May 9, 1961 R. P. HEINTZ 2,983,278

MAGNETICALLY OPERATED HYDRAULIC SERVO VALVE

Filed Dec. 26, 1956 2 Sheets-Sheet 1

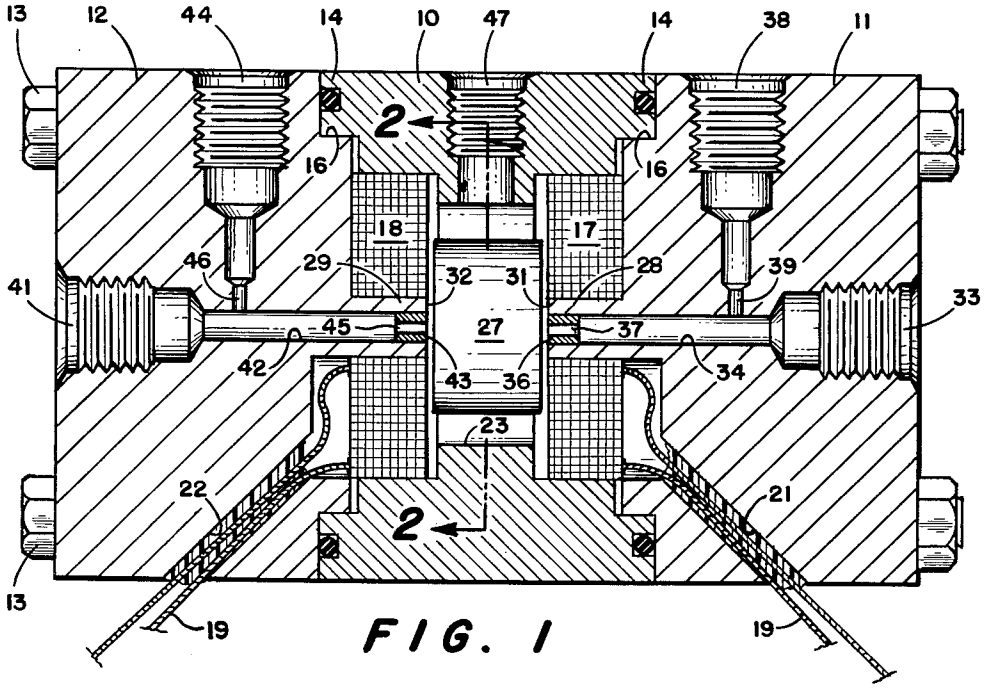


FIG. 1

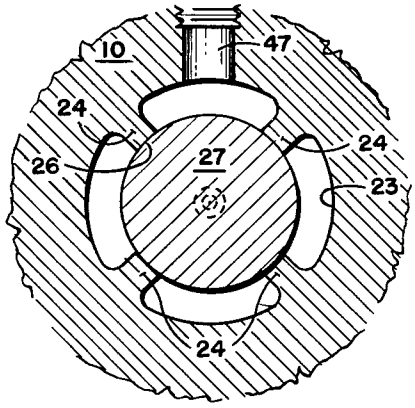


FIG. 2

INVENTOR.
RICHARD P. HEINTZ

BY

ATTORNEY

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FIG. 3

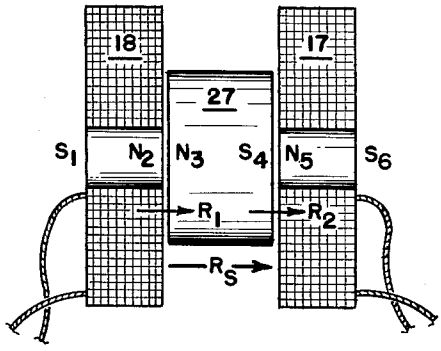
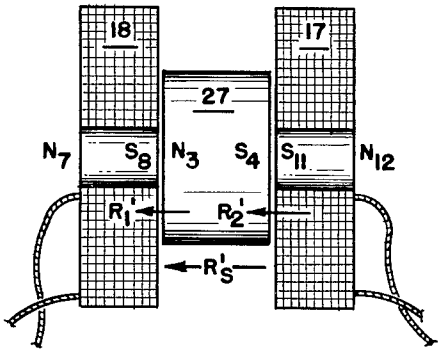


