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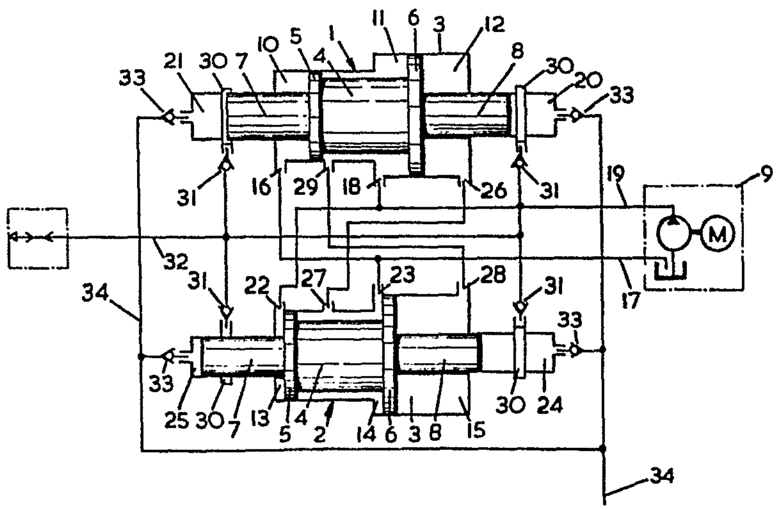
(54) **Continuous flow positive displacement pumps.**

(57) A pumping device comprising two or more hydraulic cylinder arrangements, each comprising a double ended piston the ends of which alternately pump fluid from an outlet in a respective piston cylinder. The pump is powered by a common hydraulic fluid supply which supplies motive power to each of the hydraulic cylinder arrangements and the outlets of the piston cylinders are all connected to a common outlet. An hydraulic cylinder arrangement is caused to start progressively to pump as a second hydraulic cylinder arrangement progressively and in a manner inversely proportional to the first ceases to pump.



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CONTINUOUS FLOW POSITIVE DISPLACEMENT PUMPS

The present invention relates to a piston pump capable of pumping liquid at very high pressure and maintaining constant pressure and flow rate.

In order to pump a liquid at high pressure it is known to provide a reciprocating pump comprising a number of independently operating cylinder arrangements each arranged to operate equally out of phase with respect to one another, the outputs of which are summed to provide a relatively smooth constant output.

However, whilst such pumps are capable of developing very high pressure outputs they require a multiplicity of pistons and associated valves and it is virtually impossible to smooth out completely pulsations in the pump output caused as a result of the independent cyclical operation of each cylinder. These pulsations in the pump output can cause fluctuations in the flow rate and pressure levels of the liquid pumped, which in turn can lead to noise and vibration in the circuit through which the liquid is pumped and otherwise result in a quality of flow which would be unacceptable in many applications.

It is an object of the present invention to provide a pump in which pulsation in the output thereof is minimised.

According to a first aspect of the present invention there is provided a pumping device comprising two or more hydraulic cylinder arrangements, each comprising a double ended piston the ends of which alternately pump fluid from an outlet in a respective piston cylinder, a common outlet to which said piston cylinder arrangements are all connected, a common hydraulic fluid supply whereby motive power is supplied to each of the hydraulic cylinder arrangements, and means whereby an hydraulic cylinder arrangement is cuased to start progressively to pump as another hydraulic cylinder arrangement progressively and in a manner inversely proportional to the former ceases to pump.

Preferably the pumping device comprises means whereby the outlet from a piston cylinder is progressively restricted as the piston thereof sweeps the inside thereof so as to cause the hydraulic cylinder arrangement which is comprised of the piston cylinder to gradually cease pumping such that hydraulic fluid is diverted therefrom to another hydraulic cylinder arrangement which commences to pump.

Alternatively, the pumping device may comprise means whereby the hydraulic fluid return from a piston cylinder is progressively restricted as hydraulic fluid is pumped therethrough.

According to a second aspect of the present invention there is provided a method of pumping fluid at high pressure using a plurality of hydraulic cylinder arrangements operated by high pressure hydraulic fluid and each comprising a double ended piston, the ends of which alternately pump fluid from an outlet in a respective piston cylinder into a common outlet, wherein as a piston sweeps a respective piston cylinder a deceleration of the piston and a consequent diversion of high pressure hydraulic fluid to another of the hydraulic cylinder arrangements takes place, such that a piston of one of the other hydraulic cylinder arrangements begins to accelerate into its respective cylinder arrangement and to pump fluid when the pressure developed thereby rises to that in the common outlet.

