May 13, 1969 R. H. REINICKE 3,443,585

# MAGNETICALLY OPERATED MULTI-VALVE ASSEMBLY

Filed July 3, 1967 Sheet 1 of 2

FIG. 5

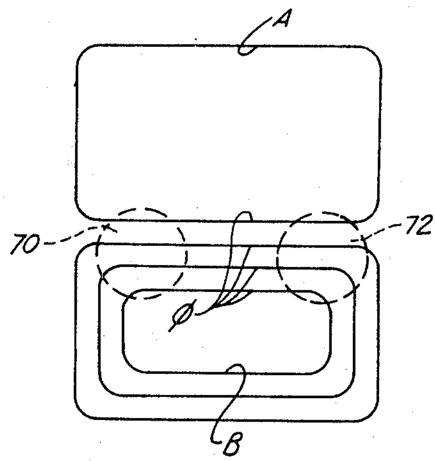


FIG. 6

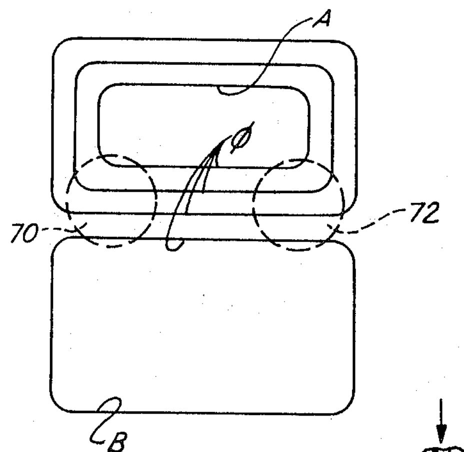


FIG. 4

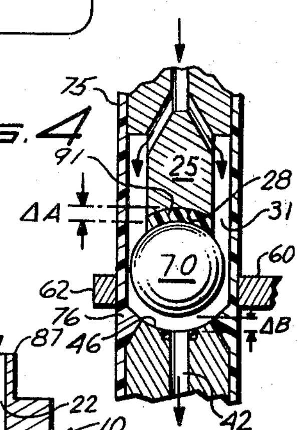


FIG. 1

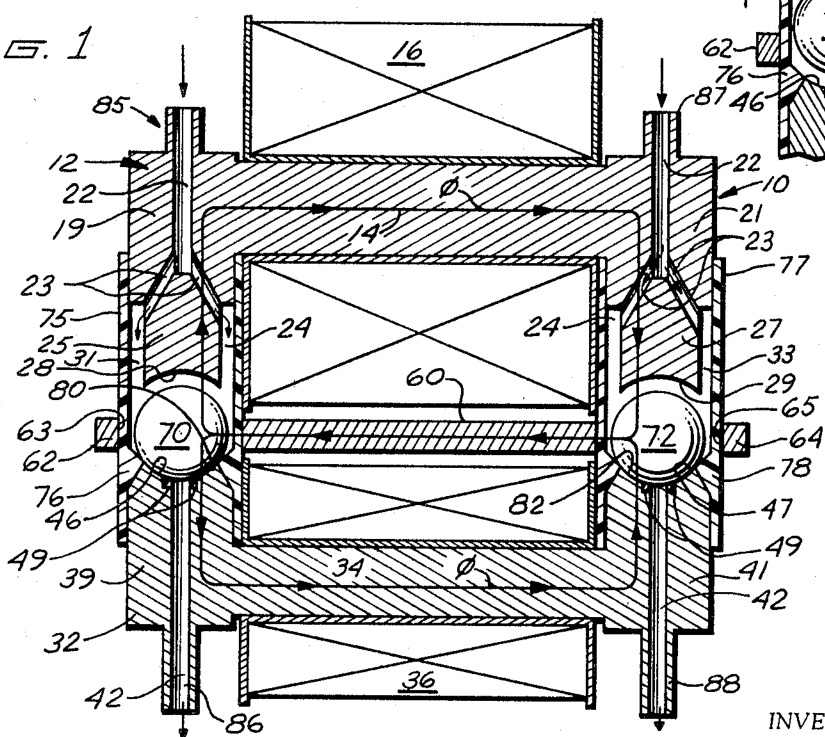


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FIG. 2

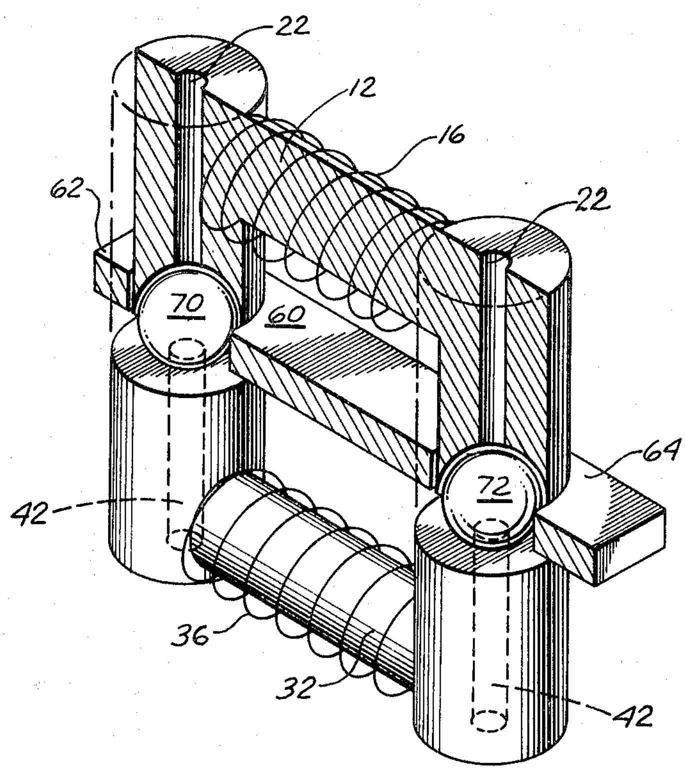
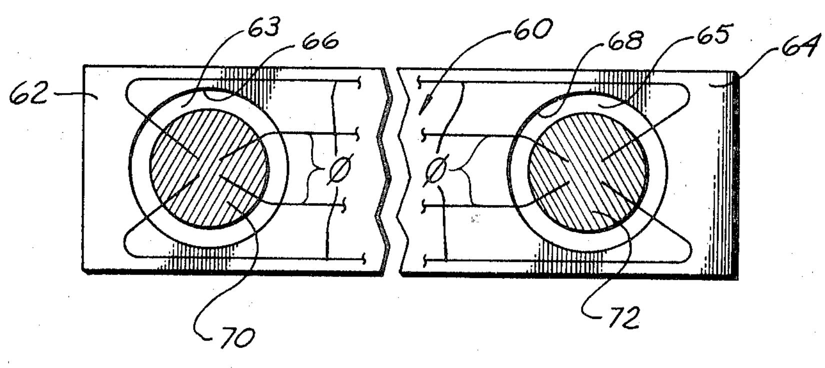



FIG. 3

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# 3,443,585
# MAGNETICALLY OPERATED MULTI-VALVE ASSEMBLY

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U.S. Cl. 137—595 14 Claims

## ABSTRACT OF THE DISCLOSURE

A multi-valve assembly having at least two ball shaped valves made of magnetizable material that act as armatures. The valves are included in a magnetic circuit which operates, without the aid of mechanical guides, dynamic seals or the like, to substantially simultaneously move the balls along substantially straight paths between their valve-closed and valve-opened positions. Valve-opened and valve-closed positions are maintained solely by magnetic forces, thereby eliminating the need for mechanical springs, detents or the like.

### *Background of the invention*

This invention relates to electrical valve actuators and more specifically to a magnetic circuit for interlinking and substantially simultaneously actuating multiple valves. The use of solenoid coils in conjunction with electromagnetic plungers or armatures for regulating valve motion is well established in the prior art. When individual solenoids are used to operate a plurality of valves, it becomes difficult to precisely regulate the valves simultaneously. Although the solenoids may be hooked up in the same electrical circuit, there is always the risk of an inductive lag timing mismatch that will result in variable rather than simultaneous valve motions. The numerous and complex components of conventional circuits, as well as their overall cost and required packaging space, renders the circuit impracticable and undesirable for many uses.