FIG. 4



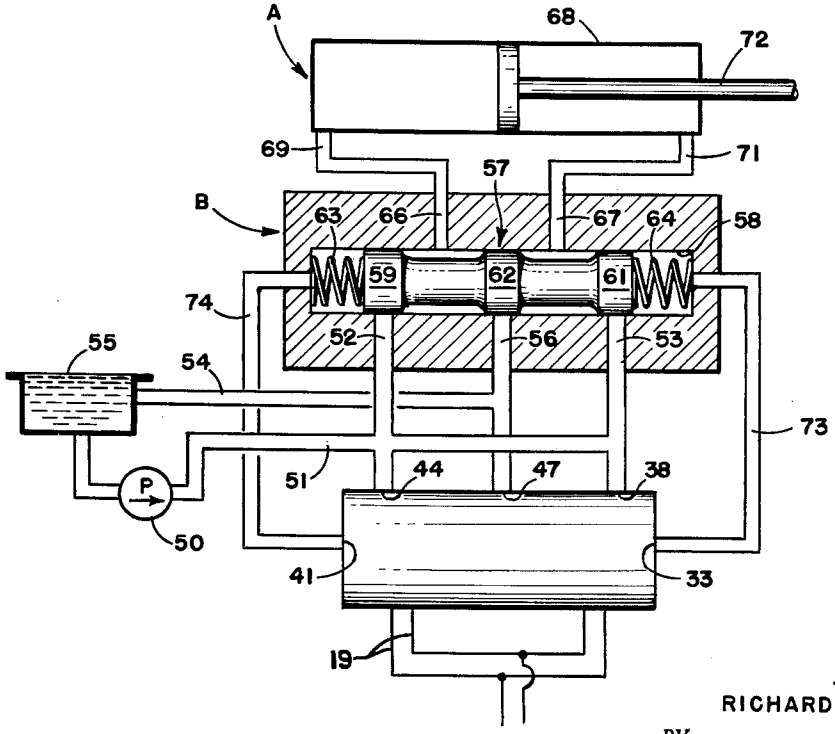


FIG. 5

INVENTOR.
RICHARD P. HEINTZ

BY

ATTORNEY

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MAGNETICALLY OPERATED HYDRAULIC SERVO VALVE

Richard P. Heintz, Kalamazoo, Mich., assignor, by mesne assignments, to Pneumo Dynamics Corporation, Cleveland, Ohio, a corporation of Delaware

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This invention relates to hydraulic control devices and more particularly to a new and improved electrohydraulic valve for controlling hydraulic fluid in response to electric signals.

It is an important object of this invention to provide an electrohydraulic control device which accurately regulates fluid pressures in response to an electrical signal.

It is another important object of this invention to provide an electrohydraulic regulator operated by small electric signals to vary the pressure of the controlled fluid.

Still another object of the invention is to provide an electrohydraulic control device utilizing a permanent magnet as a fluid control member wherein two magnetic coils cooperate to produce a force tending to move the magnet to the desired position.

It is still another object of this invention to provide an electrohydraulic regulator requiring only one moving part with no links or pivots which tend to wear and produce failure.

Further objects and advantages will appear from the following description and drawings, wherein:

Figure 1 is a longitudinal section showing the structural detail of a hydraulic regulator according to this invention;

Figure 2 is a cross section taken along line 2—2 of Figure 1;

Figure 3 is a schematic illustration of the magnetic operation when one polarity of electrical signal is provided;

Figure 4 is a view similar to Figure 3 showing the magnetic operation when the opposite polarity signal is supplied; and,

Figure 5 is a schematic illustration of one type of system in which the hydraulic regulator according to this invention is particularly suited.

