No. 628,511. Patented July 11, 1899.

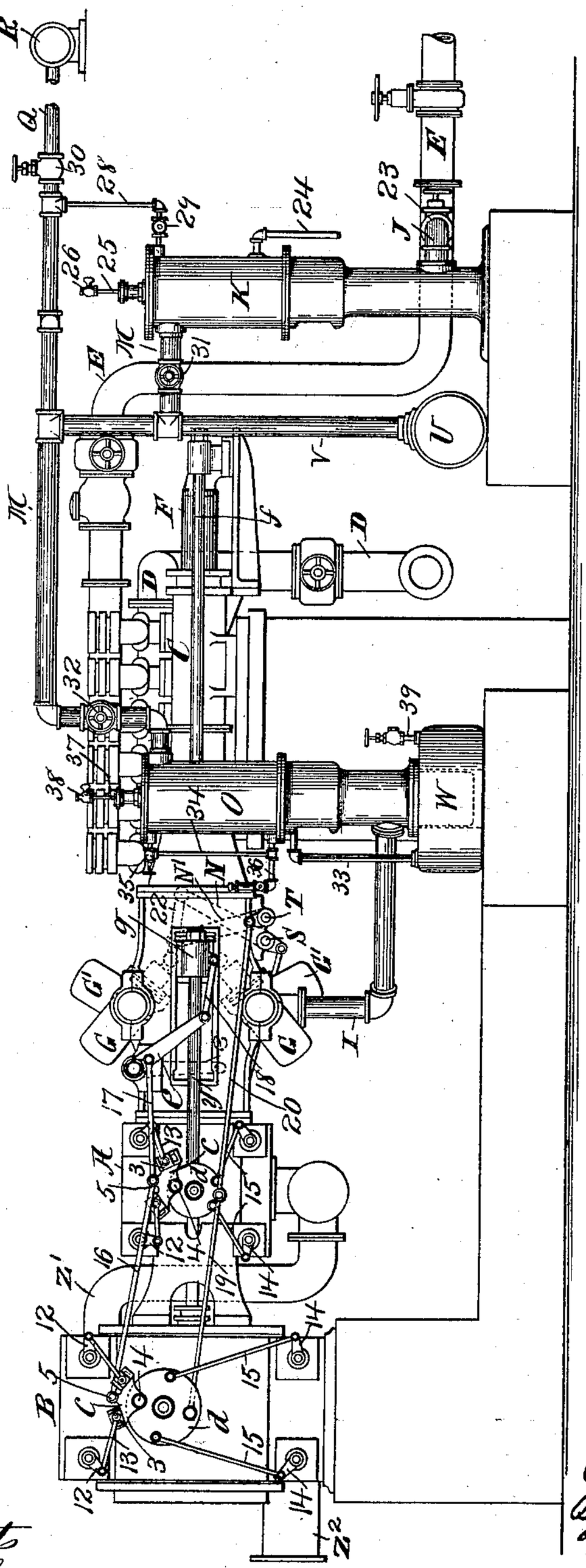
C. C. WORTHINGTON.

STEAM ENGINE.

(Application filed June 21, 1898.)

(No Model.) 3 Sheets—Sheet 1.

Fig. 1.



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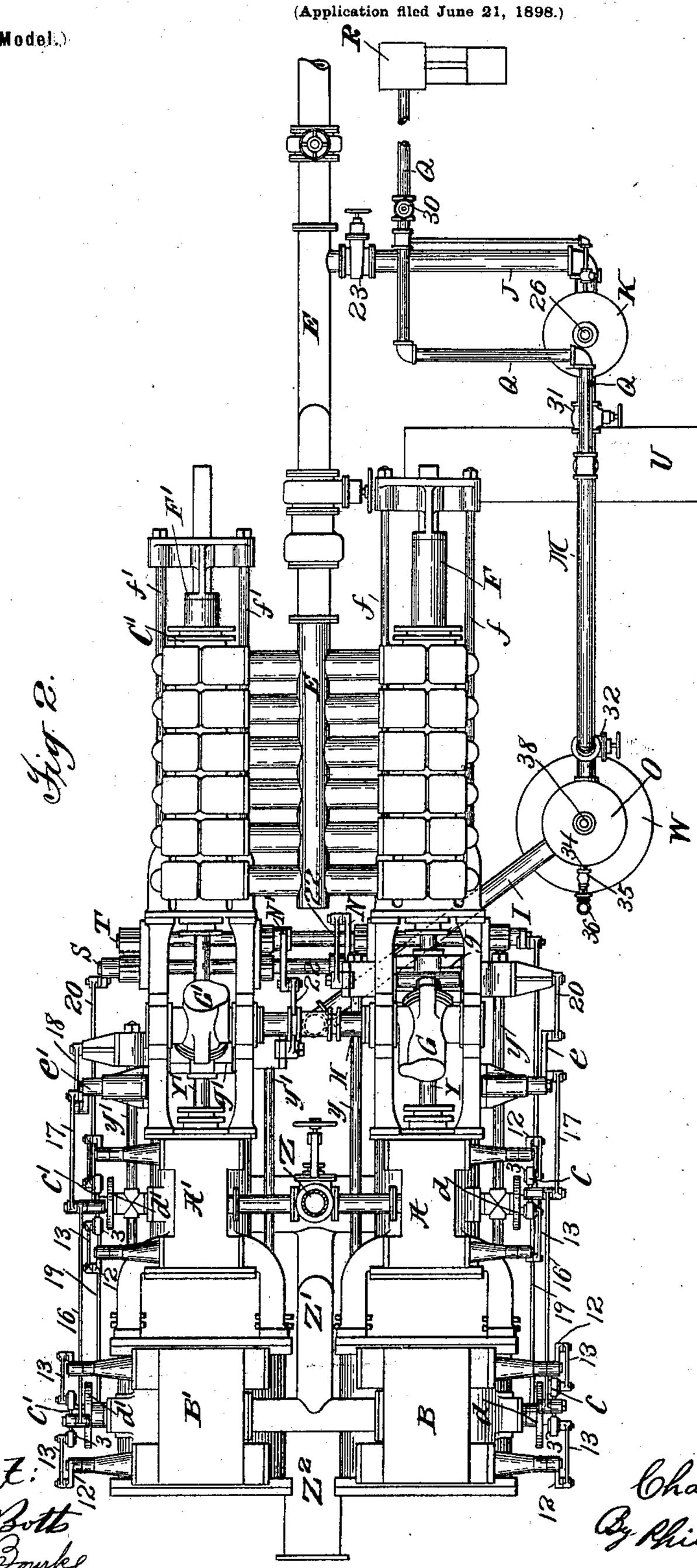
(No Model.) 3 Sheets—Sheet 2.

