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(54) **Separate hydraulic systems arranged in parallel, especially for a ship's steering apparatus.**

(57) In order that separate hydraulic systems A,B, e.g. in a ship's steering apparatus, may be simultaneously operated it is necessary to equalize the pressure between the pumps 10, 11 in the respective systems A,B.

Preferably, this is accomplished by interposing piston and cylinder assembly 128 between respective pump actuating rods 141, 143. During steering, pressures of respective systems A,B, are applied to assembly 128 at inlets 122, 121. If there is an imbalance in said pressures, piston 123 and trunnion 124 move, thereby altering the effective length of lever 125 until the stroke of pump 10 is equal to that of pump 11.

Other methods of equalising pressure between pumps 10, 11 include providing pressure sensitive control valves or spill valves between each side of each system A,B.

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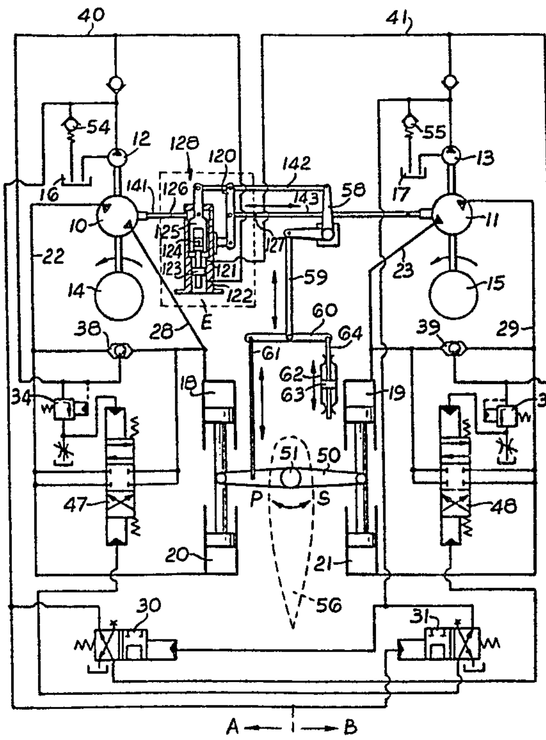
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Fig. 2

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HYDRAULICALLY OPERATED APPARATUS

SPECIFICATION

This invention relates to hydraulically operated apparatus, particularly but not exclusively steering apparatus for use in ships and incorporating an automatic failsafe system.

Hydraulic steering apparatus for ships normally have duplicated pump systems and either single or double-acting cylinders. Either one of the pump systems is capable of fulfilling normal steering requirements using all the cylinders with the other pump system as a standby in case of failure of the first system.

Although there are, in effect, two separate halfpower steering gears, each on its own capable of steering the ship in an emergency, the two steering gears are not isolated from each other. In the majority of known systems, the two steering gears are connected in parallel. The reason for the interconnection of the gears is that it is necessary to keep the hydraulic pressure balanced between the working cylinders so that they share the load evenly.

A weakness of such an interlocking system is that if one pump fails and breaks up, debris may be carried around the common system and cause failure of the second pump and thus complete failure of the steering apparatus.

Similarly a failure in one part of the hydraulic circuit due to say a broken pipe or connection would also be common to both systems and could cause complete failure of the steering apparatus due to loss of hydraulic fluid.

There is therefore a good case for having two completely separate hydraulic systems. Such systems which have been produced to date have used only one pump and one pair of cylinders at any one time with the other pair of cylinders by-passing, i.e. acting as an auxiliary system which is brought into operation only if the main system fails.

A major disadvantage of such apparatus is that each pump and cylinder pair must be large enough to meet a full steering load. This results in a steering gear of twice normal size and a proportionate increase in cost. There is also a decrease in efficiency due to the drag of the standby steering gear and a certain degree of imbalance in rudder torque due to using only half the number of cylinders.

The reason why separate systems have not been run together in the past is because similar pumps do not necessarily have identical discharge rates and similar actuators do not always have identical displacements. Even small differences between corresponding pumps or actuators in the steering gears may result in one or other of the steering gears taking a disproportionate share of the load.

An object of the present invention is to provide hydraulically-operated apparatus, particularly steering apparatus for use in a ship, which does not have the aforementioned disadvantages.

With this object in view, the present invention provides fluid-actuated apparatus comprising separate first and second hydraulic systems, each system including a fluid pump and associated pipelines, characterised in that means are provided for automatically equalising pressure between the pumps in the respective systems which are thereby capable of operating simultaneously.

Preferably, said means comprises a piston and cylinder assembly located between the pump actuating rods and automatically adjusting the stroke of the one pump in relation to that of the other pump. With such an arrangement, the piston and cylinder assembly would only be operated when the pressure of the pump in the one system differed from the pressure of the pump in the other system.

Alternatively, where each hydraulic system includes a piston and cylinder assembly (e.g. in ships steering apparatus), said means for automatically equalising pressure between the pumps in the respective hydraulic systems comprise a spill valve located between the two sides of each respective system and operable by a control valve in a pressure line from the respective pump to open and there by establish fluid communication between each side of each cylinder in the respective system.

With the aforesaid arrangement, the spill valve of each system would only be opened when the pressure of the pump in the respective system exceeded the pressure of the pump in the other system, except in the event of a leakage in the apparatus.

In a further embodiment, said means for automatically equalising pressure between the pumps in the respective systems may comprise a control valve located between the sides of each respective system and electrically operable by a transducer in the pressure line from the respective pump to establish fluid communication between each side of each cylinder in the respective system. Electrical operation of such a control valve may be accomplished by a circuit including a "Wheatstone bridge" arrangement.

Any of the aforesaid types of apparatus may also advantageously include means for detecting fluid leakage, means for automatically isolating the system in which the fluid leak is disposed and means for automatically deactivating the pump in the system in which the fluid leak is disposed.

The invention will be described further, by way of example, with reference to the accompanying drawings in which:

Fig. 1 is a schematic diagram of a conventional ship's steering apparatus with the cylinders connected in parallel;

Fig. 2 is a schematic diagram of a preferred embodiment of hydraulically operated apparatus in accordance with the present invention in the form of a ship's steering apparatus; and

Fig. 3 is an enlargement of the piston and cylinder assembly indicated at E in Fig. 2;

Fig. 4 is a schematic diagram of a second embodiment of hydraulically operated apparatus in accordance with the present invention in the form of a ship's steering apparatus;

Fig. 5 is a schematic diagram of a third embodiment of the invention which is similar to the second embodiment but is in the form of winch-actuating apparatus;

Fig. 6 is a schematic diagram of a fourth embodiment of hydraulically operated apparatus in accordance with the present invention in the form of a ship's steering apparatus;

Fig. 7 is a schematic diagram of a fifth embodiment of a ship's steering apparatus in accordance with the present invention which differs from the embodiment shown in Fig. 6 by having fixed delivery pumps instead of variable delivery pumps; and

Fig. 8 is a schematic diagram of a wheatstone bridge circuit which forms part of a sixth embodiment of the present invention in the form of a ship's steering apparatus.

As shown in Fig. 1, known steering apparatus comprise a symmetrical arrangement of two systems designated A and B. Each of these systems includes a respective one of variable delivery hydraulic pumps 10 and 11 associated with a respective one of boost pumps 12 and 13 which are fixed delivery pumps. Each associated pair of pumps is driven by a respective one of eletric motors 14 and 15.

Fluid reservoirs 16 and 17 are associated with systems A and system B respectively. Each system A and B also includes a respective single-acting piston and cylinder assembly 18, 20 and 19, 21 which assemblies are attached to respective ends of a tiller 50. It will be understood that, although the illustrated assemblies include only single-acting cylinders for clarity, in other known embodiments double-acting cylinders may alternatively be provided. A rudder post 51 projects through the centre of the tiller 50, the axis of the rudder post 51 extending substantially perpendicularly to the plane of the tiller 50. A rudder 56, indicated in broken lines in Fig. 1, is connected to the rudder post 51.