Although the use of single magnetic circuits for incorporating and actuating dual valves are known (e.g., British Patent No. 21,824, 1914), they are incapable of reliably producing substantially simultaneous movements of the valves. This inability arises in part because, unlike in the case of the instant invention, the valves in the conventional circuits are not magnetically interlinked within a common electromagnetic circuit and therefore movement of one valve exerts only minimal if any influence on the other valves. Another problem source impairing the reliability of conventional dual valve assemblies resides in the extensive use of coupling the valve with components such as mechanical springs, dynamic seals, sliding fits, flexures and the like. The risk of developing defects is greatly increased by vibration, shock, temperature cycling, contamination, fatigue, etc. The instant invention completely eliminates using these types of components. A direct benefit derived from eliminating these components is that the mass of the moving parts is substantially diminished and therefore much faster valve response periods are obtainable.

### *Summary of the invention*

Briefly stated, the instant invention contemplates a multiple valve assembly including at least two valves, each being constructed of magnetizable material. The valves serve as armatures and are arranged in a magnetic circuit which magnetically interlinks the valves so that movements of one valve automatically influences the motion of the other valve with the result that the valves move substantially simultaneously. The magnetic circuit



includes a first C-shaped electromagnet and a second C-shaped electromagnet which are spaced from and open toward one another. The free ends of the arms of the C-shaped electromagnets serve as pole faces and are spaced apart sufficient to constitute a pair of spaces in which the valves are retained. A permanent magnet is disposed between the two electromagnets and is formed at its opposing ends with circular openings that circumscribe the valves. The magnetic circuit diverts magnetic flux generated by the permanent magnet from one electromagnet to the other in order to move the valves between their valve-opened and valve-closed positions.

In accordance with one embodiment of this invention energizing the electromagnets magnetically urge the valves from either their valve-opened or valve-closed position to their other position and upon de-energization the valves remain in their latter position. In order to return the valves to their original position, the magnetic circuit is energized under reversed electrical polarity conditions. According to another embodiment of this invention, the valves are moved from one of their positions to their other positions by energizing the electromagnets, however, upon de-energization the valves automatically return to their original positions and hence energization under reverse polarity conditions is dispensed with. In the latter case the valves are positioned so that upon de-energization the magnetic forces urging the valves to their original positions exceed those tending to retain the valves.

The two electromagnets and the permanent magnet are rigidly held together by a supporting framework which assures that none of the valve assembly components other than the valves will be movable. In another aspect of this invention, fluid inlet passageways are formed through the arms of one electromagnet and are positioned to be adjacent with fluid outlet passageways formed through the arms of the other electromagnet. The inlet and outlet passageways both communicate with the spaces that occupy the valves so that when the valves are in their valve-opened positions a pair of independent and continuous fluid lines are created. Potential failure sources in the valve assembly are substantially minimized in that the valve assembly does not utilize mechanical springs, guides, sliding fits, dynamic seals, flexures, etc. This invention also comprehends moving a single valve along a straight path between its valve-opened and valve-closed positions under the magnetic forces generated by the magnetic circuit described above.

### *Brief description of the drawings*

The advantages of the instant invention will be clearly understood upon studying the following detailed description in conjunction with the detailed drawings in which:

FIG. 1 is a longitudinal, cross-sectional view through a valve assembly formed in accordance with one embodiment of the instant invention, showing a magnetic circuit incorporating a pair of spherical valves that serve as armatures;

FIG. 2 is slightly modified perspective view of the valve assembly depicted in FIG. 1 with sections removed from some of its components;

FIG. 3 is an enlarged fragmentary view of the permanent magnet depicted in FIGS. 1 and 2, showing circular openings in which the valves are disposed;

FIG. 4 is a cross-sectional view of a portion of another valve assembly;

FIG. 5 is a schematic view depicting the relative magnetic flux quantities in two flux loops of the magnetic circuit when the valves are in their valve-closed positions;

FIG. 6 schematically represents the relative magnetic flux quantities in the two flux loops of the magnetic circuit when the valves are in their valve-opened positions.

