

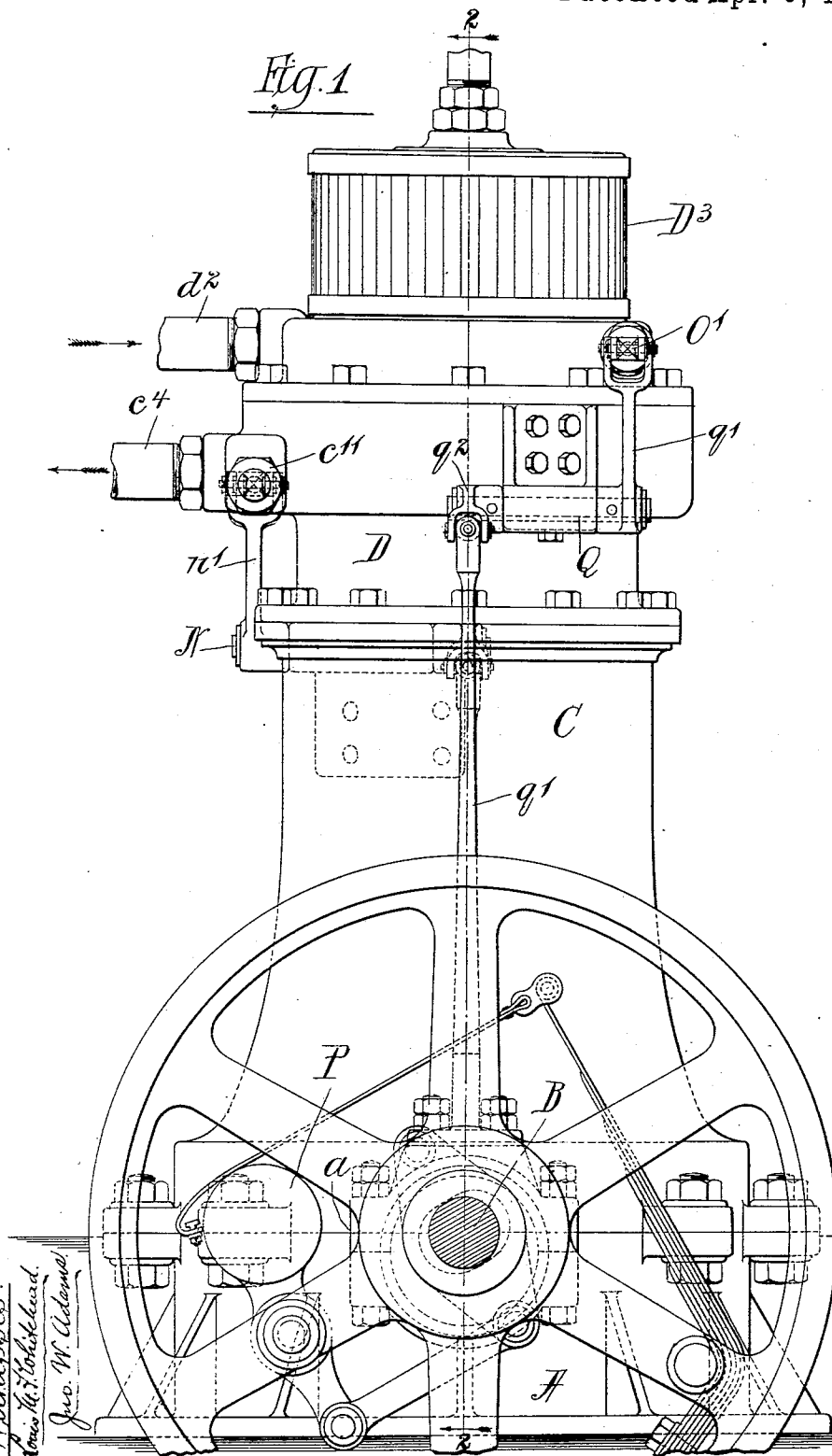
(No Model.)

M. C. BULLOCK.
STEAM ENGINE.

6 Sheets—Sheet 1.

No. 580,153.

Patented Apr. 6, 1897.



Witnesses:
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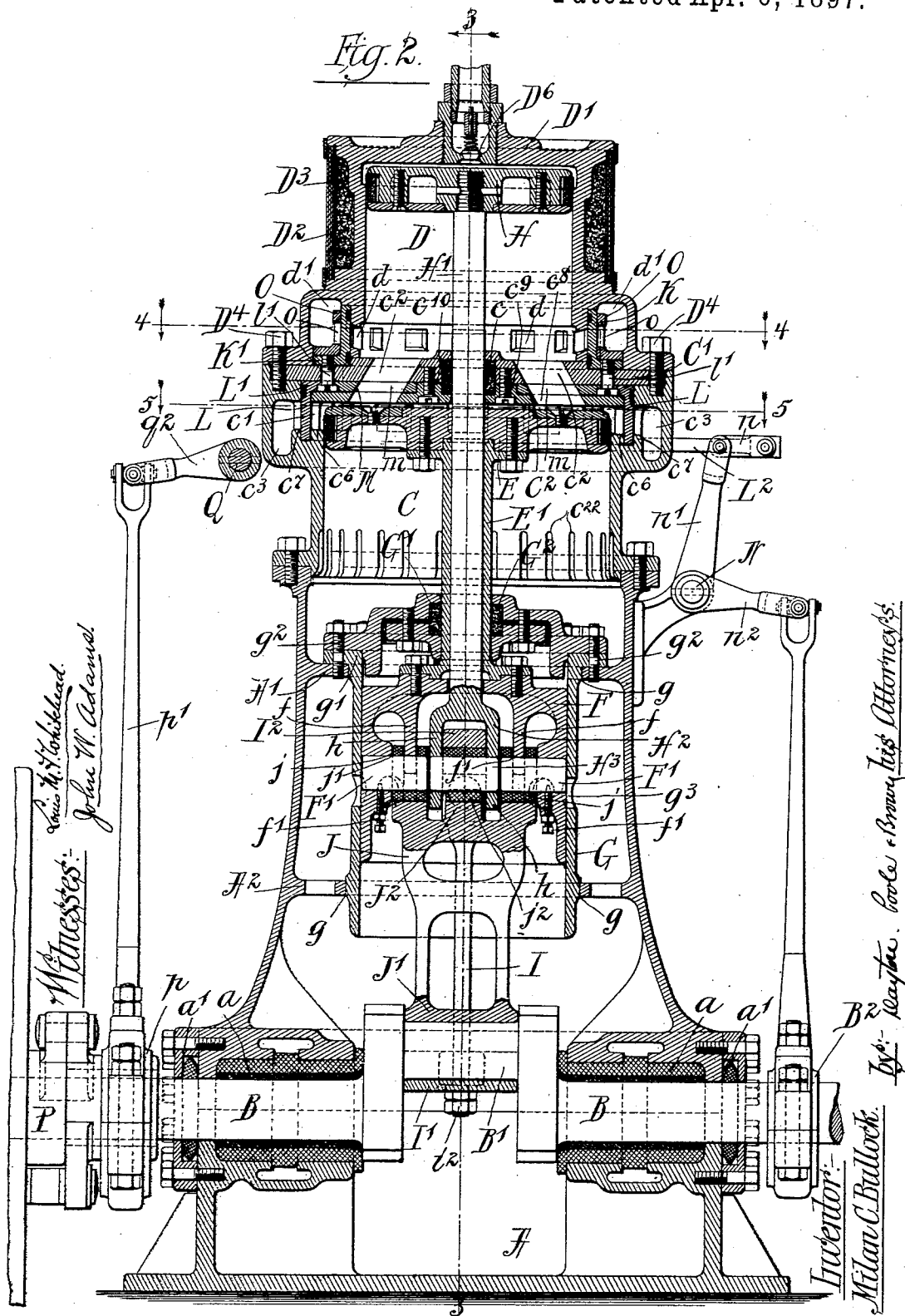
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M. C. BULLOCK.
STEAM ENGINE.