In system A, a fluid line 22 leads from one side of the pump 10 to the lower end of cylinder 20 and fluid line 28 leads from the other side of the pump 10 to the upper end of cylinder 18, these locations simply being the relative locations shown in the diagram. Corresponding fluid lines 23, and 29 are provided in system B to connect respective sides of the pump 11 to the cylinders 19 and 21. Each pair of lines 22, 28 and 23, 29 is connected through a respective shuttle valve 38, 39 to a respective one of pressure relief valves, 34, 35, and thence via respective 40, 41 back to the pumps 12 and 13.

Between each associated pair of pumps 10 and 12 and 11 and 13 the respective reservoir 16 and 17 a respective one of boost line relief valves 54 and 55 is provided.

The most important features of this known apparatus (in the context of the present invention) are the fluid lines 32, 33 which effectively connect fluid line 28 of system A with fluid line 29 of system B and fluid line 22 of system A with fluid line 23 of system B, respectively, thereby to equalize the fluid pressures in the two interacting systems A and B. The strokes of the respective pumps 10 and 11 will not, of course, be exactly equal even when identical pumps are employed.

Also shown in Fig. 1 are a steering wheel 74 and a toothed pinion 73 secured to a common shaft. The pinion 73 engages with two toothed racks 71 and 72 to which are attached hydraulic rams 69 and 70 respectively which work in cylinders 67 and 68 respectively. These cylinders 67 and 68 are connected through fluid lines 65 and 66 to the respective ends of cylinder 62.

As shown in the diagram, the cylinder 62 contains a telemotor receiver piston 63 connected via a differential lever system to respective pump stroke actuating rods 141 and 143. The piston 63 is located on a piston rod 64 which is attached at its upper end to a differential lever 60 and thus to a rod 61 and a connecting link 59. The aforesaid link 59 is connected via a substantially right-angled bell crank 58 to the pump stroke actuating rods 141 and 143.

If, for example, it is desired to move the rudder 56 to 10° port, the wheel 74 is turned to port, i.e. anticlockwise, by the requisite distance thereby causing the pinion 73 also to turn anticlockwise and through racks 71 and 72 respectively force ram 69 downwards and raise ram 70. The downward movement of the ram 69 forces hydraulic fluid down the line 65 into the top end of the cylinder 62 and moves the telemotor receiver piston 63 downwards for a distance equivalent to 10°.

The piston rod 64 is forced downwards so that, with the junction of the lever 60 to the rod 61 acting as a fulcrum, the differential lever 60 is turned clockwise pulling the connecting link 59 downwards and turning the bell crank lever 58 anticlockwise. This in turn pushes the pump actuating rods 141 and 143 to the left and applies stroke to pumps 10 and 11 causing them to pump fluid through lines 28 and 29 respectively to cylinders 18 and 21 respectively. As mentioned, these lines 28 and 29 and the cylinders 18 and 21 are connected by fluid line 32 so that the same pressure is applied to the pistons in the respective cylinders 18 and 21. The tiller 50 and with it the rudder 56 are thus caused to turn anticlockwise to 10^{o} from the straight ahead position.

As the rudder 56 is moving anticlockwise the connecting link 61 is pulled downwards thereby returning the differential lever 60 and the link 59 to their original positions. The bell crank lever 58 is thus caused to turn clockwise and moves the pump stroke actuating rods 141 and 143 to the right cancelling the stroke applied by the movement of the telemotor receiver piston 63.

The application and cancellation of stroke happens simultaneously and the stroke would be fully cancelled in this case when the rudder 56 reached 10^{o} port and the steering gear would come to rest.

A preferred embodiment of a hydraulically operated steering apparatus in accordance with the present invention is illustrated in Fig. 2 and incorporates a piston and cylinder assembly located between the pumps to automatically adjust thes stroke of one pump in relation to that of the other. Fluid lines permanently connecting systems A and B have therefore been dispensed with.

To save repetition of the description, the same reference numerals are used for parts which correspond to parts shown in Fig. 1. The steering wheel and associated parts have been omitted from Fig. 2 for the sake of clarity. The additional piston and cylinder assembly in the form of a unit 128 (which is shown to an enlarged scale in Fig. 3) is interposed between the steering control mechanism and the pump stroke mechanism. As shown, this unit 128 comprises a housing or cylinder 129 enclosing a forked lever 125 mounted upon a trunnion 124 which acts as a fulcrum for said lever 125. A piston 123 is suspended from the trunnion 124 into a chamber 140 having respective upper and lower inlet ports 121 and 122 respectively. The forked lever 125 is connected between the pump actuating rod 141 of the pump 10 and the bell crank 58 by way of opposing laterally projecting members 126 and 142. The trunnion 124 is connected to the pump actuating rod 143 of the pump 11 by way of a linkage 120 and a lateral member 127 fixed to the centre thereof.

Each system 'A' and 'B' has a respective one of main combined bypass and relief valves 47 and 48 connected between lines 22 and 28, and 23 and 29. Both functions of these valves 47 and 48 are controlled by respective bypass pilot valves 31 and 30. The bypass function is so arranged that with the steering gear shut down or with both systems operational the valves are closed but with one only system operational the valve on the non-operational side is open.

System B is, in this example, the master system in that the variable delivery pump 10 of system A may be varied in stroke in relation to the variable delivery pump 11 of systems B.

To describe the operation of the steering apparatus as shown in Fig. 2, it will be assumed that it is required to turn the tiller 50 in an anti-clockwise direction with both systems operational. Corresponding parts of system A and system B operate simultaneously. Pumps 10 and 11 are driven by constant running electric motors 14 and 15. In the quiescent condition the pumps 10 and 11 are in a 'no stroke' position and no pumping takes place, however, the fixed delivery boost pumps 12 and 13 maintain an initial pressure in the system.

When the steering wheel (not shown) is turned in the required direction to move the tiller 50 in an anticlockwise direction the pumps 10, 11 are put on stroke by means of the telemotor receiver piston 63 and the differential lever system in the same manner as described for the conventional apparatus in Fig. 1. Fluid is pumped along line 28, which thus becomes the pressure line of system A, while line 22 becomes the suction line. From line 28 pressure is transmitted to cylinder 18. Thus, by the pressure of the fluid, the piston in cylinder 18 is forced downwards so that the tiller moves anti-clockwise. At the same time, the fluid in system B is pumped along line 29 (the pressure line of system B) to the end of cylinder 21 which is forced upwards. Thus, force substantially equal to those exerted by system A are brought to bear on the tiller 50 by system B to turn said tiller 50 anti-clockwise.

During the aforesaid operation, the shuttle valves 38 and 39 will have been automatically actuated to permit fluid from the pressure lines 28 and 29 to flow along lines 40 and 41 respectively to the inlet ports 122 and 121 of the unit 128. If the capacity or discharge rate of the pump 11 is larger than that of the pump 10, the pressure at port 121 will be greater than the pressure at port 122 thereby causing the piston 123 and its attached trunnion 124 to move downwards. As the trunnion 124 is the fulcrum of the lever 125, this downward movement increases the effective length of the lever 125, thereby increasing the stroke of the pump rod 141 attached via the member 126 compared to the stroke of the pump rod 143 attached via the member 127. Thus, the output and pressure of the "slave" pump 10 is increased until it equals that of the "master" pump 11.

Conversely, if the pump 10 has the larger capacity, the piston 123 and the trunnion 124 will move upwards shortening the length of the forked lever 125 and decreasing the stroke of the "slave" pump 10 until it is in equilibrium with the "master" pump 11.

