

July 21, 1931.

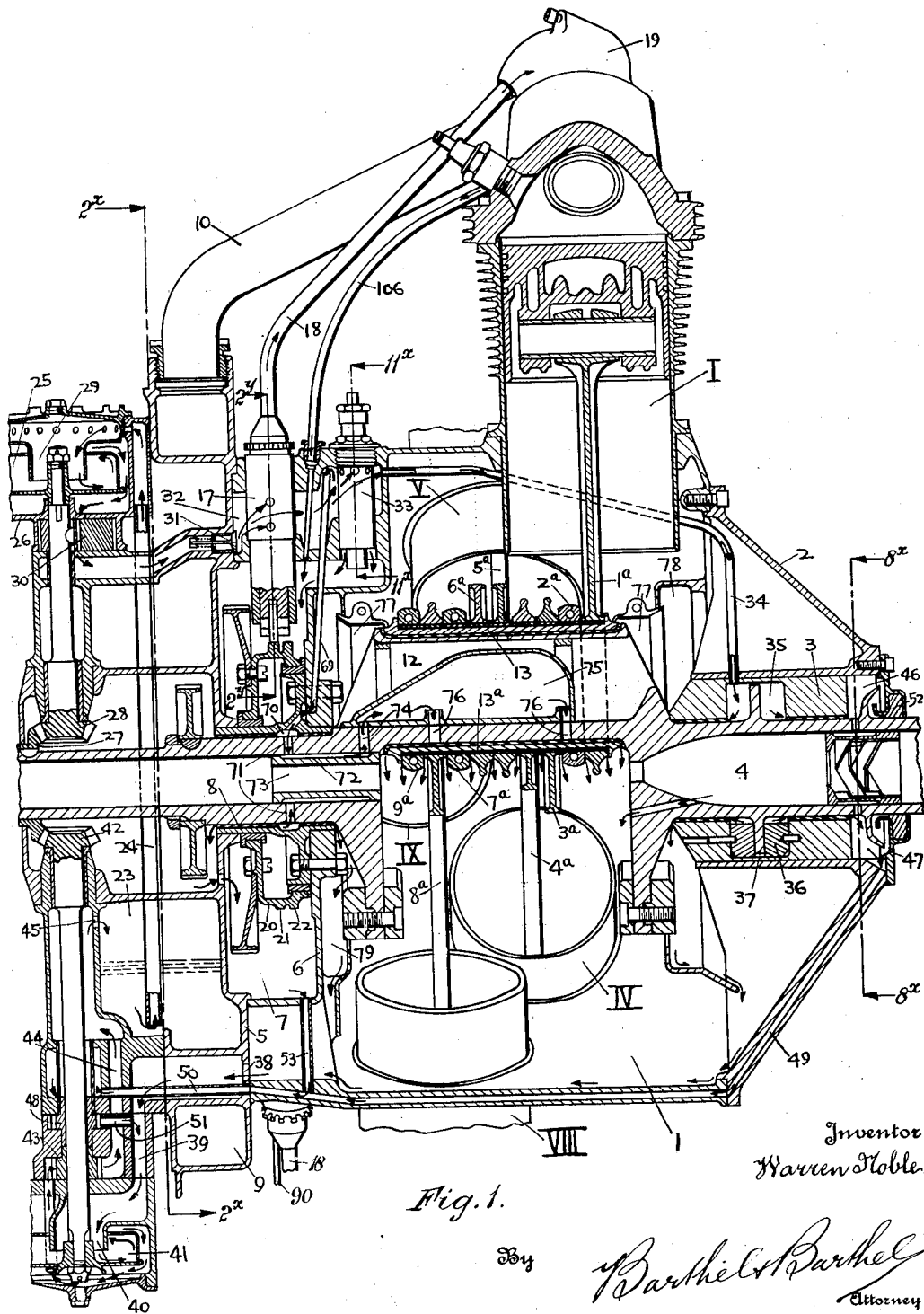
W. NOBLE

1,815,445

INTERNAL COMBUSTION ENGINE

Filed Nov. 17, 1927

7 Sheets-Sheet 1



July 21, 1931.

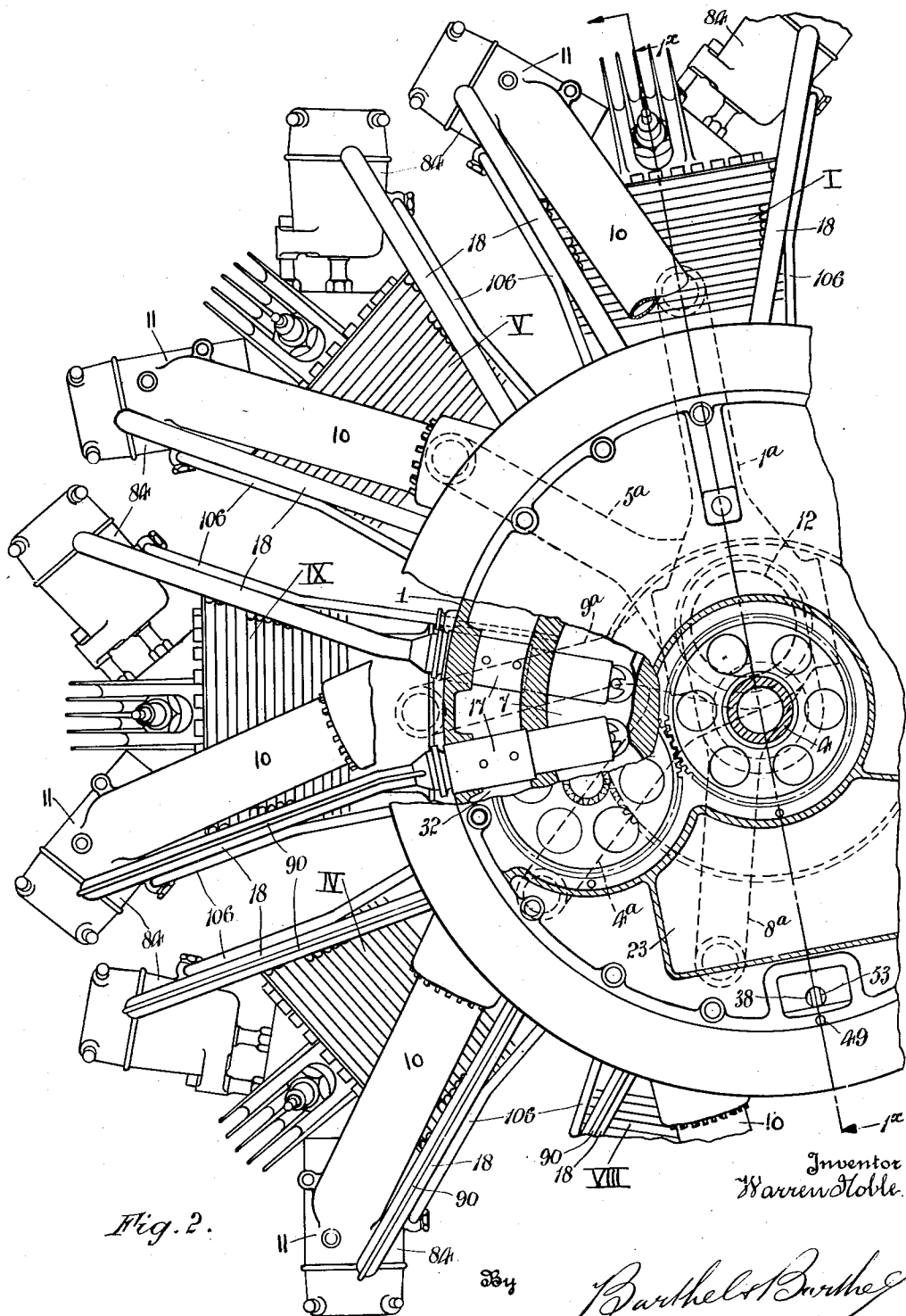
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INTERNAL COMBUSTION ENGINE

