March 12, 1957 R. M. WILCOX 2,784,671

GAS-DRIVEN PUMP DEVICE

Filed Jan. 9, 1953 2 Sheets-Sheet 1

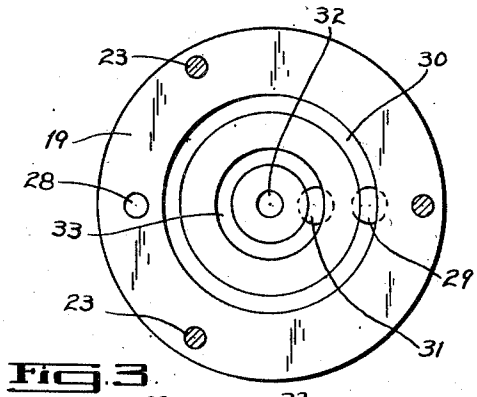


Fig. 3.

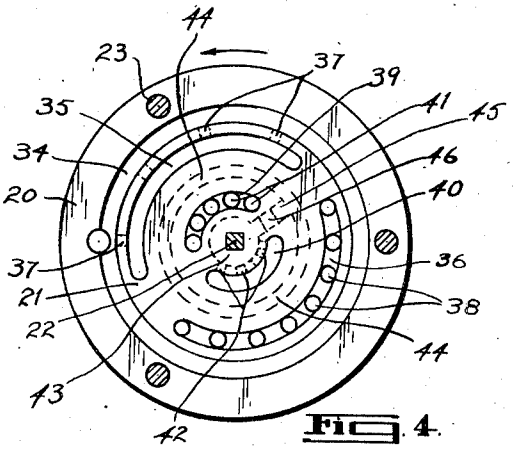


Fig. 4.

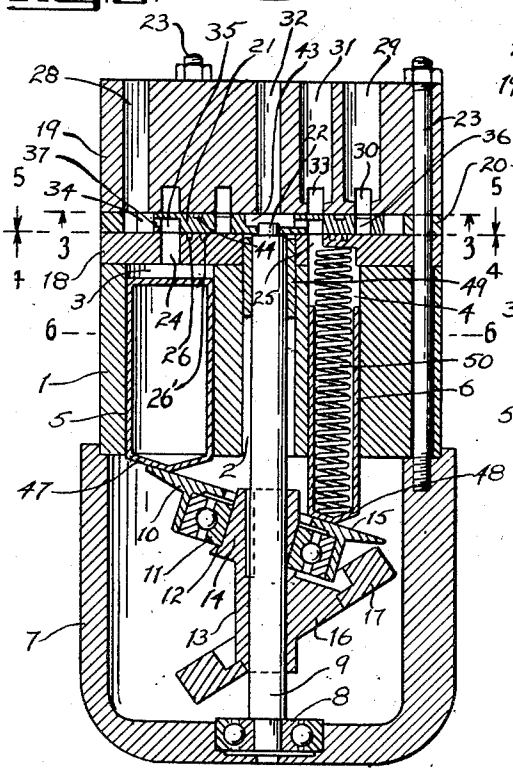


Fig. 1.

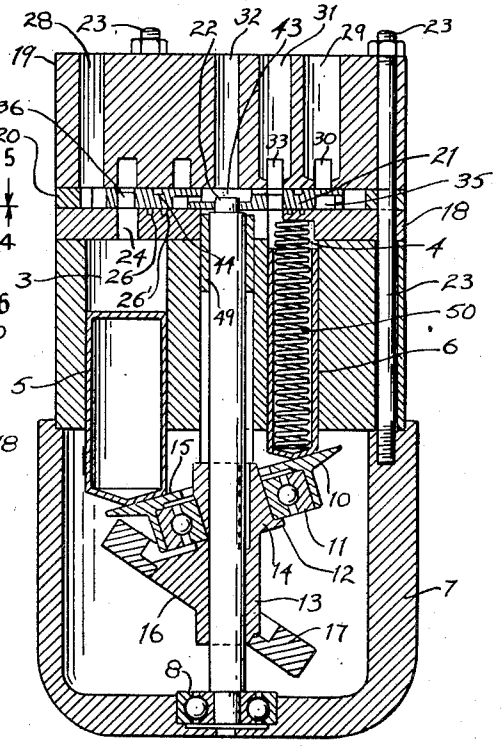


Fig. 2.