In the event of a leakage, for example due to a broken pipe or faulty connection, the fluid pressure in the system in which the leak is disposed will fall. A drop in pressure will actuate either bypass pilot valve 30 or 31 to cause opening of either main bypass valve 47 or 48 depending on which system has failed.

For example if a leak occurs in system 'A', then pressure drops in that system and bypass pilot valve 31 operates to let pressure from servo pump 13 of system B put valve 47 into the bypass position.

A corresponding converse sequence of events would occur if a leakage in system B instead of system A were to arise.

Although not illustrated in Fig. 2, there may be float switches located in the reservoirs 16, 17 which are operative to trigger alarms if the fluid level falls below a pre-set level in their respective reservoirs 16, 17, e.g. in the event of leakage from the respective systems A or B. Such switches may also be operative to deactivate the pump motor in the system in which the leak is disposed.

In the event of failure of one system the aforesaid operations would occur so that steering of the ship would not be interrupted. Indeed steering could be maintained indefinitely at full speed if the rudder angle was restricted to approximately 20° instead of a maximum 35°. Alternatively full rudder angle could be used if the ship's speed was reduced to approximately two thirds.

An advantage of the steering apparatus of the present invention compared to conventional steering gears with two separate hydraulic systems in that the need for apparatus of twice the size required for normal steering operation is obviated. Moreover, compared with steering gears having a common hydraulic system the complete separation of the two systems prevents the failure of one pump affecting the other as there is no common system around which debris might be carried. Hydraulic failure in one system does not affect the other system.

The principles involved in the aforesaid embodiment, particularly the location of the piston and cylinder assembly between the pump actuating rods of the two hydraulic systems, may equally as well be applied to other hydraulical apparatus as to a ship's steering gear.

Fig. 4 illustrates a second, less sophisticated embodiment of the present invention as applied to a ship's steering apparatus. This apparatus is not as satisfactory as that shown in Fig. 2 as it requires additional control valves, which are, of course, susceptible to malfunction just as any moving working parts.

Again, parts corresponding to the steering apparatus of Fig. 1 are given the same reference numerals, and only features of the apparatus over and above the previously described apparatus will now be described. The steering wheel and associated parts have again been omitted for the sake of clarity.

As shown in Fig. 4, in system A, the shuttle valve 38, provided between lines 22 and 28, ensures that whichever of these two lines is carrying hydraulic fluid away from the pump 10, i.e. whichever is acting as a pressure line, is connected via line 40 through a common directional control valve 42 and an isolating valve 44 to the relevant side of a piston 45 in a cylinder 46. The corresponding shuttle valve 39 between lines 23 and 29 of system B connects the pressure line via line 41 through the common directional control valve 42 and the isolating valve 44 to the relevant side of the piston 45 in the cylinder 46.

In use, in the quiescent condition, the boost pumps 12 and 13 maintain an initial pressure in the system limited to about 10 Bars to supply servo pressure to operate the control and isolating valves 42, 44 respectively while the main pumps 10 and 11 are not on stroke.

Whenever a steering operation is initiated (by movement of the ship's steering wheels in the manner described for the previous embodiment) the pumps 10, 11 pump fluid to the piston and cylinder assemblies 18, 20 and 19, 21. Fluid also flows along the lines 40, 41 through the common directional control valve 42 to the relevent sides of the piston 45 in the cylinder 46. In practice, of course, the lines 40 and 41 will already contain fluid which simply transmits the pressure from the fluid in pressure lines 28 and 29 (or 22 and 23) to the opposite sides of the piston which is in balance when the pressure from lines 28 and 29 (or 22 and 23) are equal.

In a situation where the rudder 56 is being turned to port (anti-clockwise) and the discharge rate of the pump 10 is greater than the discharge rate of the pump 11, the pressure from the line 28 will be higher than the pressure from the line 29.

The common piston 45 will move towards the low pressure side, that is the line 29 of system B, thereby decreasing the stroke of the pump 10. Increasing and decreasing of the stroke of the pump 10 will continue until the pressures are equal when the relative stroke between the pumps will be stabilised.

Obviously, a similar sequence of events would cause the common piston 45 to move in the opposite direction if the pressure in the line 29 of system B were higher than the pressure in the line 28 of system A. When the tiller is being turned in clockwise directions, lines 22 and 23 become the pressure lines of system A and B respectively and the directional valve 42 reverses the respective pump pressures to opposite sides of the common piston 45.

In the event of failure of one system, the same sequence of events would occur as in the previously described embodiment. However, in this particular embodiment, each reservoir, 16, 17, contains a respective float switch 52 and 53 operative to trigger alarms and switch off the supply of power to the pumps 10 and 11 respectively when the fluid level falls below a preset level.

Again, the principles involved in this second embodiment could equally be applied to any hydraulically driven machine where the hydraulic system was duplicated to give a high degree of reliability. Fig. 5 shows a system in which the hydraulic cylinders of the steering gear have been replaced by hydraulic drive motors 80 and 81 of a winch 82. Parts corresponding to the steering apparatus of Fig. 4 are given the same reference numerals. Instead of a steering wheel and telemotor receiver piston, an actuation lever 83 for raising and lowering a load 84 on the winch 82 is attached directly to the connecting link 59.

Operation of the winch system will readily be appreciated from the foregoing. The appropriate motor 10 or 11 is put "on stroke" by actuation of the lever 83 and the pressure in the two halves, A and B of the system is equalised by the piston 45 in the cylinder 46 affecting the stroke of the pump 10 in relation to the pump 11.

Fig. 6 illustrates a further embodiment of a ship's steering apparatus in accordance with the present invention. In this case equalisation of pressure between the pumps of the respective systems A and B is achieved by spill valves located between the sides of each system, as will now be explained.

The diagram is not exactly comparable to Figs. 1 to 5 as the two systems A and B are shown in the upper and lower halves of the page rather than at right and left sides. Also, there are four double acting piston and cylinder assemblies acting onthe tiller compared to two in the previous examples and the arrangement of fluid lines differs. Nevertheless, to save duplication, the same reference numerals are used for comparable parts wherever appropriate. For clarity, the steering control mechanism has been completely omitted.

In system A, fluid line 22 leads from one side of pump 10 to fluid lines 24, 26 which are respectively connected to the upper end of cylinder 88 and the lower end of cylinder 90, these locations simply being the relative locations shown in the diagram. Similarly, fluid line 28 leads from the other side of the pump 10 to fluid lines 130, 132 respectively connected to the lower end of cylinder 88 and to the upper end of cylinder 90. Corresponding fluid lines 23, 25, 27 and 29, 131, 133 are provided in system B to connect respective sides of pump 11 to piston and cylinder assemblies 89 and 91. Each line 22, 28, 23, 29 is provided with a respective one of pressure relief valves 34, 36, 35, 37.

In system A, the shuttle valve 38 connects the pressure line 22 or 28 via line 40 to a common pressure control valve 92 and to an isolating valve 94. In system B, the corresponding shuttle valve 39 connects pressure line 23 or 29 via line 41 to the common pressure control valve 92 and a respective isolating valve 95.

Each system A and B, has a respective one of spill valves 96 and 97 between the two sides of each pump 10 and 11 (therefore also between the two sides of each cylinder) that is between lines 22 and 28 in system A and between lines 23 and 29 in system B. These spill valves 96 and 97 are operable by the common pressure control valve 92 via drain lines 98 and 99 respectively.

To describe the operation of the steering apparatus as shown in Fig. 6, it will be assumed that it is required to turn the tiller 50 in a clockwise direction. Corresponding parts of system A and system B operate simultaneously. Pumps 10 and 11 are driven by constant running electric motors 14 and 15. In the quiescent condition the pumps 10 and 11 are in a 'no stroke' position and no pumping takes place, however the fixed delivery boost pumps 12 and 13 maintain an initial pressure in the system limited to about 10 Bars to supply servo pressure to operate the control and isolating valves 92, 94 and 95 respectively while the main pumps 10 and 11 are not on stroke.