Referring to the drawing, the preferred structure includes a central ring **10** and two end members **11** and **12** respectively. These members are bolted together by bolt fasteners **13** and cooperate to form the body assembly of the device. The ring **10** is formed with axially extending shoulders which fit into an annular groove **16** formed in each of the end members **11** and **12** to radially locate the members. A pair of electromagnetic coils **17** and **18** are positioned within the ring **10** adjacent to the end members **11** and **12** respectively. Suitable lead wires **19** connect the coils **17** and **18** and pass through passages **21** and **22** formed in the end members **11** and **12** respectively to the outside of the device. Preferably the passages **21** and **22** are filled with potting compound after the lead wires **19** are in position so that the passages are sealed around the lead wires to prevent leakage of fluid out of the device and the ring **10** is formed with a central cylindrical bore **26** in which is slidably mounted a cylindrical permanent magnet **27**. The inner wall of the bore **26** is grooved to form passageways **23** divided by lands **24**. The permanent magnet **27** has an axial length slightly less than the space between the electromagnetic coils **17** and **18** so that it is free to slide between the coils while being radially restrained by the lands **24**. The end members **11** and **12** are each formed with projections **28** and **29** respectively which project through the coils **17** and **18** and terminate at opposed parallel faces **31** and **32** which are flush with the associated faces of the electromagnetic coils **17** and **18** respectively and perpendicular to an axis of the magnet **27**.

The end member **11** is formed with a threaded aperture **33** from which extends a small bore **34**, having a nozzle **36** press fitted within one of its ends. Positioned in the inner end of the reference bore **34**, with a press fit, this nozzle is formed with an accurately sized restricted orifice **37** which connects between the bore **34** and the bore **26**. Also formed in the end member **11** is a threaded inlet port **38** connected to the bore **34** by an accurately sized restricted passage **39** and to a source of fluid under pressure by a suitable hose connection (not shown). The end member **12** is also formed with a threaded aperture **41** similar to the aperture **33**, a bore **42** similar to the reference bore **34**, a nozzle **43** provided with an orifice **45** similar to the orifice **37** and an inlet port **44** similar to the inlet port **38** connected to the bore **42** by a restricted passage **46** similar to the restricted passage **39**. The inlet port **44** is connected to the same source of fluid under pressure as the inlet port **38** by a suitable hose connection (not shown). The passages **39** and **46** are made of the same length and diameter as accurately as possible so that equal flows of liquid through the passages will be produced for a given pressure drop across the passages. Likewise the nozzles **36** and **43** are formed identical to each other so that a given pressure drop across each nozzle will create an equal amount of flow in each nozzle. A reservoir return port **47** which opens into one of the grooves **23** is formed in the ring **10** to exhaust the flow of fluid through the nozzles **36** and **43**.

Those skilled in the art will recognize that if the magnet **27** is positioned an equal distance from the nozzles **36** and **43** there will be an equal amount of flow through the two nozzles and the pressure within the bores **34** and **42** will be equal. Therefore, when the magnet **27** is in the center position, there will be an equal flow through the two passage systems and there will be an equal pressure drop across the restricted ports **39** and **46** and another equal pressure drop across the nozzles **36** and **43** so the two bores **34** and **42** will be at the same pressure. If, however, the magnet **27** is shifted to the left toward the nozzle **43** there will be an increased resistance to flow through the nozzle **43** and a decrease in the resistance to flow through the nozzle **36**. This will cause the pressure in the bore **42** to increase due to the decreased flow through the nozzle **43** and at the same time cause the pressure in the bore **34** to decrease due to the increased flow through the nozzle **36**. When the magnet **27** is in its center position and there is equal flow through the two nozzles **36** and **43** the fluid forces on the magnet are balanced. If, however, the magnet is shifted to the left or right there is an increase in the pressure of the stream of hydraulic fluid passing through the nozzle toward which the magnet moves. Simultaneously the pressure of the other stream decreases so there is an unbalance of the liquid forces acting on the magnet **27** which urges it back toward the center or neutral position. Those skilled in the art will recognize that the magnitude of the centering fluid force will be a function of the displacement of the magnet from the center position just as the pressure differential between the two reference bores **34** and **42** is a function of the displacement of the magnet. Therefore, the differential pressure between the two reference bores **34** and **42** will be a function of the forces other than the hydraulic forces urging the magnet from its center position since the magnet **27** reaches equilibrium when the hydraulic forces acting thereon balance the other forces operating on the magnet.