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GAS-DRIVEN PUMP DEVICE

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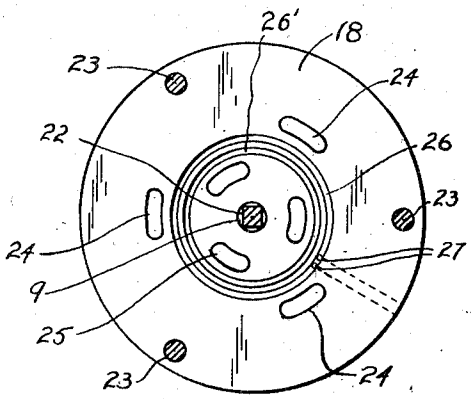


Fig. 5.

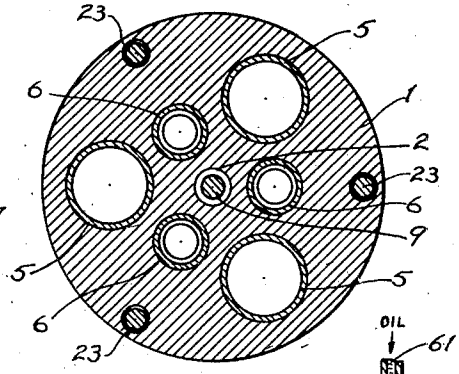


Fig. 6.

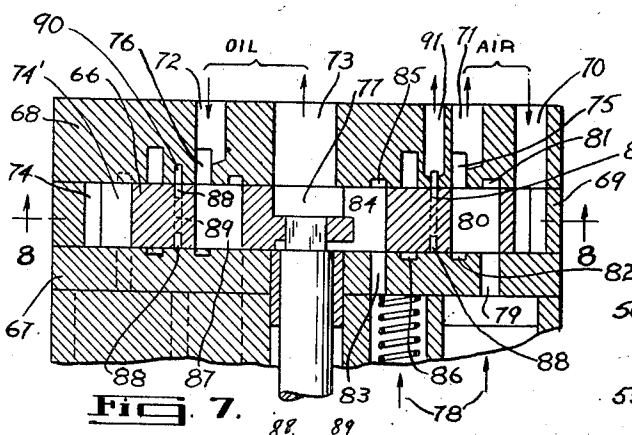


Fig. 7.

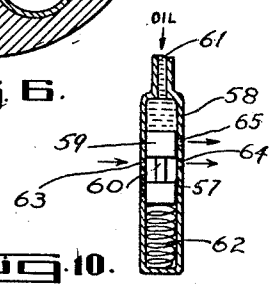


Fig. 10.

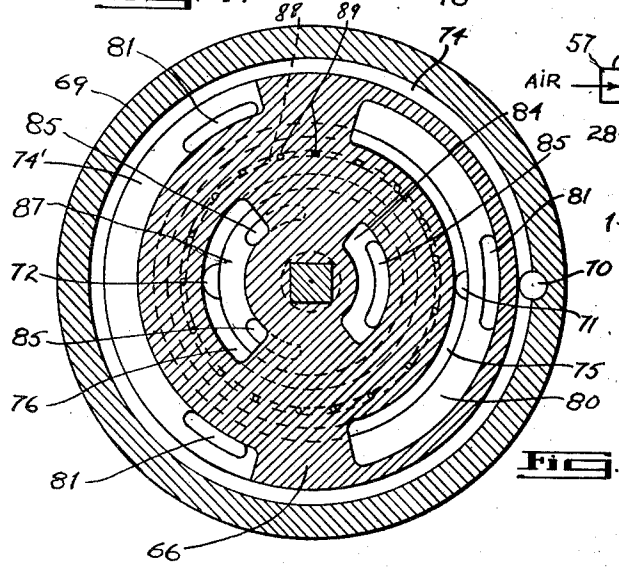


Fig. 8.

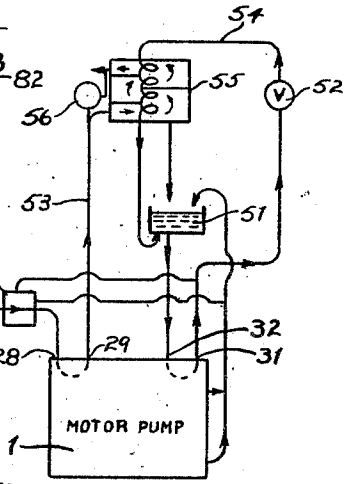


Fig. 9.

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GAS-DRIVEN PUMP DEVICE

Roy M. Wilcox, Grand Rapids, Mich.

