

April 20, 1965

A. LEHRER

3,179,060

SILENT VARIABLE DELIVERY HYDRAULIC PUMP

Filed June 28, 1962

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FIG. 3A.

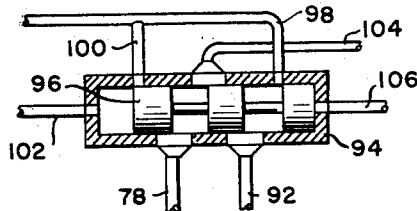
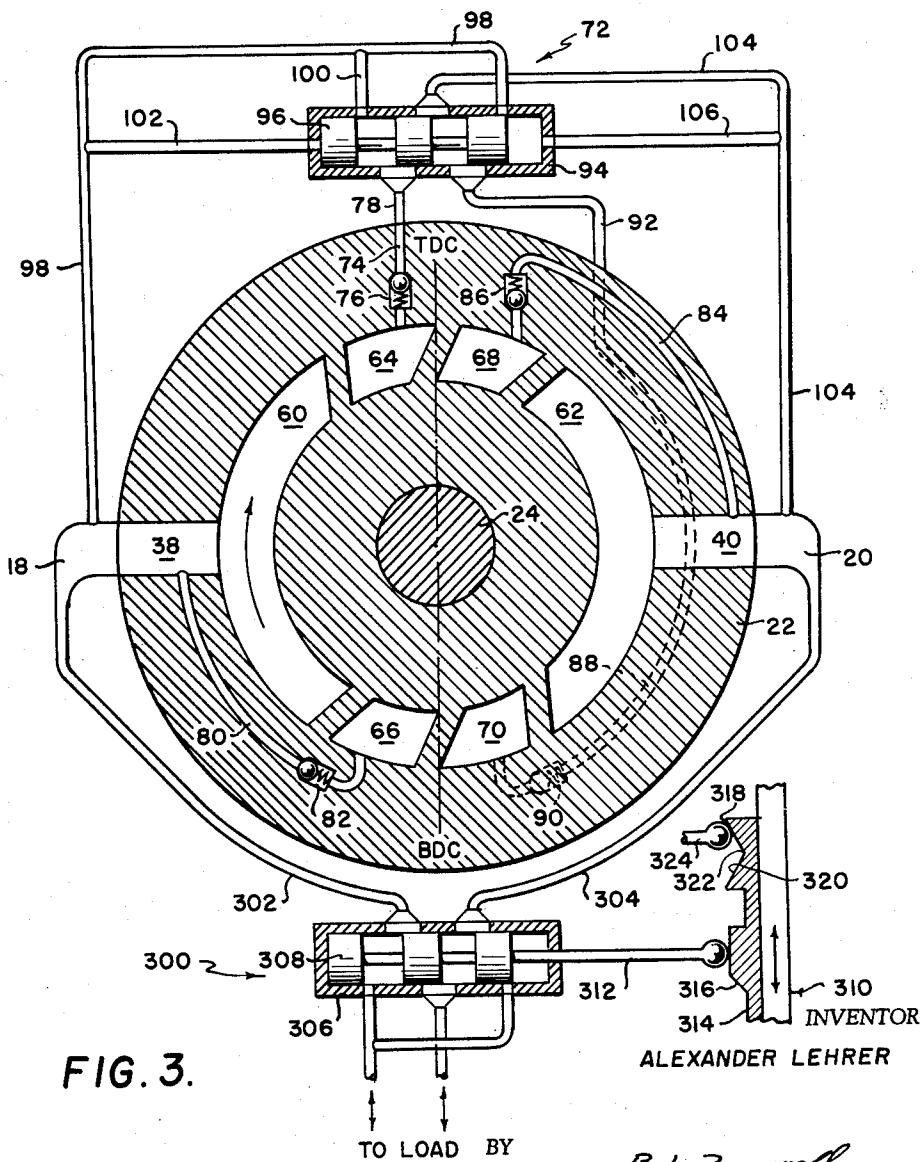


FIG. 3.