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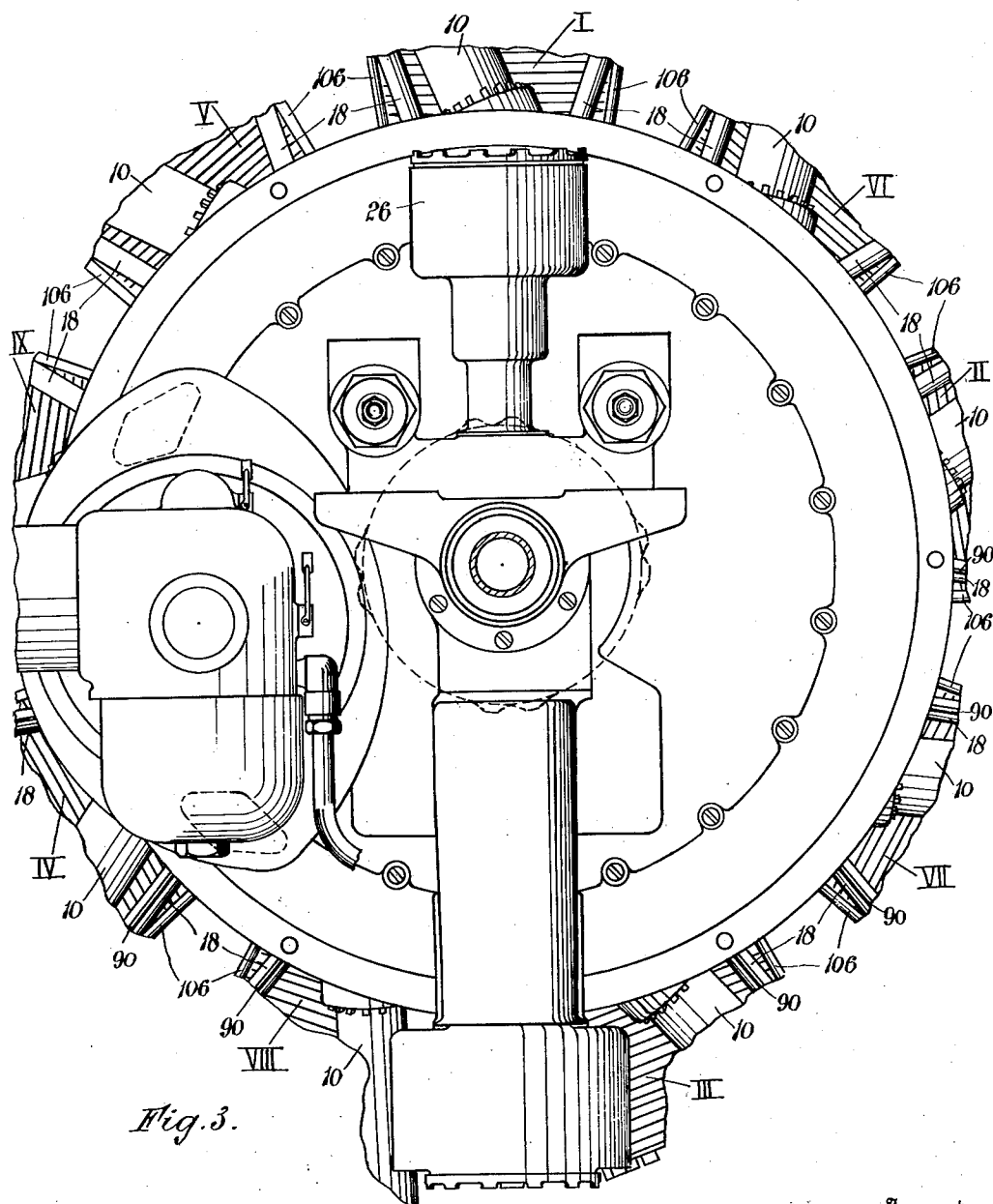


Fig. 3.

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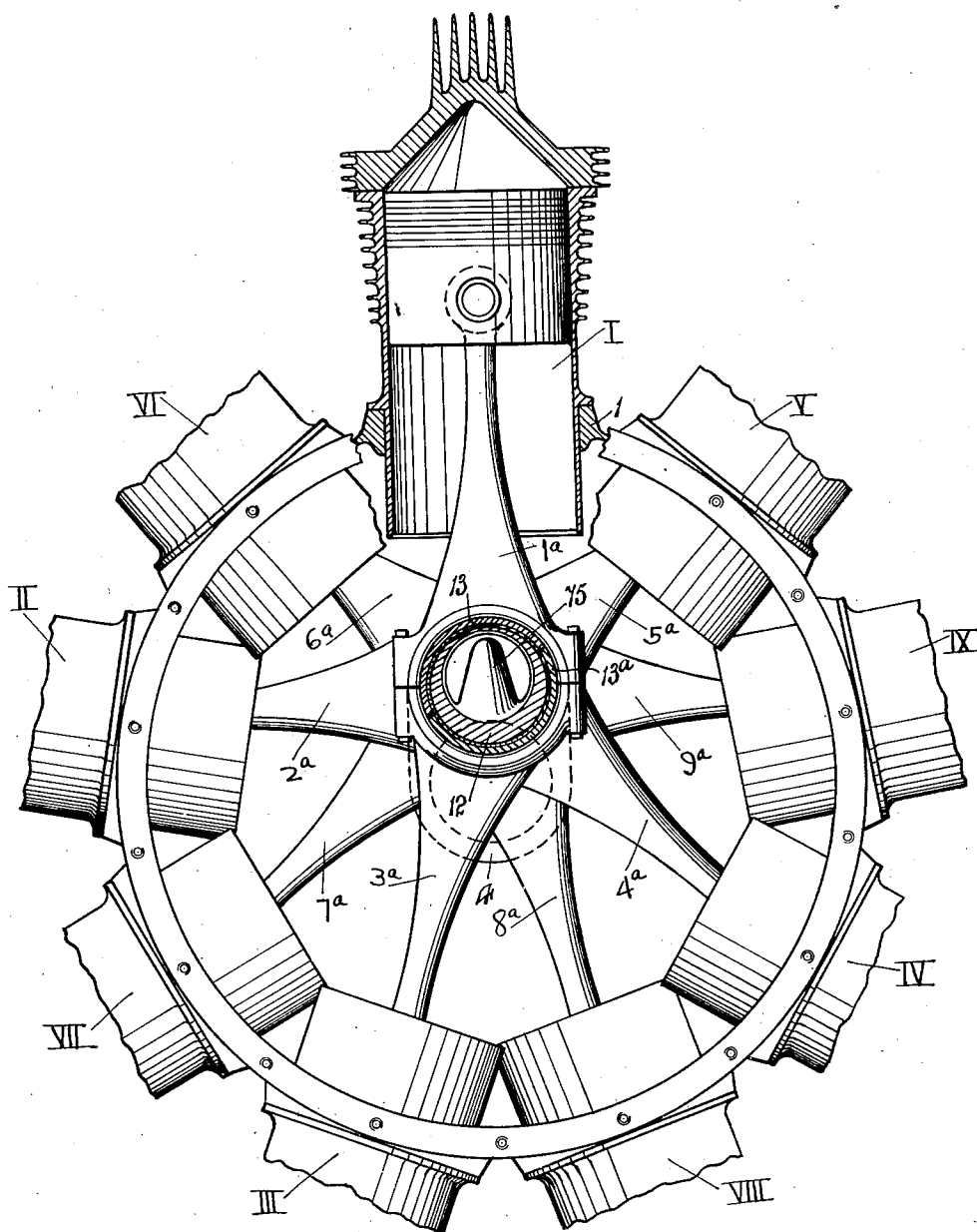


Fig. 4.