Application January 9, 1953, Serial No. 330,454

16 Claims. (Cl. 103—47)

This invention relates to improvements in hydraulic pumping systems and particularly to an improved hydraulic pump of the reciprocating piston type.

In the pumping of an hydraulic liquid, normally oil, the hydraulic energy of the liquid is normally converted in a large part to heat somewhere in the hydraulic system causing heating of the hydraulic liquid.

There are many instances where such heat is extremely undesirable such as in precision machine tools where the heat causes expansion giving rise to errors.

As explained in my co-pending application Serial No. 332,205, filed January 26, 1953, I have discovered that if a compressed gas is utilized to impart the hydraulic energy to the liquid, the gas upon being expanded affords a cooling effect which may be used to balance out the heating of the oil.

This cooling effect is obtained by expanding the gas at the expense of its enthalpy or internal heat energy, and utilizing the heat of the oil to restore the gas enthalpy to give an overall isothermal gas expansion.

I have discovered that if the entire hydraulic energy of the liquid or oil is converted into heat, as for instance by throttling, the cooling effect provided by the expansion of the gas will exactly balance out this heat together with the heat losses in the pump itself. This expansion occurs against the moving member of the motor section of the pump in the early cut-off type of motor, i. e. where the air inlet of the motor section of the pump closes shortly after the movable member has begun its power stroke after which the air expands against the member until the end of the stroke where exhaust takes place.

Where the air inlet remains open until the end of the power stroke in reciprocating late cut-off types of motors then the expansion occurs at exhaust.

Where only a portion of the liquid hydraulic energy is converted into heat, of course, only a portion of the cooling energy may be transferred to the liquid to extract the heat therefrom.

Although there are many different forms of hydraulic drives and pumps, the reciprocating piston type of drive or pump is particularly desirable because of its high pumping efficiency and low manufacturing costs.

The principal object of this invention is therefore to provide an arrangement of a compressed gas driven liquid hydraulic pump of the reciprocating piston type which will provide for the extraction of the heat from the liquid by expansion of the driving gas.

A further important object is to incorporate the compressed gas motor and liquid pump into a single simple unit which will provide a substantially constant pressure liquid flow and will be free from stalling.

Still a further object is to provide a pump as aforesaid which will be economical on air consumption, and will afford minimum friction and wear to provide long life, dependable operation.

The principal feature of the invention resides in driving an arrangement of reciprocating liquid pumping pistons by means of an arrangement of reciprocating compressed air driven pistons, and utilizing the heat generated in the oil to restore the enthalpy of the compressed air lost as it is expanded against the atmosphere.

More specifically the liquid pumping and air driven pistons are arranged in the same unit and a wabble plate is utilized to effect a drive from the air driven pistons to the pumping pistons.

A further important feature resides in arranging the cylinders in which the air and liquid pistons operate in symmetrical interspersed relation in the same block or body of metal to provide intimate uniform thermal relation between the liquid pumping and compressed gas systems.

More specifically it is a feature to provide three air and oil cylinders and to dispose the air cylinders to lie alternately between the oil cylinders in a circle with both sets of cylinders having 120° spacing and sinewave displacement to minimize pressure fluctuations and to preclude the possibility of stalling.

A further important feature resides in providing a rotary disc valve driven by the wabble plate to control the compressed air and liquid flow, and floating said disc valve between two balancing pressure films to minimize mechanical and fluid friction.

Still a further feature resides in utilizing compressed air leakage to return the liquid of the hydraulic system to its reservoir and utilizing pressure liquid leakage to lubricate its air system and the wabble plate.

Another feature resides in geometrically arranging the wabble plate so that its axis intersects that of the rotary valve shaft it drives in its plane of contact with the pistons to thereby reduce rubbing of the wabble plate against the ends of the piston to a minimum.

These and other objects and features will become apparent from the following description taken in reference to the accompanying drawings in which:

Figure 1 is a mid-vertical sectional view illustrating a gas-driven liquid pump constructed in accordance with the invention.

Figure 2 is a view similar to Figure 1 but illustrating the pump parts 180° out of phase with the pump parts shown in Figure 1.

Figure 3 is a sectional view on the line 3—3 of Figure 1.

Figure 4 is a sectional view on the line 4—4 of Figure 1.

Figure 5 is a sectional view on the line 5—5 of Figure 1 and Figure 6 is a section on the line 6—6 of Figure 1.

Figure 7 is a fragmentary vertical sectional detail illustrating somewhat modified valving arrangement for a pump of the type of Figures 1 and 2.

Figure 8 is a horizontal sectional view on the line 8—8 of Figure 7.

