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[54] **LATCHING VALVE**
8 Claims, 3 Drawing Figs.

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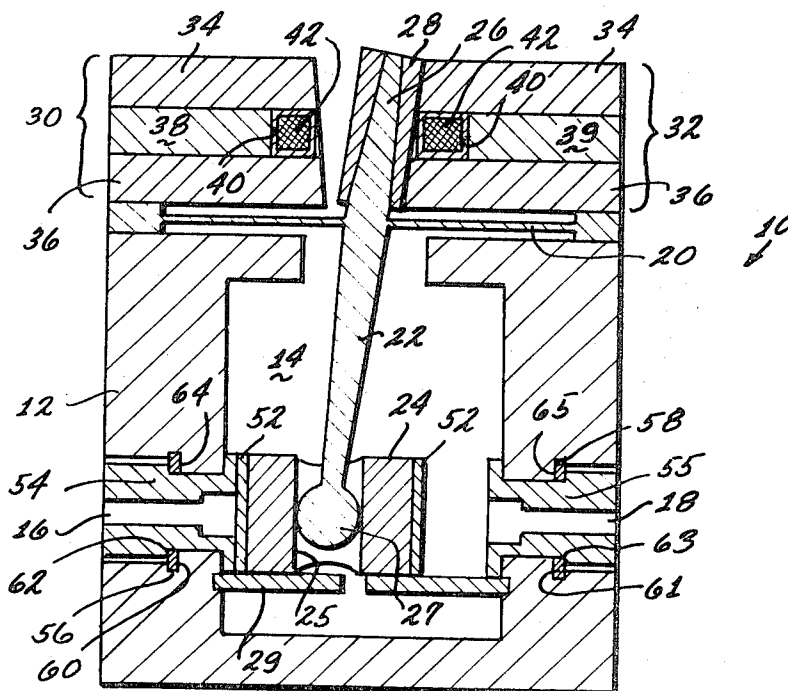
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129, 75; 137/625.4

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ABSTRACT: A latching valve containing two separate magnetic circuits of opposite polarity with a common armature and coil thereon. Each magnetic circuit consists of a permanent magnet in series with the coil. A resilient suspension plate, with high spring moment, carries a valve head on one side thereof and the armature on the other side to constitute an integrated assembly. The valve head has opposite surfaces engageable with oppositely disposed valve seats. Initially, one of the permanent magnets biases the valve head to one of these seats, with resultant deformation of the suspension plate. Upon application of a voltage of appropriate polarity, the magnetic potential of the permanent magnet decreases whereby the suspension plate moves the valve head toward the opposite seat. The other permanent magnet then secures the valve head in that position until the application of a voltage of polarity opposite to the polarity of the first-applied voltage. The suspension plate also serves to isolate the magnetic circuit from the valve head-seat area.