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No. 580,153.

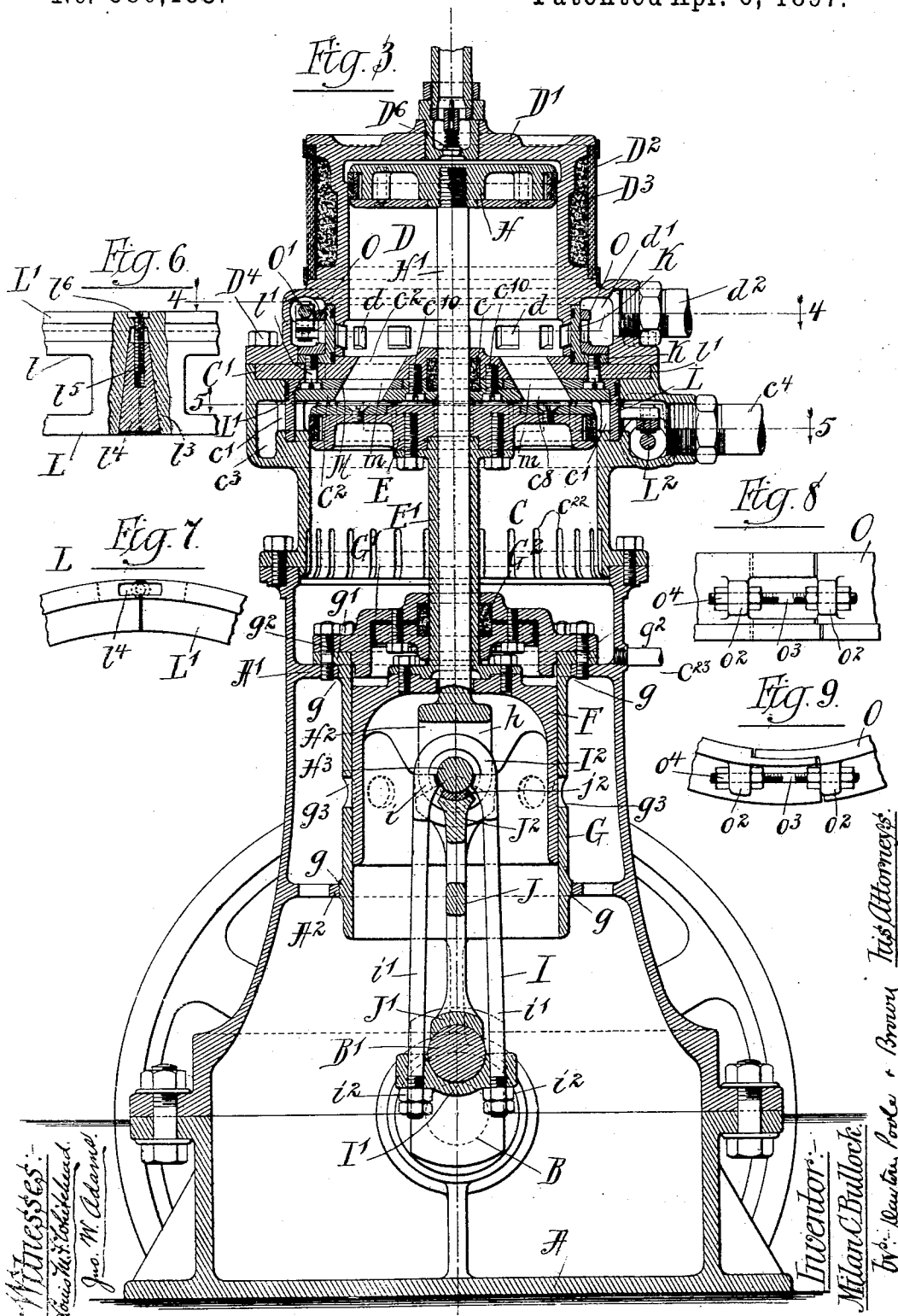
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M. C. BULLOCK.
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(No Model.)

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M. C. BULLOCK.
STEAM ENGINE.

No. 580,153.

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Fig. 4.

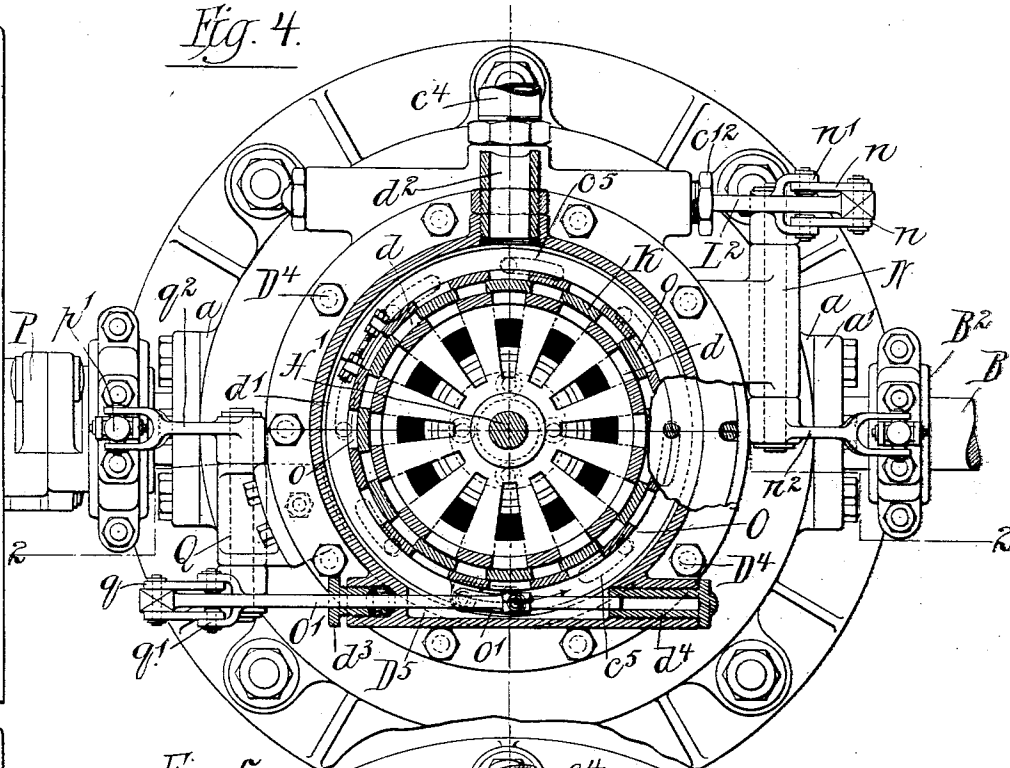
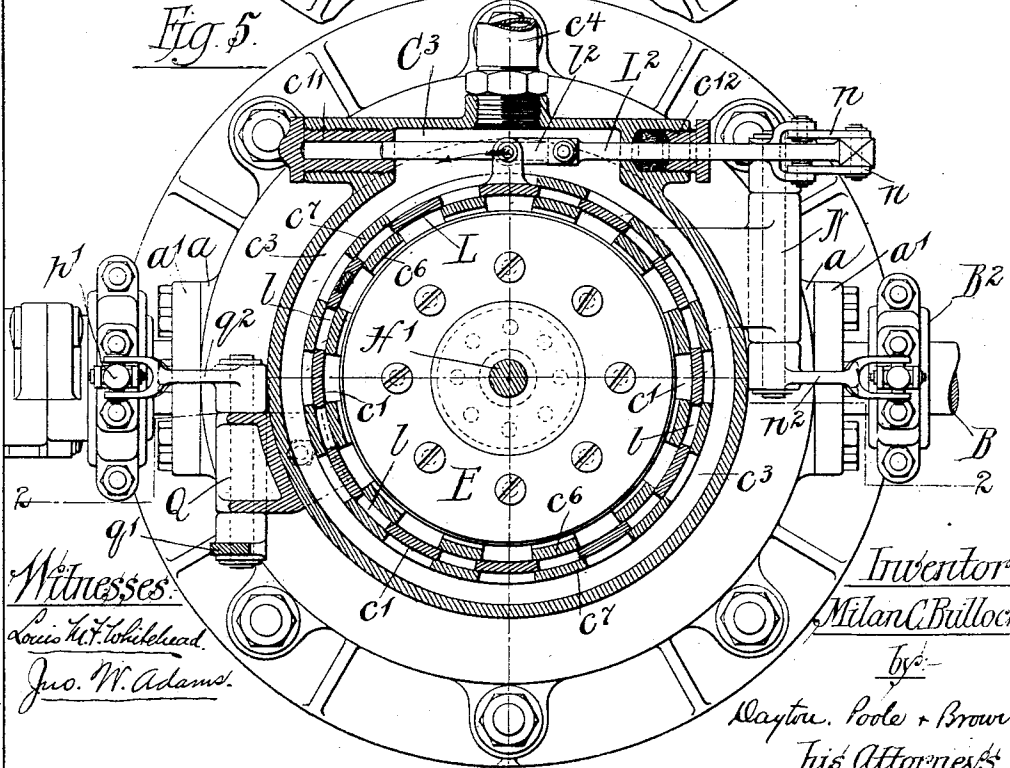