ALEXANDER LEHRER

B. L. Zangwill
ATTORNEY

April 20, 1965

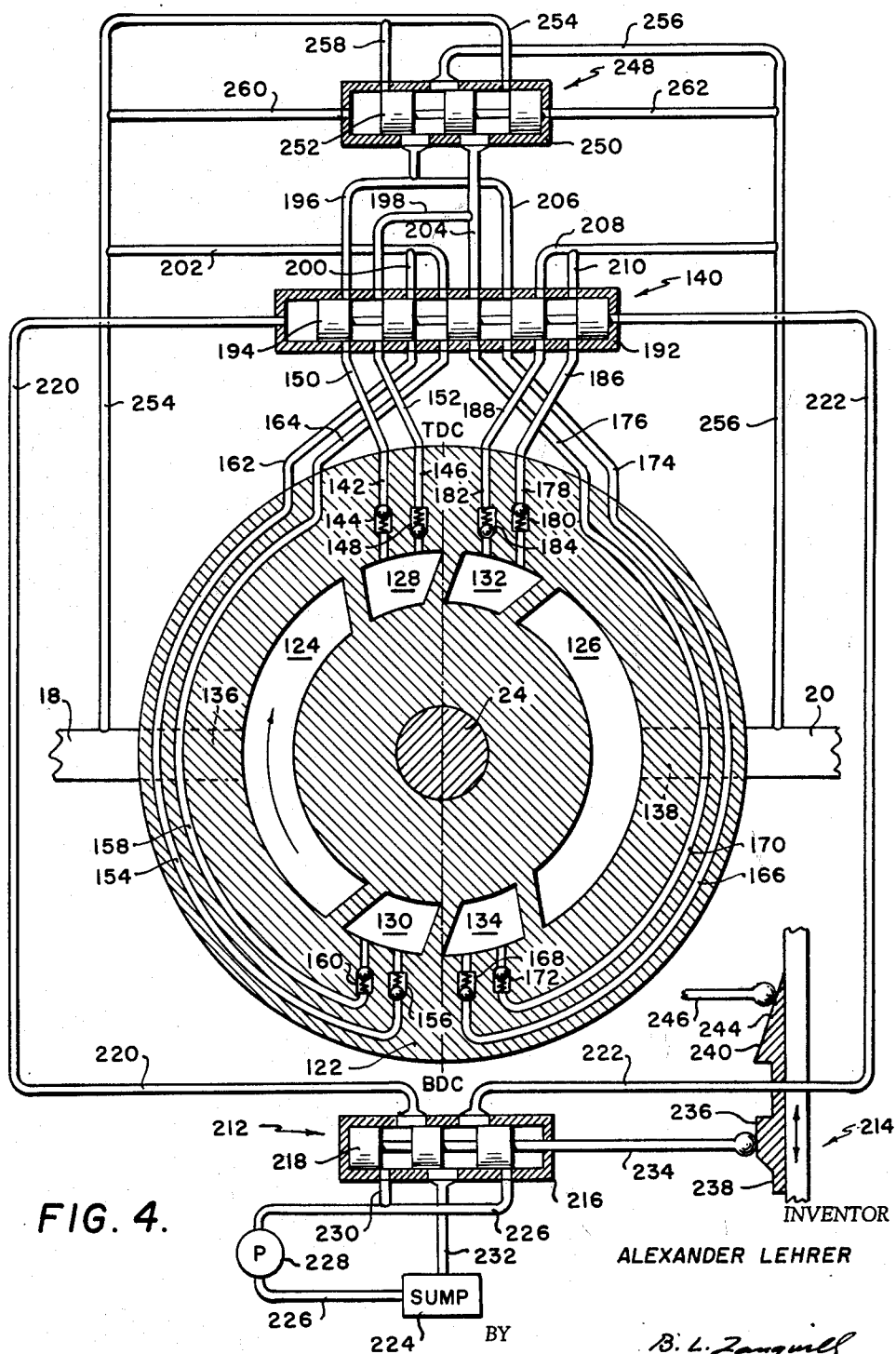
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SILENT VARIABLE DELIVERY HYDRAULIC PUMP

Alexander Lehrer, Alexandria, Va., assignor to the United States of America as represented by the Secretary of the Navy

Filed June 28, 1962, Ser. No. 206,104

4 Claims. (Cl. 103—162)

(Granted under Title 35, U.S. Code (1952), sec. 266)

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

This invention relates to hydraulic power transmission systems, and more particularly it relates to those systems which function as pumps when driven mechanically and provide a positive control of fluid flow when pumping against a pressure head or when pumping in the direction of pressure drop; the latter being known as overhauling. Machines of this type are sometimes referred to as servo pumps. The particular machine to which this invention is specifically directed is the type having a rotatable barrel containing a plurality of cylinders and a plurality of parallel pistons in the cylinders, which pistons move axially along the axis of rotation of the barrel as the machine is operated.

In hydraulic transmission machines of the type described above, it has been found that considerable noise results during machine operation, especially when such machines are operated under relatively high conditions of load or speed. Such noise may result from the shock which occurs when a cylinder having a certain pressure therein is brought into communication with a port in a valve plate having a different pressure therein. In certain environments, such as ships and submarines, hydraulic machines of the type described above have proved to be very useful; however, the noise produced by their operation has presented a serious problem. Attempts have been made to reduce or suppress such noise by acoustic treatment, flexible mountings, and the like, but such attempts have not provide entirely satisfactory. The result is that when quiet operation is a critical factor, as it is on submarines, such machines cannot be used; and, instead, designers have been forced to employ heavier, less flexible and more costly fluid transmission devices, such as constant displacement pumps.

An object of this invention is to provide a rotary barrel, parallel piston machine, of the type described above, wherein the pressure difference between the cylinders and valve ports is practically eliminated, thereby reducing noise generation caused by operation of the machine.

Another object of this invention is to provide a noise-free hydraulic power transmission system which can be used for bi-directional operation.

A further object of this invention is to provide a hydraulic power transmission machine with a high overall efficiency, which machine is simple in construction and low in cost of manufacture.