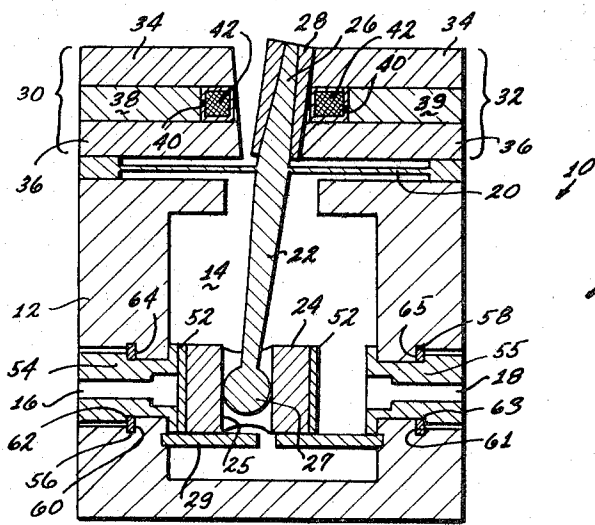


Fig. 1

Fig. 2

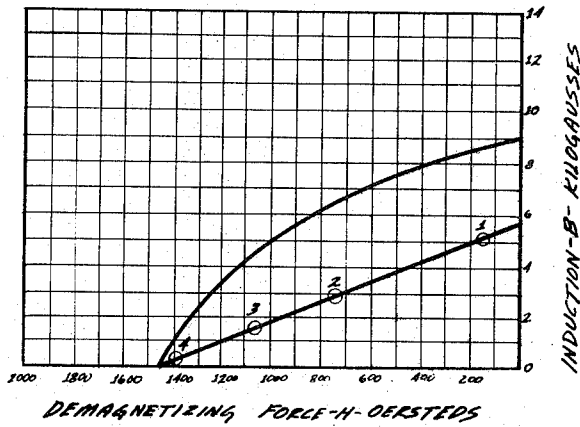
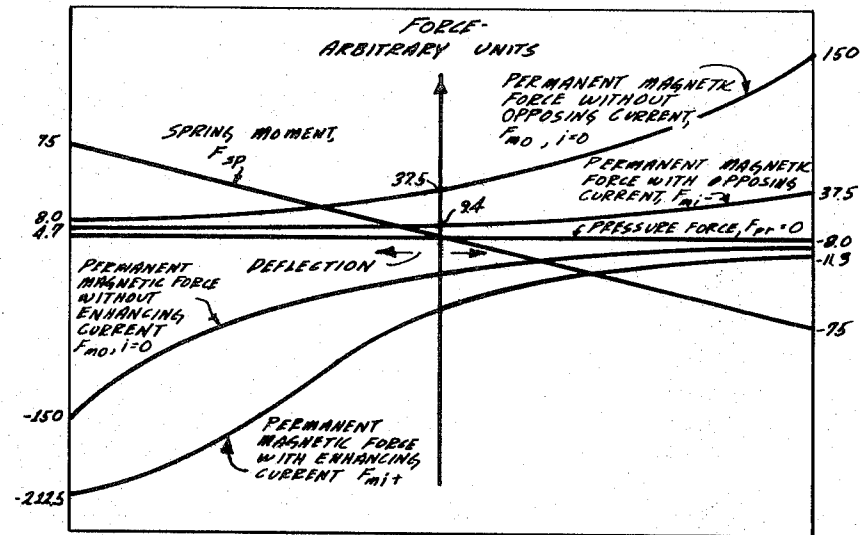


Fig. 3

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LATCHING VALVE

BACKGROUND OF THE INVENTION

1. Field of the Invention

The fields of art to which the invention pertains include the fields of fluid handling, valve and valve actuation.

2. Description of the Prior Art

Latching valves are utilized when there is a need to switch from one valve position to another upon receipt of a signal therefor and to maintain the new condition in the absence of a signal to switch back. By such means a valve can be switched open or closed, or flow can be switched from a primary inlet port to secondary inlet port, upon the receipt of an electrical voltage pulse. There is a need for latching valves having increased safety, reliability and responsiveness.

SUMMARY OF THE INVENTION

The present invention represents a new generation of latching valves. The valves provided herein are superior to present latching valves in that they are more reliable, more responsive, safer and consume less power. Specifically, a valve is provided comprising a valve assembly including a valve head, a seat for the valve head and a pair of permanent magnets for applying magnetic force on the valve assembly to bias the valve assembly to a particular position with respect to the seat. The valve assembly includes mechanical means that are deformed to a first configuration when the valve head is in a particular position. However, the spring moment of the mechanical means is less than the magnetic force of the permanent magnet biasing the valve head in its position. In order to release the valve head, voltage means are series disposed in the permanent magnetic circuit flux path for decreasing the magnetic potential of the permanent magnet. Upon the application of voltage of appropriate polarity, the magnetic force from the permanent magnet is decreased, whereby the mechanical means springs the valve head out of its position. The second permanent magnet latches the valve head in its opposite position and deforms the mechanical means to an opposite configuration. Here also, the spring moment of the mechanical means is insufficient to overcome the biasing force of the permanent magnet and in order to release the valve head another voltage pulse, of opposite polarity, must be applied. The voltage means is also series disposed in the magnetic circuit flux path of this permanent magnet and upon the application of the opposite polarity voltage pulse, the magnetic force exerted by the second permanent magnet is decreased so that the resiliency of the mechanical means returns the valve head to its initial position to be latched thereat by the first permanent magnet. The result is a latching valve that switches valve conditions upon the receipt of an appropriate electrical voltage pulse.

In particular embodiments, the mechanical means includes a suspension plate that supports the valve head on one side and an armature of magnetically permeable material on the other side movably associated with the valve head. A coil is disposed on the armature and is in series with the magnetic flux paths of both permanent magnets. The coil is energizable to develop a magnetic potential in opposition to the potential of one of the permanent magnets upon the receipt of a voltage pulse of a particular polarity, and is energizable to develop a magnetic potential in opposition to the other permanent magnet potential upon receipt of a voltage pulse of opposite polarity.