Fig. 5.



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(No Model.)

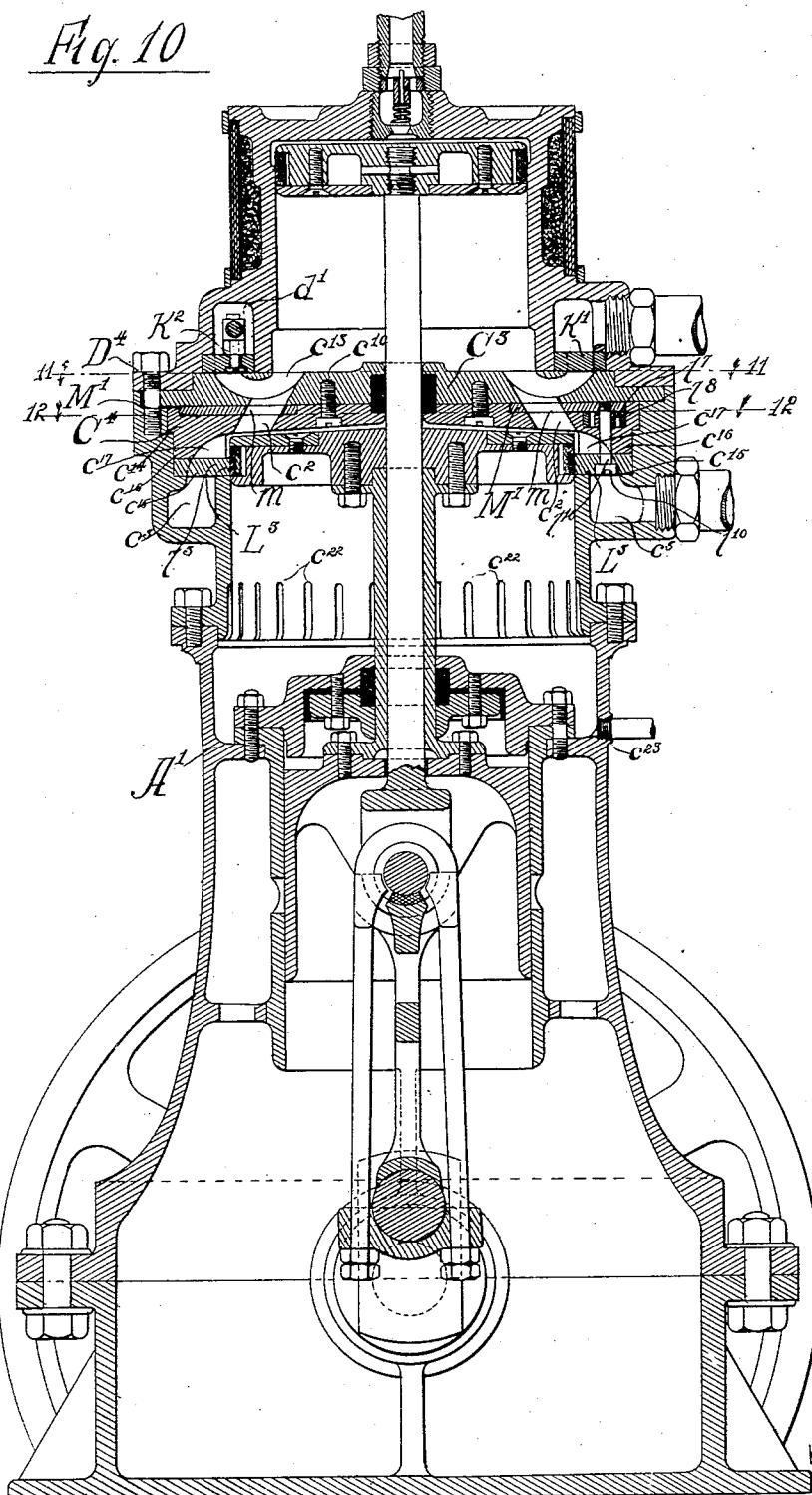
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M. C. BULLOCK.
STEAM ENGINE.

No. 580,153.

Patented Apr. 6, 1897.

Fig. 10



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(No Model.)

M. C. BULLOCK.
STEAM ENGINE.

6 Sheets—Sheet 6.

No. 580,153.

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Fig. 11

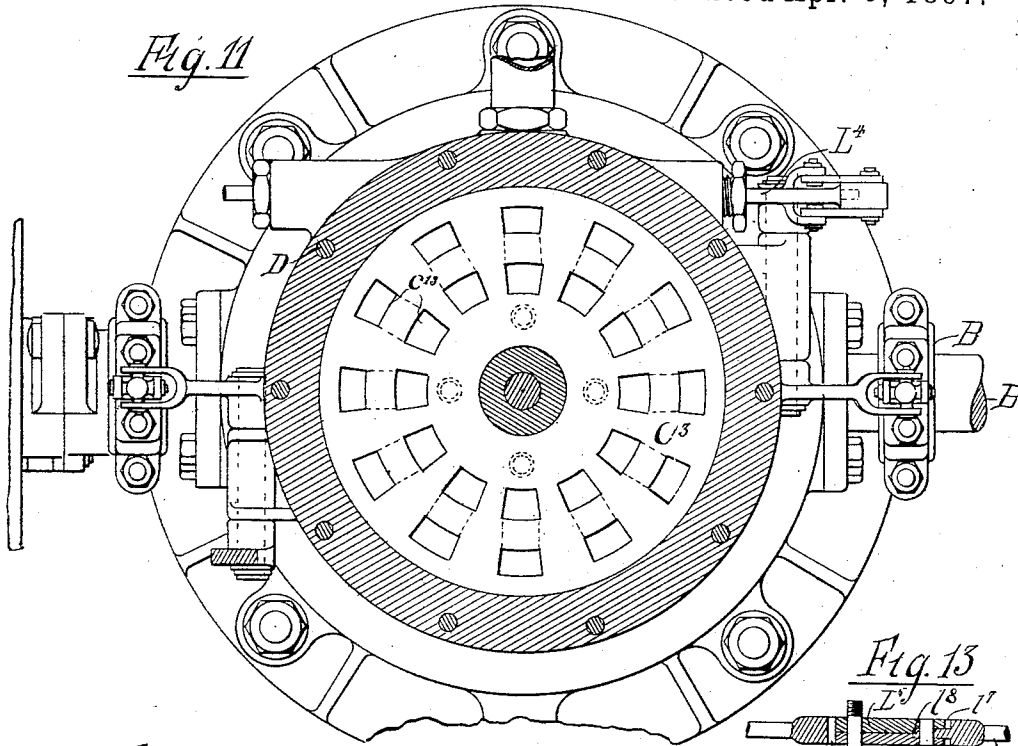
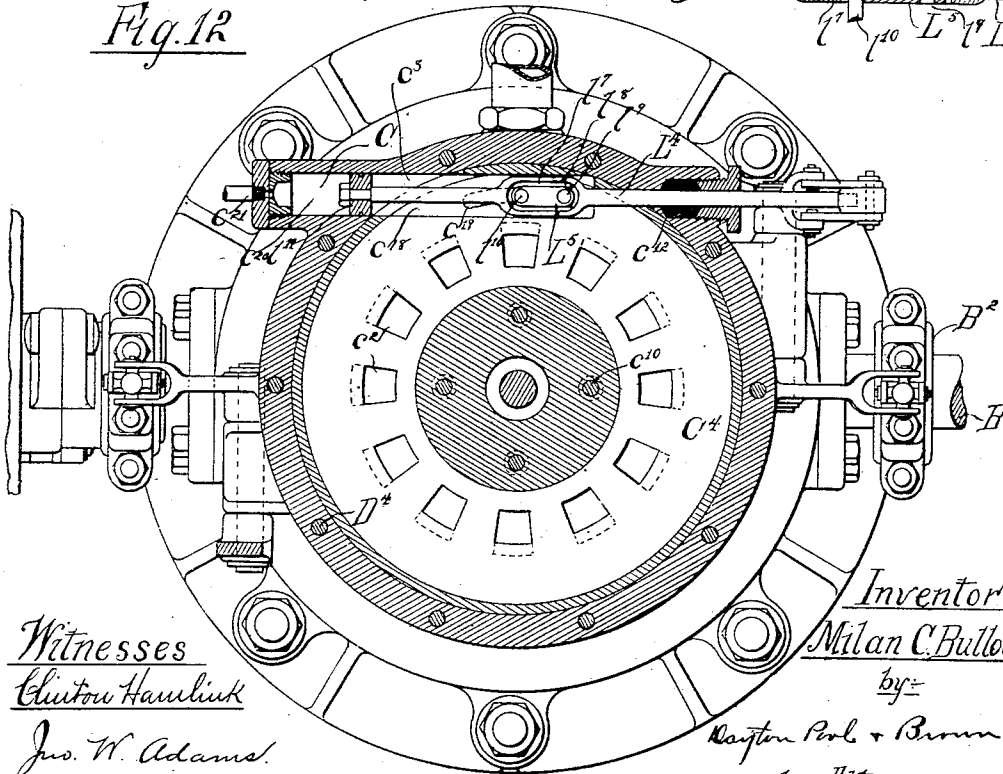