When the steering wheel (not shown) is turned in the required direction to move the tiller 50, in a clockwise direction the pump 10 in system A is put on stroke, and fluid is pumped along line 28, which thus becomes the pressure line of system A, while line 22 becomes the suction line. From line 28 pressure is transmitted via lines 130 and 132 to the lower end of cylinder 18 and the upper end of cylinder 20 respectively, as shown in the diagram. Thus, by the pressure of the fluid, the piston in cylinder 88 is forced upwards while the piston in cylinder 90 is forced downwards through exactly the same distance so that the tiller moves clockwise. At the same time, the fluid in system B is pumped along line 29 (the pressure line of system B) via lines 131 and 133 to the lower end of the cylinder 89 and the upper end of cylinder 91 respectively. Thus forces substantially equal to those exerted by system A are brought to bear on the tiller 50 by system B to turn said tiller 50 clockwise.

During the aforesaid operation, the shuttle valves 38 and 39 will have been automatically actuated to permit fluid from the pressure lines 28 and 29 to flow along lines 40 and 41 respectively to the common pressure control valve 92. In practice, the lines 40 and 41 will already contain fluid which simply transmits the pressure from the fluid in pressure lines 28 and 29 to the common control valve 42 which is in balance when the pressure from lines 28 and 29 are equal.

In a situation where the discharge rate of the pump 10 is slightly greater than the discharge rate of the pump 11, the pressure from the line 28 will be higher than the pressure from the line 29. The common control valve 92 will move towards the low pressure side, that is line 29 of system B, and at the same time will open the drain line 98 of the high pressure side, in this case system A, thus permitting the spill valve 96 to open so that hydraulic fluid spills back from line 28 to line 22, that is from the high to low pressure sides of cylinders 88 and 90. As soon as equal pressure and volume have been restored between lines 28 and 29, i.e. between pumps 10 and 11 respectively, the common pressure control valve 92 closes under the action of its spring and the spill valve 96 shuts.

Obviously, a similar sequence of events would cause spill valve 97 of system B to open if the pressure in the line 29 of system B were higher than the pressure in the line 28 of system A. Then the tiller is being turned in an anti-clockwise direction, lines 22 and 23 become the pressure lines of system A and B respectively.

In the event of a leakage, for example due to a broken pipe or faulty connection, the fluid pressure in the system in which the leak is disposed will fall. A slight drop in pressure will actuate the common pressure control valve 92 to cause opening of the drain line and spill valve in the high pressure system. However when the pressure in lines 40 or 41 falls below a pre-set level, the appropriate isolating valve 94 or 95 will move into its alternative position under the action of its spring. For example, if a leak occurs in system A, the pressure in that system drops and isolating valve 94 operates to open the drain line 98 and spill valve 96 and also to close the drain line 99 of system B, which is to maintain the ship's steering, so that spill valve 97 will not operate while there is a failure of system A.

Further fluid loss from system A lowers the fluid level in the reservoir 16 until at a pre-set level float switch 52 is actuated to trigger alarms and to switch off the motor 14.

A corresponding converse sequence of events would occur if a leakage in system B instead of system A were to arise.

In the event of failure of one system the aforesaid operations would occur so that steering of the ship would not be interrupted as previously described.

In a fifth practical embodiment of the invention, as shown in Fig. 7, fixed delivery pumps 100 and 101 and directional valves 102 and 103 are provided in place of the variable delivery and boost pumps 10 and 12 and 11 and 13 respectively and shuttle valves 38 and 39 in Fig. 6. The remainder of the steering apparatus is identical and the same reference numerals have been given to corresponding parts.

Fixed delivery pumps are less expensive than variable delivery pumps, but are only acceptable for use with small loads because unlike variable delivery pumps, they do not give the smooth acceleration and deceleration required when dealing with large loads.

In a further embodiment of the present invention, in place of a common control valve and respective spill valves for the two systems, a transducer is located in the pressure line of each system. Each transducer is capable of electrically operating a control valve in its respective system to establish fluid communication between each side of each cylinder in the respective system. An electrical circuit connecting the transducers and the control valves includes a Wheatstone bridge arrangement, as illustrated in Fig. 8.

With reference to Figs. 6 and 8, in the aforesaid embodiment, transducers R1 and R2 are installed in the equivalent lines to lines 40 and 41 respectively of Fig. 6. When a direct current is supplied to the

Wheatstone bridge circuit, which includes balancing resistances R3 and R4 as well as transducers R1 and R2, a difference in resistance between R1 and R2 (resulting from a difference in pressure between the equivalents of lines 40 and 41 of systems A and B respectively) causes a small current to flow in either line 110 or 111. This current is amplified in amplifier 113 and flows to the actuating solenoid 114 or 115 on a proportional valve 116 or 117 respectively in either system A or system B. (The proportional valves 116 and 117 and their associated solenoids are installed in place of spill valves 96 and 97 of Fig. 1). The appropriate solenoid 114 or 115 causes its associated valve 116 or 117 to open between the pressure and suction sides of the relevant system, A or B respectively, until the pressure/current difference returns to zero.

In more detail, if the resistance of transducers R1 and R2 decrease with increasing pressure and the pressure in system A is greater than the pressure in system B a current will flow via line 110 and amplifier 113 to open valve 116 and allow hydraulic fluid to pass from the pressure to the suction side of system A until the pressure between the systems A and B is equalised. Similarly, valve 117 will be opened if system B has a greater pressure than system A. In a modification where the resistances R1 and R2 increase with increasing pressure, line 110 will connect to system B valve 117 and line 111 to system A valve 116.

An advantage of the steering apparatus of the present invention compared to conventional steering gears with two separate hydraulic systems is that the need for apparatus of twice the size required for normal steering operation is obviated. Moreover, compared with steering gears having a common hydraulic system the complete separation of the two systems prevents the failure of one pump affecting the other as there is no common system around which debris might be carried.

CLAIMS

1. Fluid-actuated apparatus comprising separate first and second hydraulic systems, each system including a fluid pump and associated pipelines, characterised in that means are provided for automatically equalising pressure between the pumps in the respective systems which are thereby capable of operating simultaneously.

2. Apparatus as claimed in claim 1 wherein said means comprises a piston and cylinder assembly located between the pump actuating rods and automatically adjusting the stroke of the one pump in relation to that of the other pump.

3. Apparatus as claimed in claim 2 wherein said piston and cylinder assembly includes a lever, the fulcrum of which is movable depending on the pressure difference between the pumps to alter the effective length of said lever and thereby the stroke of the one pump in relation to that of the other pump.

4. Apparatus as claimed in claim 1 wherein each hydraulic system includes a double-acting piston and cylinder assembly and the means for automatically

equalising pressure between the two pumps comprises a spill valve located between the two sides of each respective system and operable by a control valve in a pressure line from the respective pump to open and thereby establish fluid communication between the two sides of each cylinder in the respective system.

5. Apparatus as claimed in claim 1 wherein each hydraulic system includes a double-acting piston and cylinder assembly and the means for automatically equalising pressure between the two pumps comprises a control valve located between the two sides of each respective system and electrically operable by a transducer in the pressure line from the respective pump to establish fluid communication between the two sides of each cylinder in the respective system.

6. Apparatus as claimed in claim 5 wherein the control valve is electrically operable by the transducer by way of a circuit including a Wheatstone bridge arrangements.

7. Apparatus as claimed in any preceding claim and further including means for detecting fluid leakage, means for automatically isolating, the system in which

the leak is disposed and means fora automatically deactivating the pump in the system in which the fluid leak is disposed.

8. Apparatus as claimed in claim 7 wherein the means for detecting fluid leakage comprises a float switch located in a fluid reservoir for each system.