Improved reliability is obtained as a result of design simplicity and complete magnetic circuit isolation. Design simplicity is accomplished by the use of a mechanism containing only one moving part, the armature-flapper assembly. A fast dynamic response is obtained as a result of a greatly reduced number of ampere turns, typically a reduction of 16 to 1. The reduction in ampere turns is allowed because (a) the required coil flux density to generate a given output force is reduced due to the presence of the permanent magnet fields; (b) the reluctance of the magnetic circuit is reduced because no air

gaps are required at the closed positions; and (c) a reduction of the magnetic circuit reluctance results in a decrease in the number of magnetic leakage lines. Since the time constant is directly proportional to the square of the number of coil turns, response time is dramatically decreased. Power consumption is improved since that is proportional to the square of the input current, reduced with the reduction in ampere turns. Safety is improved since the present construction readily allows designing for pre-load forces larger than necessary to meet leakage requirements, allows the force available to open the valve to be made larger than the pressure force, and allows the flow area to be made larger than required.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic, cross-sectional representation of a valve constructed in accordance with the present invention;

FIG. 2 depicts a force-deflection plot for valves of this invention; and

FIG. 3 depicts a typical demagnetization curve for an Alnico VIII permanent magnet.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to FIG. 1, a valve 10 is shown having a housing 12 defining a chamber 14, primary and secondary inlet ports 16 and 18, respectively, and an outlet port (not shown). One wall of the chamber 14 is defined by a circular suspension plate 20 that completely encloses the chamber 14 at that end thereof and isolates the chamber 14 from the magnetic circuit as more fully explained below. A flapper 22 extends into the chamber 14 from the suspension plate 20 and carries a valve head 24 at its end. A stem 26 is disposed on the other side of the suspension plate 20 as a continuation of the flapper 22. The end of the stem 26 is encased in an armature sleeve 28 of magnetically permeable material and that end is disposed between a pair of magnetic poles 30 and 32. Each pole 30 and 32 comprises upper and lower frames 34 and 36, respectively, of magnetically permeable material sandwiching an Alnico permanent magnets 38 and 39, respectively, but leaving a channel 40 adjacent the armature sleeve 28 between the upper and lower frames 34 and 36. A coil 42 is disposed on the armature sleeve 28 and supported within the channel 40 between the upper and lower frames 34 and 36. The poles 30 and 32 and permanent magnets 38 and 39 are secured to the housing 12 by means of screws (not shown) to provide a rigid assembly. Electrical leads (not shown) are provided for supplying energizing current to the coil 42.

The circular suspension plate 20 is deformable and serves both as a mechanical spring as well as to isolate the magnetic circuit from the chamber 14. The suspension plate 20 is similar to a flat flexure diaphragm only in that it physically separates the chamber 14 from the upper areas of the valve and flexes in response to movement of the armature 28, but it is much thicker and has a spring moment of much greater magnitude than typical flexure diaphragms. The thickness and spring rate of the suspension plate 20 is very important to the operation of the valve. The suspension plate 20 must be deformable but thick enough to withstand fluid pressures and have the mechanical strength to return the valve head 24. The suspension plate 20 can be constructed, as shown, as a separate member secured between the housing 12 and the underside of the poles 30 and 32, or it can be a part of the housing 12 itself, i.e., an integral wall thereof formed thin enough to be deformable; the bottom wall 50 of the housing 12 can then be separable from the remainder of the housing 12 and threadable therein to form the enclosed chamber 14.

Referring to the valve head-seat area, the valve head 24 is provided with a centrally disposed cylindrical aperture 25 for receipt therein, in ball and socket fashion, of the knob end 27 of the flapper 22. The valve head 24 is supported by a pin member 29 straddling the bottom of the valve chamber 14 and having its end embedded in opposite walls thereof.

The valve head 24 carries an ultra hard tungsten carbide tip 52 on each port-facing side thereof. Mating tungsten carbide seats 54 and 55 are retained within the ports 16 and 18. The ports 16 and 18 are provided with annular grooves 56 and 58 midway thereof. Retaining rings 60 and 61 are disposed within the grooves 56 and 58 and in opposing annular grooves 62 and 63 in the tungsten carbide seats 54 and 55, respectively. The retaining rings 60 and 61 abut annular flanges 64 and 65 on the seats 54 and 55, respectively, to thereby secure the seats within the ports.

In operation, the magnetic attraction of the stem 26, via the magnetically permeable sleeve 28, to the permanent magnet 39 on the right side, (in the drawing) pre-loads the valve head 24 against the primary inlet port seat 54, preventing fluid flow therethrough and fluid flows through the secondary inlet port 18. To allow maximum transfer of force to the valve head-seat area, the parts are sized so that the valve head 24 is pressed firmly against its seat 54 while the armature 28 barely contacts the right side pole 32.