Reference should now be made to Figures 3 and 4 for the electrical operation of the device. The two electromagnetic coils 17 and 18 are wound and connected so that an electrical signal supplied to the coils produces magnetic fields in the two coils having opposite polarities. Assuming that the magnet 27 has a polarity as indicated in Figure 3 with a north pole N_3 to the left, the south pole is toward the right as indicated by S_4 and that the coils are energized to provide a south pole S_1 to the left and a north pole N_2 to the right in the coil 18 and a north pole N_5 to the left and a south pole S_6 to the right in the coil 17, the magnet 27 will move to the right as a result of the magnetic forces created. Because the poles N_2 and N_3 are adjacent and similar there will be a repelling force R_1 urging the magnet 27 to the right and the two poles S_4 and N_5 will produce a force R_2 pulling the magnet to the right. The two forces R_1 and R_2 are in the same direction and add together to produce a resulting force R_s urging the magnet to the right. Therefore, both coils 17 and 18 operate to move the magnet 27 to the right when the coils are energized as shown in Figure 3. If the polarity of the signal supplied to the coils 17 and 18 through the lead wires 22 is reversed, the polarity of the fields will be reversed and the conditions shown in Figure 4 will be present. At this time, the coil 18 has a north pole N_7 to the left and a south pole S_8 to the right and the coil 17 has a south pole S_{11} to the left and a north pole N_{12} to the right. In this instance, the permanent magnet 27, of course, retains a north pole N_3 to the left and a south pole S_4 to the right so the south pole S_8 adjacent to the north pole N_3 will produce an attraction magnetic force $R_{1'}$ urging the magnet 27 to the left and at the same time two south poles S_4 and S_{11} produce a repelling force $R_{2'}$ urging the magnet 27 to the left. These two forces, the attracting and the repelling forces $R_{1'}$ and $R_{2'}$, add together to produce a total force $R_{s'}$ urging the magnet 27 to the left. Since the density of the magnetic field created by the coil 17 is a function of the magnitude of the electric signal supplied to the coils, the resulting force urging the magnet 27 to the right or to the left is a function of the magnitude of the electric signal. Again since the direction of the force on the magnet 27 depends upon the polarity of the signal complete control of the magnet 27 is provided by the magnitude and the polarity of the signal. As described above, the differential in pressure between the two reference bores 34 and 42 is a function of the hydraulic forces applied to the magnet 27 which are equal and opposite to the magnetic forces so the differential in pressure will be a function of the signal supplied to the coils 17 and 18.

A fluid regulator according to this invention is particularly suited for systems of the type illustrated in the schematic drawing of Figure 5. In this case, the regulator is utilized to control the operation of the piston of a cylinder actuator A. This actuator could be connected to the control surface of an aircraft or any other mechanism which must be controlled by an electric signal. In the case of an aircraft the electric signal would normally be generated by the electronic control equipment such as the automatic pilot or radar fire control. In this system, the two inlet ports 38 and 44 are connected to a source of fluid under pressure or pump 50 by suitable piping 51. A spool valve B is provided with inlet ports 52 and 53 which are also connected to the piping 51 and are, therefore, connected to the same source of fluid under pressure. The reservoir return port 47 is connected to a reservoir 55 by a second passage network 54 which also connects to a reservoir return port 56 formed in the body of the spool valve B. A spool 57 is positioned within a bore 58 formed in the body of the spool valve B and is formed with lands 59 and 61 which cover the inlet ports 52 and 53 respectively when the spool is in the neutral position shown and a central land 62 which covers the reservoir return port 56. Springs 63 and 64 operate on opposite ends of the spool 57 to resiliently maintain the spool in the neutral position so that there is normally no fluid flow through the spool valve B. Control ports 66 and 67 are open to the zone between the lands 59 and 61 and the central land 62 and are connected to the opposite ends of the cylinder 68 of the actuator A by pressure lines 69 and 71 respectively.