*Description of the preferred embodiments*

Referring now to one embodiment of this invention, FIG. 1 is a sectional view showing the essential components of a dual valve assembly **10** designed to simultaneously control the flow of fluid through two separated fluid lines. Valve assembly **10** incorporates a C-shaped electromagnetic core **12** whose central section **14** is encircled by a solenoid coil **16**. Arms **19** and **21** of core **12** are identically formed with fluid inlet passageways **22**, each of which terminates in a conically-shaped port **23** that extends into an annular passageway **24**. Alternatively each port **23** could be a plurality of diverging apertures. Integrally formed at the free ends of arms **19** and **21**, respectively, are plugs **25** and **27** which are of reduced diameter and, in part, are shaped by ports **23** and annular passageways **24**. Terminal walls **28** and **29** of plugs **25** and **27**, respectively, are spherically shaped and serve as magnetic pole faces as will be fully explained below. Valve assembly **10** includes another electromagnetic C-shaped core **32** whose central section **34** is encircled by a solenoid coil **36**. Extending centrally through arms **39** and **41** of core **32** are fluid outlet passageways **42**. Electromagnets **12** and **32** open toward one another with adjacent arms separated to constitute spaces. As will be explained the spaces retain valves. The free ends of arms **39** and **41** terminate in spherically shaped walls **46** and **47** which, as will be fully explained, serve as valve seats and magnetic pole faces. Zones of pole faces **46** and **47** surrounding fluid passageways **42** are grooved to receive sealing rings **49**.

Positioned between solenoid coils **16** and **36** as shown in FIGS. 1 and 2 is a permanent magnet whose opposing ends **62** and **64** are oriented between the adjacent pole faces of the arms of cores **12** and **32**. Circular openings **63** and **65**, shown in FIG. 3, are formed in ends **62** and **64**. The walls **66** and **68** of permanent magnet **60**, defined by circular openings **63** and **65**, entirely circumscribe a pair of poppet valves **70** and **72**, respectively. Valves **70** and **72** are movable between valve-closed and valve-opened positions so as to control fluid flow. The valves are constructed of suitable magnetizable material so they may also operate as armatures.

To securely connect together magnets **12**, **32** and **60** and eliminate all relative movement, referring again to FIG. 1, a pair of non-magnetic sleeves **75** and **77** are provided. Oppositely facing arms **19** and **39** are inserted into the opposite ends of sleeve **75**, an intermediate portion of which fits against circular wall **66**. Integrally formed on the interior wall of sleeve **75** is an inwardly extending lip **76** which together with spherical wall **46** constitutes a valve seat **80** for ball **70**. In a similar manner, oppositely facing arms **21** and **41** are inserted into opposing ends of sleeve **77** while an intermediate portion of sleeve **77** fits against circular wall **68**. Formed on the interior of sleeve **77** is an inwardly extending lip **78** that along with spherical wall **47** constitutes a valve seat **82** for ball **72**. The coaction of sleeves **75** and **77** serve to prevent all relative movement between magnets **12**, **32** and **60**.

Circular walls **66** and **68** also function as pole faces. As shown in FIG. 3, the magnetic flux lines $\theta$ bridging the annular gaps **63** and **65** between the balls and adjacent circular pole faces are substantially evenly distributed. One advantage of this arrangement is that during their lifting and seating strokes, the balls will travel along substantially straight lines. If the pole faces did not circumscribe the balls, they would tend to travel in off-centered paths. The balls are magnetically guided rather than mechanically guided by the circular pole faces. By traveling along substantially straight paths to and from their seats, the valve response time will be minimized and also the usual rolling and sliding motion experienced by the balls attempting to center themselves on their seats will also be minimized.