The Alnico magnets 38 and 39 are arranged with opposite polarities in the same direction, e.g., the permanent magnet 38 on the left hand side has its north pole facing upwardly whereas the permanent magnet 39 on the right hand side has its north pole facing downwardly. In order to release the valve head from its latched position, the coil 42 must be energized with a voltage of polarity and magnitude such as to oppose the permanent magnet 39 potential. Sufficient opposite magnetic potential must be generated to reduce the permanent magnet 39 force on the armature 28 enough to allow the spring moment of the deformed suspension plate 20 to move the armature-flapper-valve head assembly 28-26-22-24-52 out of its seat 54. The opposite permanent magnet 38 has sufficient magnetic potential, particularly in combination with the magnetic flux generated by the coil 42 current, so that at this point the armature 28 is magnetically attracted to the other permanent magnet 38 and latched thereat, even in the absence of the coil current 42. The result is that the valve head 24 is swept across the valve chamber 14 to seat against the secondary inlet port seat 55 and allow fluid to flow from the primary inlet port 16.

Referring to the operation of the valve 10 in more detail, FIG. 2 depicts changes in magnetic and spring moment with changes in deflection of the suspension plate 20 (pressure of the fluid is assumed as zero for simplicity of explanation). The valve 10 is normally closed by a pre-loading permanent magnet 39 force exerted by the flapper 22 on the valve head 24. At the initial position, the pre-loading permanent magnetic force is at its maximum since, with no air gap, the reluctance of the magnetic circuit thereat is at its minimum. The suspension plate 20 acting as a spring is unstressed when the valve head is positioned midway between the primary and secondary ports 16 and 18, but exerts a force opposing the permanent magnet 39 moment when the valve head 24 is seated. Accordingly, the pre-loading force is equal to the moment generated by the magnetic force of the permanent magnet 39 minus the moment required to bend the suspension plate 20 per unit length of the flapper 22 minus the moment generated by the opposite permanent magnet 38. With reference to FIG. 2, the pre-loading force is equal to F_{m0} , minus F_{sp} minus F_{m0} . $(150 - 75 - 8.0) = 67$ units of force. The pole 32 is sized so that it is substantially saturated by the permanent magnet.

When the coil 42 is energized, magnetic potential is developed across the armature sleeve 28. This potential opposes the permanent magnet 39 potential, thereby decreasing the force due to the permanent magnet 39. This effect can be illustrated with reference to FIG. 3 which depicts the energy product curves and major A and minor B hysteresis loop curves of an Alnico VIII permanent magnet. Importantly, demagnetization occurs on the minor hysteresis loop B as illustrated by conditions 1-4 thereof.

Referring back to FIG. 2, when the coil 42 is energized as described, the permanent magnet 39 potential is decreased to 37.5 force units. The coil 42 potential also generates magnetic

flux about the left side pole 30 loop at all positions throughout the air gap thereat of, say, 3.3 force units. The permanent magnet 38 thereat also generates magnetic flux about the left side pole loop of, say, 8.0 units on the armature sleeve 28 at the present position. The result is that the net magnetic moment (in FIG. 1, the right side minus the left side moments) is equal to $F_{m1} -$ minus $F_{m1} +$ $(37.5 - 11.3) = 26.2$ force units which is opposed by the spring bending moment of the suspension plate 20 of 75 units minus the pressure moment of the fluid between the ports 16 and 18 (here zero). This results in a total net force of -48.8 units to move the armature-flapper-valve head assembly 28-26-22-24-52 from the primary port seat 54 toward the secondary port seat 55.

At the spring null position of the spring plate 20, the magnetic potential of the permanent magnet 39 is only 9.4 units which is opposed by a magnetic potential of the current enhanced permanent magnet of about 65.6 units for a total net moment of minus 56.2 units to accelerate the armature-flapper-valve head assembly 28-26-22-24-52 past the null point. In this example, the left side pole 30 is sized so that it is not saturated by the permanent magnet 38 thereat. However, upon application of the enhancing coil potential, a saturation condition obtains to impart a force on the armature 28 when thereat of -212.5 force units. With the valve head 24 seated against the secondary port seat 55, and with the coil 42 still energized, the current enhanced left hand permanent magnet 38 force potential of 212.5 units opposes the right hand permanent magnet 39 current limited potential of 4.7 units and a spring moment of 75 units for a total net force of minus 132.8 units to bias the valve head 24 against the secondary port seat 55. When the current to the coil 42 is removed, the magnetic moment due to the coil 42 ceases; however, the left hand permanent magnet 38 still has a magnetic attraction force of 150 units which opposes the opposite permanent magnet 39 magnetic attraction of 8.0 units and the spring moment of 75 units for a total net force of minus 67 units to latch the valve head 24 against the secondary port seat 55. To release the valve head 24 from the secondary port seat 55 and switch it back into latching engagement with the primary port seat 54, one need merely energize the coil 42 with a similar voltage pulse of opposite polarity. The force-deflection diagram of FIG. 2 would again apply, but with the magnitudes appropriate to reverse operation. An inspection of the force-deflection diagram of FIG. 2 reveals that there are static moments available at all armature positions to accelerate the valve head from one seat into latching engagement with the other seat.