Figure 9 is a schematic diagram illustrating a simple system incorporating the pump of Figures 1 and 2.

Figure 10 is a sectional detail of the air inlet valve of the system of Figure 7.

With reference to Figures 1 and 2 and 6, the body of the pump comprises a cylindrical block 1 of a suitable heat-conducting metal provided with a central bore 2 and grouped around this central bore in symmetrical 120° relation with three large bores 3. Also formed in the block 1 are bores 4 of a size reduced from the bores 3, and these bores 4 are arranged in symmetrical 120° relation with a small bore 4 lying alternately between the large bores 3.

Mounted in each of the large bores 3 is a piston 5, while mounted in each of the bores 4 is a piston 6.

Secured to the lower end of the block 1 is a cup 7 which carries a journal 8 in its lower end in which is journalled a shaft 9 projecting through the central bore 2 of the block. Mounted on the shaft 9 is a wabble plate 10 and this plate is adapted to impart a rotational thrust

to the shaft 9 through a thrust type anti-friction bearing 11 seated on the inclined ledge 12 of a hub 13 keyed or otherwise secured to the shaft 9.

The axis of the wabble plate 10, bearing 11 and the cylindrical portion 14 of the hub surrounded by the bearing 11 are inclined to the axis of the shaft 9, the geometry being such that the axis of the wabble plate intersects the shaft in the plane of its face 15.

To offset the eccentric mass on the shaft 9 consisting of the wabble plate 10 and the hub portion 14 the hub has a portion 16 of opposite eccentricity to the portion 14, and this portion carries an inclined ring 17 oppositely inclined to and oppositely eccentrically loading the shaft to the wabble plate 10 to effect both static and dynamic balancing of the shaft.

Mounted on the upper end of the shaft 9 between a pair of discs 18 and 19 spaced by the ring 20 is a disc valve 21. The valve 21 is free to float axially of the shaft 9 but is driven by the shaft through the squared shaft tip 22. Securing the discs 18 and 19 and the cup 7 in assembled relation with the block 1 are a plurality of longitudinal screw-threaded members 23.

As shown in Figures 1 and 2 and Figure 5, the lower disc 18 is provided with three outer circumferentially arranged arcuate slots 24 spaced at 120° relation which are adapted to register with the large bores 3. A similar set of arcuate slots 25 within the slots 24 are arranged to register with the small bores 4. Between the sets of slots the disc 18 is provided on its upper face with grooves 26 and 26' ringing the slots 25, the groove 26 opening at 27 through the disc to the atmosphere.

As shown in Figures 1, 2 and 3, the upper disc 19 is provided with an air inlet passage 28 and an air outlet passage 29. The air outlet passage connects to an annular collector groove 30 formed on the bottom face of the disc.

Arranged radially within the air passages 28 and 29 is an oil inlet passage 31 and an oil outlet passage 32, with the inlet passage 31 connecting to a delivery groove 33 of annular formation.

Between these discs 18 and 19 operates the disc valve 21 which is spaced from the ring 20 to define an annular delivery passage 34 in communication with the air supply passage 28. The disc valve 21 is itself provided with a pair of circumferentially extending arcuate slots 35 and 36 with the slot 35 being in communication with the annular passage 34 through ports 37 through the peripheral wall of the slot, and the slot 36 being in communication with the air outlet collector groove 30 through the openings 38.

Arranged concentrically within the slots 35 and 36 are a second pair of slots 39 and 40, the slot 39 opening through the ports 41 to the annular oil delivery groove 33 and the slot 40 opening through the passages 42 to a central recess 43 in the upper face of the valve 21 in communication with the central oil output passage 32.

Between the sets of slots 35, 36 and 39 and 40 is an annular groove 44 in the upper face of the disc valve 21 and this groove is in communication with the recess 43 through a passage 45, Figure 4, which incorporates a suitable oil filter 46. The purpose of this groove 44 and the grooves 26 and 26' in the lower disc 18 will hereinafter appear.

In operation air is delivered in the showing of Figure 1 through the air inlet 28 to the air delivery passage 34 and thence through the ports 37 to the slot 35 which is in communication with one of the lower disc slots 24 registering with the bore 3 at the left of Figure 1.

At the same time that the disc valve 21 provides communication for the air inlet to the interior of bore 3, as above described, the right-hand bore 4 of Figure 1 is in communication through one of the slots 25 in the lower disc 18 and slot 40 in the valve disc 21, to the central valve recess 43 and thence to the oil outlet 32 to deliver oil being pumped by the right-hand piston 4 of Figure 1 to the hydraulic circuit in which the oil is being circulated.