Fig. 2.



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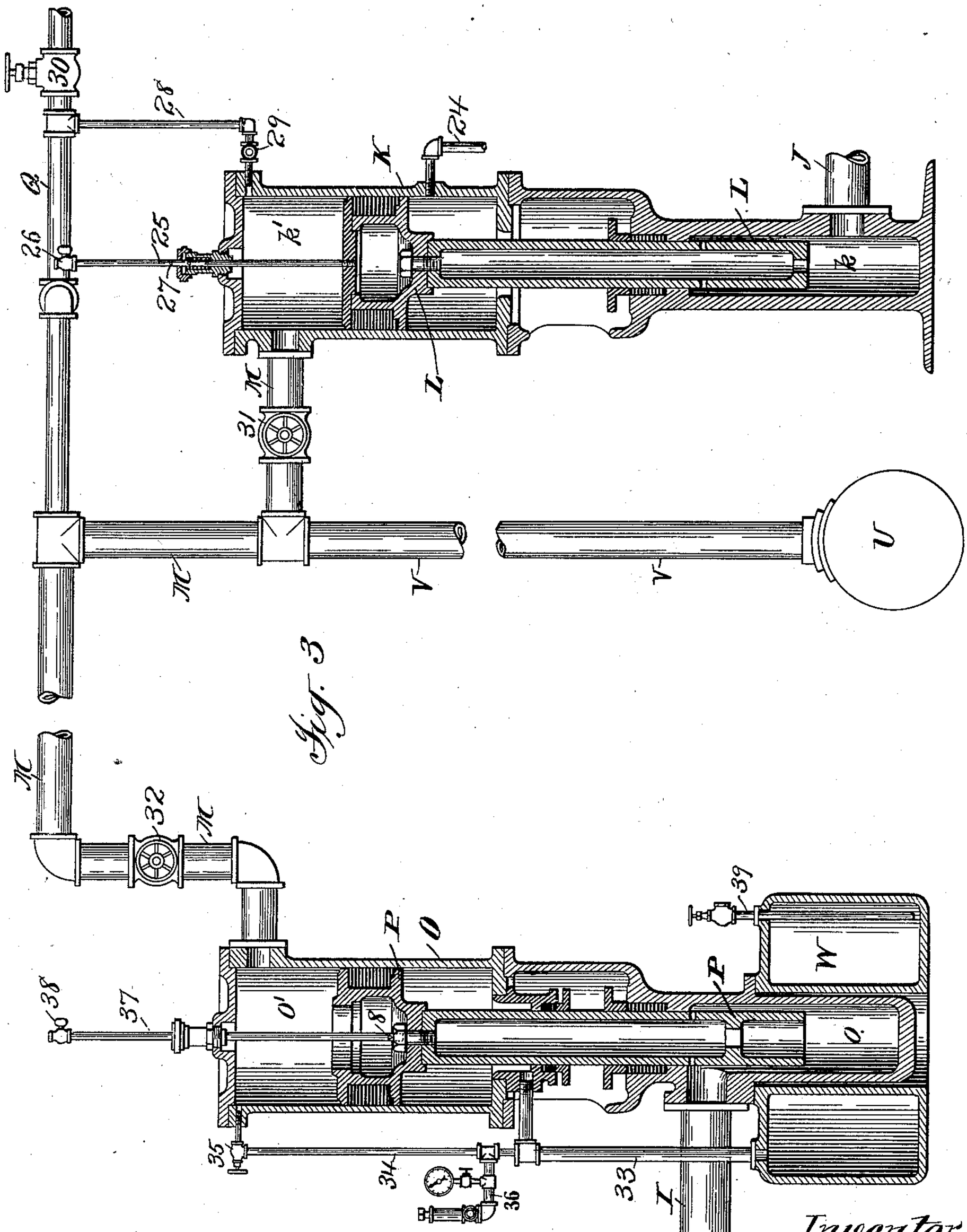

Fig. 3

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UNITED STATES PATENT OFFICE.

CHARLES C. WORTHINGTON, OF IRVINGTON, NEW YORK.

STEAM-ENGINE.

SPECIFICATION forming part of Letters Patent No. 628,511, dated July 11, 1899.

Application filed June 21, 1898. Serial No. 684,086. (No model.)

To all whom it may concern:

Be it known that I, CHARLES C. WORTHINGTON, a citizen of the United States, residing at Irvington, county of Westchester, and State of New York, have invented certain new and useful Improvements in Steam-Engines, fully described and represented in the following specification and the accompanying drawings, forming a part of the same.