When balls **70** and **72** are moved through their lifting strokes to their valve-opened positions or through their



seating strokes to their valve-closed positions, no components of assembly **10** other than balls **70** and **72** are moved. By this inventive valve arrangement there is no need for springs, mechanical guides, sliding fits, etc., which often are complex and increase the risk of valve failure. Valves **70** and **72** are urged to and from their seats under the influences of magnetic forces generated by a magnetic circuit in which they operate as armatures. The movements of balls **70** and **72** occur substantially simultaneously due to the fact that they are magnetically interlinked in a common magnetic circuit in which the motion of one valve-armature influences the motion of the other valve-armature causing the valves to move substantially simultaneously. In this aspect of the invention, i.e., magnetically interlinking a plurality of valves, the valve assembly of this invention is similar to the invention described in U.S. patent application Ser. No. 641,031 filed on May 24, 1967 which invention has been assigned to the assignee of the instant invention.

As shown in FIG. 1, valves **70** and **72** are closed against their seats **80** and **82**, and therefore fluid that has entered inlet tubes **85** and **87** is prevented from being discharged through outlet tubes **86** and **88**, respectively. In this condition, neither solenoid coil **16** nor **36** is energized. In order to understand how the magnetic circuit is utilized to actuate balls **70** and **72**, a magnetic loop constituted by core **12**, permanent magnet **60** and balls **70** and **72** will be referred to as loop A shown in FIG. 5. A second magnetic loop constituted by core **32**, permanent magnet **60** and balls **70** and **72** will be referred to as loop B. Under electrically de-energized, valve-closed conditions, the magnetic reluctance in loop A is greater than the reluctance in loop B, i.e.; the magnetic circuit permeance in loop B is greater than the permeance in loop A. This results in a greater magnetic flux density in the loop B than in loop A. The relative difference in flux density in loops A and B is depicted schematically by three flux lines $\theta$ in loop B and only one flux line $\theta$ in loop A. The resulting greater magnetic forces in loop B operate to attract the balls holding them firmly against their spherical seats.

In order to urge the balls through their lifting strokes to their valve-opened positions, coil **16** is energized so as to intensify the magnetic polarity differential between pole faces **28** and **29** and balls **70** and **72**, respectively. Simultaneously electrical coil **36** is energized to decay the magnetic polarity differential between pole faces **46** and **47** and balls **70** and **72**, respectively. At the point in time when the increased magnetic force between pole face **28** and ball **70** exceeds both, (1) the decreased magnetic force between pole face **46** and ball **70**, and (2) the unbalanced force generated by the pressure of fluid in reservoir **31** operating on the areas of sealing ring **49**, the lifting stroke of ball **70** will be initiated.

The increase of magnetic polarity differential on the upper pole faces **28** and **29** and the simultaneous decrease in polarity differential on the lower pole faces **46** and **47** causes permanent magnetic flux to be deflected from loop B to loop A. The change is depicted by the change that has occurred between FIG. 5 and FIG. 6. During the inductive lag interval from initial electrical energization to the start of ball motion, the flux output from the permanent magnet is essentially constant, and is simply being diverted from use in loop B and electromagnet **32** to use in loop A and electromagnet **12**. Because the permanent magnet flux is constant during this energization period, there is no flux change in gaps **63** and **65**, shown in FIG. 3, and thence no electrically supplied energy is wasted in these gaps. Therefore the inductive lag time is minimized for a given electrical power level. This also permits the reluctance in these gaps to be relatively high, which results in minimum ball mass (for superior vibration, shock resistance, faster movement response) and maximum gap length which increases contamination tolerance of the valves.

If for some reason, the forces on ball **70** are different than the forces on ball **72** so that after ball **70** commences its movement ball **72** remains in place, then lagging ball **72** will commence its lifting stroke very rapidly. This will occur automatically because the balls are magnetically interlinked. In addition to different fluid pressures that may cause the motion of ball **70** to precede that of ball **72** other factors affecting this situation could be sticking, different manufacturing tolerances, etc. Movement of ball **72** will quickly commence because as the gap between moving ball **70** and pole face **28** narrows, there is concomitant decrease of magnetic reluctance in loop A, accompanied by an increase in magnetic flux density urging the ball **72** to open. Also, as the gap between moving ball **70** and pole face **46** widens, there is a concomitant increase of magnetic reluctance in loop B, accompanied by a decrease in magnetic flux density tending to maintain the ball **72** in its closed position. Thus, if for one of the reasons outlined above, the motion of one ball should precede the other, the fact that they are magnetically interlinked in the same magnetic circuit, will soon correct this mismatch of motion and produce substantially simultaneous movement.