The air-operated pistons 5 each have a conical-like lower end 47 which engages the face 15 of the wabble plate 10. The pistons 5 are not only arranged in 120° spacing but are in sine wave relation with respect to their positions in their strokes as controlled by the wabble plate 10 so that, as the piston 5 seen in Figure 1 starts its downward travel, one of the other pistons 5 is arriving adjacent the bottom of its stroke and is still in communication with the annular air delivery passage 34 through the slot 35. The third piston will be moving upwardly and will be in communication with the annular collector groove 30 in the upper disc 19 which communicates with the air outlet 29 through the slot 36 in the valve 21.

Similarly the pistons 6 are not only spaced in 120° relation but are in sine wave relation with respect to their position in their strokes. Like the pistons 5, the pistons 6 are formed with bevelled or conical lower ends 48 which engage the face 15 of the wabble plate with the angled surfaces of these lower ends. The pistons 5 are forced against the wabble plate under air pressure in a sine wave relation so that the wabble plate is rocked or wabbled and acts as a rotating wave but does not itself rotate.

The wabbling of the plate 10 however imparts a rotative thrust to the shaft 9 through the thrust bearing 11 to drive the shaft in its thrust bearing 8 and locating sleeve 49 to drive the disc valve 21.

The three smaller pistons 6 are held in engagement with the face 15 of the wabble plate by springs 50, and as one piston is pumping oil out through the outlet 32 the other pistons are successively drawing oil in through the oil inlet 31 and delivery groove 33 by slot 39 in valve 21 and slot 25 in lower disc 18.

Because of their sinewave displacement and 120° spacing the oil pistons 6 minimize pressure fluctuations and the use of the three driving pistons 5 precludes the possibility of stalling.

With the axis of the wabble plate 10 intersecting that of the shaft 9 at the face 15 of the plate the rubbing of the plate against the ends 47 and 48 of the pistons 5 and 6 respective is at a minimum and this thoroughly random motion highly polishes the piston ends and face 15 so that in time friction and wear tend toward zero.

With the disc type of valve 21 utilized being operated adjacent the ends of the cylinders or bores 3 and 4, dead air space at the ends of the cylinders is small and air consumption is minimum. By having the disc valve 21 floating on the shaft 9 the fluid pressure against the cylinder side of the valve is balanced by introducing high pressure oil into the annular groove 44 through the passage 45. This groove 44 serves to prevent air under pressure finding its way between the upper face of valve 21 and the upper disc 19 into the oil stream. Instead because of the higher pressure of the oil there is a small leakage of oil into the air cylinders which serves as a lubricant.

The grooves 26 and 26' in the upper face of the lower disc 18 also serve to prevent pressure air from seeping between the bottom face of the valve disc 21 and the lower disc 18. Groove 26 provides a ready path to the atmosphere through the openings 27 for any air moving radially inwardly beneath the disc. Groove 26' is fed with leakage oil from arcuate slots 25 when these are at high pressure to provide a protective encircling reservoir of oil to prevent air being sucked from groove 26' into slots 25 when these may be at less than atmospheric pressure during the intake stroke of the pistons 6.

The pump is operated in a vertical position so that leakage of oil past the pistons 6 flows down over the wabble plate 10, through the ball bearings 11 and 8 and back to the reservoir 51, Figure 9. This flow is maintained even though the reservoir is above the pump because the air that leaks past the pistons 5 forces the oil from the bottom of the pump up to the reservoir.

Figure 2 illustrates the pump parts in 180° phase re-

lation from their position in Figure 1. The wabble plate 10 has been wabbled through 180° while the shaft 9 has been rotated through 180°. The position of the disc valve 21 is reversed from Figure 1 and the left-hand cylinder or bore 3 is in communication with the air exhaust through the respective slots in the upper and lower discs and the valve 21. The right-hand cylinder or bore 4 is in communication with the oil inlet 31 through the respective slots of the upper and lower disc and valve 21.

The liquid hydraulic portion of the system comprised by the cylinders or bores 4 and the pistons 6, and the entrances to and from such cylinders, is in intimate thermal contact with the compressed gas portion of the system comprised by the cylinders or bores 3, pistons 5 and entrances to and outlets from the bores 3 through the block 1 and the discs 18, 19 and 21. As a result the cooling effect produced by the exhausting of the gas from the bores 3, that is, expanding the gas against the atmosphere absorbs the heat from the liquid or oil which is pumped by the pistons 6.