Still another object of this invention is to provide a valve plate for use with a hydraulic transmission machine of the type described, said valve plate including all the valves and passages therein and thus being easily adaptable to install on presently existing hydraulic machines in place of their present valve plates.

Yet another object of this invention is to provide a valve plate containing all auxiliary ports, valves and passages, thus allowing the cylinder ports to be substantially larger than would be possible if the auxiliary ports, valves and passages were located in the barrel.

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Further objects and advantages will become apparent from the ensuing descriptive matter.

The preferred embodiment of this invention is broadly comprised of a valve means in the form of a plate, and a multi-cylinder, parallel piston pump. The pump includes a rotatable assembly comprised of a barrel body having a plurality of parallel cylinders therein, each of said cylinders containing a piston. The valve means is located adjacent the cylinder ports at one end of the barrel body and a swash plate or cam means is located adjacent the barrel body at its other end. As the barrel body is rotated, the swash plate causes the pistons to reciprocate within the cylinders and thus draw fluid in through the valve means at one pressure and expel it through the valve means at another pressure.

The valve means is provided with a main suction and a main discharge port. It is also provided with auxiliary discharge and suction ports which communicate with the cylinders through check valve equipped passages and which also communicate with the main ports of the valve means through a shuttle valve assembly. The check valve controlled passages, the auxiliary ports, and the shuttle valve assembly all cooperate so that fluid trapped in each cylinder at suction port closure is either expanded or compressed, as necessary, during its transit of the auxiliary ports so that its pressure will be changed to the pressure of the discharge main port. Also residual fluid in each cylinder after discharge is also compressed or expanded, as necessary, so that its pressure will be changed to the pressure of the suction main port. Thus, when the fluid is discharged from the cylinder, there is almost no pressure difference and, therefore, substantially no noise caused by shock.

The present invention is a modification of the invention of Francis J. Sisk, disclosed in application Serial No. 200,005 filed June 4, 1962 (Navy Case No. 33,256).

The important and advantageous feature of the hydraulic transmission herein lies in the range of operation which it is capable of performing. There are two main operational variables to consider. The first variable is directionality; that is, the direction of flow of the fluid through the pump (either right to left or left to right). The second variable is pressure conversion; that is, whether the machine converts fluid from low pressure to high pressure (pumping) or whether it converts fluid from high pressure to low pressure (overhauling or motor-ing). Obviously, the interaction of the two variables creates four conditions under which the machine must operate; namely:

- (1) Pumping right to left
- (2) Overhauling right to left
- (3) Pumping left to right
- (4) Overhauling left to right

The machine of the present invention will, depending upon the valve plate used, handle two of the above conditions or all of them without valving of the main pump flow.

The invention will be more completely understood from the following detailed description and claims, read in conjunction with the annexed drawings, in which:

FIG. 1 is a partial longitudinal section view of an embodiment of a machine in accordance with the present invention;

FIG. 2 is a transverse sectional view taken on a plane indicated by the line 2—2 of FIG. 1;

FIG. 3 is a transverse sectional view of one embodiment of a valve plate and its associated valve means, showing the shuttle valve in a position for pumping from left to right;

FIG. 3A is a partial sectional view showing the shuttle

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valve of FIG. 3 in a position for overhauling or motoring from left to right. In this embodiment the swash plate operates from zero stroke position to full stroke in one direction only.

FIG. 4 is a transverse sectional view of another embodiment of the valve plate, shown as part of a schematic illustration of a complete system capable of performing under all the operational conditions previously discussed; that is, pumping with or against a pressure differential and pumping in either direction. In this embodiment the swash plate operates through a range from full displacement in one direction through the zero position to full displacement in the opposite direction.

Referring now to FIG. 1, a hydraulic power transmission machine or servo pump in accordance with the present invention is shown in which a casing 10 is closed at one end by a head 12 and at the other end by an annular cover 14 which is attached to the casing by bolts 16. The head 12 is provided with an inlet passage 18 and an outlet passage 20, which passages are arranged to communicate with a valve means in the form of a stationary circular valve plate 22. A cylindrical shaft 24 is journaled in anti-friction bearings 26 and extends through the valve plate 22 into the interior of the casing 10. A cylindrical barrel assembly 28 is fixedly mounted on the shaft 24 and adapted to rotate therewith. The barrel assembly is spaced from the interior of the casing 10 by means of roller bearings 30 which allow the barrel assembly to rotate within the casing.

The cylindrical barrel assembly comprises a cylindrical barrel body having a plurality of circumferentially spaced cylinders 34 formed therein, said cylinders being equally radially spaced from and extending parallel to their axis of rotation which is represented by the shaft 24, as can best be seen in FIG. 2. The cylinder ports or flow slots 36 are located adjacent the valve plate 22 and are adapted to effect a communication, through the valve plate 22, with the inlet passage 18 and the outlet passage 20.

A piston 42 having a ball head 44 is located within each cylinder and is adapted to reciprocate therein. Each ball head 44 is journaled in an associated shoe or slipper 48 which rides freely along the face of a swash plate 48 as the shaft 24 rotates the barrel assembly. The swash plate has a control shaft 50 which controls its angularity. Since the swash plate is disposed angularly or inclined to the axes of the cylinders and pistons, it actually forms a cam surface that causes the pistons 42 to reciprocate as they are being rotated by the barrel 32.

