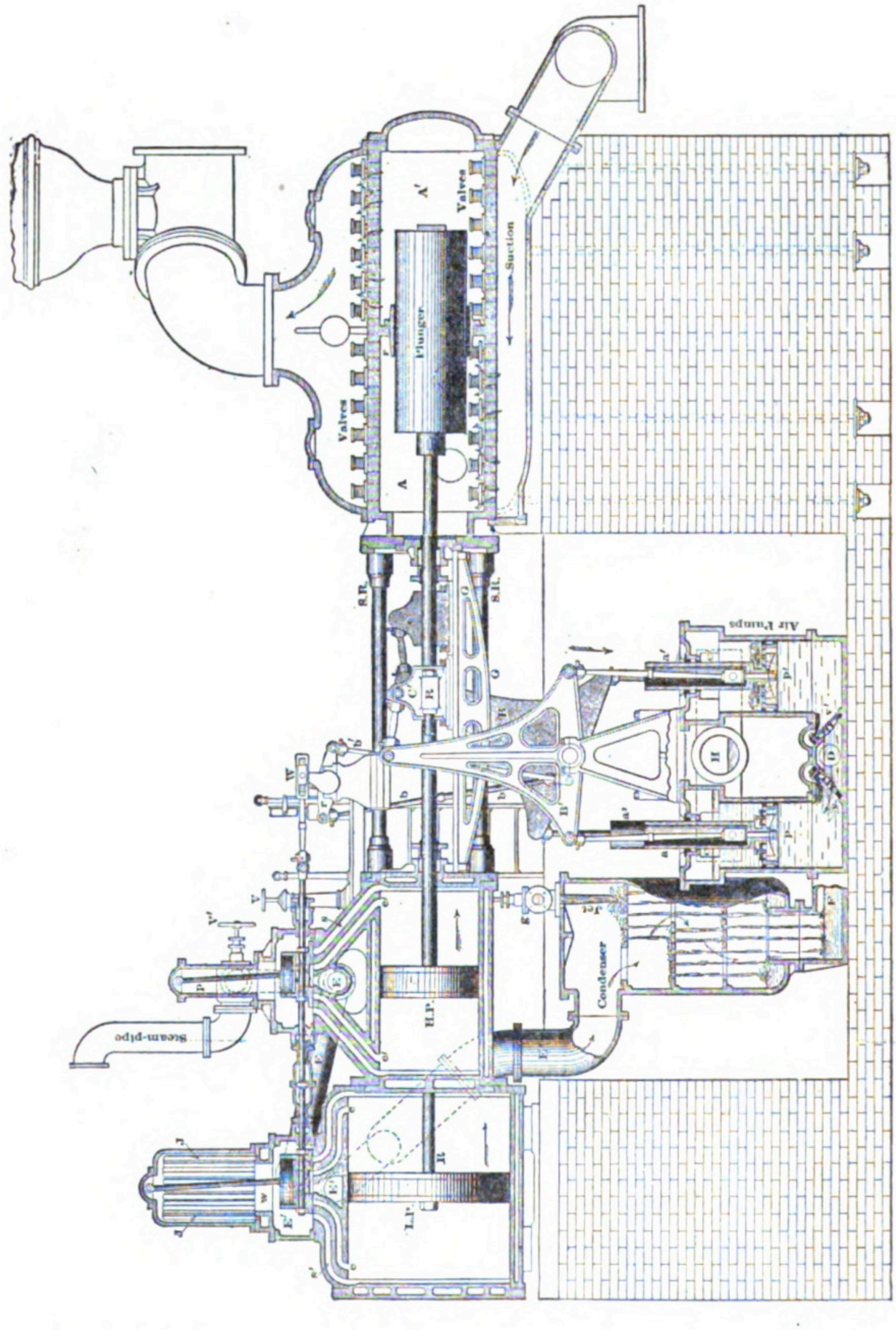


Fig. 73.—Worthington Compound Water Works Pump.

passage for the starting steam. In such an arrangement the piston starts slowly because all of the steam to start it would have to pass the relief valve.

The cross connection of the low-pressure cylinders, Fig. 71, is one which is used to supply steam for the demands of either cylinders *C* or *D* from the exhaust of both of the high-pressure cylinders *A* or *B*. Without the cross connection, the steam from *A* would be used only in *C* and that of *B* in *D*, but by this cross connection of the valve chests a steady motion is obtained.

The duplex Worthington pump was also made in the compound form, and one tested in 1873 at the Belmont Water Works of Philadelphia gave a duty of 54,416,694 foot-pounds on 100 pounds of coal. This pump had steam cylinders of 29 and 50¼ inches in diameter, while the water cylinder was 22½ inches in diameter. The common stroke was 50 inches. The capacity of the pump was 5,000,000. Fig. 72 shows the general form of this pump. A similar one at Newark, N. J., gave 77,358,478 foot-pounds duty.

The difference between the duty of the Leavitt pumping engine and that of the direct-acting duplex Worthington is rather marked, and where the engine is to run at full capacity for considerable length of time these figures show conclusively that such a high-duty engine, even though its cost is much greater than the simpler pump, would prove to be a paying investment. However this may be, when the use of the pump is quite intermittent, if the pump is too large for the average consumption of water, the loss in starting up, together with interest, depreciation, insurance, taxes, and repairs on the more expensive machine might make the cost of pumping greater than it would be with the less efficient machine.

This important fact was emphasized by Mr. Worthington and undoubtedly accounts for the greater use of these duplex machines in the years which immediately followed.