This invention relates especially to that class of direct-acting engines which are provided with one or more compensating or auxiliary cylinders and pistons which are supplied with a suitable motor fluid and are arranged to act in opposition to the main piston or pistons during the first part of the stroke of the latter and in conjunction therewith during the last part of the stroke, so that the admission of steam to the main cylinder or cylinders may be cut off before the stroke is completed without reducing the power of the engine at the end of the stroke. Such engines are well known, and different forms are shown and described in United States Letters Patent Nos. 292,525, 332,857, 341,534, 451,148, and 455,935, heretofore granted to me.

The present invention relates more particularly, however, to pumping-engines of this general class in which the compensating cylinder or cylinders are connected to the force-main, so that the compensating-cylinder pressure is dependent on the force-pressure.

The chief object of the invention is to provide an improved construction of this class, and especially to provide a simple and efficient construction by which the desired action of the compensating cylinders shall be secured under sudden or wide differences of pressure in the force-main, the production of pulsations in the column of fluid in the force-main by action of the compensating cylinders be avoided, and a smooth and efficient operation of the apparatus under all running conditions be secured.

The broader features of the invention by which the above objects are attained are applicable in connection with engines of any form employing one or more compensating cylinders; but the invention includes also certain combinations in engines of that class known as "duplex" engines, having the valves on each side operated from the other side, in which engines the relative movement of the pistons on each side and the control of each side by the other through the valve-movement and connections for supplying fluid to the compensating cylinders result in a special action of the compensating apparatus not existing in single engines, and it includes also certain features that are not limited to constructions in which the compensating pressure is derived from or dependent on the force-pressure.

While the invention relates especially to compensating steam-engines, also it includes certain features of construction that may be used in other apparatus, one of the specific objects of the invention being to provide an efficient means by which pulsations or variations in the pressure of the force-main of pumping-engines may be relieved through the medium of air-pressure without requiring the air-pressure to be the same or as great as that of the main-pressure, so as to secure the well-known advantages of the ordinary air-chamber without the necessity of maintaining the air-pressure at a point which would be difficult in the case of pumping-engines working under unusually high pressure in the force-main.

As a full understanding of the various improvements constituting the present invention can best be given by a detailed description of the organization and operation of a construction embodying the same, all further preliminary description will be omitted and such a description be now given, reference being had to the accompanying drawings, in which a pumping apparatus is shown embodying all the features of the invention applied in their preferred form in connection with a duplex direct-acting pumping-engine of a well-known class, and the features forming the invention will then be specifically pointed out in the claims.

In the drawings, Figure 1 is a side elevation of the apparatus. Fig. 2 is a plan view of the same. Fig. 3 is a detail sectional elevation, on an enlarged scale, of the connections between the force-main and the compensating cylinders.

Referring to said drawings, the engine shown is in general construction a horizon-

tal compound direct-acting duplex-pressure pumping-engine, having the high and low pressure cylinders A B and A′ B′ on opposite sides arranged in line and two water-cylinders C C′ on opposite sides of the pump and having suction-main D and force-main E connected with the cylinders C C′ through valve-pots on the top of the water-cylinders, as well known in connection with such pressure-pumps. The plungers F F′ are shown as extending through the water-cylinders and connected by side rods *f f′* to cross-heads *g g′* on opposite sides of the engine in the manner common in such pumps, and these cross-heads are shown as connected in the usual manner to the high-pressure pistons on opposite sides by the main piston-rods Y Y′, and the low-pressure pistons are connected to these cross-heads by side rods *y y′* on opposite sides of the high-pressure cylinders. To these cross-heads are connected also the pistons of the compensating cylinders G G′ on opposite sides of the engine, two compensating cylinders being shown, although it will be understood that a single cylinder or more than two cylinders on each side may be used, these compensating cylinders receiving fluid through their hollow trunnions, as usual in such constructions, from cross-pipes H, connecting the trunnions of the upper and lower pairs of cylinders on opposite sides, and a pipe I, connecting the accumulator with these cross-pipes. Steam is supplied to the high-pressure cylinders through the induction-pipe Z, the exhaust passing from the high-pressure to the low-pressure cylinders through the pipe Z′ and the low-pressure cylinders exhausting through the pipe Z^2 to the condenser, or otherwise, as desired.

The steam-cylinders may be provided with valves of any suitable form, and any suitable valve-movement may be used for actuating the valves for admission and cut-off, many forms of such valves and valve-movements being now well known. In the drawings the steam-cylinders are shown as having single oscillating valves at the tops of the cylinders controlling the admission and cut-off and oscillating exhaust-valves at the bottoms of the cylinders. For actuating these valves the admission and cut-off valves are connected by crank-arms 12 on the valve-stems and links 13 to rockers *c c′* on opposite sides of the engine, and these rockers *c c′* are pivotally mounted by suitable pivots 4 on rockers *d d′* on the steam-cylinders, these rockers *d d′* also actuating the separate exhaust-valves through crank-arms 14 on the valve-stems and links 15, connecting the crank-arms with the rockers *d d′*. The rockers *c c′* of the low-pressure cylinders are connected to the rockers *c c′* of the high-pressure cylinders by connecting-rods 16, pivotally connected to the rockers by pivots 5, so as to be actuated together, and the rockers *c c′* of the high-pressure cylinders are pivotally connected by pivots 5 to connecting-rods 17, the other ends of which are connected to swinging levers *e e′* on the opposite sides of the engine, which are connected to the piston-rod cross-heads on the same side of the engine by links 18.