As was aforementioned, the inclination or angularity of the swash plate is controlled by the control shaft 50. When the plane of the swash plate is perpendicular to the axes of the pistons, which is vertical in the embodiment shown in FIG. 1, the stroke of the pistons is zero. As the swash plate is inclined, the stroke of the pistons is increased. At maximum inclination of the swash plate, forty-five-degrees displaced from the vertical, the stroke of the pistons is at its maximum.

An insert 52 is mounted in the end of shaft 24 and locked to the barrel body 32, thereby locking the shaft and barrel body together so that they rotate as a unit. A plunger 54 is mounted in the insert 52 and extends to the center of the swash plate, with one end of the plunger being spaced away from the bottom of the insert by compression spring 56 and the other end of the plunger pressing against a spherical ball 58. The ball 58 freely seats in a seat on the swash plate 48 in such a manner that the spherical ball 58 acts as a bearing against which the swash plate bears, so that the swash plate can be rotated through a range of positions on opposite sides of the shaft 24 as indicated by the arrow 59 in FIG. 1. The swash plate can be moved to any position within 45 degrees on either side of the vertical position, thereby allowing reversible or bi-directional flow. For example, FIG. 1 shows the machine operating as a pump, with lower pressure fluid being introduced through inlet 18

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and as the cylinder assembly 28 is rotated by the shaft 24, the pistons compress the fluid, and the fluid is discharged under high pressure when the associated cylinder communicates with the outlet 20.

The machine of FIG. 1 can also pump in the opposite direction as that recited above. That is, lower pressure fluid could be introduced through the outlet 20, and as the cylinder assembly is rotated by the shaft 24, the pistons would compress the fluid and discharge it under high pressure when the associated cylinder is in communication with the inlet 18. To accomplish this, the swash plate 48 would have to be moved by the control shaft 50 to a position where it was angularly displaced on the other side of the vertical position. An upwardly directed centerline for the control shaft 50 is shown in FIG. 1 at the upper arrow 59, which would correspond to the position of the control shaft under such reversed conditions.

If it were desired to use the machine only for unidirectional flow, that is only for pumping and overhauling in one direction the swash plate could be mounted to rotate about a line normal to an axis of one of the pistons, rather than normal to the axis of the centerline of the shaft. An arrangement such as this is shown in United States Patent No. 1,506,892. Such an arrangement has the advantages of allowing greater variations in the length of stroke of the pistons, and also of keeping to a minimum the volume in each cylinder at zero stroke, thus keeping to a minimum the amount of energy that can cause noise; however, such operation is achieved through the sacrifice of the feature of reversible or bi-directional flow. The reversing flow can then be provided by a valve operated with the pump stroke control as shown in FIG. 3.

Referring now to FIG. 3, a valve plate 22 is shown, which plate is adapted for use in the above described machine having the non-reversible type of swash plate mounting. The valve plate is provided with a circular series of ports which are radially arranged to align with the cylinder slots 36. The ports include two elongated main ports 60 and 62 and four auxiliary ports 64, 66, 68 and 70. Each auxiliary port is provided with a valve controlled passage which connects the auxiliary port either directly or indirectly to a main port. The indirect connection is accomplished by connecting the passage to an overhauling shuttle valve means or assembly 72 which in turn connects to the main ports. A passage or bore 38 connects the main port 60 with the inlet 18 and a passage or bore 40 connects the main port 62 with the outlet 20.

The auxiliary port 64 is provided with a passage 74 having a one way valve 76 therein which allows only inflow to said port. The passage 74 connects to a conduit 78 which leads to the shuttle valve assembly 72. The one way valve illustrated is comprised of a spherical ball and a compression spring, but the valve 76 and other similar valves described herein are not limited to this particular structure. Any one way valve well known in the art can be used.

The auxiliary port 66 is provided with a passage 80 having a one way valve 82 therein which allows only inflow to said port. The passage 80 connects to the bore 38 which in turn directly connects to the main port 60.

The auxiliary port 68 is provided with a passage 84 having a one way valve 86 therein which allows only outflow from said port. The passage 84 connects to the bore 40 which in turn directly connects to the main port 62.

The auxiliary port 70 is provided with a passage 88 having a one way check valve 90 therein which allows only outflow from said port. The passage 88 passes behind bore 40 and connects to a conduit 92 which leads to the shuttle valve assembly 72.

The shuttle valve means or assembly is comprised of a valve body 94 having a plurality of ports therein and a three spool valve member 96 adapted to reciprocate

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selectively in said body to cover or expose certain of the ports. The conduits 78 and 92 connect to the ports on the lower portion of the valve body 94. A conduit 98, which is connected at one end to the inlet 18 and thus is also connected to the main port 60, is connected at its other end to one of the ports on the upper portion of the valve body 94. The conduit 98 has a branch line 100 which also connects into a port on the upper portion of the valve body, and a branch line 102 which connects into a port at one end of the valve body. A conduit 104, which is connected at one end to the outlet 20 and thus is also connected to the main port 62, is connected at its other end to the port on the upper portion of the valve body 94 intermediate the ports which are connected to conduit 98 and branch line 100. The conduit 102 has a branch line 106 which connects into a port at the end of the valve body opposite to the end where branch line 102 connects.