When coils **16** and **36** are de-energized, balls **70** and **72** will remain in their valve-opened positions bearing against pole faces **28** and **29** due to the fact that the magnetic reluctance in loop B will remain greater than that in loop A. This necessarily results because the gaps between the balls and their associated pole faces of loop A are approximately zero or at least the gaps are substantially smaller than the gaps between the balls in their associated pole faces in loop B.

In accordance with this valve arrangement, the balls are returned from their valve-opened to their valve-closed positions simply by energizing the coils with electrical polarities opposite to that used to open the valve. Thus, the electrical current in coil **16** is transmitted in the opposite direction so as to decay the polarity between pole faces **28** and **29** and balls **70** and **72**, respectively. Simultaneously, the electrical current in coil **36** is transmitted in the opposite direction so as to intensify the polarity and hence magnetic attracting force between pole faces **46** and **47** with balls **70** and **72**, respectively. Should the movement of one ball precede the movement of the other ball, then due to the fact that the balls are magnetically interlinked, they will be returned to their valve-closed positions substantially simultaneously.

Valve assembly **10** may be used in a broad variety of environments and is not limited to any specific use. It may, for example, be used to achieve a highly reliable and precise mixture of two different liquids such as a fuel propellant entering inlet tube **85** and an oxidizer propellant entering inlet tube **87**. With the balls in their valve-opened positions, fuel propellant would be conducted successively through passageway **22**, conically shaped port **23**, annular passageway **24** and into reservoir **31**. It should be noted that the liquid flow is uniformly distributed around the ball, thereby tending to maintain the ball in a stable, centered position during valve opening and closing motion periods. The fuel eventually flows outwardly through passageway **42** and is ultimately discharged through outlet tube **86**. The flowing oxidizer stream is entirely segregated from the flowing fuel stream. Oxidizer entering inlet tube **87** flows successively, in a continuous stream, through passageway **22**, conically shaped port **23**, annular passageway **24**, reservoir **23**, passageway **42** and ultimately outlet tube **88**. It is important in many instances to maintain the fluids, whether or not they are flowing, separated from one another. This is especially important in the case where premature mingling of volatile fluids capable of developing a hypergolic reaction may occur. Unless safeguards are taken catastrophic ramifications could result in destroying the valve assembly **10** and more important the structure in which it is incorporated.

Another embodiment of this invention shown in FIG. 4, is constructed so that the balls will maintain their valve-opened positions only with electrical energization and automatically return to their valve-closed positions when the electrical coils are de-energized. This is to be contrasted with the construction of the invention shown in FIG. 1 in which the balls remained in their valve-opened positions upon de-energizing the coils. It should be noted that the valve assemblies of FIGS. 1 and 4 are very similar and therefore many of the same numerals are utilized to explain the construction and operation of the valve assembly depicted in FIG. 4. As shown, ball **70** is raised by the maximum distance from its spherical seat **46**. In its valve-opened position, ball **70** rests against a shim or stop **91** which is connected to the pole face **28** of plug **25**. Shim **91** is constructed from any suitable non-magnetizable material and is positioned such that when ball **70** is raised to its valve-opened position the distance $\Delta A$ between the ball and pole face **28** will always exceed the distance $\Delta B$ between the ball and pole face **46**. Therefore, when the electrical coils are de-energized, the magnetic reluctance across gap $\Delta A$ will exceed the magnetic reluctance across gap $\Delta B$. A direct consequence of this arrangement is that the magnetic attracting force exerted by pole face **46** will exceed that exerted by pole face **28** and therefore will be sufficient to draw ball **70** back to its valve-closed position. There is no need to reverse the current flow through the coils to create a reverse polarity situation in order to return the balls to their valve-closed positions.

It should be noted that while this invention is characterized by superior advantages over conventional dual valve assemblies, the invention may also be used to achieve superior results in controlling fluid flow through a single valve. In a single valve construction there would be no need for magnetic interlinking.