The rockers *d d′* of the low-pressure cylinders are connected to the rockers *d d′* of the high-pressure cylinders by connecting-rods 19, so as to be actuated therewith. These rockers are connected by connecting-rods 20 to crank-arms on crossover rock-shafts S T, which are actuated by the piston-rods through the valve-movement levers N N′ and links 22 from the cross-heads on opposite sides of the engine, the rock-shaft S thus being actuated from the A-cylinder side of the engine and the rock-shaft T from the A′-cylinder side of the engine, so that each of the rockers *d d′* is actuated from the opposite side of the engine for admission and exhaust. With this valve-movement each of the rockers *c c′* is rocked on its pivot 4 from its own side of the engine to actuate the valves at the top of the cylinder for cut-off and on its pivot 5 from the opposite side of the engine through rocker *d* or *d′*, on which it is mounted, to actuate these valves for admission, and this movement of the rockers *d d′* from the opposite side of the engine also actuates the exhaust-valves at the bottom of the cylinder, although it will be understood that these exhaust-valves may be actuated by any other suitable connections to the opposite side of the engine. The links 13 are preferably connected to the rockers *c c′* by adjustable connection-blocks 3, as shown, so that the point of cut-off may be adjusted as desired. By detaching the levers *e e′* from the cross-heads and securing them in central position, as shown in dotted lines in Fig. 1, or otherwise detaching rockers *c c′* from the pistons on their own side of the engine and holding pivots 5 in proper position the engine may be run without cut-off. This valve-movement is fully described and claimed in United States Letters Patent No. 609,953, and in itself forms no part of the present invention, so that a more extended description of its construction and operation is unnecessary.

Referring now to the parts of the apparatus shown for supplying the compensating cylinders with fluid under pressure through pipe I and securing the desired operation of the construction, the force-main E is connected by a pipe J with the lower chamber *k* of a vertical accumulator-cylinder K on one side of the differential piston L, so as to transmit the force-pressure to the smaller end of the piston, and the opposite or larger end of the piston is under air-pressure in the chamber *k′* at the top of the cylinder and connected by pipe M with the upper chamber *o′* of a similar vertical accumulator-cylinder O, having therein the differential piston P, the larger upper end of the piston P being subjected to the air-pressure in the cylinder-chamber *o′* and pipe M and the lower smaller end of the piston P transmitting the pressure through the lower

chamber *o* of the cylinder O to pipe I, which connects therewith, and thus to pipes H and the compensating cylinders G G′, the compensating cylinders, pipes H I, and the chamber *o* being filled with any suitable liquid, such as water or oil, for the operation of the compensating cylinders.

The air system, consisting of the upper chambers *k′ o′* of the cylinders K O and the connecting-pipe M, is supplied with air through a pipe Q from an air-compressor R, which may be of any suitable construction, and this air system is preferably enlarged, so as to secure a large air capacity without enlarging the cylinders K O for that purpose by an air-tank U, which may be placed at any suitable point and is shown as connected to the pipe M by pipe V. The pistons L and P are shown as single differential pistons; but it will be understood that this is not essential and that any suitable arrangement of cylinders and pistons may be used to secure the desired result and that the differential action may be secured by a proper single piston or by two pistons connected in any suitable manner.

Referring now to the details of the construction, the cylinder K may be and is shown as being substantially the same in construction as accumulator-cylinders heretofore used; but it may be of any suitable construction, so as to secure the application of the force-main pressure through the pipe J to one side of the differential piston L and the transmission of this pressure through the body of air or other elastic fluid opposing the piston on the opposite side. The pipe J is preferably provided with a suitable valve 23, by which the compensating construction can be cut off the force-main when necessary. The upper chamber of the cylinder K is preferably provided with a pipe 24, as shown, which is located at such a point that the piston L passes this pipe in descending before striking the bottom cylinder-head, so that the air will escape from the space above the piston through pipe 24 as the latter passes this pipe, and thus quickly relieve the system of pressure in case the force-main pressure should suddenly fall below the normal.

The piston L carries a pipe 25, which extends through the chamber *k′* and the upper head of the cylinder, being packed therein in any suitable manner, and is provided at the top with an escape valve or cock 26, which is normally open, and with one or more openings 27 along the pipe, which are outside the cylinder when the piston is in the upper part of the cylinder-chamber, but are moved below the cylinder-head and inside the cylinder-chamber when the piston descends into the lower part of the cylinder-chamber, so as to then permit the passage of air through these openings and cock 26. Any other suitable means may be used by which the position of the piston controls the escape of air from the chamber *k′*, so as to secure the result hereinafter described; but the construction shown is simple and efficient and is preferably used.

The piston L preferably closes the port of pipe M before it reaches the top of the cylinder-chamber *k′*, so as to cushion the piston to prevent striking the cylinder-head, and a pipe 28 is preferably used, connecting the top of the cylinder-chamber with the air-pipe Q from the compressor R, so as to permit air to be admitted to the cylinder-chamber *k′* above the piston L after the latter has closed pipe M, this pipe 28 being controlled by a cock 29. A cock 30 is also used on the pipe Q between the air-compressor and the air system supplied thereby, so that the air-compressor may be cut off the air system when desired, as explained hereinafter. The pipe M is also preferably provided with throttle-valves 31 32 on opposite sides of the connection of pipe M with pipes Q V and between such connection and the respective cylinders K O, so that by these throttle-valves one or both of the cylinders may be cut out or the air system otherwise controlled.

The cylinder O and piston P are shown as similar to accumulators now well known, but may be of any other suitable construction to secure the desired transmission of pressure to the compensating cylinders. With this cylinder and piston are shown means which are preferably used for adjusting the power produced by the accumulator by pressure applied to counterbalance the pressure on the upper end of the accumulator-piston, as follows: An air-tank W is used, which is preferably of circular form, as shown, inclosing and supporting the lower end of the cylinder O, although it may be arranged otherwise, and this tank W is connected by a pipe 33 with the upper chamber *o′* of cylinder O, below the piston P therein, so that the pressure of the air in tank W is opposed to the pressure on the opposite side of the piston and the power developed by the latter through the lower end of the piston acting upon the liquid in the lower chamber of the cylinder and pipe I reduced according to the counterbalancing pressure from tank W. Pipe 33 is shown as connected by pipe 34, controlled by cock 35, with the air-chamber at the upper end of the cylinder P, although it will be understood that the tank W may be supplied with air from any other part of the system. An outlet-pipe 36, provided with a safety-valve, is preferably used in connection with pipe 33, so as to permit the air to blow out in case of excess of pressure.