9. Apparatus as claimed in claim 8 wherein each float switch will actuate an alarm and deactivate the pump in its respective system if the fluid in the respective reservoir fall below a pre-set level.

10. Fluid actuated apparatus substantially as hereinbefore described with reference to the embodiments illustrated in Figs. 2 and 3, Fig. 4, Fig. 5, Fig. 6, Fig. 7 or Fig. 8 of the accompanying drawings.

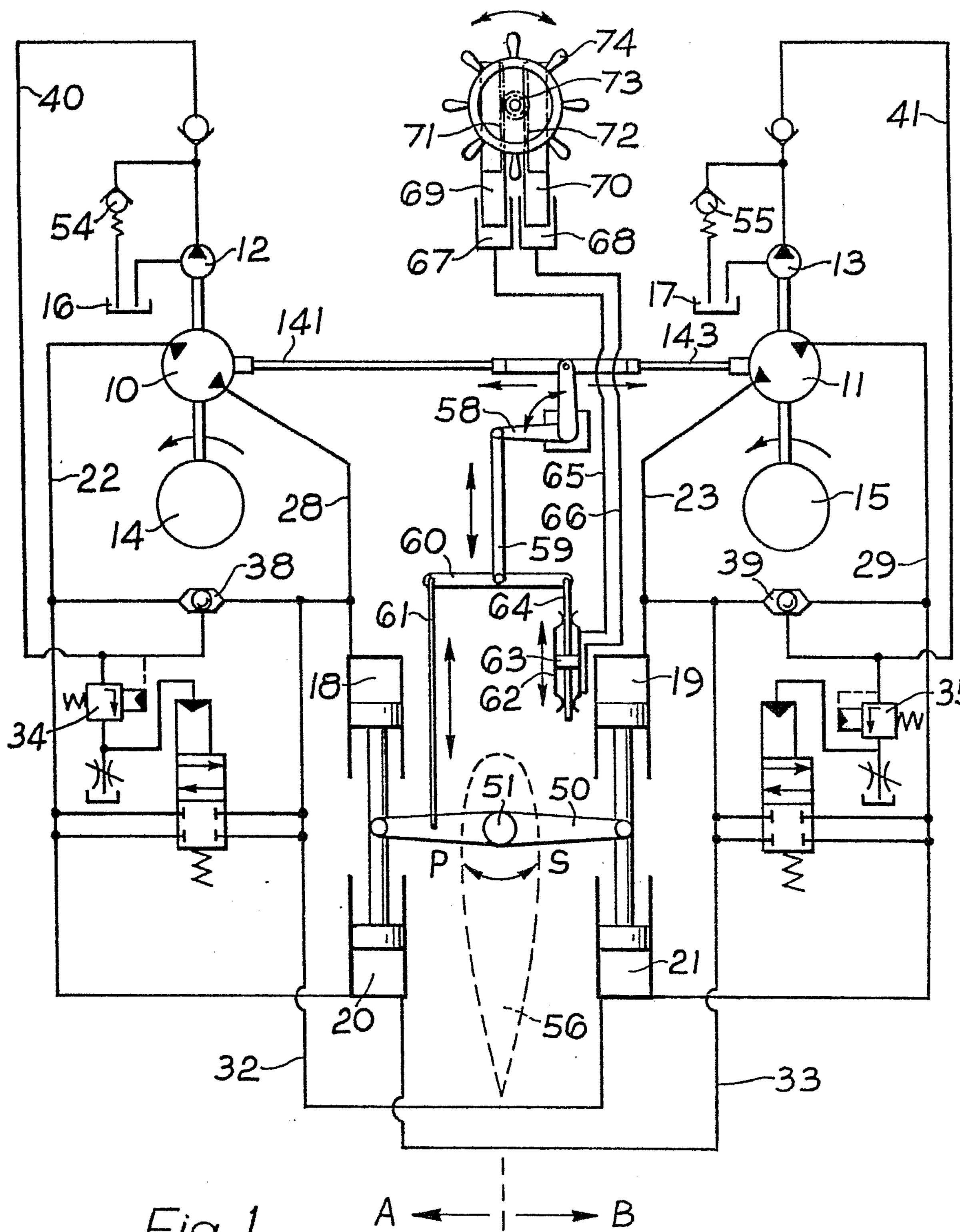
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Fig. 1