An embodiment of the present invention will now be described, by way of example, with reference to the accompanying drawing which shows a schematic diagram of a pump embodying the present invention, comprising two hydraulic cylinder arrangements.

By way of explanation pulseless pumps find application in situations where it is required to convey fluid at very high pressure. One such application is in a pump for pumping water from a mine shaft or workings. In this situation it is necessary for the pump to be able to develop a force sufficient to overcome the head and other losses encountered passing the water up through the distance required. A second application is in rock cutting and drilling machines having a rotating cutting head. By directing a fine water jet under high pressure onto the rock immediately ahead of the cutting tool vibration at the cutting head is reduced, the useful life of the cutting head is increased, a reduction in horsepower to drive the cutter for the same cutting rate is possible and rock of a higher compressive strength can be cut than hitherto. In this application it is necessary to generate the high water pressure as close to the cutting tool as possible and avoid the danger of exposed high pressure hoses. The simplicity of this principle facilitates a compact design housable in the rotating components of the cutting head.

Referring to the accompanying drawing there is shown a schematic diagram of a pump embodying the present invention comprising two identical cylinder/piston arrangements 1 and 2. The arrangements 1 and 2 each comprise a cylinder casing 3, the internal diameter of which varies along its length to slidably accommodate therein a piston assembly 4 having two unequal diameter lands 5 and 6, and two equal diameter piston rods 7 and 8. The piston assemblies 4 are both slidably actuated within their respective casings by a supply of hydraulic fluid delivered from and returned to the same hydraulic fluid supply 9.

The cylinder casings 3 of arrangements 1 and 2 are each divided by the lands 5 and 6 of their respective piston assemblies 4 into three separate chambers 10, 11 and 12, and 13, 14 and 15 respectively. The effective cross-sectional area of each of the chambers 10, 11, 13 and 14 is the same, but the effective cross-sectional area of chambers 12 and 15 is twice that of any one of the chambers 10, 11, 13 and 14.

Chamber 10 is continually open to low pressure via the hydraulic fluid return port 16 and return line 17, and chamber 11 is continually open to high pressure via hydraulic fluid inlet 18 and supply line 19. In consequence there exists across the piston assembly 4 a force continually biasing the piston assembly 4 in such a direction as to reduce the volume of piston rod chamber 20 and increase the volume of piston rod chamber 21. However, movement in this direction can only occur if chamber 12 is connected to the low pressure return side of the hydraulic fluid supply 9. If, on the other hand, the chamber 12 is connected to the high pressure side of the supply 9 then the force exerted on the piston assembly 4 is greater than the bias and the piston assembly 4 will move in the opposite direction thereto. From the above it will be appreciated that if things are so arranged that the chamber 12 is exposed to a continuously alternating source of high pressure hydraulic fluid and low pressure hydraulic fluid the piston assembly 4 will reciprocate back and forth at a frequency equal to that of the alternating hydraulic source.

Referring now to arrangement 2, chamber 13 is continually open to high pressure via hydraulic fluid inlet 22 and supply line 19, and chamber 14 is continually open to low pressure via hydraulic fluid return port 23 and return line 17. In consequence, there exists across the piston assembly 4 a force continually biasing the piston assembly 4 in such a direction as to reduce the volume of piston rod chamber 24 and increase the volume of piston rod chamber 25. However, movement in this direction can only take place if chamber 15 is connected to the low pressure return side of the hydraulic fluid supply 9. If the chamber 15 is connected to the high pressure side of the supply 9 then the force exerted on the piston assembly 4 is greater than the bias and the piston assembly 4 will move in the opposite direction thereto. Again, it will be appreciated that if the chamber 15 is exposed to a continuously alternating source of high pressure hydraulic fluid and low pressure hydraulic fluid the piston assembly 4 will reciprocate back and forth at a frequency equal to that of the alternating hydraulic source.

In the arrangement of the accompanying drawing it will be seen that the chamber 12 is connected to the low pressure side of the supply 9 via a port 26, a port 27, chamber 14, return port 23 and return line 17. Therefore, the piston assembly 4 of arrangement 1 is moving towards piston rod chamber 20. On the other hand, the chamber 15 is connected to the high pressure side of supply 9 via a port 28, a port 29, chamber 11, hydraulic fluid inlet 18 and supply line 19. Therefore, the piston assembly 4 of arrangement 2 is moving towards piston rod chamber 25.