The piston P preferably carries a pipe 37, extending through the head of the cylinder and suitably packed, this pipe carrying at its upper end a cock 38, normally closed, and having at its lower end one or more openings 8. This pipe serves as a gage to show the position of the piston P, as in the case of the pipe 25 on piston L, and by opening cock 38 also oil or water that may be used or may collect on the top of the piston P may be

blown out. The air-tank W is also preferably provided with a blow-off pipe 39, provided with a cock, by opening which any oil or water collected in the tank W may be blown out, and the pressure in the tank W may thus also be reduced by opening the cock and permitting the air to escape.

The operation of the apparatus will be understood from a brief description.

We will assume that the engine is in operation and that the normal or ordinary pressure exists in the main E and in the air system and that the pistons of the cylinders A B are commencing their stroke toward the water-cylinders. During the first half of the stroke the liquid will be forced out of the compensating cylinders G into the cross-connection pipes H and through the pipe I into the chamber *o* at the lower end of the cylinder O, where it will act upon the smaller end of the plunger P in said chamber and raise the plunger against the pressure of the air in chamber *o'* and the air system and, indirectly through the air system and piston L, upon the liquid in the force-main through the smaller end of piston L in chamber *k* and pipe J. During the latter half of the stroke the operation will be reversed, and the plunger P, acted upon by the pressure from the force-main acting indirectly through the air system, will move downward and force the liquid out of chamber *o* in cylinder O into pipes I H and the compensating cylinders G, thus giving back the power which was expended in raising the plunger P. The power exerted upon the plunger F in water-cylinder C is thus maintained to the end of the stroke, although the admission of steam to the steam-cylinders A B has been cut off at the point in the stroke for which the construction is adjusted by the movement of the pistons acting through the lever *e* and connections to rockers *c* and the valves. As the pistons of the cylinders A B approach the end of their stroke they will operate the valves of the cylinders A′ B′ on the opposite side of the engine through crossover-shaft S and connections to the rockers *d′* and the valves, so as to start the pistons of cylinders A′ B′ upon their stroke in the same direction as the pistons of cylinders A B are then moving. During this stroke of the pistons of cylinders A′ B′ the operation just described will be repeated in connection with the compensating cylinders G′, the compensating cylinders G thus giving out power and the compensating cylinders G′ storing up power during the remainder of the stroke of the pistons in cylinders A B, and as the pistons of the cylinders A′ B′ pass half-stroke the compensating cylinders G′ will in turn give back the power thus stored up thereby, the admission of steam to the cylinders A′ B′ being cut off at the proper point by the pistons acting through the lever *e′* and connections to the rockers *c′* and the valves. The pistons of cylinders A B will reach the end of their stroke and rest until as the pistons of cylinders A′ B′ approach the end of their stroke the latter will operate the valves of cylinders A B through crossover-shaft T and the connections to rockers *d* and the valves, so as to start the pistons of cylinders A B upon their return stroke, the compensating cylinders G then storing up power and the compensating cylinders G′ giving back power during the rest of the stroke of the pistons of cylinders A′ B′. The operation will thus continue during the normal running of the engine. It will be seen that this operation of the compensating cylinders would result in producing pulsations in the column of fluid in the force-main and shock in the engine and apparatus if the pressure were transmitted between the cylinders and force-main directly or through an inelastic medium and that sudden changes of pressure in the force-main would be transmitted to and cause sudden and injurious changes in the action of the compensating cylinders upon the engine. The elastic cushion between the pistons L P, formed by the air system, prevents these results and secures a smooth and uniform operation of the engine without shock or pulsations in the force-main, the elasticity of the air resulting in the gradual transmission of changes in pressure and the absorption of the pulsations that otherwise would result, while at the same time the compensating-cylinder pressure is controlled by and conforms to the load on the engine, so that the power developed by the compensating cylinders increases with the load, as in starting the engine, whenever the force-main has become empty or partly empty or on pipe-lines, where the load depends on the friction, and thus on the velocity of the column of liquid. In case of breakage of the force-main also the pressure upon the compensating cylinders will be immediately relieved, as the pressure in the air system is dependent upon the pressure in the force-main, and the compensating cylinders will at once cease to develop more power than is necessary to overcome the reduced load on the plungers.

When used where the force-main pressure and other running conditions are substantially uniform, the air-compressor R may be cut off the system by closing cock 30, when the desired air-pressure in the system is secured after starting the engine, the air-compressor R then being operated only at intervals as required to supply air-leakage or when it is desired to increase the air-pressure for any reason. In starting the engine, however, and when the main pressure is liable to sudden or considerable variations it is preferable to run the air-compressor on the air system continuously, the apparatus then being self-adjusting to secure the desired air-pressure and operation under different force-pressures or other changes in running conditions producing changes of pressure in the system. This operation is as follows: We