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INTERNAL COMBUSTION ENGINE

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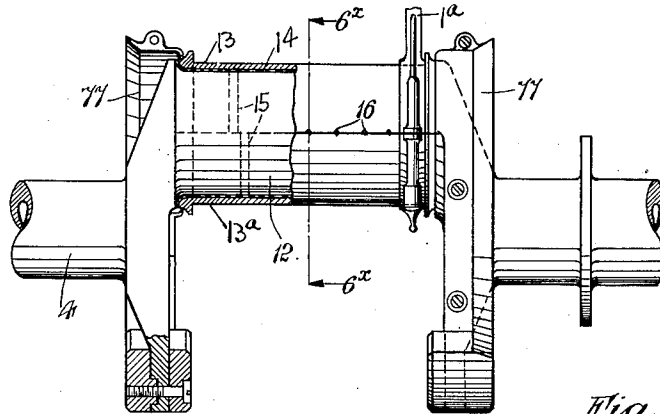


Fig. 5.

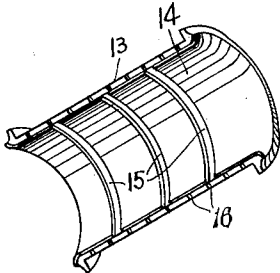


Fig. 7.

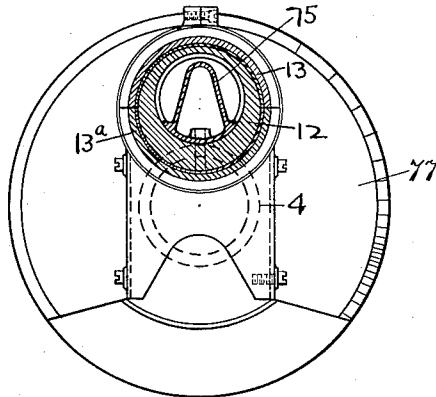


Fig. 6.

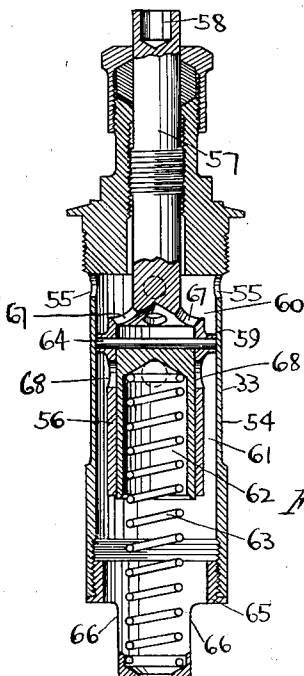


Fig. 11.

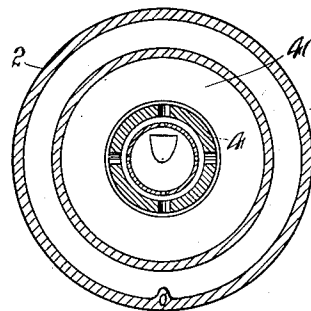


Fig. 8.

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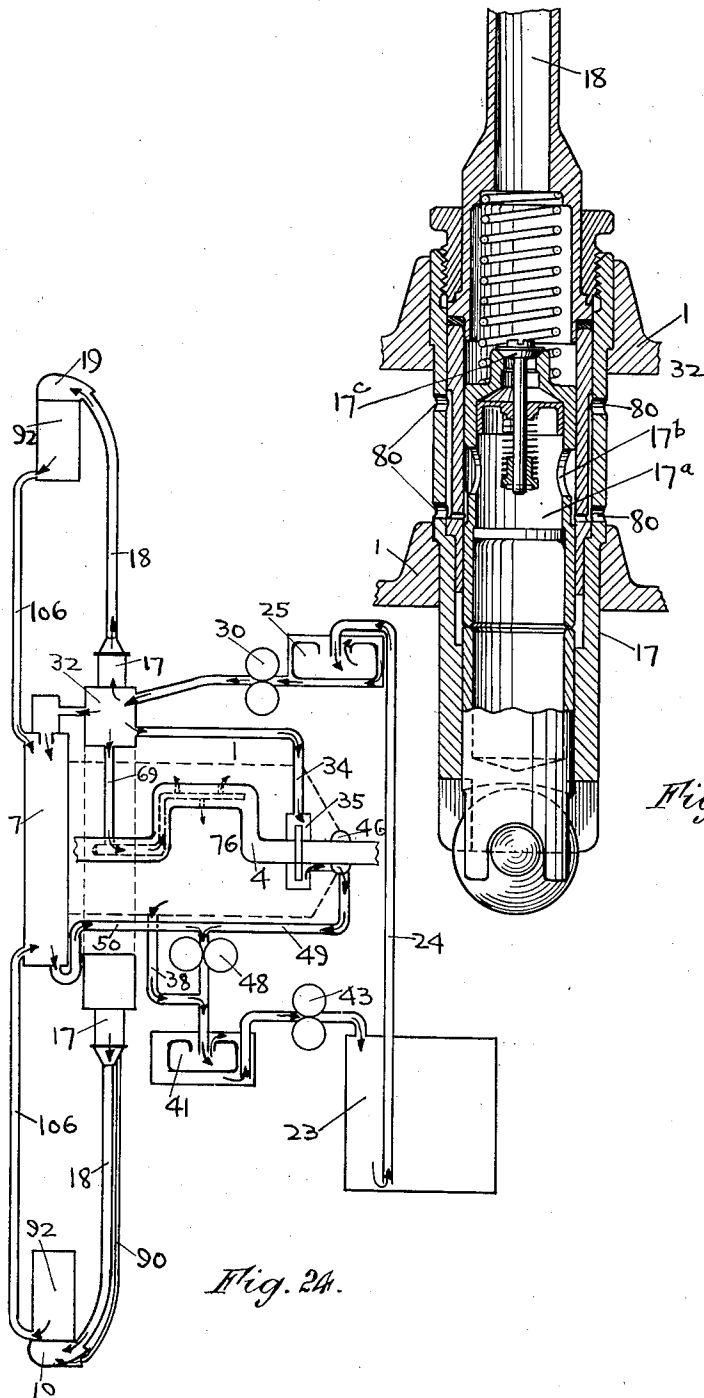


Fig. 24.

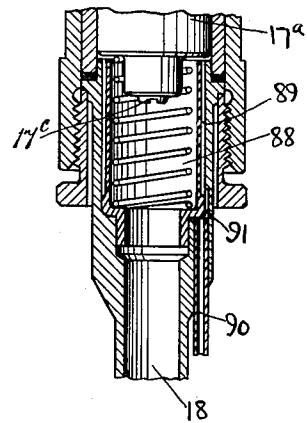


Fig. 10.

Fig. 9.