If the spool 57 is shifted to the left, the control port 66 is brought into communication with the inlet port 52 to connect the left end of the cylinder 68 to the source of fluid under pressure and at the same time the reservoir return port 56 is brought into communication with the control port 67 so the right end of the cylinder 68 is connected to the reservoir return. When such movement of the spool 57 occurs the piston 72 moves to the right. When the spool 57 moves to the right, the opposite connection will be made and the piston 72 moves to the left. To produce motion of the spool valve B, the two ends of the spool 57 are connected to the apertures 33 and 41 by suitable piping 73 and 74 so that the opposite ends of the spool 57 will be exposed to the pressure in the bores 34 and 42 shown in Figure 1.

In operation an electric signal is supplied to the coils 17 and 18 causing the magnet 27 to shift from the neutral position toward a position closer to one of the nozzles 36 or 43 to produce a differential pressure between the reference bores 34 and 42 which is a function of the signal. This differential pressure is supplied to the ends of the spool valve 57 and causes the spool to shift from its neutral position an amount which is a function of the differential pressure and in turn a function of the signal. Because the flow of fluid under pressure through the spool valve B is determined by the magnitude of the movement of the spool 57 which is in turn a function of the electric signal, the rate of movement of the piston 72 will be a function of the electric signal and the direction of movement will be determined by the polarity of the signal.

Because the magnet 27 is completely submersed within the fluid flowing through the regulator, magnetic silting is virtually eliminated due to the washing action of the fluid as it flows over the magnet. This magnetic silting, which is the building up of deposits of finely divided magnetic particles in the fluid in areas of high magnetic intensity is normally troublesome in devices of the types used in the past to perform the functions performed by the regulator according to this invention. This tendency is also reduced by the fact that the magnetic densities need not be as large in a device according to this invention because both of the coils 17 and 18 operate to move the magnet 27 and because the movable member itself is a magnet. Since the only forces acting on the magnet are the fluid flow forces and the magnetic forces, springs and the like have been completely eliminated from the device and adjustment difficulties are eliminated.

It is important to form the regulator body of non-magnetic material so that there will be no stray magnetic forces created by the permanent magnet 27 which would affect the operation of the device. The nozzles 36 and 43 can be formed of steel so that tolerances can be maintained and the fact that the nozzles may be magnetic is not too important because they are small. Even so, it is preferable to form the nozzles of non-magnetic steel.

Although the preferred embodiment of this invention is illustrated, it will be realized that various modifications of the structural details may be made without departing from the mode of operation and the essence of the invention. Therefore, except insofar as they are claimed in the appended claims, structural details may be varied widely without modifying the mode of operation. Accordingly, the appended claims and not the aforesaid detailed description is determinative of the scope of the invention.

I claim:

1. A fluid control device comprising a body formed with a duality or orifices connected to a source of fluid under pressure, a permanent magnet mounted within said body

for movement toward one of said orifices and away from the other to vary the fluid flow through said orifices, and electromagnetic means fixed relative to said body producing a magnetic field simultaneously active in the same direction on both poles of said magnet to effect said movement.

2. A flow control device comprising first and second orifices through which fluid under pressure flows, a magnet formed with first and second faces adjacent to said first and second orifices respectively and impinged upon by the flow through said respective orifices mounted so that movement of one face away from its respective orifice produces movement of the other face toward its respective orifice, the reaction of the flow of fluid through each orifice on its respective face urging it away therefrom, and means fixed relative to said body producing magnetic forces simultaneously active in the same direction on both poles of said magnet urging one of said faces toward its respective orifice.