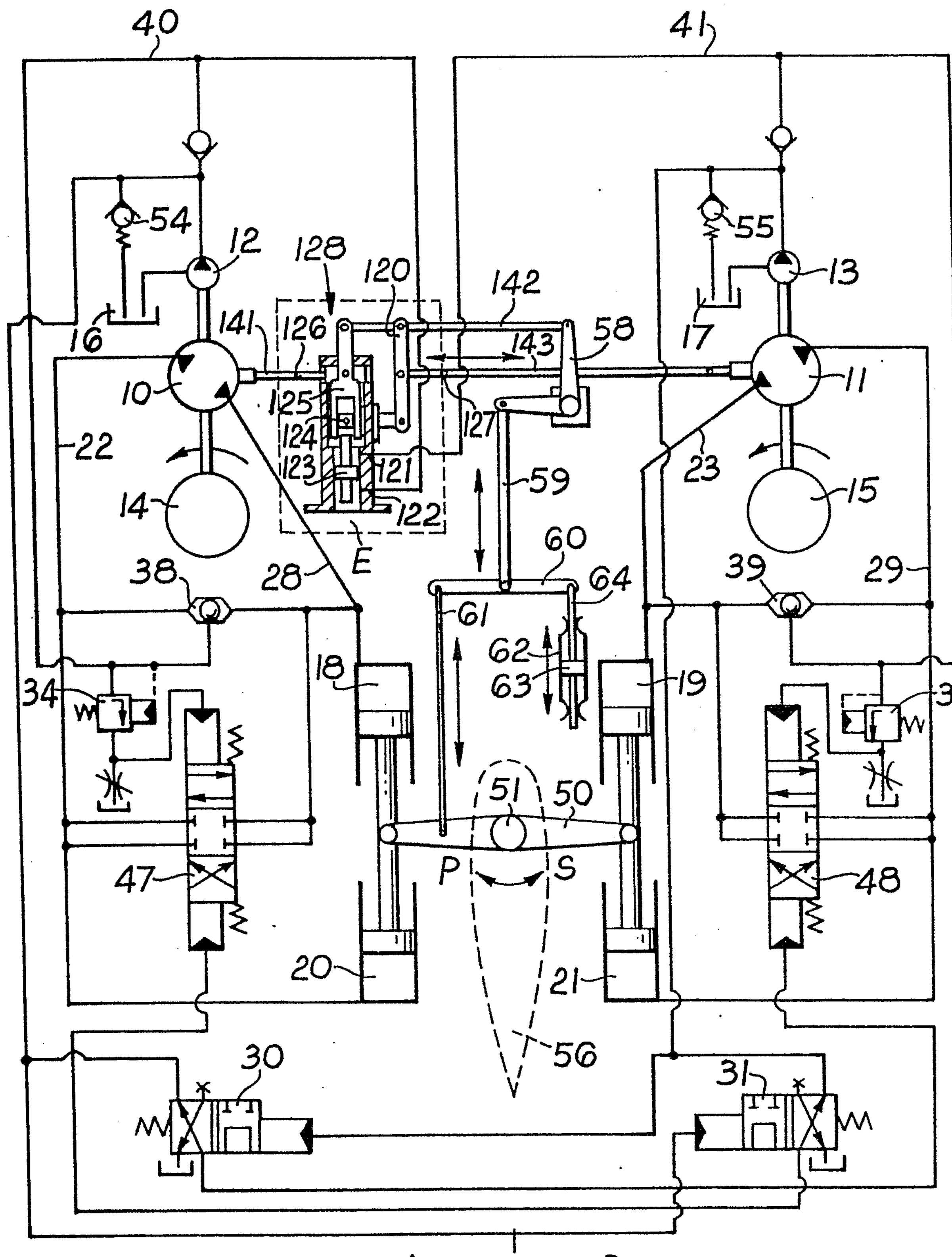
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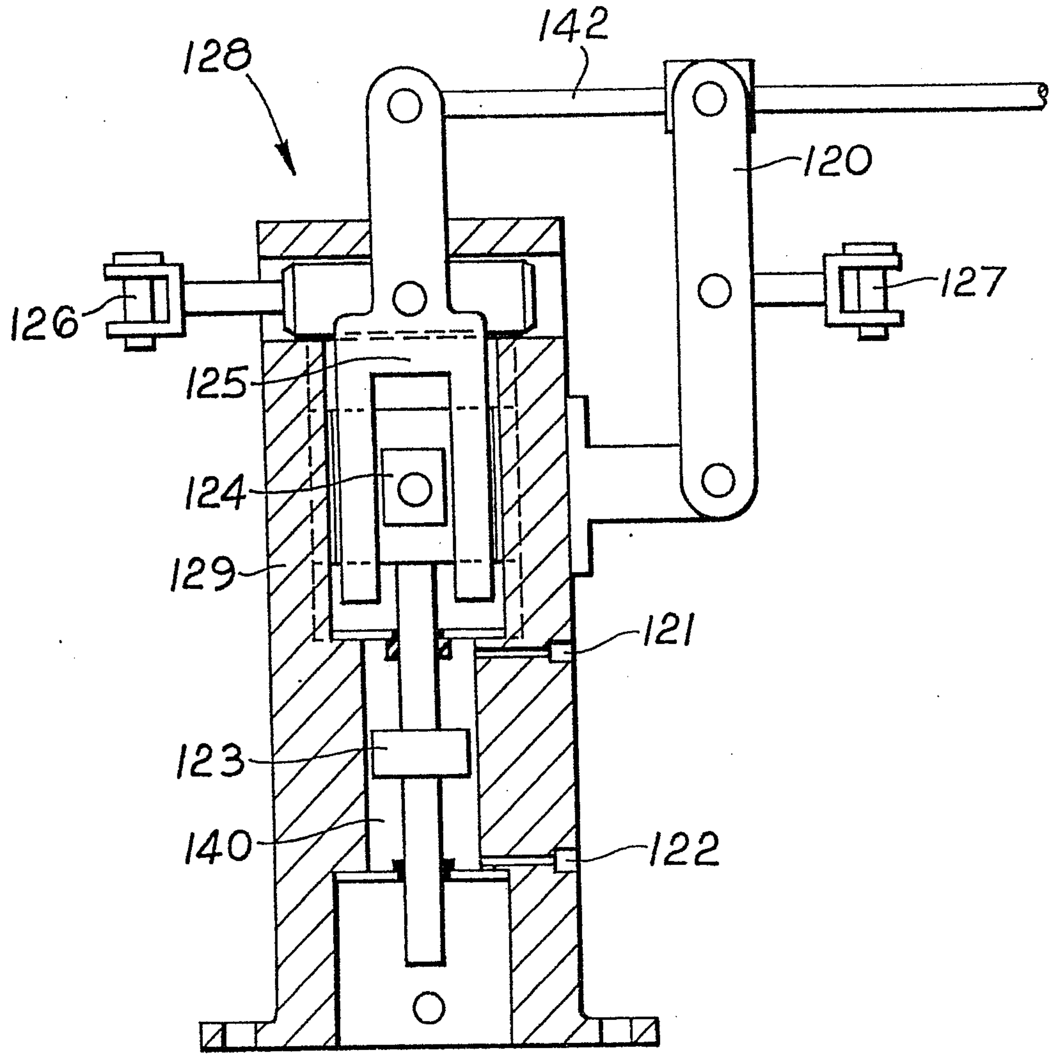
Fig. 2



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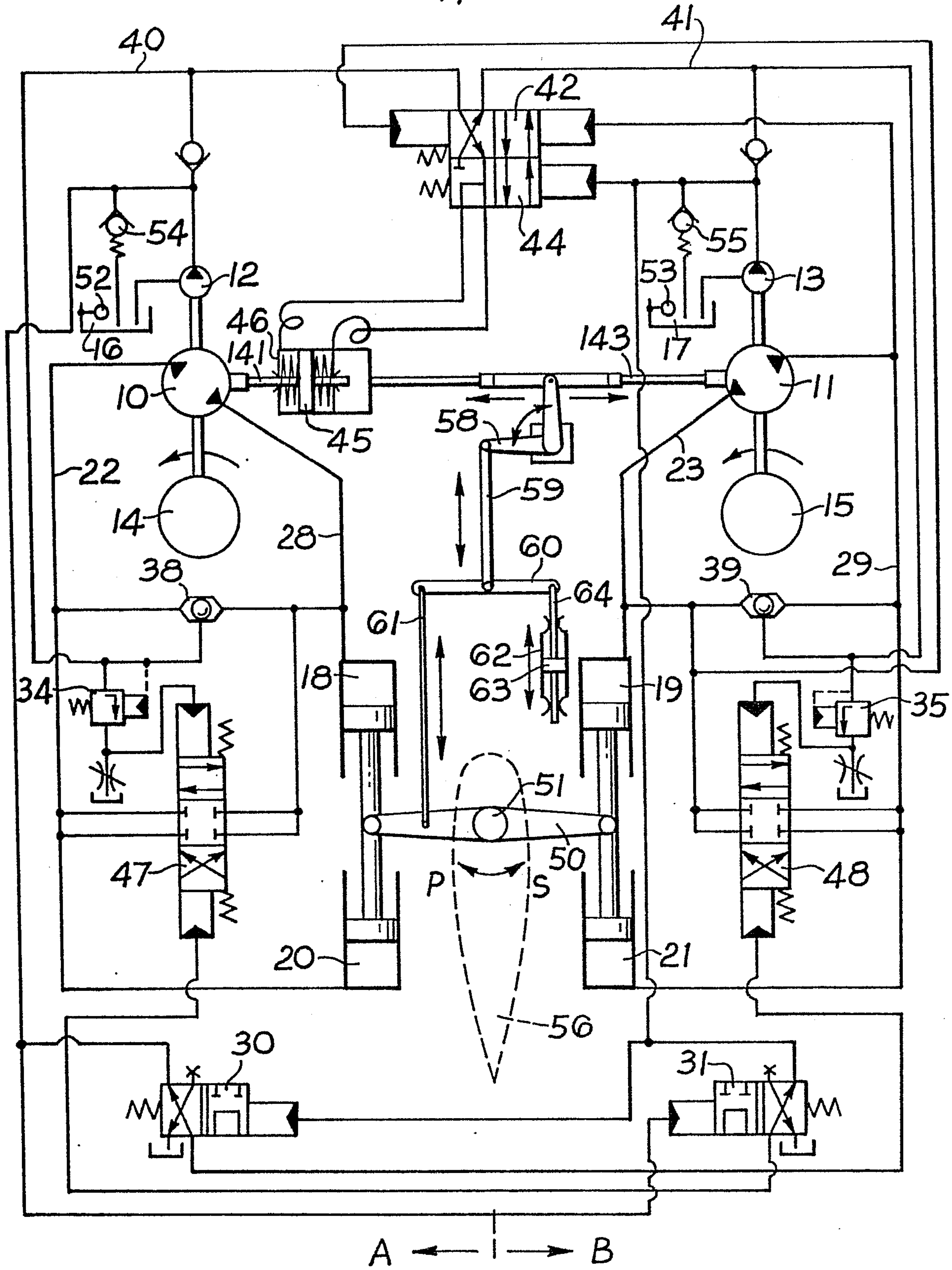
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Fig. 4