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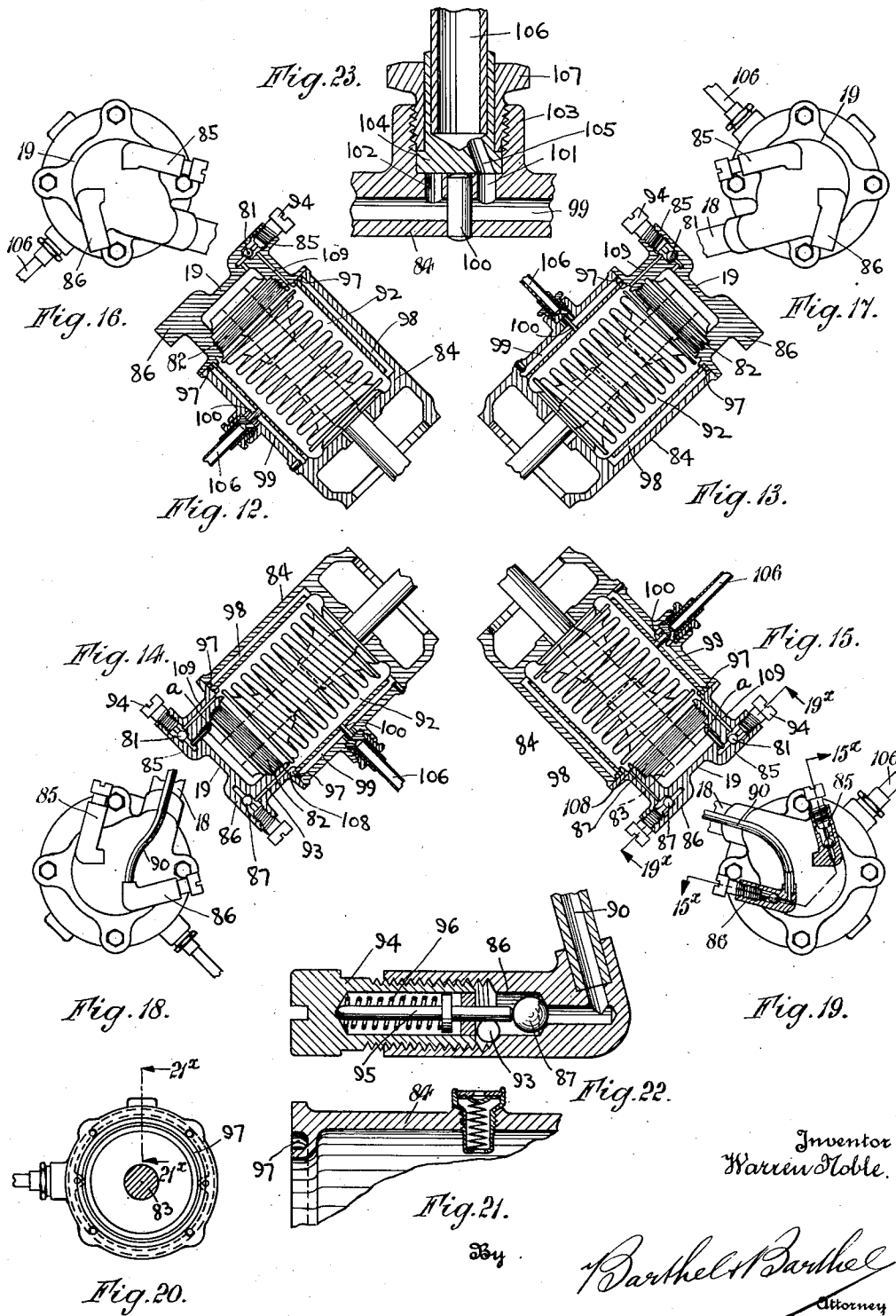
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INTERNAL COMBUSTION ENGINE

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INTERNAL COMBUSTION ENGINE

Application filed November 17, 1927. Serial No. 233,957.

This invention relates to internal combustion engines, more particularly of the fixed radial type wherein a number of cylinders are mounted in circular series about a crankshaft common to all cylinders, a construction which has hitherto in this art presented many problems which have been generally conceded by those conversant with the art and engaged in actual manufacture of radial engines to be difficult or practically impossible to overcome.

One of the most outstanding of these problems is that of connecting rod arrangement brought about by the desirability of using a short crankshaft with a single throw, and it has been and is the accepted practice to use what is known as an articulated rod system wherein a "master" connecting rod extends from the crankpin to the piston of one of the cylinders, and the connecting rods (known as "articulated rods") of the other cylinders are attached by means of wrist pins to the big end of the master rod. Apart from objections to the form of the master rod involved and the nature of the connections between the master rod and the articulated rods of the type referred to, numerous disadvantages accrue from such an arrangement among which it is thought well to point out the following:—

It is obvious that the centers of the wrist pins by which the articulated rods are connected to the master rod are not concentric with the center of the crankpin and, therefore, travel in individual orbits of their own, and, as a matter of fact, these orbits are of a substantially elliptic form with their major axes lying in different planes relative to each other. The said orbits, moreover, do not all agree in their general dimensions and their major axes also lie at angles to the axes of their respective cylinders, which angles also vary with different cylinders. Changing angularity of the master rod with relation to the articulated rods produces a variation in length between the wrist pins of the pistons of the different cylinders and the center of the crankpin.

The result is a consequent variation in the characteristics of operation of different cylinders in the engine and lack of properly synchronized functioning of many elements and operations entering into the working of the several cylinders, which is, in turn, reflected in a lack of smoothness and of reliability of operation of the engine as a whole.

In explanation certain marked instances are cited:—

(a) With the articulated rod system the piston stroke varies in extent and the relationship of the crankshaft and all cylinders except those symmetrical to one another on each side of the master rod and even in such symmetrical cylinders the timing of various parts of the stroke cycle varies due to reverse disposition of the major axes of the orbits of the outer ends of their articulated rods relative to the cylinders. (b) Unless specially provided for, ignition occurs at a different stage of piston operation in different cylinders. (c) The elliptical path of the articulated rods results in increased piston throws within the cylinders. (d) Valve timing difficulties are encountered due to lack of synchronization of piston strokes relative to crankshaft operation, and, due to difference in stroke length and so forth, it is impossible to have a correct relation between a counterbalance of the crankshaft and all of the cylinders of the engine. (e) It will be readily seen that differences in compression ratio on different cylinders occur unless each cylinder is specially designed for its position on the engine.

Such objectionable features as those referred to naturally interfere with harmonic operation of an engine, but, nevertheless, are standard in fixed radial engine practice at the present time; and it is an important object of this invention to overcome these disadvantages in a simple and highly satisfactory manner by attaching the connecting rods of a circular series of cylinders of a radial engine directly to the crankpin of its crankshaft, thereby avoiding recourse to the use of a master rod, and to accomplish this by offsetting the cylinders along the axis of the engine to the extent of the relative disposition of the connecting rods along the crankpin.

The invention also has for its object to provide for direct connecting rod attachment to a crankpin in a radial engine involving a combination including the connecting rods of a circular series of cylinders, the said rods being arranged in close formation along the crankpin and the cylinders staggered around the crankcase of the engine to agree with the limit of their respective connecting rods together with a valve gear arrangement wherein circular series of actuators are arranged in substantially common planes and operatively connected by means of relative varying extent and form with their respective valves, and more particularly the invention contemplates the utilizing of hydraulic fluid conduits of varying lengths or varying form as the means of operatively connecting the actuators with the valves.

A further object is to provide, in the improved arrangement hereinbefore referred to, intake pipes of various lengths leading to the staggered cylinders from a common ring manifold whereby the receiving ends of the said intake pipes are disposed in a common plane irrespective of the staggered nature of the cylinders.

From the foregoing it will be apparent that an important object of the invention is to avoid the mechanical complications which would be imposed on the staggered cylinder arrangement were mechanical valve operation resorted to involving push rods, rocker arms and so forth, requiring individually designed valve actuating mechanisms for each cylinder or an undue multiplicity of cams to compensate for the staggering of the cylinders which would add unnecessary length to the engine and result in such complications as have been largely responsible for the generally accepted belief among those conversant with the radial engine art that the individual connecting rod arrangement such as proposed by this invention is not practically feasible.

A further object is to provide a lubricating system in an engine wherein vacuum chambers are arranged at opposite ends of the engine crankcase to which chambers lubricating oil is drawn by sub-atmospheric pressure thereby preventing oil leaking from the engine or into the crankcase of the engine in an undue manner, the said vacuum chambers being connected with various parts of the engine to which oil is supplied for the purpose of inducing or assisting in the promotion of flow about said parts or the conveying of oil therefrom to a desired point of disposal.

The oil circulation system includes several novel features of application of different local conditions throughout the engine, the nature of which will be hereinafter explained in describing each certain operation of the illustrated example, and the invention further

aims to combine the oil circulating system with a hydraulic valve actuating system in such manner that replenishment of oil in the valve actuating system may be effected from the lubricating system and the draining of oil which may leak from the valve actuating system or otherwise bled therefrom may be promoted or assisted by a sub-atmospheric pressure in the vacuum chambers aforesaid, such draining being preferably utilized for lubricating purposes. It is proposed to house mechanisms to be lubricated in the aforesaid vacuum chambers whereby they will be adequately supplied with oil entering the said chambers and isolated from parts of the engine to which it is desirable that oil should not escape from said lubricated mechanisms.