Fig. 12



Witnesses

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UNITED STATES PATENT OFFICE.

MILAN C. BULLOCK, OF CHICAGO, ILLINOIS.

STEAM-ENGINE.

SPECIFICATION forming part of Letters Patent No. 580,153, dated April 6, 1897.

Application filed June 28, 1894. Serial No. 515,954. (No model.)

To all whom it may concern:

Be it known that I, MILAN C. BULLOCK, of Chicago, in the county of Cook and State of Illinois, have invented certain new and useful Improvements in Steam-Engines; and I do hereby declare that the following is a full, clear, and exact description thereof, reference being had to the accompanying drawings, and to the letters of reference marked thereon, which form a part of, this specification.

This invention relates to improvements in that class of compound engines in which the high and low pressure pistons are each single acting or subjected to steam-pressure on one side only, but are arranged to exert their actuating force on opposite sides of a common crank-pin through separate piston-rods and connections, so as to produce in effect a double-acting engine.

The object of my invention is to provide an improved construction in engines of the character referred to; and it consists in the matter hereinafter set forth, and particularly pointed out in the appended claims.

In the accompanying drawings, showing my improvements as embodied in a compound engine of the vertical tandem type, Figure 1 is a side elevation of the engine. Fig. 2 is a sectional elevation taken on line 2 2 of Fig. 1. Fig. 3 is a similar view on line 3 3 of Fig. 2. Figs. 4 and 5 are horizontal sections on lines 4 4 and 5 5, respectively, of Fig. 3. Fig. 6 is a sectional elevation of one form of such devices for adjusting the valve-ring. Fig. 7 is a plan view thereof. Fig. 8 is a detail elevation of another form of such devices for adjusting the valve-ring. Fig. 9 is a plan detail thereof. Fig. 10 is a vertical section of my improved engine with its valves arranged somewhat differently from the form previously shown. Figs. 11 and 12 are horizontal sections on lines 11 11 and 12 12 of Fig. 10. Fig. 13 is a detail of the low-pressure valve-rod used in this instance.

A designates a cast-iron base provided with bearings *a a*, within which the crank-shaft B is horizontally journaled, the base and bearings being divided on a horizontal plane through the axis of the shaft to permit the insertion of the latter. Preferably the base is made to form an inclosure which may be kept

partially filled with oil, by which the working parts will be constantly lubricated, the bearings *a* in this case being provided at their outer ends with packing-boxes *a'* to prevent leakage of oil through the same. The low-pressure cylinder C is bolted directly to the top of the base A and is left open at its lower end, but is closed at its upper end by a head or diaphragm C', herein shown made as a separate part and consequently removable. The high-pressure cylinder D is bolted upon the end of the low-pressure cylinder C and is likewise open at its lower end, while closed at its upper end by a head D', in this instance cast integral with the cylinder. An ordinary lagging D² is shown as surrounding the cylinder D, and inserted between it and the outer wall of the cylinder a suitable non-conducting packing D³ is applied, the same tending to maintain a high temperature in the cylinder-walls.

E designates the low-pressure piston, from the lower side of which a piston-rod E' leads downwardly to a rigidly-attached cross-head in the form of a cylindric piston F. Said piston F reciprocates within a cylinder G, which is supported within the base A by transverse diaphragms A' and A². The cylinder G is in this instance made as a separate part or casting, having bearing portions *g* on its exterior adapted to fit within suitable apertures in the diaphragms A' and A², and has a flange *g'* at its upper end upon the diaphragm A' and through which stud-bolts *g*³ are passed to secure the cylinder in place.

H designates the high-pressure piston, and H' its piston-rod, which latter extends downwardly through a stuffing-box *c* in the cylinder-head or diaphragm C' and through a suitable axial bore in the low-pressure piston E and its piston-rod E' and is provided at its lower end with a cross-head H², located within the hollow interior of the piston F. The cross-head H² is herein shown as forged integral with the piston-rod H' and comprises two depending parallel arms *h*, which rigidly engage the opposite ends of a transverse cross-head pin H³. From the cross-head pin H³ a connecting-rod I extends downwardly to the crank-pin B' and is provided with a bearing-block I', engaging the lower side of the said crank-pin. The connecting-rod I is herein

shown as formed by a single bent link, the loop portion *i* of which is provided with a bearing-brass *I*², resting on the upper side of the cross-head pin *H*³ between the arms *h*, and the two depending ends *i'* of which pass through the lower bearing block or brass *I'* and are secured by nuts *i''* on their lower ends.

Within the cross-head or piston *F* on either side of the pin *H*³ and in axial alinement therewith are rigidly secured two cross-head pins *F'*, the inner ends of which are pivotally engaged by the two bearing-brasses *j* of a forked connecting-rod *J*, which extends downwardly between the sides of the connecting-rod *I* and is provided with a bearing-block *J'*, engaging the upper side of the crank-pin *B'*. The inner ends of the pins *F'* are herein shown as supported against upward deflection by interior depending lugs *f* of the piston *F*, which engage the upper surface of said pins, so as to hold the same from upward movement. The upper bearing-brasses *j* of the connecting-rod *J* are provided with slots *j'*, through which said lugs *f* pass, said slots being made of sufficient width to avoid interference between the lugs and brasses in the oscillatory movement of said rod *J*. Set-screws *f'* are also herein shown for the purpose of locking the pins *F'* rigidly in place.