will assume that in the position of parts shown in the drawings the air-compressor R is pumping continuously into the air system, so as to increase the pressure therein, the pressure in the force-main acting on the lower end of the differential piston L having just been increased, so that the piston is raised into the position shown, with the openings 27 in pipe 25 outside the cylinder-chamber *k'*, and no air is escaping from chamber *k'* through this pipe. Under the continuous pumping of the air-compressor R the piston L will be forced downward if the pressure in the force-main remains constant, so that when the desired pressure in the air system corresponding to the actual pressure in the force-main and the normal position for which piston L is adjusted is reached one or more of the openings 27 will connect the chamber *k'* with the pipe 25 and air thus be permitted to escape from the chamber *k'* and the air system, so that the pressure within the system is not further increased or the piston L moved downward farther, but the excess of air pumped by the compressor R escapes through the pipe 25. In case of a further decrease of the pressure in the force-main the downward movement of the piston L under the pressure in the chamber *k'* will bring more of the openings 27 within the chamber *k'*, and thus the air will escape more rapidly from the chamber *k'* until the pressure in the air system is thus reduced to correspond to the reduced force-main pressure, and the normal position of the piston L, with the excess of air pumped escaping through the pipe 25, is again secured. In case of a breakage of the main or sudden large decrease of pressure therein producing a larger movement of the piston L the air-pressure in chamber *k'* and the air system will be relieved through pipe 24 as the piston L passes below this pipe, so that the pressure is removed before the piston could reach the cylinder-head, and the piston also is preferably cushioned by the air below it being partially confined in the space between the pipe 24 and the cylinder-head.

With the air-compressor R pumping continuously into the air system and the piston L in such position that the excess of air pumped by the air-compressor R escapes through openings 27 in pipe 25 if the pressure in the force-main be suddenly or largely increased the piston L will be raised, so as to move the pipe 25 upward and close the openings 27 by moving them into or outside the packing-gland in the cylinder-head, and the continuous delivery of the air to the system by the air-compressor R will then operate to gradually increase the pressure in the air system to correspond to the increased pressure in the force-main and move the piston L downward again to normal position. As the piston L is moved upward against the pressure of the air system by increase of pressure in the force-main, it will close the port of pipe M before it can strike the top cylinder-head, so that the further passage of air from the chamber *k'* is thus prevented and an air-cushion formed between the piston L and the top of the cylinder, thus avoiding danger of injury by the piston striking the cylinder-head. In case of such an increased pressure in the main and its continuance, so that the piston L is not again lowered by the pressure of the air confined between the cylinder L and the cylinder-head, the cock 29, which preferably will always be slightly opened, will admit air from the air system and compressor through pipe 28 to the chamber *k'* above the piston, and the pressure in the chamber *k'* thus increased will move the piston L downward again.

It will be seen that the air system, with the continuously-operating air-compressor, is thus self-adjusting to changes in main-pressure and that after starting the engine, with the compressor R in operation, the pressure in the air system required for the existing main-pressure is soon attained, this being determined by the construction itself in actual operation. When this point is reached, however, it is obvious that if the force-pressure and other running conditions are uniform the air-compressor R may then be cut out of the system by closing the cock 30 and the air-compressor then operated only as required to maintain the desired pressure, the pressure existing in the system being shown by any suitable pressure-gage and the position and operation of the pistons L P being indicated by the pipes 25 37. On opening the cock 30 the desired pressure in the system will be automatically secured to correspond to the pressure in the force-main, the cock 30 then being closed again. It will be understood also that such an air system may be used without any means for permitting the escape of air, so as to automatically secure the required pressure corresponding to the main-pressure.

The power developed by the accumulator may readily be adjusted by increasing or decreasing the counterbalancing pressure applied to piston P from tank W and exactly the desired development of power by the compensating cylinders relatively to the pressure in the force-main be thus secured, so that the construction shown may be used with force-pressures differing widely and exactly the desired position secured without change of parts of the accumulator-pistons to adjust the power. A comparatively large air system is preferably used, so as to secure a large elastic cushion for the absorption of pulsations, and an air-tank, as U, is preferably employed to secure this result without inconveniently large air-cylinders. It will be understood, however, that such separate air-tank may be omitted and that the air-cushion may be of any desired size.

The use of the differential pistons shown is not absolutely essential, and their size and arrangement will depend somewhat upon the

conditions of use; but differential pistons, with the air-pressure applied to the larger ends or equivalent constructions, are preferably used, so that the air-pressure maintained in the system need not be as high as the force-pressure. In the construction shown the cylder K or O may be cut off the system by closing cock 31 or 32 and the cylinder K used only as an air-cushion for the force-main, or the compensating cylinders and accumulator O can be run independently of the force-main, if desired for any purpose.

It will be understood that the invention, broadly considered, is not limited to the use of a plurality of cylinders with the pressure transmitted between their pistons through an elastic cushion, but that other suitable constructions may be used with one or more cylinders operating on the same principle and including the features claimed hereinafter, and that many modifications may be made in the construction shown without departing from the invention.

The invention is especially applicable in connection with pumping-engines used on oil-lines and has been designed in connection therewith, although it will be understood that it is of general application. In oil pipe-lines the pressure is usually very high, so that it is necessary to reduce the main-pressure considerably in applying it to the compensating cylinders, especially through the medium of air-pressure, owing to the practical difficulty of using air under as high pressure as that of the main pipe-line, and in such constructions also it is especially important that the compensating pressure should be dependent on the force-pressure, but the latter not be directly transmitted to the compensating cylinders. The present invention makes it possible to secure the proper pressure in the compensating cylinders corresponding to and dependent on the pressure in the force-main, while at the same time pulsations in the force-main or shock in the system are avoided under wide variations of pressure and different running conditions. The construction shown also effectually prevents the passage of oil or dirt from the pipe-line to the compensating cylinders, and the compensating power may readily be adjusted as desired.

What I claim is—

1. The combination with a main cylinder or cylinders and piston or pistons, and a compensating cylinder or cylinders and piston or pistons arranged to act in opposition to the main piston or pistons during the first part of the stroke and in conjunction therewith during the last part of the stroke, of two pistons arranged between the compensating cylinder or cylinders and the source from which the pressure in said cylinder or cylinders is derived and an elastic cushion between said two pistons, substantially as described.