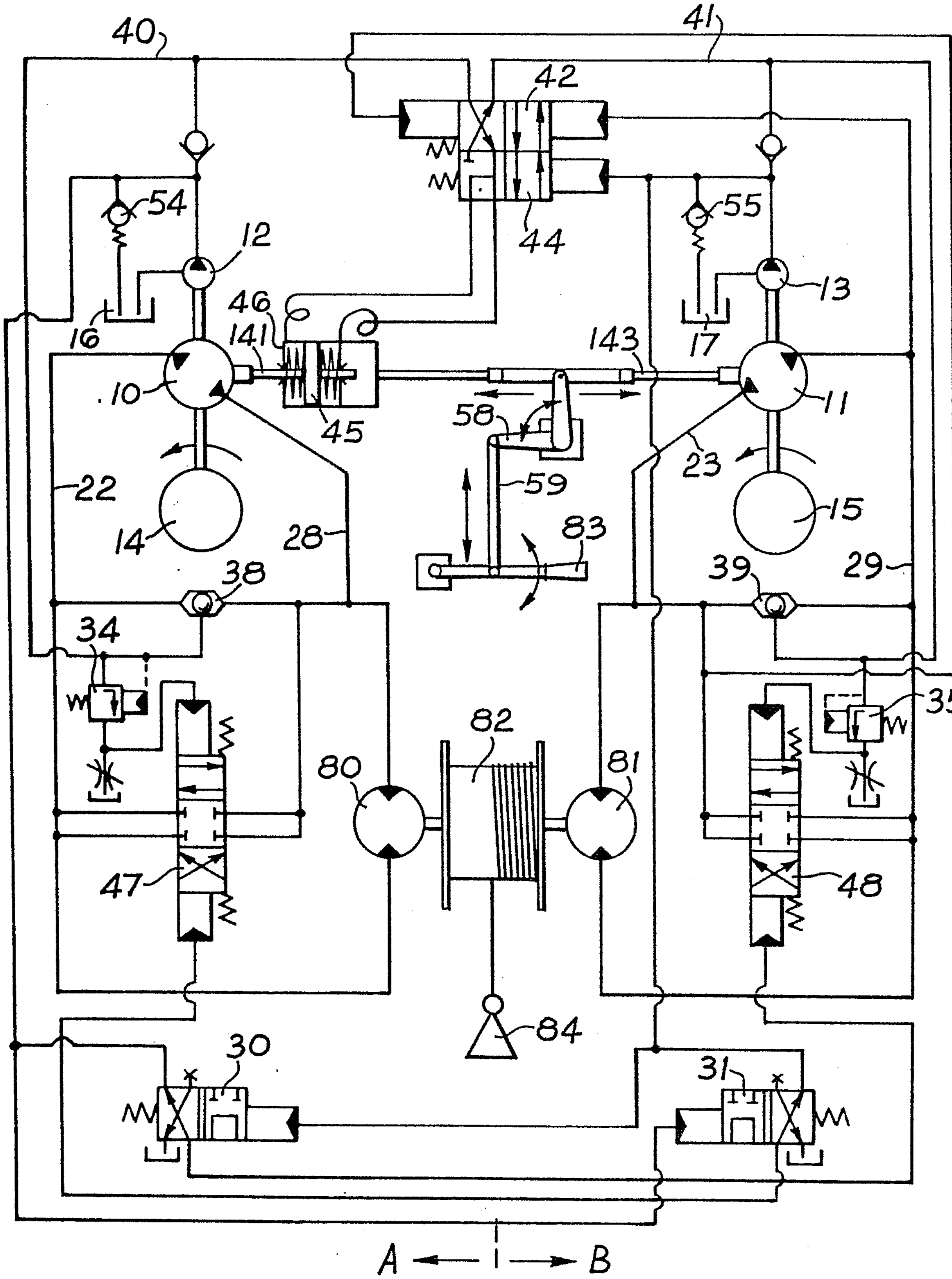
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Fig. 5