Steam is admitted to the high-pressure cylinder at the bottom thereof and acts on the lower face only of the high-pressure piston. It is then exhausted into the upper part of the low-pressure cylinder and acts on the upper face only of the low-pressure piston. Normally, therefore, the only strain on the high-pressure connections is the upward pull of the high-pressure piston, while the only strain on the low-pressure connections is the downward thrust of the low-pressure piston. For the purpose, however, of preventing the high-pressure piston from dropping down by its own weight and the weight of its connections when the engine is not in operation the low-pressure connecting-rod *J* is further provided at its upper end with a central bearing portion *J*², the bearing-brass *j*² of which engages the lower side of the cross-head pin *H*³ between the arm *h* of the cross-head and between the sides of the connecting-rod *I*. Said brass *j*² may be conveniently bored out at the same time as the brasses *j* and is not designed to sustain any pressure beyond that due to the weight of the high-pressure parts when the engine is idle, as hereinbefore stated.

One form of valve mechanism for controlling the action of the steam in the manner described (see Figs. 2, 3, 4 and 5) comprises an annular series of port-openings *d* in the side wall of the cylinder *D* near the lower end thereof, a similar series of ports *c'* in the side wall of the cylinder *C* near the top thereof, and a series of ports *c*², extending through the diaphragm *C'* and serving to afford direct connection between the high and low pressure cylinders. The ports *d* lead inward from an annular passage *d'*, cored in the wall of

the cylinder *D* and supplied with steam by a suitable pipe *d*², and the ports *c'* lead outwardly into an annular passage *c*³, cored in the wall of the cylinder *C*, and which discharges into an exhaust-pipe *c*⁴. The inlet-ports are controlled by an annular valve-ring *K*, having apertures to correspond with said ports *d*, and the exhaust-ports *c'* are controlled by a similar ring-valve *L*, having openings *l*, corresponding with said exhaust-port *c'*. Both of said valves are, as a convenient construction, rigidly connected together and are oscillated through suitable connections by a common eccentric *B*², fixed on the shaft *B*. The rigid connection between the valve-rings is in this instance accomplished by screws *l'*, engaging horizontal flanges *K'* and *L'*, respectively, of the valve-rings *K* and *L* and passing through slots *c*⁵ in the diaphragm *C'*. Said slots are made long enough to permit the full oscillatory movement of the valve-rings. The diaphragm *C'* is in this instance shown as countersunk into the upper end of the cylinder *C* and is clamped between the same and the lower end of the cylinder *D* by means of the bolts *D*⁴, which secure the two cylinders together, the outer margin of the diaphragm being provided with apertures through which said bolts *D*⁴ pass, so that it is positively held against rotation. The valve-ring *L* is in this instance seated within an annular groove turned in the upper end of the wall of the cylinder which separates its interior from the annular passage *c*³, said wall being thus divided at this point into inner and outer parts *c*⁶ and *c*⁷, respectively, between which the valve-ring *L* is seated and through which the ports *c'* are cored. The lower edge of the valve-ring *L* rests upon the bottom of the grooves between the walls *c*⁶ and *c*⁷, and its upper surface and flange *L'* engage the under surface of the diaphragm *C'*.

The ports *c*², which afford connection between the high and low pressure cylinders, are controlled by a circular valve-plate *M*, placed directly beneath and in contact with the under surface of the diaphragm *C'* and provided with ports *m*, corresponding to the ports *c*². Said plate *M* is rotatively supported upon a stationary plate *C*², which is also provided with port-openings *c*⁸, forming a part or continuation of the ports *c*². The plate *C*² rests at its outer edge upon the inner part *c*⁶ of the grooved wall of the cylinder and fits closely within the valve-ring *L* and beneath the flange *L'* thereof. The central portion of the plate *C*² is formed in its upper surface with a circular boss *c*⁹, which projects up through a closely-fitting circular aperture in the valve-plate *M* and is secured to the lower surface of the diaphragm *C'* by screw-bolts *c*¹⁰. As herein shown, said plate *C*² also forms the cover of the stuffing-box *c*, through which the piston-rod *H'* reciprocates, the body of said stuffing-box being formed within the diaphragm *C'*. The valve-plate *M* is in this instance operated simultaneously with the

valve-rings K and L by being rigidly connected therewith. Such connection is herein shown as conveniently provided by making the valve-plate M of suitable diameter to closely fit within the flange L' of the valve-ring L and making such diameter just equal to that of the circle upon which the connecting-screws l' are arranged, opposing semicircular recesses being provided in the inner margin of the flange and outer margin of the plate to form the apertures through which said screws are passed. Each of the screws l' will thus obviously act as a key to secure the ring and plate against relative rotation.

The several port and valve openings are so arranged that the admission-ports d and exhaust-ports c² will be open at the same time, or during the upward stroke of the pistons, while the ports c³, which connect the two cylinders, will be opened alternately therewith, or during the downward stroke of the pistons. The controlling of all said ports in the foregoing construction will thus be accomplished by what amounts to a single-moving part.

The connections for oscillating the valve-rings K and L from the eccentric B², as herein shown, are constructed as follows: c³ designates a horizontal recess provided in the wall of the cylinder C at one side of the annular passage c³, within which a valve-rod L² is adapted to reciprocate in close proximity to the valve-ring L, said valve-rod being operatively connected with the valve-ring by means of pivotal links l². The inner end of said rod L² is shown as supported within a closed sleeve c¹¹, provided in one end of the recess C³, and said valve-rod extends out through a suitable stuffing-box c¹² at the other end of said recess. The outer end of the valve-rod is connected by links n with the arm n' of an oscillating rock-shaft N, journaled to the side of the engine-frame, said rock-shaft being oscillated by means of a rigid arm n², with which the end of the eccentric-rod B³ is pivotally connected.

The flange K' of the valve-ring K rests upon the top surface of the diaphragm C' and affords an ample bearing-surface for said valve. In this instance also and as a further improvement I have provided an automatic cut-off valve in the form of a ring-valve O, surrounding the valve K and riding upon the flange K' thereof. Said valve may have its movement controlled by any desired form of governing device, but is in this instance operated from the eccentric p of a shaft-governor P of any usual or preferred type. The valve-ring O is provided with apertures o, corresponding to the apertures k of the ring K, and will operate in relation thereto in the manner common to all riding cut-off valves of the same general type. The connections shown in this instance for operating the riding cut-off valve O from the eccentric p are generally similar to the connections hereinbefore described between the valve-ring L

and eccentric B³ and comprise a reciprocatory valve-rod O', located in a horizontal recess D⁵, provided in the wall of the cylinder D at one side of the annular passage d' thereof, said rod being connected with the valve-ring O by pivoted links o'. The inner end of the valve-rod O' is supported within a closed sleeve d⁴, provided in one end of the recess D⁵, and said valve-rod extends out through a suitable stuffing-box d³ at the other end of said recess. The outer end of the valve-rod is connected by links q with a radial arm q' of a rock-shaft Q, journaled on the side of the cylinder C, said shaft being oscillated by a radial arm q², with which the end of the eccentric-rod p' is pivotally connected.

In Figs. 6 and 7 I have shown a means by which the valve-ring L may be adjusted and any wear occurring thereon provided for. In this construction the valve-ring is radially divided at one point and is provided in its vertical flange with a V-shaped slot l³. Within said slot a wedge-shaped block l⁴ is adapted to be moved vertically by a screw-bolt l⁵, the head l⁶ of which rests in a recess at the top of the ring. By turning the screw l⁵ the wedge l⁴ may be drawn farther into the slot l³ and will obviously force the adjacent ends of the ring apart and enlarge its circumference, so as to take up any wear which may have occurred on its outer face.

In Figs. 8 and 9 I have shown a convenient device for adjusting the riding cut-off valve O. In this construction the valve-ring is divided at one point, at which its ends are made to overlap, as shown in Fig. 9. Lugs o² are provided on each of the overlapping ends, and a bolt o³, provided with adjusting-nuts o⁴, serves to adjustably connect said lugs, and consequently the two ends of the ring. The circumference of the ring may thus be increased or diminished, as desired, to secure the proper adjustment or make up for any wear.