Although particular embodiments have been chosen to illustrate this invention, it should be noted that the scope of this invention is to be limited only by the following claims.

I claim:

**1.** A multiple valve assembly for magnetically moving at least two valves between valve-closed and valve-opened positions comprising:

a first electromagnet having two pole faces,

a second electromagnet having two pole faces, the pole faces of the first and second electromagnets being positioned adjacent one another to define a pair of spaces,

a permanent magnet disposed between the two electromagnets and extending between said pair of spaces,

support structure for interconnecting the electromagnets and permanent magnet,

a pair of valves made of magnetizable material disposed wtihin the spaces, and

a magnetic circuit including the valves, for diverting permanent magnet generated flux from one electromagnet to the other in order to move the valves between their valve-closed and valve-opened positions.

**2.** The structure according to claim **1** wherein the magnetic circuit includes a first magnetic loop constituted by the first electromagnet, the permanent magnet and the valves and a second magnetic loop constituted by the second electromagnet, the permanent magnet and the valves, and

the valves are magnetically interlinked for substantially simultaneous movement.

**3.** The structure according to claim **2** wherein when the circuit is energized the valves are moved from one position adjacent one loop to their other position adjacent the other loop and when the circuit is de-energized, the valves remain in the other position, the valves being returned to their said one position by energizing and reversing the polarity of the magnetic circuit.

**4.** The structure according to claim **3** wherein when the valves are in their said other position and the circuit is de-energized the magnetic reluctance in said one loop is greater than that in said other loop.

**5.** The structure according to claim **2** wherein when the circuit is energized the valves are moved from one position adjacent one loop to their other position adjacent the other loop and when the circuit is de-energized the valves automatically return to their said one position.

**6.** The structure according to claim **5** wherein when the valves are in their said other position and the circuit is de-energized the magnetic reluctance in said one loop is less than that in said other loop.

**7.** The structure according to claim **6** further comprising stops positioned adjacent the pole faces associated with said other loop for preventing the valves from being closer to these pole faces than the pole faces associated with said one loop.

**8.** The structure according to claim **1** further comprising a pair of fluid inlet passageways formed in one electromagnet communicating with the spaces,

a pair of outlet passageways formed in the other electromagnet communicating with the spaces,

wherein when the valves are in their valve-opened positions a pair of separated continuous flow lines are formed.

**9.** The structure according to claim **8** wherein each inlet passageway has an annular port surrounding one pole face of said one electromagnet and each outlet passageway passes through one pole face of the said other electromagnet.

**10.** The structure according to claim **1** wherein the electromagnets are C-shaped, opening towards one another and the support structure is a pair of sleeves, the opposing ends of one sleeve receiving one set of the adjacent arms of the electromagnets while the other sleeve receives the other set of adjacent arms of the electromagnets.

**11.** The structure according to claim **8** wherein the valves are balls and the permanent magnet is formed on its opposite ends with a pair of circular openings that encircle the balls and serve as pole faces so as to promote substantial straight line movement of the balls between their positions.



**12.** The structure according to claim **11** wherein the pole faces of the electromagnets are spherically shaped and serve as valve seats to promote centering of the balls.

**13.** A valve assembly for magnetically moving a valve between valve-closed and valve-opened positions comprising:

a first electromagnet having a pole face,

a second electromagnet having a pole face, the pole faces of the first and second electromagnets forming at least one valve seat being positioned adjacent one another to define a space,

a permanent magnet disposed between the two electromagnets and around said space,

a valve made of magnetizable material disposed within the space, and

a magnetic circuit including the valve for diverting permanent magnet generated flux from one electromagnet to the other in order to move and magnetically guide the valve with respect to said valve seat between its valve-closed and valve-opened positions.

**14.** The structure according to claim **13** wherein:

the valve is a ball,

the pole faces of the electromagnets are spherically shaped and serve as valve seats to promote centering of the ball, and

the permanent magnet is formed with a circular opening that encircles the ball and serves as a pole face so as to promote substantial straight line movement of the ball.


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HENRY T. KLINKSIEK, *Primary Examiner.*

U.S. Cl. X.R.

251—137, 141; 335—229