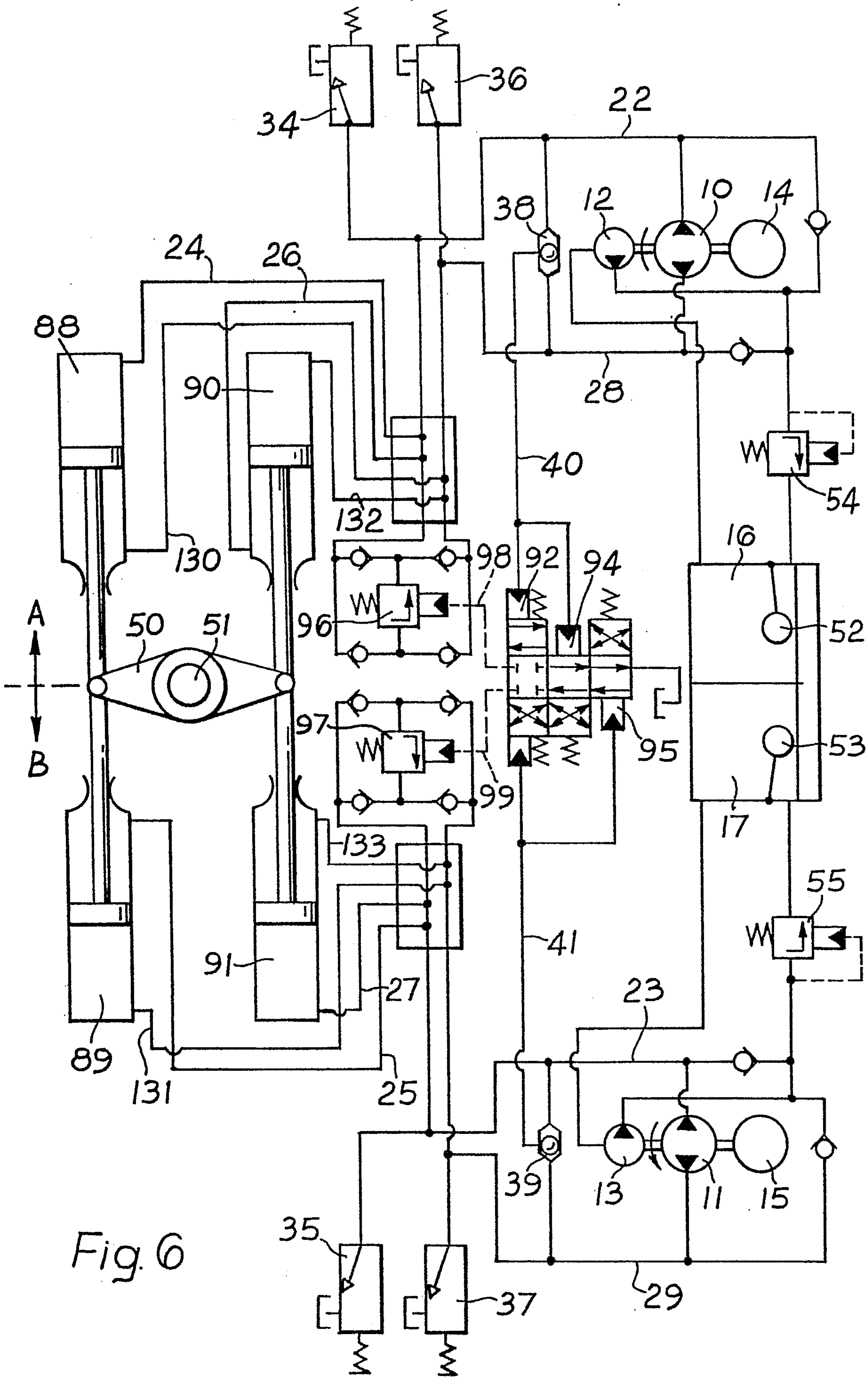

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Fig. 6

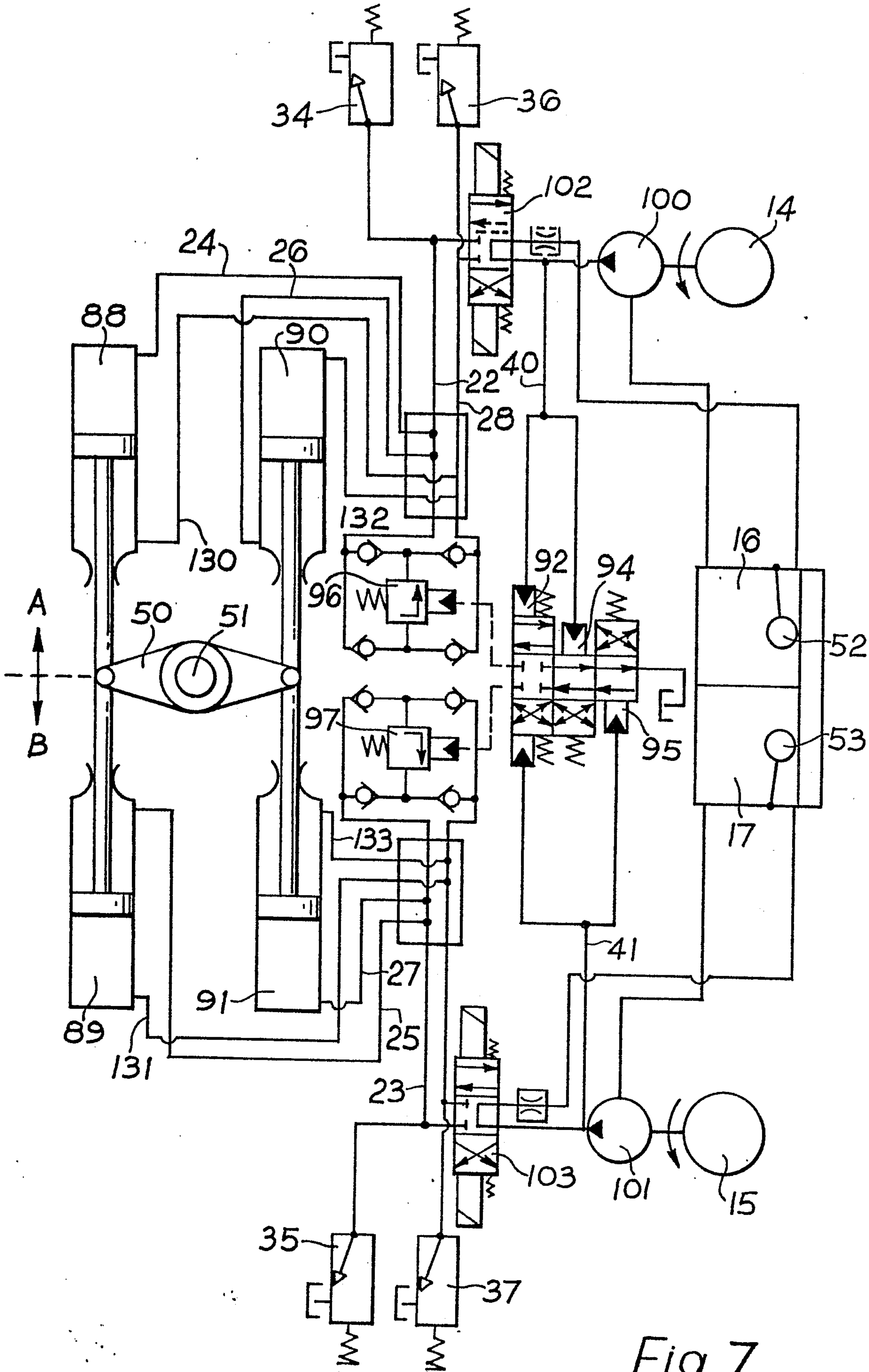
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Fig. 7

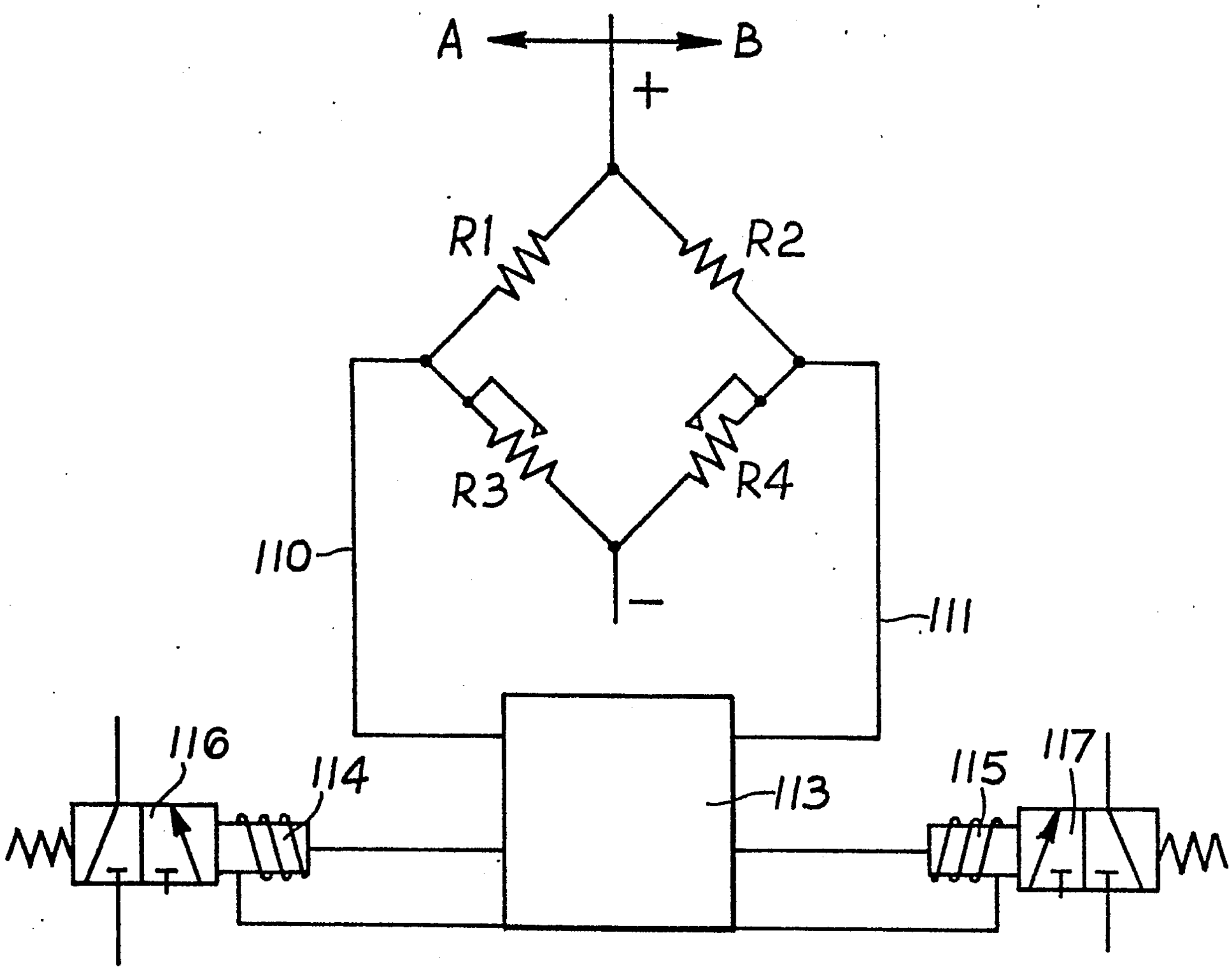

Fig. 8