A valve mechanism somewhat modified from that just described and in many respects superior to it is illustrated in Figs. 10, 11, 12, and 13. In said figures, C³ designates the diaphragm which separates the high and low pressure cylinders. Said diaphragm is countersunk into the adjacent ends of both the cylinders and is clamped between the same by means of the bolts D⁴, which secure the two cylinders together. The high-pressure steam-ports c¹³ in this construction are located entirely within the body of the diaphragm C³ and extend in curved form beneath the lower edge of the wall of the high-pressure cylinder, so as to connect the interior of the latter with the annular live-steam passage d'.

K² designates the steam-valve, which is a plain cylindric ring resting upon the upper surface of the diaphragm as a seat and provided with port-apertures k', corresponding with the ports c¹³. Said valve K² is essentially a simple gridiron-valve of annular form and fits loosely within the lower part of the recess d', the contact of its under surface

with the top of the diaphragm C^3 being solely depended upon to afford a steam-tight joint. Consequently no adjusting device for the ring is required, and all danger of its binding by reason of the unequal expansion of the parts is avoided. The riding cut-off valve is omitted in this instance and the valve K^2 itself operated through the medium of an automatic cut-off governor by means of connections substantially similar to those before shown for operating the riding cut-off valve O . Obviously, however, the valve K^2 may be operated as a main valve and a separate riding cut-off valve employed in connection therewith, as before, if so desired.

The lower part of the diaphragm C^3 is formed by a separate plate C^4 , which rests at its outer edge upon an annular shoulder c^{14} of the wall of the cylinder C and at its middle portion is secured to the body C^3 of the diaphragm by means of the screw-bolts c^{10} . The upper face of the plate C^4 is recessed to receive the low-pressure admission-valve M' . Said valve consists of a single flat plate of annular form inserted between the upper and lower sections C^3 C^4 of the diaphragm and provided with port-apertures m , corresponding with the ports c^2 , which extend through the diaphragm, as before, to afford communication between the two cylinders. The upper ends of the ports c^2 are in this instance made coincident with the inner ends or the high-pressure steam-ports c^{13} .

The inner wall of the cylinder C , which separates its interior from the annular exhaust-passage c^3 , terminates in this instance at a point some distance below the plate C^4 , and the cylinder is bored out above this point to receive an annular exhaust-valve L^3 . Said valve L^3 consists of a plain cylindric ring, similar to the high-pressure valve K^2 , provided with exhaust-ports l^3 , opening outwardly and downwardly from the top and upper inner surface thereof and coöperating with corresponding port-openings c^{15} , leading into the exhaust-passage c^3 . To reduce the clearance the lower diaphragm-plate C^4 is provided at its outer edge with a depending annular flange c^{16} , the bottom of which engages the top of the valve L^3 , said flange being provided around its lower inner margin with a series of notches c^{17} , corresponding with the ports l^3 and affording a free entrance to the same.

As herein shown, the low-pressure inlet and exhaust valves are arranged to be operated simultaneously from the eccentric B^2 by means similar to that before described and including a valve-rod L^4 , reciprocating in a tangential recess c^3 of the cylinder C . This rod L^4 in this instance passes through a groove c^{18} , cut in the upper surface of the lower diaphragm-plate C^4 . The middle portion of the rod is made rectangular and is provided with an elongated slot l^7 . A thin flat lug l^8 projects into the slot at one end thereof and is provided with a vertical pin l^9 ,

the upper and lower ends of which pivotally engage the adjacent ends of two links L^5 . The latter are made sufficiently narrower than the slot to oscillate freely within the same, and their combined thickness is substantially equal to the thickness of the rod L^4 at this point, their pivoted ends being recessed on their adjacent faces to receive the lug l^8 between them. The free ends of the links L^5 are pivotally connected with the valves M' and L^3 by a screw bolt or pin l^{10} , which engages suitable apertures in each of said parts and passes freely through a curved slot c^{19} in the plate C^4 beneath the recess c^{18} . By this construction as the rod L^4 is reciprocated by its connection with the cam B^2 the valve-rings M' and L^3 will obviously be operated to open and close the low-pressure inlet and exhaust ports, the relative arrangement of the port-openings being such that the exhaust and steam ports are opened at alternate intervals. The end of the valve-rod L^4 , which is connected with the cam B^2 , extends out of the recess c^3 through a stuffing-box c^{12} , as before described. At its other end, however, the rod is herein shown as provided with a piston-head l^{11} , fitting within a short horizontal cylinder c^{20} , formed at the end of the recess c^3 opposite the stuffing-box c^{12} . Steam is admitted to the cylinder c^{20} through a pipe c^{21} in the head thereof and exerts a continuous pressure on the valve-rod, by reason of which the direction of pressure is maintained constant throughout all the bearings of the connections between the valve-rod and cam B^2 , thus preventing any lost motion or backlash in such bearings no matter how worn they may become.

One great advantage of the construction thus described is that the arrangement of the port-openings is such as to almost instantly drain off any water of condensation which may form in either cylinder. Water in the high-pressure cylinder will run naturally into the ports c^{13} and c^2 and through the latter into the low-pressure cylinder, while water formed or collected in the low-pressure cylinder will be swept up by the low-pressure piston to the top of the cylinder and will flow off the edges of the piston through the exhaust-port openings l^3 and c^{15} into the recess or exhaust-passage c^3 . To facilitate the flow of water from the top of the piston, the upper surface of the latter is herein shown as made of slightly conical form, so that any water collecting upon it runs naturally toward its outer margin, the under surface of the diaphragm-plate C^4 being correspondingly hollowed out, so as not to increase the necessary clearance-space.

As a further improvement for insuring the drainage of the low-pressure cylinder the latter is herein shown provided on its inner surface near the lower end of the cylinder with a plurality of vertical grooves c^{22} , the upper ends of which terminates slightly above the upper margin of the low-pressure piston

when in its lowermost position and which extend at their lower ends to the lower margin of the cylinder. Thus any water which may have collected on the piston during its downward stroke will be discharged through the grooves c^{22} into the cavity of the engine-frame above the diaphragm A' , from whence it may be drawn off through a drain-pipe c^{23} . No appreciable loss of efficiency can occur by reason of the grooves c^{22} , since the latter are uncovered by the piston only for an instant in each stroke, and that just at the beginning of the exhaust stroke, so that the discharge through them merely constitutes in effect an auxiliary exhaust. Obviously, also, said grooves may be employed in any similar type of single-acting vertical engine and are herein shown as applied to both the forms illustrated.

One great advantage of engines of the type under consideration, *i. e.*, in which two single-acting pistons are arranged to exert their actuating force on opposite sides of a common crank-pin through separate connections therewith, lies in the fact that the steam-pressure on each piston always tends to maintain the direction of pressure constant in the bearings of its connections with the crank-pin, so that no matter how long the engine may be run without adjustment or how great the wear in said bearings there can be no lost motion, and consequently no pounding or lack of smoothness in its operation. The inertia of each piston and its connected reciprocating parts, however, tends at certain points in the strokes to reverse the direction of thrust, such tendency being greatest toward the end of the return or exhaust stroke, when the steam has been expanded to a minimum of pressure, and being particularly liable to be present in high-speed engines and engines in which the reciprocating parts are made relatively very heavy. For example, in the engine herein set forth the inertia of the low-pressure piston E and its connected reciprocating parts tends during the last half of the upward stroke to maintain in said parts the maximum speed acquired at the middle of the stroke, and consequently to carry the cross-head pin F' away from its normal engagement with the lower half of the bearing-brass J^2 of the connecting-rod J and to carry the lower end of said connecting-rod away from its normal engagement with the upper surface of the crank-pin B' . In a similar manner the inertia of the piston H and connected reciprocating parts tends during the latter part of its downward stroke to cause a separation between the bearing-block J' and the lower side of cross-head pin F^3 . So, also, at the beginning of the active stroke of each piston if the steam-supply should be withheld by the action of the automatic governor or for any other reason a similar separation of the bearing pins and brasses would tend to be produced.