Movement of the shuttle valve member 96 is controlled exclusively by pressure. When the pressure at main port 62 exceeds the pressure at main port 60 the valve member 96 shifts to the left, as is shown in FIG. 3, because the pressure flowing into the valve through the line 106 exceeds the pressure flowing into the valve through the line 102. If the pressure at main port 60 exceeded the pressure at main port 62, the valve would shift to the position shown in FIG. 3A.

The function of the shuttle valve assembly 72 is merely to alternately connect auxiliary ports 64 and 70 with the main ports. That is, when the valve member 96 is in the position shown in FIG. 3, the auxiliary port 64 is in communication with the main port 60 (through passage 74, conduit 78, line 100, conduit 98 and bore 38) and the auxiliary port 70 is in communication with the main port 62 (through passage 88, conduit 92, conduit 104 and bore 40).

If the valve member is shifted to the position shown in FIG. 3A, the connections are reversed so that the auxiliary port 64 is now in communication with the main port 62 (through passage 74, conduit 78, conduit 104 and bore 40) and the auxiliary port 70 is now in communication with the main port 60 (through passage 88, conduit 92, conduit 98 and bore 38).

Operation (FIG. 3)

Assume that the device is pumping low pressure fluid from the inlet 18 and discharging it as high pressure fluid to the outlet 20. As described above, this causes the valve member 96 to assume its FIG. 3 position. Assume also that the swash plate 48 is in the position shown in FIG. 1.

When operating under such conditions, as the barrel 32 is rotated, a cylinder 34 is moved to communicate with the main port 60 and low pressure fluid is drawn into said cylinder through the flow passage 36 by a suction force created by the piston 42 in that cylinder being withdrawn. As the barrel continues to rotate, the cylinder moves into communication with the auxiliary port 64 and out of communication with the main port 60. Since, as was described above, the auxiliary port 64 is in communication with the main port 60, and since the one way valve 76 allows inflow, additional low pressure fluid is drawn into the cylinder as the piston 42 continues to withdraw while the cylinder makes its transit across auxiliary port 64. When the cylinder reaches top dead center (TDC), the piston 42 is completely withdrawn and the cylinder is substantially filled with low pressure fluid.

As the cylinder 34 passes top dead center (TDC) and starts its transit across auxiliary port 68, the piston 42 starts to move into the cylinder to compress the fluid contained therein. The fluid will continue to be compressed until it reaches the high pressure present at the main port 62. When the pressure in the cylinder starts to exceed the main port high pressure, the fluid pressure will open the outflow check valve 86 and fluid will flow from the auxiliary port 68 to the main port 62. When

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the cylinder 34 finally moves out of communication with the auxiliary port 68 and into communication with the main port 62, the pressure of the fluid in the cylinder 34 is substantially the same as the pressure of the fluid at the main port 62, so no shock noise occurs.

The cylinder 34 has so far moved from the main port 60 to the main port 62. The return trip from the main port 62 back to the main port 60 becomes obvious in view of the above description. Briefly stated, when the cylinder 34 moves across the auxiliary port 70, the high pressure fluid continues to flow back past the one way valve 90 to the main port 62 as the piston 42 continues to move into the cylinder. At bottom dead center (BDC), the piston 42 is substantially all the way into the cylinder. As the cylinder moves past bottom dead center and across the auxiliary port 66, the residual fluid in the piston expands and its pressure is reduced until low pressure fluid from the main port 60 is drawn past the one way valve 82 and into the auxiliary port 66 as the piston 42 creates a suction as it withdraws from the cylinder 34. When the cylinder moves out of communication with the auxiliary port 66 and into communication with the main port 60, the pressure of the fluid in the cylinder 34 is substantially the same as the pressure of the fluid in the main port 60, so no shock noise occurs. The cylinder has thus completed a 360 degree transit around the valve plate without any appreciable shock noise occurring.

When the pressures are reversed, so the machine is motoring or overhauling, the outlet 20 becomes the low pressure end and the inlet 18 becomes the high pressure end. Thus, high pressure fluid enters at the main port 60 and leaves at the main port 62 as low pressure fluid. This change in pressures causes the shuttle valve member 96 to shift to the right, as shown in FIG. 3A. The machine will now operate without shock noise as described above while delivering fluid in the same direction.

If this pump is to be used for reversible flow, a reversing valve is required in the hydraulic main ports 18 and 20. A reversing valve 300 is shown interconnected to the ports 18 and 20 by means of conduits 302 and 304 respectively. The valve 300 is comprised of a multiported valve body 306 having a three spool valve member 308 slidable therein to alternately connect the load to either the inlet 18 or the outlet 20. Movement of the valve member 308 is controlled by a cam means 310 which connects to the valve member 308 by means of a control rod 312.