The foregoing described latching valve utilizes differently sized poles and is particularly useful when a large difference in pressure differential is encountered in different latching directions. The description is analogously applicable to symmetrically formed valves; for example, the force-deflection diagram of FIG. 2 can apply to operation in either direction of a symmetrical valve.

The suspension plate 20 not only acts as a mechanical spring but also isolates the magnetic circuits from the fluid in the chamber 14. Further, magnetically permeable material is utilized only in the vicinity of the magnetic circuit so that the fluid chamber 14 area is unaffected by generated magnetic fields.

We Claim:

1. A latching valve, comprising:

a valve assembly including a valve head;
a seat for said valve head;

first permanent magnet means for applying a first predetermined magnetic force on said valve assembly to bias said valve head to a first position with respect to said seat;

said valve assembly including mechanical means that are deformed to a first configuration when said valve head is in said first position to urge said valve head toward a second position, with respect to said seat, with a spring moment less than said first predetermined magnetic force;

voltage means series disposed in the first permanent magnet flux path for decreasing the magnetic potential of said first permanent magnet upon the application of first voltage of appropriate polarity to thereby decrease said first magnetic force whereby said mechanical means can move said valve head toward said second position;

second permanent magnet means for applying a second predetermined magnetic force on said valve assembly of polarity opposite to said first magnetic force to bias said valve head to said second position;

said mechanical means being deformed to a second configuration when said valve head is in said second position to urge said valve head toward said first position with a spring moment less than said second predetermined magnetic force; and

said voltage means being series disposed in the second permanent magnet flux path for decreasing the magnetic potential of said second permanent magnet upon the application of voltage of polarity opposite to said first voltage to thereby decrease said second magnetic force whereby said mechanical means can move said valve head toward said first position.

2. The valve of claim 1 including means isolating said magnetic potentials from said seat.

3. The valve of claim 1 wherein said valve assembly comprises a magnetically permeable member supported between said first and second permanent magnets on one side of said mechanical means and said valve head supported on another side thereof, said mechanical means being shaped and disposed to isolate said magnetic potentials from said seat.

4. The valve of claim 1 wherein said valve assembly comprises an armature of magnetically permeable material, spaced from said valve head but movably associated therewith and subject to said magnetic forces, and said voltage means comprises a coil on said armature energizable to selectively oppose one or the other of said magnetic potentials.

5. The valve of claim 1 wherein said seat is disposed at said first position and including a second valve head seat at said second position, said valve head having opposite surfaces en-

gageable with respective ones of said seats.

6. The valve of claim 5 wherein each seat defines a port of said valve, said valve defining an additional port communicating with one seat when the valve is in one latched condition and with the other seat when said valve is in an opposite latched condition.

7. A latching valve, comprising:

a housing defining a chamber having first and second ports and at least one deformable wall;

a member carrying a valve head between said ports on one side of said deformable wall;

a seat for said valve head at each of said ports, said valve head having opposite surfaces engageable with respective ones of said seats;

an armature of magnetically permeable material carried on the opposite side of said deformable wall;

a first permanent magnet operative with a first magnetic force to magnetically attract said armature to bias said valve head to one of said seats and deform said wall to be a first configuration;

a coil on said armature series disposed in the first permanent magnet flux path and energizable with a voltage of appropriate first polarity to oppose the magnetic potential of said first permanent magnet to thereby decrease its magnetic attraction;

a second permanent magnet operative with a magnetic force of opposite polarity to said first magnetic force to magnetically attract said armature when said coil is energized with said voltage of first polarity to bias said valve head to the other of said seats and deform said wall to a second configuration; and

said coil being series disposed in second permanent magnet flux path and energizable with a voltage of polarity opposite to said first polarity to oppose the magnetic potential of said second permanent magnet to thereby decrease its magnetic attraction.

8. The valve of claim 7 wherein said deformable wall has sufficient spring moment to carry said valve head out of its seated position when said coil is appropriately energized.

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