A principal feature of my present invention consists in the employment of pneumatic cushioning devices for overcoming the inertia of the reciprocating parts and maintaining the direction of pressure constant in all of the bearings in the connections between each of the pistons and the crank-pin independently of the usual steam-cushion effected by providing for the early closing of the exhaust parts. In this instance I employ both a vacuum and air-compression for the purpose stated, the vacuum being employed in connection with the high-pressure piston and the air-compression devices with the low-pressure piston, although, broadly considered, this arrangement might be reversed or both pistons supplied with the same type of cushioning device of either kind.

The independent cushioning of the low-pressure piston is effected by the cross-head F , which, as hereinbefore stated, is made in the form of the piston working within the cylinder G . The upper end of said cylinder is closed by a suitable head or diaphragm G' , secured in place by the stud-bolts g^2 , which are made of proper length for this purpose. A suitable stuffing-box G^2 provides for the passage of the piston-rod E' and prevents leakage about the same. Air is admitted to the cylinder when the piston is at the lowermost limit of its stroke through openings g^3 in the side walls of the cylinder near the lower end thereof and is compressed so as to overcome the inertia of the reciprocating parts and to maintain constant the direction of pressure in the bearings of the low-pressure connections. With such construction the work done in compressing the air on the upstroke of the piston will be substantially all given out on the downstroke thereof, since at that time the pressure of air on the cross-head would be added to the pressure of steam on the piston in imparting to the crank-shaft its actuating impulse. Consequently there will be no loss of power by reason of the employment of such auxiliary air-cylinder and piston.

The vacuum device for overcoming the inertia of the high-pressure piston and connections is herein shown as conveniently provided by making the upper part of the high-pressure cylinder air-tight, except for a relief-valve D^6 , which permits the escape of air from the cylinder, but prevents the admission of air thereto. With this construction the first few strokes of the piston H will obviously operate to expel all the air or vapor which may have accumulated in the upper part of the cylinder, and any leakage of air or vapor past the piston-packing occurring thereafter at any time will be expelled in a like manner, so that a practically perfect vacuum will be formed and maintained in the top of the cylinder as soon as the engine is started. The suction of the vacuum thus provided, or, in other words, the atmospheric pressure acting in consequence of the vacuum, will obviously

exert a continuous upward pressure on the high-pressure piston, tending to raise the same and to constantly maintain in the bearings of the connections with the crank-pin the same direction of pressure as that produced by the steam admitted beneath the piston.

Any predetermined degree of compression may obviously be had in the air-cylinder G by properly proportioning the size of the clearance-space at its upper end, and with the same degree of compression a greater or less cushion will be provided for the low-pressure cylinder, according as the air-cylinder is made of greater or less diameter. The proper proportions of the parts will ordinarily be provided for when the engine is designed, leaving any slight variations in the amount of suction to be had by varying the point of exhaust-closure in the ordinary manner.

The effective suction of the vacuum above the high-pressure piston upon the latter can obviously never exceed the pressure of the atmosphere, and the amount of cushion provided thereby will therefore be fixed by the size of said piston. Any regulation of the total cushion of the high-pressure piston must consequently consist in adjusting the exhaust-closure to add to the vacuum-pressure in greater or less degree, as desired.

An important feature of my invention is embraced in the construction described, wherein the cylinders are separated by a diaphragm having ports which directly connect the cylinders and which contains only the moving part of the valve necessary for opening and closing said ports in the diaphragm, in connection with inlet-ports for the high-pressure cylinder, separate from the diaphragm ports, in the end of said cylinder adjacent to the diaphragm and exhaust ports for the low-pressure cylinder, also made separate from the diaphragm-ports and similarly located at the end of the cylinder adjacent to the said diaphragm. This construction and arrangement of the diaphragm and adjacent cylinder ports has the important advantage of affording a direct passage for steam from the high to the low pressure cylinder practically without any clearance-space between the two cylinders, the clearance-space in the construction employed being only that arising from the necessary thickness of the diaphragm at either side of the valve therein. A general advantage afforded by such direct communication between the high and low pressure cylinders is that it, in effect, brings the two cylinders into open communication with each other when the valve in the diaphragm is open, by reason of the relatively large area of ports which may be provided in a diaphragm such as is shown, thus giving perfect freedom of movement to the steam as it expands from the high into the low cylinder and thereby enabling the engine to run with increased speed and economy, while affording an exceedingly cheap and simple construction in the engine as a whole.

My improved valve mechanism described is obviously of value in situations analogous to that in which it is herein placed independently of the other structural features set forth. Furthermore, my pneumatic cushioning devices may obviously be employed on engines of this and similar types without regard to the style of valve mechanism used thereon. As a complete machine, however, an engine provided with the principal or all of the improvements hereinbefore referred to possesses many advantages, and is accordingly herein claimed.

I claim as my invention—

1. In a compound engine the combination with single-acting high and low pressure cylinders arranged end to end and provided at their adjacent ends with steam and exhaust ports, and pistons within the cylinders, of piston-rods and connections affording separate connections between said pistons and a common crank-pin, an air-cylinder provided with a piston which is rigidly connected with the piston of one of the steam-cylinders, the other cylinder being provided with a vacuum-space for controlling the inertia of the piston of said cylinder, substantially as described.

2. In a compound engine having high and low pressure cylinders attached to each other end to end and pistons within the cylinders, of piston-rods and connections affording separate connection between each piston and a common crank-pin, said cylinders being provided with steam inlet and exhaust ports at their adjacent ends, an air-cylinder provided with a piston which is rigidly connected with the piston of the low-pressure cylinder, the said high-pressure cylinder being closed at its outer end to provide a vacuum-space for controlling the inertia of the piston in said cylinder and connected parts, substantially as described.

3. In a compound engine the combination with high and low pressure cylinders arranged end to end and separated by a partition or diaphragm provided with ports which afford direct communication between the cylinders, said cylinders being provided with inlet and exhaust ports at their adjacent ends, and pistons within the cylinders, of piston-rods and connections affording separate connection between the said pistons and a common crank-pin, an air-cylinder provided with a piston which is rigidly connected with the piston of one of the steam-cylinders, the other of said steam-cylinders being provided at its end remote from that at which the ports thereof are located with a vacuum-space for controlling the inertia of the piston of said cylinder, substantially as described.

4. The combination with high and low pressure steam-cylinders arranged end to end and separated by a partition or diaphragm having ports which afford direct communication between the cylinders, said cylinders being provided with inlet and exhaust ports at their adjacent ends, valves controlling said ports,

pistons in the cylinders, piston-rods and connections affording separate connection between each piston and a common crank-pin, and an air-cylinder provided with a piston which is attached to the piston-rod of the low-pressure cylinder and forms the cross-head thereof, the outer end of the said high-pressure cylinder being closed and provided with an outwardly-discharging air-valve, substantially as described.

5. In a compound engine, the combination with high and low pressure cylinders arranged end to end and separated by a partition or diaphragm provided with ports affording direct communication between the cylinders, the said high-pressure cylinder being provided with an annular steam-supply passage located exterior to its side wall and with steam-inlet ports leading from said supply-passage to the interior of the cylinder at points adjacent to the outer margin of said diaphragm and the low-pressure cylinder being similarly provided with an annular exhaust-passage exterior to its side wall, and with exhaust-ports leading from points adjacent to the outer margin of the diaphragm outwardly to said exhaust-passage, and valves controlling the said ports, substantially as described.

6. In a compound engine the combination with high and low pressure cylinders arranged end to end and separated by a partition or diaphragm containing ports which afford direct communication between the cylinders, the said high-pressure cylinder being provided with an annular steam-supply passage located exterior to its side wall and with steam-inlet ports leading from said supply-passage to the interior of the cylinder at points adjacent to the outer margin of said diaphragm and the low-pressure cylinder being similarly provided with an annular exhaust-passage exterior to its side wall, and with exhaust-ports leading from points adjacent to the outer margin of the diaphragm outwardly to said exhaust-passage, valves controlling said ports, pistons in the cylinders, and piston-rods and connections affording independent connection between said pistons and a common crank-pin, substantially as described.