The cam means 310 includes a lower portion for controlling movement of the valve member 308 and an upper portion for controlling movement of the swash plate 48. The lower portion is comprised of an lower surface 314 and an upper surface 315. When the control rod 312 bears upon the upper surface 316, the valve member 308 is moved to the left, as illustrated in FIG. 3. If the cam were moved so the control rod 314 bore upon the lower surface 314, the valve member 308 would shift to the right.

The upper portion of the cam means 310 consists of two sloped planar surfaces 318 and 320 which form an obtuse angle having a vertex at a point 322. A control rod 324 rides along the surfaces 318 and 320 and has its other end linked to the control shaft 50 of the swash plate 48. Thus the stroke of the pump is controlled by movement of the cam means 300 so that the stroke is reduced from full stroke at the upper end of 318 to zero at 322 and then back to full stroke again at the lower end of 320. When the stroke passes through zero (at mid-point 322), the lower portion of the cam means 300 shifts to reversing valve member 308 to reverse the flow delivered by the pump. Thus, as the stroke is raised again in the same direction, delivery of fluid to the load is increased in the reverse direction.

When the reversing valve 300 is in its neutral position, the valve member 308 blocks the piping to the load,

out provides a small by pass or crossflow between the ports for the conduits 302 and 304 to permit a small delivery of fluid from the pump to circulate through the valve plate without a build-up of pressure in the pump.

Referring now to FIG. 4, a modified form of the invention is shown, wherein a valve plate 122 is shown having elongated main ports 124 and 126 and auxiliary ports 128, 130, 132 and 134, said main and auxiliary ports being equiradially spaced from the longitudinal axis of the shaft 24. A passage or bore 136 connects the main port 124 to the inlet 18 and a passage or bore 138 connects the main port 126 to the outlet 20.

Each auxiliary port is provided with two valve controlled passages, one of which allows inflow to the auxiliary port and the other of which allows outflow from it. Each of the passages connects to a conduct which in turn connects to a flow reversing valve assembly 140.

The auxiliary port 128 is provided with a passage 142 having a one way valve 144 therein which allows only inflow to said port, and is also provided with a passage 146 having a one way valve 148 therein which allows only outflow from said port. The passages 142 and 146 connect respectively to conduits 150 and 152 which lead to the flow reversing valve assembly 140.

The auxiliary port 130 is provided with a passage 154 having a one way valve 156 therein which allows only inflow to said port, and is also provided with a passage 158 having a one way valve 160 therein which allows only outflow from said port. The passages 154 and 158 connect respectively to conduits 162 and 164 which lead to the flow reversing valve assembly 140.

The auxiliary port 134 is provided with a passage 166 having a one way valve 168 therein which allows only inflow to said port, and is also provided with a passage 170 having a one way valve 172 therein which allows only outflow from said port. The passages 166 and 170 connect respectively to conduits 174 and 176 which lead to the flow reversing valve assembly 140.

The auxiliary port 132 is provided with a passage 178 having a one way valve 180 therein which allows only inflow to said port, and is also provided with a passage 182 having a one way valve 184 therein which allows only outflow from said port. The passages 178 and 182 connect respectively to conduits 186 and 188 which lead to the flow reversing valve assembly 140.

The flow reversing valve assembly 140 is comprised of a multi-ported valve body 192 and a five spool valve member 194 slidable therein. The valve body 192 has eight equally spaced ports in both its upper and lower portions, said ports being arranged so the upper ports align directly over the lower ports. Reading from left to right in FIG. 4, the first lower port connects with the conduit 150, the second with the conduit 152, the third with the conduit 162, the fourth with the conduit 164, the fifth with the conduit 176, the sixth with the conduit 174, the seventh with the conduit 188 and the eighth with the conduit 186.

Again reading from left to right in FIG. 4, the first upper port connects with a line or conduit 196, the second with a conduit 198, the third with a conduit 200, the fourth with a conduit 202, the fifth with a conduit 204, the sixth with a conduit 206, the seventh with a conduit 208 and the eighth with a conduit 210. Since the first upper port aligns with the first lower port, the conduit 196 aligns with the conduit 150. Similarly, the conduit 198 aligns with the conduit 152, and so on.

The valve member 194 is movable within the valve body 192 to a right hand position (as shown in FIG. 4) where the second, fourth, sixth and eighth ports are open, or to a left hand position where the first, third, fifth and seventh ports are opened. Movement of the valve member 194 is controlled by a bi-directional control valve means 212 which in turn is controlled by a cam means 214.

The bi-directional control valve means 212 is comprised of a ported valve body 216 and a three spool valve mem-

ber 218 slidable within said body. The valve means 212 is connected to the valve assembly 146 by two conduits 220 and 222 which extend from ports on the top of the valve body 216 to ports in the opposite ends of the valve body 192. At the lower portion of the valve body 216, three ports are provided to connect the conduits 220 and 222, through the valve means 212 to a sump or reservoir 224 which contains a fluid of suitable characteristic for operating or moving the valve member 194. A line or conduit 226, having a pump 228 therein, leads from the sump 224 to one of the ports in the lower portion of the valve body 216, and a branch line 230 of the conduit leads to another port in the lower portion of the valve body 216. Another conduit 232 leads from the lower portion of the valve body 216 to the sump 224.