It is a further and important object of the invention to provide for the effective cleaning of oil both before being supplied to the mechanisms requiring lubrication and to the valve gears and after leaving the said mechanisms and valve gears so that pressure oil supplied to the engine will be cleaned of any undesirable matter, and oil which has passed through the engine will also be cleaned of any undesirable matter which may have accumulated during such passage. In this connection, the invention further contemplates the use of centrifuges as means of cleaning the oil and also as a means of effecting elimination of air from the oil whereby the entraining of air with the oil to the valve gears is prevented to a marked degree.

Still further objects or advantages subsidiary or incidental to the aforesaid objects, or resulting from the construction or operation of the invention as it may be carried into effect, will become apparent as the said invention is hereinafter further disclosed.

In carrying the invention into effect, I may adopt the novel construction and arrangement of parts hereinafter described, by way of example, having reference to the accompanying drawings, wherein:—

Figure 1 is a somewhat fragmentary sectional elevation of a radial engine embodying novel features of the said invention, the section being taken on a plane indicated by the line 1*—1* in Figure 2;

Figure 2 is a fragmentary transverse section of the same taken on the line 2*—2*, Figure 1, with the crankcase partly broken away and in section taken on the line 2*—2*, Figure 1, to illustrate the valve actuator mounting;

Figure 3 is a fragmentary rear elevation of the engine;

Figure 4 is a fragmentary front elevation of the engine with the front crankcase cover removed, the said figure being partly in section on a plane passing through the upper cylinder;

Figure 5 is a fragmentary elevation part-

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ly in section of the engine crankshaft illustrating a form of bearing for the connecting rods;

Figure 6 is a transverse section of the same taken on the line 6*-6* of Figure 5;

Figure 7 is a detail perspective view of one of the crankpin bearing shells removed;

Figure 8 is a detail sectional view taken on the line 8*-8* of Figure 1;

Figure 9 is a detail sectional view of one of the upper valve actuators;

Figure 10 is a fragmentary sectional view of the lower valve actuators showing the modification of form of the actuator, Figure 9, to meet the inverted condition;

Figure 11 is a detail sectional view taken on the line 11*-11* of Figure 1, illustrating a relief valve incorporated in the oil circulation system;

Figures 12, 13, 14 and 15 are sectional detail views illustrating four typical arrangements of valve casings and valve actuator heads designed to meet conditions obtaining in different angular disposition of the engine valves relative to their actuating means and point of drainage. The actuator heads of Figures 12, 13, 14 and 15 are shown in section taken on planes passing through bleed valve bosses as indicated by the line 15*-15* of Figure 19;

Figures 16, 17, 18 and 19 are plan views of the actuator heads shown in Figures 12, 13, 14 and 15, respectively, Figure 19 being shown partly in section on a plane indicated by the line 19*-19* of Figure 15;

Figure 20 is a typical end view of any one of the valve casings illustrated in Figures 12, 13, 14 and 15 of the actuator head and internal parts removed;

Figure 21 is a fragmentary detail sectional view taken on the line 21*-21* of Figure 20;

Figure 22 is an enlarged detail sectional view through one of the bleed valve bosses of an actuator head;

Figure 23 is an enlarged detail sectional view illustrating the upper casing of an oil drainage selector plug applied to a valve casing; and

Figure 24 is a diagrammatic view illustrating the general oil circulation system of the engine.

Similar characters of reference indicate similar parts in the several figures of the drawings.

A nine cylinder static radial engine is illustrated wherein the cylinders numbered I, II, III, IV, V, VI, VII, VIII, IX, in their firing order are shown extending from a crankcase 1, which crankcase is provided with a front cover 2 housing a main bearing 3 in which the crankshaft 4 is journaled. 5 is a rear crankcase cover which co-operates with a rear wall 6 of the crankcase in providing a cam chamber 7 in which is located a rear bearing 8 which is mounted in a man-

ner more particularly described in my co-pending application, Serial Number 377,667 filed the tenth day of July, 1929.

This rear cover has a hollow peripheral portion forming an annular manifold chamber 9 from which inlet pipes 10 extend to inlet valve casings 11 of the several cylinders.

The crankshaft is of single throw, the crankpin 12 of which is of a sufficient length to accommodate connecting rods 1^a, 2^a, 3^a, 4^a, 5^a, 6^a, 7^a, 8^a and 9^a of the pistons of the cylinders I, II, III, IV, V, VI, VII, VIII, IX, respectively, and it will be seen that contrary to ordinary radial engine practice all of these connecting rods are in different planes and transverse to the crankpin and that the cylinders are in correspondingly different planes transverse of the axis of the engine so that they are offset or staggered rearwardly of the engine in the order of their firing as will be readily seen by comparing the radial positions of the cylinders with the longitudinal positions of their connecting rods. In other words, the cylinders are not progressively offset from the front of the engine in their circular order, which would add some length to the engine due to the necessity of avoiding skirt or cylinder interference, but the adjacent cylinders are relatively offset to an extent which is a multiple of the spacing of the planes involved, which admits of a very compact arrangement of the cylinders and a close arrangement of the connecting rods and the crankpin 12. Actual practice has determined that wide connecting rod bearings are not essential and it will be seen that the connecting rods are comparatively thin and the bearings thereof quite short so that they are compactly arranged along the crankpin.

As a means of reducing wear on the connecting rod bearings and affording at the same time substantial bearing on the crankpin, it is proposed to provide the crankpin with a sleeve bearing or shell in two halves 13 and 13^a of suitable material, such as steel faced with bronze or babbitt 14 and held in place by the bearing ends of the connecting rods. This admits of the crankpin rotating within the said sleeve bearing and the connecting rod simply oscillating on the said sleeve bearing so that wear on the bearing of the connecting rods is thereby reduced to a minimum.

Each half of the said sleeve is provided with inner oil connecting grooves 15, the grooves of half of the sleeve being offset from one another, as indicated in Figure 5, to prevent direct communication therebetween so that too free flow of oil between the grooves in the halves of the sleeve may be avoided and tendency created to cause lubricant to find its way between the meeting edges of the halves of the sleeves to the connecting rod bearings.

Additional lubricating ducts 16 may be

provided, if so desired, in the sleeve to convey lubricant to the connecting rod bearings. A very satisfactory method of conveying lubricant to this sleeve and incidentally to the connecting rod bearing will be more fully described hereinafter.

The cylinders are provided with hydraulically operated valves, such as of the type involving principles set forth in my co-pending application, Serial Number 180,119, filed April 1, 1927, wherein generally speaking the valve actuator 17 is hydraulically connected by a fluid operating line or pipe 18 with an actuator head 19 to the interior of which a valve stem is exposed for operation by a cam actuated plunger in said actuator 17 through the medium of a column of hydraulic fluid in the operating line 18. Further details of the specific arrangement illustrated in this example will also be more particularly described hereinafter.

Within the chamber 7 of the engine is a cam member 20 which includes two cam clusters 21 and 22 lying in closely related planes, the first cam cluster 21 actuating the plungers of the actuators 17 which operate the exhaust valves of the engine and the cluster 22 actuating the plungers of the actuators which operates the inlet valves so that all of the inlet valve actuators are in a common plane transverse of the crankshaft as are all of the exhaust valve actuators, the said actuators being arranged in circular series about the cam member.

The variation in the offset of the different cylinders along the crankcase of the engine is simply accommodated by variation in the length and form of the actuator pipes 18, no mechanical change in the actuators or the actuator heads being required to compensate for this variation. Similarly the intake pipes 10 are varied in length to accommodate variations in distance of the cylinders from the annular manifold 9.