7. In a compound engine the combination with high and low pressure cylinders placed end to end and separated from each other by a partition or diaphragm provided with ports which afford direct communication between the cylinders, the said high-pressure cylinder being provided with an annular steam-supply passage located exterior to its side wall and with steam-inlet ports leading from said supply-passage to the interior of the cylinder at points adjacent to the outer margin of said diaphragm and the low-pressure cylinder being similarly provided with an annular exhaust-passage exterior to its side wall and with exhaust-ports leading from points adjacent to the outer margin of the diaphragm

outwardly to said exhaust-passage, annular valves controlling said exhaust-ports, and a flat annular valve controlling the ports in said diaphragm, said valves being rigidly connected with each other and being moved simultaneously, substantially as described.

8. In a compound engine, the combination with high and low pressure cylinders arranged end to end and separated by a diaphragm or partition containing ports which afford direct communication between the cylinders, the said high-pressure cylinder being provided with an annular steam-supply passage located exterior to its side wall with steam-inlet ports leading from said supply-passage to the interior of the cylinder at points adjacent to the outer margin of said diaphragm, and the low-pressure cylinder being similarly provided with an annular exhaust-passage exterior to its side wall, and with exhaust-ports leading from points adjacent to the outer margin of the diaphragm outwardly to said exhaust-passage, valves for controlling the said diaphragm-ports and the exhaust-ports, and means embracing an automatic cut-off mechanism applied to operate the valves which control the inlet-ports of the high-pressure cylinder, substantially as described.

9. In a compound engine, the combination with high and low pressure cylinders arranged end to end and separated by a partition or diaphragm provided with ports which afford direct communication between the cylinders, the said high-pressure cylinder being provided with an annular steam-supply passage located exterior to its side wall and with steam-inlet ports leading from said supply-passage to the interior of the cylinder at points adjacent to the outer margin of said diaphragm, and the low-pressure cylinder being similarly provided with an annular exhaust-passage exterior to its side wall, and with exhaust-ports leading from points adjacent to the outer margin of the diaphragm outwardly to said exhaust-passage, annular valves controlling said ports, said diaphragm-valves and exhaust-valves being rigidly connected with each other, and means embracing an automatic cut-off mechanism for actuating the valve by which the inlet-ports of the high-pressure cylinder are controlled, substantially as described.

10. In a compound engine, the combination with high and low pressure cylinders arranged end to end and separated by a partition or diaphragm containing ports which afford direct communication between the cylinders, the said high-pressure cylinder being provided with an annular steam-supply passage located exterior to its side wall and with steam-inlet ports leading from said supply-passage to the interior of the cylinder at points adjacent to the outer margin of said diaphragm, and the low-pressure cylinder being similarly provided with an annular exhaust-passage exterior to its side wall, and with exhaust-ports leading from points adjacent to the outer

margin of the diaphragm outwardly to said exhaust-passage and a flat or plate valve applied to control said ports in the diaphragm, substantially as described.

11. In a compound engine, the combination with high and low pressure cylinders arranged end to end and separated by a partition or diaphragm containing ports which afford direct communication between the cylinders, the said high-pressure cylinder being provided with an annular steam-supply passage located exterior to its side wall and with steam-inlet ports leading from said supply-passage to the interior of the cylinder at points adjacent to the outer margins of said diaphragm, and the low-pressure cylinder being similarly provided with an annular exhaust-passage exterior to its side wall, and with exhaust-ports leading from points adjacent to the outer margin of the diaphragm outwardly to said exhaust-passage and annular valves controlling said ports, said annular valves controlling the diaphragm-ports and exhaust-ports being rigidly connected with each other so as to move together in the operation of the same, substantially as described.

12. In a compound engine, the combination with high and low pressure cylinders arranged end to end and separated from each other by a partition or diaphragm containing ports which afford direct communication between the cylinders, the said high-pressure cylinder being provided with an annular steam-supply passage located exterior to its side wall and with steam-inlet ports leading from said supply-passage to the interior of the cylinder at points adjacent to the outer margins of said diaphragm, and the low-pressure cylinder being similarly provided with an annular exhaust-passage exterior to its side wall, and with exhaust-ports leading from points adjacent to the outer margin of the diaphragm outwardly to said exhaust-passage, a circular valve-plate applied to control the ports of said diaphragm, a valve-ring applied to control the exhaust-ports of the low-pressure cylinder, and a valve-ring applied to control the steam-inlet ports of the high-pressure cylinder, said valve-rings of the diaphragm and exhaust ports being rigidly connected with each other whereby they are moved together in the operation of the engine, substantially as described.

13. The combination with high and low pressure cylinders arranged end to end and separated by a partition or diaphragm containing ports which afford direct communication between the cylinders, the said high-pressure cylinder being provided with an annular steam-supply passage located exterior to its side wall and with steam-inlet ports leading from said supply-passage to the interior of the cylinder at points adjacent to the outer margin of said diaphragm, and the low-pressure cylinder being similarly provided with an annular exhaust-passage exterior to its side wall, and with exhaust-ports leading

from points adjacent to the outer margin of the diaphragm outwardly to said exhaust-passage, valve-rings controlling said several sets of valve-ports, said valve-rings of the diaphragm and exhaust ports being rigidly connected with each other, and means for actuating the several valve-rings comprising a reciprocating rod which passes through the said exhaust-passage and is connected with the valve-ring therein, and means operated from the crank-shaft of the engine by which reciprocatory motion is given to said rod, substantially as described.

14. The combination with high and low pressure cylinders arranged end to end and separated by a diaphragm containing steam-ports, the high-pressure cylinder being provided with an annular steam-inlet passage and with annularly-arranged steam-ports at its end adjacent to the said diaphragm, and the low-pressure cylinder being provided with an annular exhaust-passage and with annularly-arranged exhaust-ports at its end adjacent to said diaphragm, of an annular valve-plate applied to control the ports in said diaphragm, a valve-ring applied to control the said exhaust-ports, said valve-ring being attached to the valve-plate of the diaphragm-ports by means of a stud extending through a slot in the said diaphragm, substantially as described.

15. The combination with two cylinders arranged end to end and provided one with steam inlet and the other with exhaust ports located at their adjacent ends, of a diaphragm separating the cylinders and provided with steam-ports, a valve-plate for controlling the ports in the diaphragm, and valve-rings for controlling the steam inlet and exhaust ports, said diaphragm being provided with two plates located one at each side of the valve-plate, whereby the latter is held in place under pressure from either direction, substantially as described.

16. The combination with two cylinders arranged end to end and provided one with steam inlet and the other with exhaust ports located at their adjacent ends, of a diaphragm separating the cylinders provided with steam-ports, and consisting of two plates, one of which is engaged at its edges with the adjacent ends of both cylinders, and the other of which is engaged at its edges with the end of one of the cylinders and is secured to the central part of the first plate, a circular valve-plate located between the said plates of the diaphragm, a valve-ring for controlling the said exhaust-ports, said valve plate and ring being rigidly connected together to move simultaneously, substantially as described.

17. In a single-acting compound engine, the combination with high and low pressure cylinders arranged end to end and separated by a partition or diaphragm containing ports which afford direct communication between the cylinders, said cylinders being respectively provided at their adjacent ends with

annular live-steam and exhaust passages located outside of the side walls of the cylinders, ports in the diaphragm leading from the live-steam passage beneath the walls of the high-pressure cylinder into the interior thereof at points adjacent to the margin of the diaphragm, an annular valve-seat and ring-valve within the live-steam passage for controlling the live-steam ports, ports leading from the low-pressure cylinder at points adjacent to the margin of the diaphragm into

the annular exhaust-passage thereof and operatively - connected valves controlling the low-pressure steam and exhaust ports, substantially as described.

In testimony that I claim the foregoing as my invention I affix my signature in presence of two witnesses.

MILAN C. BULLOCK.

Witnesses:

HENRY W. CARTER,
ALBERT H. GRAVES.