The valve member 218 is alternately and selectively movable to connect the sump 224 with the conduits 222 which in turn carry fluid to the valve assembly 146 to move the valve member 194 to compensate for the direction of flow. For example, the valve member 218 is shown in the position which will accommodate flow from right to left, as seen in FIG. 4. The pump 228 pumps fluid from the sump 224 through the conduit 226, the branch line 230 and the conduit 220 and into the valve body 192. This fluid causes the valve member 194 to shift to the right, thus opening the second, fourth, sixth and eighth ports in the valve body 192. Any excess fluid which was contained on the right side of the valve body 192 is forced out by the valve member 194, and it flows through the conduit 222, through the valve body 216 and through the conduit 232 into the sump 224.

If it is desired to have flow from left to right, the valve member 218 is moved to the right. The pump 228 then pumps fluid from the sump 224 through the conduit 226 and the conduit 222 into the valve body 192, where it will force the valve member 194 to move to the left, thus exposing or opening the first, third, fifth, and seventh ports in the valve body 192.

A control rod 234 extends between the valve member 218 and the cam means 214 for the purpose of controlling movement of said valve member. The cam means 214 includes a lower portion for controlling movement of the valve member 218 and an upper portion for controlling movement of the swash plate 48.

The lower portion of the cam means 214 is comprised of an upper surface 236 and a lower surface 238. When the control rod 234 bears upon the upper surface 236, the valve member 218 is moved to the left, as illustrated in FIG. 4. If the cam were moved to the control rod 234 bore upon the lower surface 238, the valve member 218 would shift to the right.

The upper portion of the cam means 214 consists of a sloped planar surface 240. A control rod 246 rides along the surface 240 and has its other end linked to the control shaft 50 of the swash plate 48. Thus, it can be seen that as the cam means 214 moves, the inclination of the swash plate is changed from full stroke inclination (at the highest point of surfaces 240) to no inclination (at mid point 244), to full stroke inclination in the opposite direction (at the lower point of surface 240). When the control rod 246 is at the point 244, the control rod 234 is midway between the surfaces 236 and 238, thus causing the valve member 218 to assume the neutral center position.

The conduits which lead from the upper ports of the valve body 192 of the valve assembly 140 are connected to the main ports 124 and 126, either directly or by passing through an overhauling valve means 248. The overhauling valve means comprises a multi-ported valve body 250 having a three spool valve member slidable therein to alternately cover and expose certain of said ports.

The conduits 196 and 206 merge together to form a single conduit which connects into a port on the lower portion of the valve body 250. The conduits 198 and 204

likewise merge together to form a single conduit which connects into a port on the lower portion of the valve body 250. The conduits 200 and 202 merge together to form a single conduit which connects into another conduit 254 which in turn connects to the inlet 18 (and thus also to the main port 124). The conduits 208 and 210 merge together to form a single conduit which connects into another conduit 256 which in turn connects to the outlet 20 (and thus also to the main port 126).

The conduit 254 connects, at its upper end, into a port on the upper portion of the valve body 250. A branch line 258 extends from the conduit 254 into another port on the upper portion of the valve body 250. The conduit 256 connects, at its upper end, into a port on the upper portion of the valve body 250, said port being located between the ports which connect to the conduit 254 and the line 258.

A branch line 260 extends from the conduit 254 into a port on the left end of the valve body 250. A branch line 262 extends from the conduit 256 into a port on the right end of the valve body 250. Fluid flow through these branch lines 260 and 262 determines the position of the overhauling valve member 252. If high pressure exists at the outlet 20 and low pressure exists at the inlet 18, the fluid pressure in the branch line 262 will exceed that in the branch line 260, thus causing the valve member 252 to shift to the left. If conditions are reversed, so the inlet is at high pressure and the outlet is at low pressure, the valve member 252 will shift to the right, as shown.

Operation (FIG. 4)

The system shown in FIG. 4 is capable of operating under all the conditions recited hereinabove; namely, pumping or overhauling in either direction. Since the operation of the machine is substantially the same for all the different conditions, with only the valve positions varying, it is not deemed necessary to illustrate all conditions. The various conditions, and the various valve positions necessary for achieving such conditions, are presented in the following table. Orientation is as illustrated in FIG. 4.

Operation	Flow Direction	Valve Member Position		
		Valve 252	Valve 194	Valve 218
Pumping.....	Right to Left...	Right...	Right...	Left...
Do.....	Left to Right...	Left...	Left...	Right...
Overhauling.....	Right to Left...	do.....	Right...	Left...
Do.....	Left to Right...	Right...	Left...	Right...

As can be seen by comparing the table and the drawing, FIG. 4 illustrates the first condition in the table; that is, pumping with a flow from right to left.