The cooling results from a sudden expansion of the air in the bores 3 when the disc valve 21 is rotated to connect the bores to the air outlet 29. During exhaustion of the cylinders or bores the air remaining behind performs mechanical work at the expense of its own internal heat energy or enthalpy, forcing the foregoing air out through the exhaust passage 29 against the latter's inertial resistance.

It may be shown that the loss of internal heat energy exactly balances the hydraulic energy imparted to the oil and the fluid and friction losses in the pump when such liquid hydraulic energy is converted into heat by throttling or other energy dissipating means represented by the throttling valve 52 in the circuit of Figure 9.

Since there must be drop in temperature in the exhaust air issuing from the cylinders 3, in order to effect the heat transfer from the oil to the air a complete thermal balance of the air and hydraulic portions of the system may not be obtained in the pump unit itself and it is therefore desirable to lead the exhausting air through the line 53, as shown in Figure 9, into thermal association with the oil in the circuit 54 in a heat exchanger 55.

Where the entire cooling effect of the air is not required the air may be by-passed from the heat exchanger by a suitable temperature control butterfly valve 56.

The air input of the motor pump comprised in the block 1 is also preferably automatically controlled to hold the output of the pump at constant pressure. Figure 10 illustrates a simple form of valve which not only provides constant pressure output but allows for the by-passing of pressure surges in the circuit 54 and effects an automatic stopping of the pump because of low oil or air pressure, thereby protecting the pump and the apparatus being operated by the circuit 54.

This valve 57 comprises a cylinder 58 in which is arranged a piston 59 having a reduced central portion 60. Oil under pressure from the pump is admitted to one end of the cylinder 58 through the opening 61 to operate the piston against a spring 62. The walls of the cylinder are provided with ports 63—64 through which air is delivered to the air inlet 28 of the motor pump.

With the pump operating at normal output pressure the pressure oil acting against piston 59 moves the piston into a position where its reduced central portion 60 registers with the openings 63—64 to provide unimpeded air flow to the motor pump. If the output pressure increases even slightly it moves the piston toward the spring closing off the supply of air to the pump. If the oil pressure drops below a value predetermined by the length of the reduced portion 60, spring 62 will operate the piston 59 to close off air flow, thus stopping the pump. If a sudden surge of oil pressure occurs piston 59 is forced down against the spring to uncover port 65 which provides a by-pass for the oil leading to the reservoir 51. To start the pump air must be momentarily by-passed around the valve, and to stop the pump the air flowing through the valve need only be momentarily interrupted.

Referring to Figures 7 and 8, a somewhat modified form of valve arrangement is provided in which the ports and grooves on the two sides of the valve disc 66 are identical so that the fluid pressure is completely balanced. As before the valve disc 66 floats between lower and upper discs 67 and 68 separated by a ring 69.

The air inlet is indicated at 70 and the air outlet at 71, while the oil inlet is indicated at 72 and the oil outlet at 73. The air inlet connects with an annular delivery passage 74 defined between the disc valve and the ring 69 in communication with the valving recess 74, and the air outlet connects to a collecting groove 75 in the upper disc 68. The oil inlet 72 connects with an annular delivery groove 76 in the upper disc and the oil outlet connects with a central recess 77 in the disc valve 66.

As indicated by the arrows 78, Figure 7, the oil and air pistons are moving upwardly, the air is exhausting through a slot 79 in lower disc 67, and through the registering slot 80 in the valve disc and air outlet 71. The upper disc 68 is provided with arcuate slots 81 directly opposite the air exhaust slots 79 to deliver air at exhausting pressure to the upper side of the valve disc to balance exhausting air pressure against the underside of the valve disc.

The lower disc 67 is provided with an annular groove 82 directly opposite the air-collecting groove 75 to also effect a balance of air pressure on the upper and lower sides of the valve disc.

The oil exhausting from the oil cylinder through a slot 83 in the lower disc passes through a slot 84 in the valve disc which connects to the central recess 77. The upper disc 68 is provided with an arcuate slot formation 85 corresponding to the slot formations 83 in the lower disc to receive oil under pressure to counterbalance oil pressure against the underside of the valve disc.

The lower disc 67 is also provided with an annular groove 86 disposed oppositely to the oil delivery groove 76 to receive inlet oil through the arcuate slot 87 in the disc valve.