It will thus be seen that a combination of hydraulic valve actuating means, with their ability to disregard planes of interacting mechanical movements due to the flexibility possible in arrangement and length of the pipes 18, together with the staggered nature of the cylinders affords a simple means of rendering possible the use of individual connecting rods for each of the cylinders directly connected to a singular crankpin of the engine crank and the avoidance of the use of articulated rods such as is necessary where the cylinders are all in one plane or a number of cylinders are in a common plane, or the mechanical complications which would be involved in the application of mechanical valve gear such as is commonly employed to staggered cylinders.

The engine is provided with an oil circulation system which involves a number of novel features as will become apparent. The

rear cover is shown, for purposes of illustration, as having formed therein an oil chamber or tank 23 from which the pipe 24 leads upwardly to an oil cleaning centrifuge 25 arranged within the casing 26 and operated by the crankshaft through gears 27 and 28; this centrifuge having an inlet funnel 29 through which the oil enters the centrifuge and about which the oil leaves the said centrifuge as clearly indicated by the arrows in Figure 1, the flow of oil through the centrifuge being induced by a gear pump 30 which pumps the oil from the centrifuge through a non-return valve 31 to a pressure oil manifold 32 through which the actuators 17 pass. This provides pressure oil for admission to said actuators as will be further explained, and a relief valve 33 releases excess oil from the manifold when required pressure within the said manifold 32 is attained, oil so released when passing through the relief valve flowing into the chamber 7 hereinbefore referred to. A pipe 34 also conducts oil from the manifold 32 to a chamber 35 in the main bearing 3, which chamber accommodates a thrust bearing 36 engaging a flange 37 on the crankshaft. This provides for lubrication of the said thrust bearing and also lubrication for the main bearing, excess oil passing in either direction along the said main bearing and being spilled at the rear end into the crankcase as indicated by the arrows from whence it escapes through an opening 38 in the rear cover by way of a passage 39 to a funnel 40 of a second centrifuge 41 operated from the crankshaft through the gear 42. Flow through the second centrifuge, as indicated by the arrows, is induced by a second pump 43 which pumps oil from the said second centrifuge 41 through a passage 44 and opening 45 back to the oil tank 23.

Oil passing forwardly through the said bearing 3 enters a chamber 46 provided between the end of the said bearing and an end plate 47 carried by the cover plate 2, this being a vacuum chamber subject to the influence of a vacuum pump 48 which draws oil from the said chamber 47 through a passage 49 formed in the lower part of the crankcase and the tube 50 through the rear cover discharging oil through the outlet 51 into the second centrifuge 41 by way of the passage 39 and funnel 40; this oil being thence returned to the tank 23 as previously explained.

Provision of the vacuum chamber 46 about the crankshaft at the front end of the bearing 3 effectually prevents oil flowing along the crankshaft beyond this chamber and admits a simple seal or gasket 52 being used in the cover plate 47.

It will be seen that the cam chamber 7 is also a vacuum chamber being connected by the pipe 53 with the passage 49 and there-

fore subject to the influence of the vacuum pump 48 so that the crankshaft passes through vacuum chambers at both ends of the crankcase, which vacuum chambers isolate the engine mechanism so far as lubrication is concerned against movement of lubricant outwardly along the crankshaft from the crankcase.

The relief valve generally numbered 33 is shown in Figure 11 as comprising a casing 54 perforated at 55 to provide communication with the pressure oil manifold 32 of the engine and accommodating a cylinder 56 having a stem 57 threaded into the upper part of the said casing to provide for longitudinal distance of the said cylinder within the casing, which adjustment is effected by rotating the said stem 57 which is provided with a wrench socket 58 to facilitate said rotation. The said cylinder has formed thereon an annular rib 59 which slidably fits the casing 54 and partitions the stem into upper and lower chambers 60 and 61, respectively.

The cylinder 56 accommodates a plunger 62 pressed upwardly therewithin by a spring 63 against a stop pin 64, the lower end of the said spring seating in a cap 65 attached to the lower end of the casing 54, which cap is cut away to provide outlet openings 66.

The cylinder 56 is ported above the partition 59 at 67 and below the said partition at 68 so that when pressure in the upper chamber 60 of the relief valve overcomes the resistance of the spring 63 the plunger is depressed within the cylinder 56 to disclose the opening 68, whereupon fluid so relieved may pass to the lower chamber 61 of the relief valve and escape through the outlet openings 66. Longitudinal adjustment of the cylinder in the manner already explained determines the adjustment of the pressure of the spring 63 and consequently determines the pressure on the pressure oil manifold of the engine.

Relief oil escaping from the relief valve through the orifices 66 passes into the vacuum chamber 7, as indicated by arrows in Figure 1, affording or assisting in cam lubrication, or lubrication of such other members as may be housed in the said vacuum chamber 7, which oil eventually escapes by way of the pipe 33 and the connecting passages to the second centrifuge 41.

Lubrication of the rear bearing 8 of the engine is effected through a pipe 69 passing from the pressure oil chamber 32 of the engine to an oil groove 70 in the said bearing, oil leaking through the forward end of the bearing passing into the crankcase thence through the orifices 38 into the rear cover to the centrifuge 41, and oil seeping through the rear end of the said bearing 8 passes into the vacuum chamber 7 and from thence by way of the pipe 50 to the said centrifuge 41.

The crankshaft within the said rear bearing is provided with radial orifices 71 communicating with an annular chamber 72 formed around a bushing 73 inserted in the crankshaft. This chamber extends forwardly to a point in advance of the rear bearing 8, where the crankshaft is again ported at 74 to permit passage of lubricant from the said chamber 72 into an oil collector 72 in the form of a chambered shell housed within the crankpin 12, which is hollow. This oil collector prevents the escape of oil through the ends of the crankpin and directs it through crankpin ports 76 to the sleeve bearing 13^a from which it eventually finds its way to a connecting rod bearing and eventually drains into the crankcase and from there back to the centrifuge 41.

Oil escaping from the ends of the sleeve bearing 13 and 13^a is caught by fingers 77 which throw it into receptive members 78 and 79 from which it drains into the lower part of the crankcase for eventual disposal through the orifices 38 to the centrifuge 41.

The vacuum induced in chamber 7 by the action of the vacuum pump 48 is also effective in promoting drainage from points which would ordinarily form oil traps and especially so in connection with hydraulic valve gears. These valve gears include in their actuator 17 actuating plungers 17^a suitably ported and valved at 17^b and 17^c to co-operate with ports 80 in the actuator in providing for replenishment of oil in the valve gear when required in a manner more particularly explained in the said co-pending application, Serial Number 180,119 hereinbefore referred to, so that this feature of the valve gear will not be further dwelt on in detail.

The actuator heads 19 are also provided with air bleed valves 81 for bleeding air from points of air accumulation in the said actuator heads as referred to in the said application Serial Number 180,119 with provision for the utilizing of vacuum induced by the vacuum pump 48 as a means of effecting, influencing or assisting the bleeding of air from such points of air accumulation according to conditions of operation. In this connection, attention is directed to Figures 9 and 10 and Figures 12 to 23 of the drawings.

Points of air accumulation and also points of drainage oil accumulation vary with different dispositions of the parts of the valve gears as will be readily understood when it is recollected that those valve gears which are situated above a horizontal plane passing through the axis of the engine have their actuator heads 19 higher than the actuators 17, whereas the valve gears below such planes have their valve heads lower than their actuators. In other words, the lower cylinders of the engine have an inverted form of valve gear in which a point of air accumulation oc-

curs in the actuators 17 adjacent the plungers 50 thereof as distinguished from a point of air accumulation in the actuator heads remote from the actuators of the valve gears of the upper cylinders.

5 This does not necessarily preclude the possibility of air accumulation at more than one point in each valve gear, and to illustrate such a condition the Figures 14 and 15 show
10 inverted actuator heads in which there is a point of air accumulation *a* in the heads in spite of their inverted condition adjacent the cylinder 82 in which the valve stem 83 reciprocates under the influence which the
15 plunger 17^a exerts thereon through the medium of hydraulic fluid in the valve gear.