3. A flow control device comprising a body formed with a duality of orifices connected to a source of fluid under pressure, permanent magnet means within said body moveable relative to said orifices varying the fluid flow therethrough, and magnetic means fixed relative to said body and simultaneously active in the same direction on both poles of said magnet producing movement thereof increasing the fluid flow through one of said orifices and simultaneously reducing the fluid flow through the other orifice.

4. A hydraulic control device comprising a body formed with opposed coaxial nozzles connected to a source of fluid under pressure, a magnet having a face adjacent to each of said nozzles movable along a line parallel to the axis of said nozzles, the spacing between said faces of said magnet being less than the spacing between said nozzles, and electromagnetic means in said body producing a pair of opposed magnetic fields each substantially parallel to the axes of said nozzles and each producing a force in the same direction on said magnet moving said magnet along toward one nozzle and away from the other.

5. A flow control device comprising a body provided with opposed nozzles connected to a source of fluid under pressure, a magnet having a face adjacent to each nozzle, the spacing between said faces of said magnet being less than the spacing between said nozzles, and an electromagnetic means adjacent to opposite ends of said magnet producing magnetic fields of opposite polarity when supplied with an electric signal whereby one electromagnetic means produces a force pulling said magnet toward one of said nozzles and the other electromagnetic means produces a force pushing said magnet toward said one nozzle so that the flow through said one nozzle is reduced and the flow through the other nozzle is increased.

6. A flow control device comprising a body formed with a chamber having opposed surfaces, an orifice opening through each surface connected to a source of fluid under pressure, a magnet in said chamber having a face adjacent to each of said orifices, the spacing between said faces of said magnet being less than the spacing between said orifices, and electromagnetic means adjacent to each surface producing magnetic fields of opposite polarity when supplied with an electric signal whereby one electromagnetic means produces a force pulling said magnet toward one of said surfaces and the other electromagnetic means produces a force pushing said magnet toward said one surface so that the flow through the orifice in said one surface is reduced and the flow through the orifice in the other surface is increased.

7. An electrohydraulic valve comprising a pair of similar flow restrictions adapted to be connected to a source of hydraulic fluid under pressure, a nozzle associated with each flow restriction positioned in a coaxial opposed relationship relative to each other, means connecting each flow restriction and its associated nozzle, a permanent magnet positioned between said nozzles movable along a line parallel to the axis of said nozzles, and electromagnetic means creating opposed magnetic fields adjacent to each end of said magnet in response to electric signals whereby one of said fields pulls said magnet toward one of said nozzles and the other of said fields pushes said magnet toward said one nozzle when said electromagnetic means are energized by an electric signal thereby reducing the flow through said one nozzle and causing the pressure in the associated connecting means to increase and at the same time causing an increased flow through the other of said nozzles and decreasing the pressure in the associated connecting means.

References Cited in the file of this patent

UNITED STATES PATENTS

2,231,158	Davis	Feb. 11, 1941
2,472,090	Brewer	June 7, 1949
2,579,723	Best	Dec. 25, 1951
2,670,464	Wuensch	Feb. 23, 1954
2,678,436	Compare	May 11, 1954
2,709,421	Avery	May 31, 1955
2,711,754	McKinney	June 28, 1955
2,750,961	Uritis	June 19, 1956
2,767,689	Moog	Oct. 23, 1956
2,780,230	Freeman	Feb. 5, 1957
2,835,265	Brandstadter	May 20, 1958
2,836,154	Lantz	May 27, 1958
2,910,089	Yarber	Oct. 27, 1959
2,912,008	Blackburn	Nov. 10, 1959

FOREIGN PATENTS

665,565	Germany	Sept. 29, 1938
730,965	Great Britain	June 1, 1955