As the piston assembly 4 of arrangement 1 continues to move as described above the land 5 progressively isolates port 29 from chamber 11 and therefore high pressure, and opens it to chamber 10 and therefore low pressure. Once this occurs the piston assembly 4 in arrangement 2 is free to move towards piston rod chamber 24. As the piston assembly 4 in arrangement 2 moves towards piston rod chamber 24 the land 5 thereof progressively isolates port 27 from chamber 14 and therefore low pressure, and opens it to chamber 13 and therefore high pressure. This results in the piston assembly 4 of arrangement 1 moving towards piston rod chamber 21. As the piston assembly 4 of arrangement 1 moves towards piston rod chamber 21 the land 5 thereof isolates port 29 from chamber 10, and therefore low pressure, and opens it to chamber 11, and therefore high pressure. As a result the chamber 15 of arrangement 2 is subject to high pressure which results in the piston assembly 4 thereof moving towards piston rod chamber 25. Finally, as the piston assembly 4 of arrangement 2 moves towards piston rod chamber 25 the land 5 thereof progressively isolates port 27 from chamber 13, and therefore high pressure, and opens it to chamber 14 and therefore low pressure. As a result the chamber 12 of arrangement 1 is subject to high pressure and the piston assembly 4 thereof moves towards piston rod chamber 21. The above described sequence of events is then repeated all over again.

As the piston assembly 4 of each arrangement 1 and 2 moves towards a piston rod chamber the piston rod therein displaces fluid therefrom through an annular recess 30 and a fluid outlet valve 31 into a high pressure outlet manifold 32. Each piston rod chamber also comprises a fluid inlet valve 33 which allows fluid to be admitted to the piston rod chamber from a low pressure supply manifold 34 as the piston rod thereof retreats from the piston rod chamber.

Consider now the case where the piston assembly 4 of arrangement 1 is moving towards piston rod chamber 20. As the piston assembly 4 begins to move it will accelerate to a constant velocity and will possess a predictable amount of kinetic energy. As the piston assembly 4 continues to move the land 5 thereof will cross port 29 which will signal the piston assembly 4 in arrangement 2 to move towards piston rod chamber 24. However, as the force urging the piston assembly 4 to move is equal to the force driving the piston assembly 4 of arrangement 1 and as the cross-sectional area of each of the piston rods is the same, it follows that the pressure developed in piston rod chamber 24 is equal to the pressure in chamber 20 and outlet manifold 32. As a result the piston assembly 4 in arrangement 2 is in equilibrium. As the piston assebly 4 in arrangement 1 continues to move towards chamber 20, piston rod 8 progressively closes the annular recess 30 in piston rod chamber 20 and moves over the land extending therebeyond which restricts the discharge of fluid from chamber 20 and results in a rise in the pressure of the fluid contained in chamber 20 occasioned by the progressive transfer of energy accumulated by the piston assembly 4 during its acceleration period. As the energy transfer takes place the piston assembly velocity reduces and so the rate at which chamber 11 can accept fluid progressively reduces causing a rise in the pressure of the fluid in the hydraulic fluid supply line 19, and so the state of equilibrium of the piston assembly 4 of arrangement 2 is destroyed and the piston assembly 4 thereof commences to move towards chamber 24 displacing the fluid contained in chamber 24 into the outlet manifold 32 via annular recess 30 and outlet valve 31.

The hydraulic fluid supply 9 is selected to provide hydraulic fluid at a constant flow rate and so as the velocity of the piston assembly 4 of arrangement 1 decreases the surplus hydraulic fluid is diverted to and accepted by the piston assembly 4 of arrangement 2 so that the change in velocity of one piston assembly 4 is inversely proportional to that of the other. Thus, as the flow rate from piston rod chamber 20 into the outlet manifold 32 decreases the flow rate from chamber 24 increases in an inversely proportional manner and the summation of the two flow rates at any time during the changer over period will be equal to the flow rate delivered by one piston rod when travelling at full velocity. Thus, the flow rate passing from the outlet manifold 32 will be constant. As the piston assembly 4 of arrangement 1 comes to rest the piston assembly 4 of arrangement 2 reaches full velocity and as the land 5 thereof crosses port 27 it establishes the piston assembly 4 of arrangement 1 in a state of equilibrium, as described hereinbefore. As the piston rod 8 of arrangement 2 crosses the annular recess 30 of piston rod chamber 24 the piston assembly 4 begins to decelerate as the piston assembly