Each actuator head 19 is secured to the outer end of a spring casing 84 and these spring casings are preferably identical to the extent of affording interchangeability so far
20 as their application to different cylinders is concerned as are also the actuator heads 19, changes being made in the application of several parts or connections thereto to meet special conditions resulting from the particular
25 location and position in which the actuator heads and spring casings occur on the engine.

Each of the actuator heads is provided with two bosses 85 and 86, the first of which
30 is machined on both the upper and lower actuator heads for the accommodation of the air bleed valves 81 hereinbefore referred to, whereas the bosses 86 are only machined in the case of lower actuator heads, as shown in
35 Figures 14 and 15, to accommodate check valves 87. These bosses 86 might well be eliminated from the upper actuator heads as illustrated in Figures 12 and 13, except that they provide for interchangeability of the head
40 blanks in production.

An examination of Figures 9 and 10 will reveal that the inner end of the pipe 18 of the inverted type of actuator illustrated in
45 Figure 10 is characterized by its including an internal thimble or liner 88, the cylindrical wall of which is slightly spaced from the wall of the inner end of the said pipe 18 providing a restricted annular passage 89 which
50 opens from the extremity of the said pipe 18, which closely approaches the plunger 17^a of the actuator when said plunger is at the end of its stroke in direction of the pipe 18, and as in the inverted type of actuator there is a point of air accumulation at the head of the
55 plunger the said restricted annular passage 89 thus opens from said point of air accumulation when the plunger approaches the end of the said pipe 18.

An air bleed pipe 90 communicates through
60 a port 91 in the inner end of the pipe 18 with the annular passage 89 and this pipe extends to the boss 86 of the actuator head of the lower valve gear and has communication with the inner chamber 92 of its respective spring
65 casing through a passage 93, such communi-

cation being controlled by the valve 87. These features are not found in the upper valve gears in which the pipes 18, as shown in Figure 9, are not provided with a bleed pipe such as 90 or its associated passages as the point of air accumulation is not located in the actuators 17 in the case of such upper valve gears.

A suitable form of bleed valve regulator is shown in detail in Figure 22 wherein the boss 86 is shown as receiving a threaded plug 94 in which is housed a spring pressed rod or stop member 95 adapted, when the said plug is screwed into the boss to its fullest extent, to engage both the ball valve 87 and the inner end wall of the bore of the plug so as to positively close the said ball valve. By slightly retracting the plug, the inner end wall of its bore will be freed from the end of the said rod 95 so that it will be permitted to move inwardly of the plug against the resistance of its spring 96 when pressure on the ball valve warrants such movement. Incidentally adjustment of the plug 94 may be effected to determine the extent to which the ball valve may leave its seat so that simple control of the ball valve is so obtained. This described arrangement is equally applicable to both the ball valves 87 and to the valves 81.

From an examination of the spring chambers 84 of the engine valves as illustrated in Figures 12, 13, 14, 15 and 20, it will be seen that the outer ends of the said spring casings, that is, the ends to which the actuator heads are secured are each provided with an annular groove 97, and that the walls of the said spring casings are drilled at diametrically opposite points to provide longitudinal passages 98 and 99 therein leading from the annular groove 97 to the opposite end of the spring chamber 92.

The passage 98 is interrupted intermediate of its length by a plug 100 inserted in the wall of the spring casing for that purpose. On opposite sides of this plug are ports 101 and 102, which are most clearly shown in the detail Figure 23, these ports opening from the passage 99 to the bore of a boss 103 formed on the casing and receiving a selector plug 104 having a single orifice 105 which may, according to the position of the said plug, register with one or other of the ports 101 and 102. This plug 104 is carried by the end of a drain pipe 106 and is secured in position in the boss 103 by a nut 107.

It will be apparent that the port 105 establishes communication between the pipe 106 and that part of the passage 99 extending to the annular groove 97 of the spring casing, or with the other part of the said passage which extends to the opposite end of the spring casing chamber 92, according to the position of the said passage 105 relative to the ports 101 and 102.

It will also be seen that the faces of the ac-

tuator heads 19 of the lower valve gears wherein the actuator heads are inverted as in Figures 14 and 15 are recessed or cut away at 108 to provide communication between that end of the spring chamber 92 adjacent the actuator head and one or other of the passages 98 or 99 according to the angular position in which the spring casing is located.

Thus, in the position illustrated in Figure 14 said recess 108 communicates directly with the lower end of the passage 99, and in the position indicated in Figure 15 the said recess 108 communicates with the lower end of the passage 98; the requirement being that the recess shall be at the lowermost point of the spring chamber 92, its object being to receive oil which may accumulate within the said spring chamber.

With the ports 105 of the plugs 104 set as shown in Figures 12, 13, 14 and 15, communication is established between the pipes 106 and the lowermost point of the spring chamber 92 in each case. In Figure 12, this port communicates with the lower part of the passage 99 which opens directly into the lowermost point of the said spring chamber and the same may be said of Figure 14. In Figure 15, this port opens into the lower part of the passage 99 which communicates through the medium of the annular groove 97 with the recess 108 at the lowermost point of the said spring chamber 92, and in Figure 13, the port 105 opens from the upper part of the passage 99 which communicates with the lowermost part of the spring casing 92 through the medium of the recess and annular groove 97 and the passage 98.

The pipes 106 lead from the spring casing to the vacuum chamber 7 of the engine as clearly shown in Figure 1 and in the diagram Figure 24, so that oil is drawn from the lowermost point in the spring casing through the said pipes 106 into the said vacuum chamber by suction. Such oil, which may be the result of leakage within the valve stems 83 and their cylinders 82, if such should take place, or the result of oil passing the air bleed valves 81 or 87 when they are operated, is, therefore, drained by vacuum back to the chamber 7 and from there to the centrifuge 41.

Vacuum in the chamber 7, of course, induces vacuum in the spring chambers 92 of the spring casings 84 by reason of the oil drainage system described, so that if there be any air accumulation or a desire to guard against air accumulation in the actuator heads the air bleed valves 81 are relieved by manipulating their respective plugs 94, whereupon suction in the said spring chambers 92 will assist or effect the withdrawal of air through passages 109 from the interior of the actuator heads. The port arrangement of the actuators 17 and their plungers 80,

however, provides for pressure oil inlet to the valve gears for promoting the forcing of air from the said valve gears during rest periods as explained in the said co-pending application Serial Number 180,119, so that the vacuum in the spring chambers 92 is not essential to the bleeding operation, but assists materially in the disposal of oil which may escape past the bleed valves during this bleeding operation into the said spring chambers.

Opening of the bleed valves 87 effects air bleeding communication between the inverted actuators through the annular passage 89 thereof and bleed pipe 90 with the said spring chambers 92, as will be quite apparent, so that air upon opening of such valves is bled from the interior of the actuators to the said spring chambers and oil which may also be bled therefrom enters the spring chambers by the same passage and is disposed of by the vacuum drainage as explained.

The restricted nature of the annular passages 89 and bleed pipes 90 of the inverted actuators ensures accumulated air being entrained downwardly with oil passing to the same spring chambers 92, instead of such oil having an opportunity to rise in the bleed column as might occur were there no such restrictions.

It has been previously explained that the engine is provided with two centrifuges 25 and 41, the centrifuge 25 receiving oil passing from the tank 23 to the engine, and the centrifuge 41 receiving oil passing from the engine back to the said tank 23. These centrifuges serve to centrifugally separate grit, dirt or similar heavy foreign matter from the oil, the first centrifuge 25, therefore, cleaning oil of grit or dirt which it may have contained when first placed into the tank 23 or before entering the engine, and the second centrifuge 41 cleaning oil of any grit, dirt or heavy foreign matter which it may have accumulated in its passage through the engine. Thus, a double precaution is taken against undesirable foreign matter finding its way into bearings, valve gears or other parts of the engine which might be fouled thereby.