2. The combination with a main cylinder or cylinders and piston or pistons, and a compensating cylinder or cylinders and piston or pistons arranged to act in opposition to the main piston or pistons during the first part of the stroke and in conjunction therewith during the last part of the stroke, of two pistons arranged between the compensating cylinder or cylinders and the source from which the pressure in said cylinder or cylinders is derived and a body of elastic fluid between said two pistons, substantially as described.

3. The combination with a main cylinder or cylinders and piston or pistons, and a compensating cylinder or cylinders and piston or pistons arranged to act in opposition to the main piston or pistons during the first part of the stroke and in conjunction therewith during the last part of the stroke, of two cylinders and pistons arranged between the compensating cylinder or cylinders and the source from which the pressure in said cylinder or cylinders is derived, one of said pistons being subjected on one side to the pressure of the fluid from said source and the other of said pistons on one side to the pressure of the fluid in the compensating cylinder or cylinders, connections between said cylinders on the other side of said pistons, and a body of elastic fluid filling said chambers and connections through which pressure is transmitted between said two pistons, substantially as described.

4. The combination with a main cylinder or cylinders and piston or pistons, and a compensating cylinder or cylinders and piston or pistons arranged to act in opposition to the main piston or pistons during the first part of the stroke and in conjunction therewith during the last part of the stroke, of two differential pistons arranged between the compensating cylinder or cylinders and the source from which the pressure in said cylinder or cylinders is derived, one of said pistons being subjected on its smaller end to the pressure of the fluid from said source and the smaller end of the other piston to the pressure in the compensating cylinder or cylinders and a body of elastic fluid between said differential pistons, substantially as described.

5. The combination with the main cylinders and pistons forming the two sides of a duplex engine and having connections by which the valve or valves of each side is or are operated from the other side, and a compensating cylinder or cylinders and piston or pistons for each side of the engine arranged to act in opposition to the main pistons during the first part of the stroke and in conjunction therewith during the last part of the stroke, of two pistons arranged between the compensating cylinders and the source from which the pressure in said cylinder or cylinders is derived and an elastic cushion between said two pistons, substantially as described.

6. The combination with the main cylinders and pistons forming the two sides of a duplex engine and having connections by which the valve or valves of each side is or are operated from the other side, and a compensating cyl-

inder or cylinders and piston or pistons for each side of the engine arranged to act in opposition to the main pistons during the first part of the stroke and in conjunction therewith during the last part of the stroke, of two pistons arranged between the compensating cylinders and the source from which the pressure in said cylinder or cylinders is derived and a body of elastic fluid between said two pistons, substantially as described.

7. The combination with the main cylinder or cylinders and piston or pistons of a pumping-engine, and a compensating cylinder or cylinders and piston or pistons arranged to act in opposition to the main piston or pistons during the first part of the stroke and in conjunction therewith during the last part of the stroke, of a piston between said compensating cylinder or cylinders and the force-main subjected on one side to the pressure in the force-main and a body of elastic fluid acting on the opposite side of said piston through which pressure is transmitted from the force-main to the compensating cylinder or cylinders, substantially as described.

8. The combination with the main cylinder or cylinders and piston or pistons of a pumping-engine, and a compensating cylinder or cylinders and piston or pistons arranged to act in opposition to the main piston or pistons during the first part of the stroke and in conjunction therewith during the last part of the stroke, of two pistons between said compensating cylinder or cylinders and the force-main through which pressure is transmitted from the force-main to said compensating cylinder or cylinders, and an elastic cushion between said two pistons, substantially as described.

9. The combination with the main cylinder or cylinders and piston or pistons of a pumping-engine, and a compensating cylinder or cylinders and piston or pistons arranged to act in opposition to the main piston or pistons during the first part of the stroke and in conjunction therewith during the last part of the stroke, of two pistons between said compensating cylinder or cylinders and the force-main through which pressure is transmitted from the force-main to said compensating cylinder or cylinders and a body of elastic fluid between said two pistons, substantially as described.

10. The combination with the main cylinder or cylinders and piston or pistons of a pumping-engine, and a compensating cylinder or cylinders and piston or pistons arranged to act in opposition to the main piston or pistons during the first part of the stroke and in conjunction therewith during the last part of the stroke, of two differential pistons arranged between the compensating cylinder or cylinders and the force-main through which pressure is transmitted from the force-main to said compensating cylinder or cylinders, said differential pistons being subjected on one side, respectively, to the pressure of the fluid in the force-main and in the compensating cylinder or cylinders, and a body of elastic fluid between the other sides of said differential pistons, substantially as described.

11. The combination with the main cylinders and pistons forming the two sides of a duplex pumping-engine and having connections by which the valve or valves on each side is or are operated from the other side and a compensating cylinder or cylinders and piston or pistons for each side of the engine arranged to act in opposition to the main pistons during the first part of the stroke, and in conjunction therewith during the last part of the stroke, of a piston between said compensating cylinders and the force-main subjected on one side to the pressure in the force-main and a body of elastic fluid acting on the opposite side of said piston through which pressure is transmitted from the force-main to the compensating cylinders, substantially as described.

12. The combination with the main cylinders and pistons forming the two sides of a duplex pumping-engine and having connections by which the valve or valves on each side is or are operated from the other side and a compensating cylinder or cylinders and piston or pistons for each side of the engine arranged to act in opposition to the main pistons during the first part of the stroke, and in conjunction therewith during the last part of the stroke, of two pistons between said compensating cylinders and the force-main through which pressure is transmitted from the force-main to said compensating cylinders and an elastic cushion between said two pistons, substantially as described.

13. The combination with the main cylinders and pistons forming the two sides of a duplex pumping-engine and having connections by which the valve or valves on each side is or are operated from the other side and a compensating cylinder or cylinders and piston or pistons for each side of the engine arranged to act in opposition to the main pistons during the first part of the stroke and in conjunction therewith during the last part of the stroke, of two pistons between said compensating cylinders and the force-main through which pressure is transmitted from the force-main to said compensating cylinders, and a body of elastic fluid between said two pistons, substantially as described.