At the Centennial Exhibition of 1876 the Worthington pump was used to supply all of the water. The pump is shown in Figs. 72 and 73. The dimensions were as follows:

Diameter high-pressure cylinder	29	ins.
" low-pressure cylinder	$50\frac{1}{4}$	"
" water plunger	$22\frac{1}{4}$	"
Stroke	48	"
Air-pump diameter	$29\frac{3}{4}$	"
" stroke	24	"

From the sectional view of the pump it is seen that the steam and water cylinders are in tandem on each side of the pump and that the valves are of the swinging-piston balanced type. The cylinders have separate steam and exhaust passages and the outside cut shows the adjusting relief valves. The cylinders were jacketed on the barrel and heads. It will be noted that the valves are driven from bell-crank levers attached to the walking beams of the air pumps by connecting rods. The air-pump beams are worked from cross heads on the piston rods through short connecting rods. It is evident that the connections of the rods, beams, and levers are such that the motion of one engine controls the valve of the other engine.

The construction of the jet condenser and the air pump is seen in the picture. The water end of the pump shows the small valves advocated by Worthington as well as the use of the plunger and ring. The direct path of the water through the pump is one which diminishes the friction loss in the machine.

The centennial year 1876 marks the installation of another Leavitt pump at Lawrence, Mass. This pump was built on the same lines as the Lynn pump, but it gave a duty of 117,550,800 foot-pounds per 100 pounds of coal, making a new record.

The Corliss engine of the Centennial Exposition was one of the most remarkable features of the exhibition. In 1878 Mr. George H. Corliss used his engine in the construction of a pump for Pawtucket, R. I. This pump, Fig. 74, consisted of two steam cylinders, each one in tandem with a water cylinder. The tail rod from the water end was attached by a connecting rod to a vibrating lever, pivoted in the base and joined by a rod to the crank of the engine. By use of the fly wheel in this and the other fly-wheel engines, steam could be used expansively without the use of heavy reciprocating parts. The fly wheel was mounted on the shaft carried by the bearings, which were supported by the air chambers of the pump. A diagonal brace was carried from the bearings to the main center pedestals.

The steam cylinders were 15 and $30\frac{1}{8}$ inches in diameter, 30 inches in stroke, and were furnished with the Corliss valve gear. They were steam jacketed on the barrels, heads, and

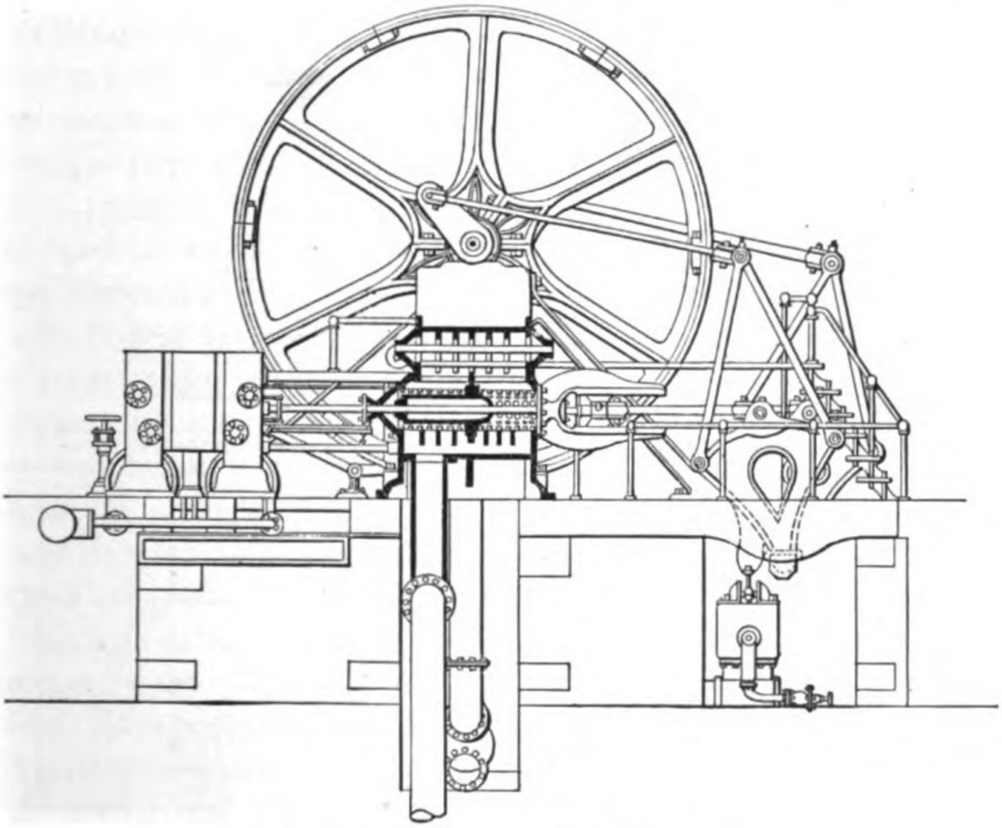


FIG. 74.—Corliss Pump for Pawtucket.

valve boxes. There was a receiver between the cylinders, the volume of which was equal to that of the low-pressure cylinder. The drips from the jackets were delivered into the boiler feed, heating it, while the drip from the receiver was passed through a coil in the boiler flue and returned to the receiver in a superheated condition. The steam throttle valves were so connected with the governor that they limited the speed to 52 revolutions.

Continued in Part-4