Under such conditions, as a cylinder 34 rotates into communication with the main port 126, fluid at low pressure is drawn into that cylinder as the piston 42 within that cylinder withdraws. As the cylinder moves out of communication with the main port 126 and into communication with the auxiliary port 134, the outflow passage 170 is closed and the inflow passage 166 connects to the main port 126. Fluid continues to be drawn into the cylinder. At bottom dead center (BDC), the piston 42 is furthest withdrawn from the cylinder 34.

As the cylinder moves into communication with the auxiliary port 130 and the piston 42 starts to move back into the cylinder, it compresses the fluid contained therein and raises its pressure. When the pressure is raised to the pressure of the outlet port 124, fluid flows through the outflow passage to main port 124. Thus, as the cylinder moves into communication with the main port 124, the pressure in the cylinder is substantially the same as that in the main port, so no shock noise occurs.

As the cylinder rotates past the main port 124 and into communication with the auxiliary port 128, high

pressure fluid from the cylinder continues to enter the main port 124 through the outflow passage 146. At top dead center (TDC), the piston 42 is furthest into the cylinder, and the fluid in the cylinder is at high pressure at least equal to that in the main port 124.

As the cylinder moves past top dead center and into communication with the auxiliary port 132, the piston 42 starts to withdraw from the cylinder, thus lowering the fluid pressure in the cylinder by allowing such fluid to expand. When the pressure has lowered to the pressure of the main port 126, fluid will be drawn into the cylinder from the main port through the inlet passage 178. When the cylinder finally rotates back into communication with the main port 126, the pressure in the cylinder is substantially the same as the pressure in the main port, so no shock noise occurs. At this point, the cylinder will have completed a 360 degree, substantially silent transit.

In light of the above description of operation, the operation of the machine for the other conditions listed in the above table becomes obvious. It can thus be seen that the present invention provides a silent fluid transfer device which can be used for pumping fluid from low pressure to high pressure in either direction (i.e. either left to right or right to left) and which can also be used for overhauling or motoring fluid from high pressure to low pressure in either direction.

It will be understood that various changes in the details, materials, steps and arrangements of parts, which have been herein described and illustrated in order to explain the nature of the invention, may be made by those skilled in the art within the principle and scope of the invention as expressed in the appended claims.

What is claimed is:

1. In a hydraulic power transmission machine of the type having an inlet, an outlet, a rotatable barrel with a plurality of equally spaced cylinders arranged parallel to the axis of rotation of said barrel, a plurality of pistons located one within each cylinder, and adjustable cam means to move said pistons axially along axis of rotation as said barrel is rotated, that improvement for permitting silent flow between said cylinders and said inlet and outlet, which comprises in combination with said machine:

a valve plate having a plurality of apertures and a plurality of valve controlled passages therein; and an overhauling valve means including a movable valve member, the position of which is determined by the pressure differential existing between said inlet and outlet;

said valve plate apertures also comprising a pair of spaced opposed elongated main ports and two pairs of spaced opposed auxiliary ports, each of said auxiliary ports communicating with a pair of valve controlled passages, the pair being comprised of one passage having an inflow valve and of one passage having an outflow valve;

each of said four pair of passages being connected to a flow reversing valve means which alternately closes one of the passages of each pair and opens the other of said passages, the direction of fluid flow within said machine determining which passage of each pair will be open and which will be closed, the passages being arranged so that the open passages will always comprise two outflow passages and two inflow passages, and thus the closed passages will always comprise the same, one of said passages connecting its associated auxiliary port to one of said main ports, another of said passages connecting its associated auxiliary port to the other of said main ports, the other two auxiliary ports being connected by said passages to said overhauling valve means which alternately connects such associated auxiliary ports to one or the other of said main ports depending upon the position of said movable valve member, which in turn depends upon whether the machine is operating as a pump or as a fluid motor;

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two of said auxiliary ports having valve controlled passages which allow only inflow to their associated auxiliary ports and the other two of said auxiliary ports having valve controlled passages which allow only outflow from their associated auxiliary ports, said passages being so connected that one inflow and one outflow passage connect to said overhauling valve means, and one inflow and one outflow passage connect to said main ports.

2. A machine as defined in claim 1 wherein the passages which are opened by said flow reversing valve are arranged so that one open inflow passage connects its associated auxiliary port to a main port and one open outflow passage connects its associated auxiliary port to the other main port, the other open inflow passage and the other open outflow passage connecting their associated auxiliary ports to an overhauling valve which alternately connects such associated auxiliary ports to one or the other of the main ports depending upon whether the machine is operating as a fluid motor.

3. A machine as defined in claim 1 wherein movement of said flow reversing valve is controlled by a bi-directional control valve means which in turn is con-

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trolled by a movable cam means, said bi-directional control valve means being movable by said cam means to selectively admit pressurized fluid to either the sinistral or dextral end of said flow reversing valve means, said pressurized fluid thereby causing said flow reversing valve means to shift to a position at the end opposite to that end at which said pressurized fluid enters.

4. A machine as defined in claim 3 wherein said movable cam means comprises two cam portions, one of which controls the position of said bi-directional control valve means and the other of which controls the position of said variable cam means.

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LAURENCE V. EFNER, *Primary Examiner*.