Between the ports and grooves connected with the air portion of the pump system and the ports and grooves connected with the oil portion of the pump system the disc valve is provided on both the upper and lower faces with annular grooves 88 connected by orifices 89, and these grooves communicate with an annular groove 90 in the upper disc which discharges to an outlet 91.

The grooves 88 will trap any air leakage across either the top or bottom of the floating disc valve 66 and such leakage air will be conducted away through the outlet 91.

The above type of disc valves are preferable in the fact that dead air space is substantially eliminated and by balancing the fluid pressure on opposite sides of the disc valve the valve operates smoothly and efficiently with minimum loss of torque.

However it will be appreciated that other valving means may be employed and other details of the pump may be varied while maintaining the pumping action afforded by the air pistons operating on a drive or wabble plate driving the oil pistons to provide a system wherein the air and oil portions are in thermal association to maintain the air and oil systems in thermal balance.

While particular reference has been made to compressed air as the driving medium, it will be understood that compressed gas other than air may be employed where practicable and it is understood that the word "air" where used in the appended claims is synonomous with the word "gas."

What I claim as my invention is:

1. In a liquid pumping system, a heat conducting body having a plurality of thermally associated cylinders therein, liquid pumping piston means reciprocating in certain of said cylinders, a circuit in which liquid pumped by said piston means is circulated giving rise to undesired heat,

compressed gas driven piston means reciprocating in other of said cylinders, an exhaust system from said latter cylinders giving rise to cooling of the gas, said conducting body forming a means for exchanging the undesired heat of the circulating liquid with the coolness of the gas, means driving said liquid pumping piston means on reciprocation of said compressed air driven piston means, and valve means controlling fluid flow to and from said cylinders.

2. In a liquid pumping system, liquid pumping reciprocating piston means, a circuit in which liquid pumped by said piston means is circulated giving rise to undesired heat, compressed gas driven reciprocating piston means and an exhaust system from said compressed gas driven means giving rise to cooling of the gas, means driven by said second-mentioned piston means reciprocating said first-mentioned piston means, means for exchanging the undesired heat of the circulating liquid with the coolness of the gas comprising thermally associated cylinder means in which each of said piston means operate and valve means driven by reciprocation of said second-mentioned piston means controlling fluid flow to and from said cylinder means.

3. A device as claimed in claim 2 in which the means driven by said second-mentioned piston means and reciprocating said first-mentioned piston means comprises a wabble plate.

4. A device as claimed in claim 15 in which said valve comprises a perforated disc operating above and arranged to open and close the entrances to said cylindrical passages, and urged outwardly of said passages under fluid pressure, and means to apply a fluid pressure urging said disc towards the entrances to said passages.

5. A liquid pump comprising a heat conducting body having a plurality of symmetrically arranged cylindrical bores therethrough, compressed air-driven pistons reciprocally mounted in certain of said bores, liquid pumping pistons arranged in the other of said bores, a rotatable shaft extending centrally of said bores through said body, a thrust bearing mounted on said shaft at one end of said body, a valve disc floatingly mounted on said shaft for movement axially thereof at the other end of said body, a wabble plate mounted on said thrust bearing and engaged by said piston means to drive said shaft and liquid pumping pistons upon reciprocation of said compressed air-driven piston means, said valve disc being driven upon rotation of the shaft over the entrances to said bores and having port means therethrough to control air flow to and from the bores in which said compressed air-driven pistons reciprocate and to control liquid flow to and from the bores in which said liquid pumping pistons reciprocate, and means to apply fluid pressure urging said disc towards the entrances to said bores to balance fluid pressures in said bores acting on said disc.

6. A pump as claimed in claim 5 in which the bores in which said compressed air-driven pistons operate are arranged in a circular formation at 120° spacing, and similarly the bores in which said liquid pumping pistons operate are arranged in a circular formation at 120° spacing with the first-mentioned bores lying alternately between the second-mentioned bores.

7. A pump as claimed in claim 5 in which spring means are provided to urge said liquid pumping pistons against said wabble plate.

8. A pump as claimed in claim 5 in which said disc valve floats between a pair of spaced plates, one of said plates overlying said body beneath said disc and having slot means therein affording communication to the interior of said bores, the other of said plates having an air inlet and outlet formation therein, and a liquid inlet and outlet formation therein displaced inwardly with respect to said air inlet and outlet formations, one of said discs and said plate provided with said inlet and outlet formations having a circular groove formation therein isolating said air inlet and outlet formations from said liquid inlet and outlet formations, and passage means leading pressure liquid into said circular groove.