4 of arrangement 1 begins to move in the direction of piston rod chamber 21. Thus, by the time the piston assembly 4 of arrangement 1 reaches full velocity the piston assembly 4 of arrangement 2 has come to rest. As the piston assembly 4 of arrangement 1 continues to move towards piston rod chamber 21 the land 5 thereof crosses port 29 and causes the piston assembly 4 of arrangement 2 to adopt a state of equilibrium in readiness to move towards chamber 25. When the piston rod 7 of arrangement 1 crosses the annular recess 30 in the piston rod chamber 21 thereof the piston assembly 4 of arrangement 1 begins to decelerate and the piston assembly 4 of arrangement 2 begins to move towards piston rod chamber 25. As the piston assembly 4 of arrangement 1 comes to rest the piston assembly 4 of arrangement 2 reaches full velocity and as it continues to move the land 5 thereof crosses port 27. At this point the piston assembly 4 of arrangement 1 is placed in a state of equilibrium in readiness to move towards piston rod chamber 20. As the piston assembly 4 of arrangement 2 continues to move piston 7 crosses the annular recess 30 in piston rod chamber 25 and the piston assembly 4 of arrangement 1 begins to move

in the direction of piston rod chamber 21, and so a new cycle begins.

The pressure differential established between the annular recess 30 and the chamber of the control device when the piston rod enter its piston rod chamber is increased by the degree of penetration of the piston rod into the piston chamber, but is decreased by a reduction of flow rate and is otherwise controlled by the choice of clearance between the diameter of the piston rod and the diameter of the piston rod chamber wall so that for a given resistance to flow in the outlet manifold a constant pressure level is maintained.

It will be appreciated that the smooth operation of the pressure intensifier according to the present invention is dependant upon the smooth deacceleration of an already moving piston assembly and the smooth acceleration of a piston assembly which is beginning to move. In order to ensure a smooth transfer from one piston assembly to another the shape of each piston rod, to provide a gap along which fluid can pass back to the output valve from the piston rod cylinder when the end face of the piston rod has passed the outlet valve, is best determined by a computer simulation. However, to the person skilled in the art this should not present any real problems.

Whilst the pump described with reference to the accompanying drawing comprises only two cylinder/piston arrangements it will be appreciated that more may be used. Where the number of cylinder/piston arrangements are even the connections to each cylinder/piston arrangement are the same as those for the two cylinder arrangement. That is the high pressure inlet and the low pressure return are the reverse in each cylinder/piston arrangement from those of its immediate neighbours. However, where an odd number of cylinder/piston arrangements are provided the high pressure inlets are each taken to ports corresponding to ports 16 and 22 of the arrangements 1 and 2 in the accompanying drawing and the low pressure returns are each taken to ports corresponding to ports 18 and 23 of arrangements 1 and 2 in the accompanying drawing.

It will be appreciated that for any number of cylinder/piston arrangements operation of the pump according to the present invention is the same as that described hereinabove for the two cylinder/piston arrangement pump. In this respect, when the pump commences operation one of the cylinder/piston arrangements will commence to pump fluid from one of its piston rod chambers depnding on the direction of movement the piston assembly thereof. As the piston assembly passes the switching port of the cylinder/piston arrangement movement of one of the remaining cylinder/piston arrangements is initiated, although it does not commence until the pressure exerted thereby rises to that in the common outlet.

In order to ensure that the piston assemblies, all commencing to move in the hydraulic fluid reservoirs from the same position do not each cover their respective ports to the large pressure switching diameter of the neighbouring arrangement and thus jam the pump, the port of one of the arrangements may be larger than the others, or the land of one of the piston assemblies which covers the port may be slightly smaller is size.

Finally, it will be appreicated that the present invention is not limited to restricting the cylinder outlets from which fluid is pumped. The present invention may also be embodied in an arrangement in which the hydraulic fluid low pressure returns are progressively restricted as the respective piston assemblies move to pump hydraulic fluid from the piston cylinder arrangements. This arrangement is particularly useful where the fluid to be pumped is lumpy in nature and therefore will not easily pass through a restricted cylinder outlet.

CLAIMS:

1. A pumping device comprising two or more hydraulic cylinder arrangements, each comprising a double ended piston the ends of which alternately pump fluid from an outlet in a respective piston cylinder, a common outlet to which said piston cylinder arrangements are all connected, a common hydraulic fluid supply whereby motive power is supplied to each of the hydraulic cylinder arrangements, and means whereby an hydraulic cylinder arrangement is caused to start progressively to pump as another hydraulic cylinder arrangement progressively and in a manner inversely proportional to the first ceases to pump.

2. A pumping device according to claim 1, wherein the pumping device comprises means whereby the outlet from a piston cylinder is progressively restricted as the piston thereof sweeps the inside thereof.

3. A pumping device according to claim 2, wherein the fluid outlet is located in the side of the piston cylinder and the means restricting the fluid outlet comprises the piston which progressively restricts it as it passes thereover.

4. A pumping device according to claim 1, wherein the pumping device comprises means whereby the hydraulic fluid return from a piston cylinder is progressively restricted as hydraulic fluid is pumped therethrough.