Furthermore, the centrifuge 25 tends to eliminate air which may be entrained in oil drawn from the tank 23 by centrifugally separating the air and oil so that oil is delivered to the valve gears through the pressure oil manifold 32 in an air free or comparatively air free condition, which reduces the frequency with which air is required to be bled from the valve gears.

In considering the question of bleeding air from the valve gears it should be recollected that in initially loading the valve gears of a dry engine with oil all the air which originally filled the said valve gears may be effec-

tively eliminated by the means provided and described and quickly replaced by oil delivered through the pressure oil manifold 32 by simply cranking the engine.

5 This invention may be developed within the scope of the following claims without departing from the essential features of the said invention, and it is desired that the specification and drawings be read as being merely
10 illustrative and not in a limiting sense, except as necessitated by the prior art.

What I claim is:—

1. In a radial engine, a circular series of
15 cylinders arranged with their axes in individual planes transverse to the axis of the engine and with adjacent cylinders in other than adjacent planes, a crankshaft having a common crank for said circular series of cylinders, and connecting rods connecting the
20 pistons of said cylinders with said common crank.

2. In a radial engine, a circular series of cylinders arranged in circular series with the
25 axes of the cylinders in individual planes transverse of the axis of the engine, and the axes of adjacent cylinders in other than adjacent planes, whereby the plane of a non-adjacent cylinder falls between the planes of adjacent cylinders, a crankshaft having a
30 common crank for said circular series of cylinders, and connecting rods connecting the pistons of said cylinders with said common crank.

3. In a radial engine, a circular series of
35 cylinders arranged with their axes in individual planes transverse of the axis of the engine with alternate cylinders in their circular order in adjacent planes, a crankshaft having a common crank for said circular series of cylinders, and connecting rods connecting the pistons of said cylinders with said
40 common crank.

4. In a radial engine, a circular series of
45 cylinders arranged in alternate firing order common to radial engines, said cylinders being arranged in individual planes transverse to the axis of the engine, the planes progressing along the axis of the engine in firing order
50 of the cylinders, a crankshaft having a common crank for said circular series of cylinders, and connecting rods connecting the pistons of said cylinders with said common crank, said connecting rods being arranged progressively along said crank in the firing
55 order of the cylinders.

5. In a radial engine, a circular series of cylinders, a crankshaft having a crank common to all of said cylinders, and connecting
60 rods for the pistons of said cylinders arranged in substantially side by side relation on said crank, said cylinders being arranged with their axes in planes agreeing with said connecting rods and in a non-uniform staggered relation to a given plane transverse of
65 the axis of the engine.

6. In a radial engine, a circular series of cylinders, a crankshaft having a common crank for said series of cylinders, a sleeve bearing rotatable on said crank, and connecting rods connecting the pistons of said cylinders with said sleeve bearing, the said sleeve bearing being free to rotate in said connecting rods.

7. In a radial engine, a circular series of cylinders arranged with their axes in individual planes transverse to the axis of the engine and with adjacent cylinders in other than adjacent planes, a crankshaft having a common crank for said circular series of cylinders, connecting rods connecting the pistons of said cylinders with said common crank, and a sleeve bearing freely interposed between said crank and said connecting rods.

8. In a radial engine, a circular series of cylinders, a crankshaft having a crank common to all of said cylinders, and connecting rods for the pistons of said cylinders arranged in substantially side by side relation on said crank, said cylinders being arranged with their axes in planes agreeing with said connecting rods and in a non-uniform staggered relation to a given plane transverse of the axis of the engine, and a sleeve bearing freely interposed between said crank and said connecting rods.

9. In a multi-cylinder engine including a plurality of connecting rods, a crankshaft having a common crank to which said rods are connected, a sleeve bearing extending substantially the entire length of the crank-pin and common to said rods freely interposed between said crank and said rods whereby said rods are relieved of rotary contact with said crank.

10. In a multi-cylinder engine including a plurality of connecting rods and a crankshaft having a common crank to which said rods are connected, a longitudinally divided sleeve bearing common to said rods freely interposed between said rods and said crank.

11. In a radial engine, in combination, a circular series of cylinders arranged with their axes in individual planes transverse to the axis of the engine, valves carried by said cylinders, a valve-operating cam member, a circular series of plungers operably arranged in a substantially common plane about said cam member, and hydraulic means operatively connecting said plungers with said valves.

12. In a radial engine, in combination, a circular series of cylinders arranged with their axes in individual planes transverse to the axis of the engine, hydraulic valve gears for said cylinders, said valve gears including actuator heads varying in position along the length of said engine with the varying positions of said cylinders, actuators in circular series arranged in a substantially common plane transverse to the axis of the engine, and connecting pipes between said actuators

and said actuator heads, said pipes being of lengths varying with the difference between the cylinder planes and the actuator planes, and a common cam member for and in the plane of said actuators.

13. In a radial engine, in combination, a circular series of cylinders arranged in individual planes transverse to the axis of the engine, inlet and exhaust valves carried by said cylinders, an inlet valve operating cam cluster, an exhaust valve operating cam cluster, a circular series of inlet valve operating plungers actuated by the first mentioned cluster and arranged in a common plane transverse to the axis of the engine, a circular series of exhaust valve operating plungers similarly operably arranged in a common plane with said second cluster, and hydraulic means operatively connecting said inlet and exhaust valve operating plungers with said inlet and exhaust valves.

14. In a radial engine, in combination, a circular series of cylinders arranged with their axes in individual planes transverse to the axis of the engine and with adjacent cylinders in other than adjacent planes, a crankshaft having a common crank for said circular series of cylinders, connecting rods connecting the pistons of said cylinders with said common crank, valves carried by said cylinders, a valve operating cam member, a circular series of plungers operably arranged in a substantially common plane about said cam member, and hydraulic means operatively connecting said plungers with said valves.

15. In a radial engine, in combination, a circular series of cylinders, a crankshaft having a crank common to all of said cylinders, connecting rods for the pistons of said cylinders arranged in substantially side by side relation on said crank, said cylinders being arranged with their axes in planes agreeing with said connecting rods and in a non-uniform staggered relation to a given plane transverse to the axis of the engine, valves carried by said cylinders, a valve operating cam member, a circular series of plungers operably arranged in a substantially common plane about said cam member, and hydraulic means operatively connecting said plungers with said valves.

16. In a radial engine, in combination, a circular series of cylinders, a crankshaft having a common crank for said series of cylinders, a sleeve bearing rotatable on said crank, connecting rods connecting the pistons of said cylinders with said sleeve bearing, said sleeve bearing being free to rotate in said connecting rods, valves carried by said cylinders, a valve operating cam member, a circular series of plungers operably arranged in a substantially common plane about said cam member, and hydraulic means operatively connecting said plungers with said valves.

17. In a radial engine, in combination, a circular series of cylinders arranged with their axes in individual planes transverse to the axis of the engine and with adjacent cylinders in other than adjacent planes, a crankshaft having a common crank for said circular series of cylinders, connecting rods connecting the pistons of said cylinders with said common crank, a sleeve bearing freely interposed between said crank and said connecting rods, valves carried by said cylinders, a valve operating cam member, a circular series of plungers operably arranged in a substantially common plane about said cam member, and hydraulic means operatively connecting said plungers with said valves.

18. In a multi-cylinder engine having cylinders arranged in differing planes transverse to the axis of the engine, in combination, valves carried by said cylinders, valve actuating plungers arranged in a substantially common plane transverse to the axis of the engine, cam means operating said plungers, and hydraulic means operatively connecting said plungers with said valves.

19. In a multi-cylinder engine having cylinders arranged in differing planes transverse to the axis of the engine, in combination, valves carried by said cylinders, a circular series of valve actuating plungers arranged in a substantially common plane transverse to the axis of the engine, a common cam cluster operating said plungers, and hydraulic means operatively connecting said plungers with said valves.

In testimony whereof I affix my signature.
WARREN NOBLE.

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