9. A device as claimed in claim 8 in which one of said discs and said plate beneath said disc is provided with a groove formation encompassing the slot means in said latter plate communicating with the interior of said bores in which said liquid pumping pistons operate, said groove formation communicating to the atmosphere to isolate air leakage towards said latter bores.

10. A device as claimed in claim 5 in which said wabble plate and thrust bearing are enclosed in a housing forming a chamber at the end of said bores opposite said valve disc, and means leading from said chamber to convey leakage oil under leakage air pressure to a reservoir.

11. A device as claimed in claim 5 in which said piston means comprise pistons having ends bevelled from the circumference to the centre to form cone-like end surfaces engaging said wabble plate and said wabble plate comprises an annular inclined plate having its axis inclined to thte axis of said shaft and intersecting said shaft axis in the plane of contact of said wabble plate with said piston ends.

12. A system as claimed in claim 14 in which said valve is mounted to float axially of said shaft above the entrances to said bores, and means to conduct pressure liquid to the side of said valve remote from said bores to balance fluid pressure on opposite sides of said valve.

13. A device as claimed in claim 15 in which the ends of said cylindrical passages underlying said valve have ports leading to thte interior of said passages, and said valve comprises a disc having arcuate radially displaced air and oil grooves therein to form cylinder connections opening to and leading from said cylindrical passages through the aforesaid ports on valve rotation, said pump having an arrangement of radially spaced annular air and oil grooves on opposite sides of said disc and connecting with said arcuate disc grooves delivering fluid to and conducting fluid from said disc grooves, an arrangement of grooves corresponding and opposite to said first-mentioned ports arranged above said valve, and an arrangement of annular isolating grooves on opposite sides of said disc located between said radially spaced arcuate and annular air and oil grooves and in communication with each other through said disc, and with an isolating fluid, said groove arrangements being constituted to provide a hydraulic balance on opposite sides of the disc.

14. A liquid pumping system comprising a motor pump in the form of a heat conducting metal block, a central bore, a plurality of bores grouped around said central bore, liquid pumping pistons arranged to reciprocate in certain of said grouped bores, compressed air-driven pistons reciprocating in other of said grouped bores so that a bore in which a liquid pumping piston operates alternates with a bore in which a compressed air piston operates, a shaft rotatable in said central bore, a wobble plate mounted on said shaft and engaged by said pistons to effect drive of said pumping pistons and said shaft by said compressed air-driven pistons, valve means controlling fluid flow to and from said bores comprising a rotary valve driven by said shaft, a hydraulic circulating circuit through which a liquid is adapted to be pumped by said pumping pistons, an exhaust system through which compressed gas is adapted to be exhausted from the bores in which said compressed-air-driven pistons reciprocate, and means thermally associating said hydraulic circulating circuit and said air exhaust system.

15. In a liquid pumping system a heat conducting body having a plurality of cylindrical passages therein, compressed gas driven piston means reciprocally arranged in certain of said passages and an exhaust system from said compressed gas driving means giving rise to cooling of the gas, liquid pumping piston means reciprocally arranged in the other of said passages, a closed circuit in which liquid pumped by said liquid pumping

piston means is circulated giving rise to undesired heat, said conductor body forming a means for exchanging the undesired heat of the circulating liquid with the coolness of the gas, a wobble plate arranged to be contacted by each of said piston means to reciprocate said liquid pumping piston means, a rotatable shaft, a thrust bearing driving said shaft from said wobble plate, and a rotatable valve carried by said shaft and controlling fluid flow to and from said cylinder.

16. A fluid power system comprising a closed liquid hydraulic circuit including a liquid pumping means for circulating a liquid in said liquid hydraulic circuit, a compressed air circuit including compressed air driven means driving said liquid pumping means to impart hydraulic pressure to a liquid in said closed liquid circuit, and an exhaust system giving rise to the cooling of compressed air below the temperature of a liquid in said closed liquid circuit, means external to said liquid pumping means thermally associating compressed air exhausting from said compressed air circuit with a liquid being pumped and means for regulating compressed air flow comprising, a cylinder, a piston arranged in said cylinder, a connection between one end of said cylinder and said liquid circuit to urge said piston under liquid pressure in one direction in said cylinder, a spring opposing piston movement under liquid pressure, said piston having a reduced central portion, an air inlet and outlet formed in the wall of said cylinder and connected in series into said air circuit and registering with the reduced portion of said piston under normal liquid pressure, and a liquid relief outlet in the wall of said cylinder closed by said piston under normal liquid pressure and adapted to be opened under abnormal liquid pressure.

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