14. The combination with a pumping-engine having one or more compensating cylinders and pistons, of connections between said compensating cylinder or cylinders and the force-main including a piston acted upon on one side directly by the liquid in the force-main, and a body of elastic fluid acting on the opposite side of the piston and through which pressure is transmitted from the force-main to the compensating cylinder or cylinders, substantially as described.

15. The combination with a pumping-engine having one or more compensating cylin-

ders and pistons, of connections between said compensating cylinder or cylinders and the force-main including a piston subjected on one side to the pressure in the force-main, a second piston having one end subjected to the pressure in the compensating cylinder or cylinders, a body of elastic fluid between said two last-mentioned pistons through which pressure is transmitted from the force-main to the compensating cylinder or cylinders, and means for applying adjustable pressure to said second piston independently of said body of elastic fluid to regulate the pressure in the compensating cylinder or cylinders, substantially as described.

16. The combination with a pumping-engine having one or more compensating cylinders and pistons, of connections between said compensating cylinder or cylinders and the force-main including a piston subjected on one side to the pressure in the force-main, a body of elastic fluid acting on the opposite side of the piston and through which pressure is transmitted from the force-main to the compensating cylinder or cylinders, and means controlled by said piston for permitting the escape of elastic fluid from said body of fluid when the piston is moved against the force-pressure beyond a certain point, substantially as described.

17. The combination with a pumping-engine having one or more compensating cylinders and pistons, of a piston subjected on one side to the pressure in the force-main, a second piston subjected on one side to the pressure in the compensating cylinder or cylinders, a body of elastic fluid between said pistons, a continuously-operating pump for supplying the elastic fluid, and means controlled by the position of the piston subjected to the force-main pressure to permit the escape of elastic fluid and prevent its escape to secure the proper pressure of the elastic fluid under changes of main-pressure, substantially as described.

18. The combination with a pumping-engine having one or more compensating cylinders and pistons, of a piston subjected on one side to the pressure in the force-main, a second piston subjected on one side to the pressure in the compensating cylinder or cylinders, a body of elastic fluid between said two last-mentioned pistons through which pressure is transmitted from the force-main to the compensating cylinder or cylinders, and means controlled by the piston subjected to the force-main pressure to permit the escape of elastic fluid from between the pistons when said piston subjected to the force-main pressure is moved against the force-pressure beyond a certain point and to prevent the escape of elastic fluid when the same piston is moved in the opposite direction beyond a certain point, substantially as described.

19. The combination with a piston acted upon by a column of liquid under pressure, of a body of elastic fluid acting on the opposite side of said piston, a continuously-operating pump for supplying the elastic fluid, and means controlled by the position of the piston to permit the escape of elastic fluid from said body and prevent its escape to secure the proper pressure of the elastic fluid under changes of liquid-pressure, substantially as described.

20. The combination with a piston acted upon by a column of liquid under pressure, of a body of elastic fluid acting on the opposite side of said piston and through which pressure is transmitted from said piston and means controlled by the piston to permit the escape of elastic fluid from said body when the pressure of the fluid has moved the piston beyond a certain point and to prevent the escape of elastic fluid when the pressure of the column of liquid has moved the piston in the opposite direction beyond a certain point, substantially as described.

21. The combination with a piston acted upon by a column of liquid under pressure, of a body of elastic fluid acting on the opposite side of said piston, a continuously-operating pump for supplying the elastic fluid, and means actuated on the movement of the piston against the pressure of the liquid to permit the escape of elastic fluid from said body and on the movement of the piston in the opposite direction to prevent the escape of elastic fluid, substantially as described.

22. The combination with a piston acted upon by a column of liquid under pressure, of a body of elastic fluid acting on the opposite side of said piston, means actuated on the movement of the piston against the pressure of the liquid to permit the escape of elastic fluid from said body up to a certain point of travel of said piston, and means for permitting a large escape of said elastic fluid from said body upon the further movement of the said piston, substantially as described.

23. The combination with a piston acted upon by a column of liquid under pressure, of a body of elastic fluid acting on the opposite side of said piston, means actuated on the movement of the piston against the pressure of the liquid to permit the escape of elastic fluid from said body in gradually-increasing quantity as the said piston moves against the pressure of the liquid and to permit escape of a large quantity of the fluid when the piston has passed a certain point, substantially as described.

24. The combination with a piston acted upon by a column of fluid under pressure, of a body of elastic fluid acting upon the opposite side of said piston, a pipe connecting said cylinder with an elastic fluid-supply and arranged inside the end of the cylinder so as to be closed by the piston before the latter reaches the end of the cylinder, and a normally open small connection between the cylinder and air-supply through which air is admitted when the main connection is closed, substantially as described.

25. The combination with a column of liquid under pressure, of a piston subjected to the pressure of the column of liquid, a second piston opposing the movement of the first-mentioned piston by said liquid, and a body of elastic fluid between said pistons for relieving variations in pressure of the column of liquid and a casing inclosing the pistons and body of elastic fluid for transmitting the pressure of the column of liquid to the second piston through said elastic fluid, substantially as described.

26. The combination with the force-main of a pumping-engine, of a piston subjected to the pressure of the force-main, a second piston opposing the movement of the first-mentioned piston by said liquid, and a body of elastic fluid between said pistons for relieving variations in force-main pressure and a casing inclosing the pistons and body of elastic fluid for transmitting pressure from the force-main to the second piston through the elastic fluid, substantially as described.

In testimony whereof I have hereunto set my hand in the presence of two subscribing witnesses.

CHARLES C. WORTHINGTON.

Witnesses:
ANDREW J. CALDWELL,
B. W. PIERSON.