5. A method of pumping fluid at high pressure,

using a plurality of hydraulic cylinder arrangements operated by high pressure hydraulic fluid and each comprising a double ended piston, the ends of which alternatively pump fluid from an outlet in a respective piston cylinder into a common outlet, wherein as a piston sweeps a respective piston cylinder a deceleration of the piston, and a consequent diversion of high pressure hydraulic fluid to another of the hydraulic cylinder arrangements takes place, such that a piston of one of the other hydraulic cylinder arrangements begins to accelerate into its respective cylinder arrangement and to pump fluid when the pressure developed thereby rises to that in the common outlet.

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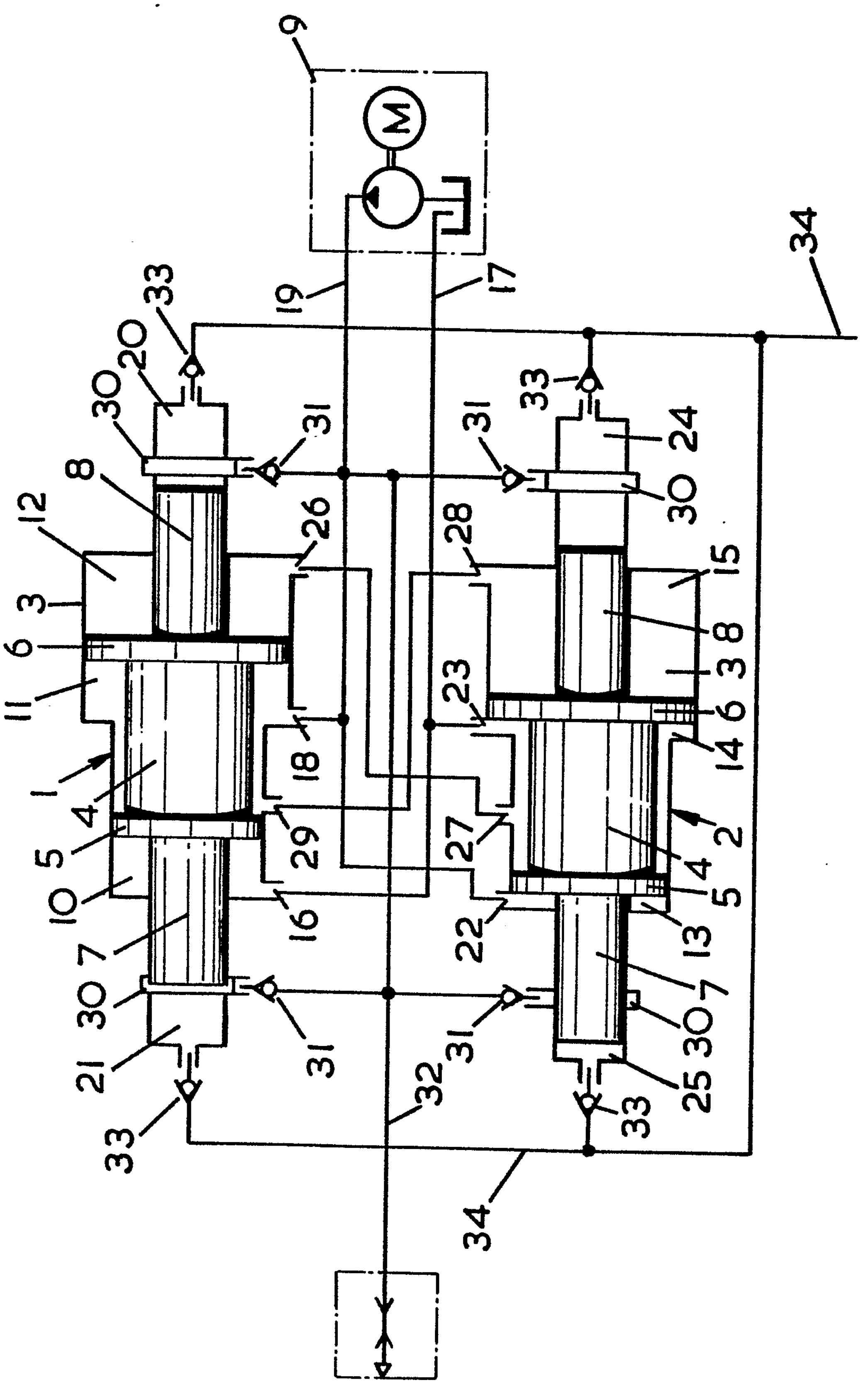

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