

[54] HALL SWITCH PUMP

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[\*] Notice: The portion of the term of this patent subsequent to Nov. 8, 2000 has been disclaimed.

[21] Appl. No.: 548,369

[22] Filed: Nov. 3, 1983

Related U.S. Application Data

[63] Continuation of Ser. No. 191,055, Sep. 25, 1980, Pat. No. 4,413,950.

[51] Int. Cl.<sup>4</sup> ..... F04B 17/04; H02K 33/10

[52] U.S. Cl. .... 417/53; 310/34; 318/127; 417/417

[58] Field of Search ..... 417/53, 417; 310/30, 310/31, 34, DIG. 3; 318/127, 128, 132; 324/208, 251, 235

[56] References Cited

U.S. PATENT DOCUMENTS

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3,364,361	1/1968	Burger .....	91/275 X
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4,413,950	11/1983	Wiernicki .....	417/53

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M. Oppenheimer, "I IC Form, Hall-Effect Devices Can Take on Many New Applications", Electronics, pp. 46-49, Aug. 2, 1971.

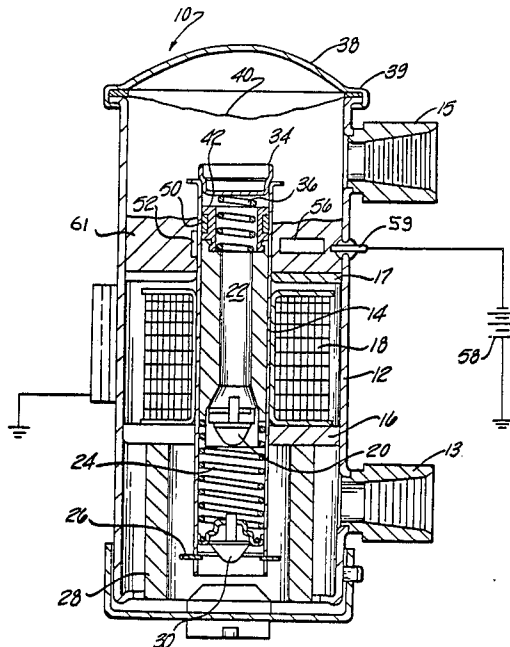
J. L. Di Filippo, "A Silicon Hall Effect Latching Switch", Conference Proc., 30th Electronic Components Conference (28-30 Apr. 1980), IEEE.

Primary Examiner—Leonard E. Smith  
Attorney, Agent, or Firm—Remy J. VanOphem

[57] ABSTRACT

An electromagnetic fluid pump having a magnet attached to a reciprocating piston and a hall effect switch detecting the magnetic field generated by the moving magnet. In a first position of the magnet, the magnetic field through the hall effect switch is in a first direction causing the hall effect switch to generate a signal having a first polarity. In a second position of the magnet the magnetic field through the hall effect switch is reversed, reversing the polarity of the signal generated by the hall effect switch. An electronic switch circuit responsive to the signal generated by the hall effect having the first polarity to energize the solenoid coil to retract the piston from the first position to the second position against the force of a spring and further responsive to the signal having a reversed polarity to deenergize the solenoid coil when the piston is in the second position.

23 Claims, 3 Drawing Sheets



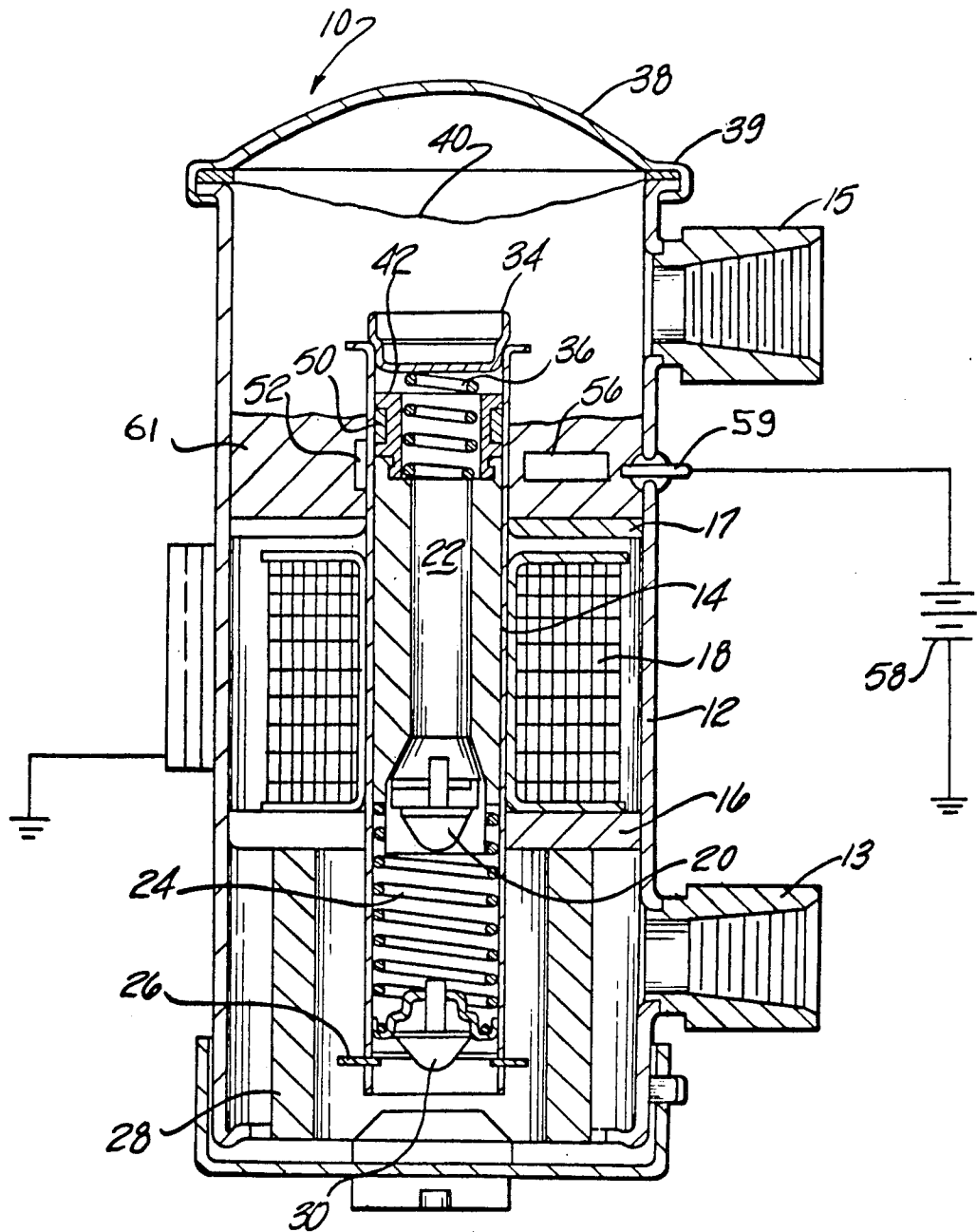


Fig-1

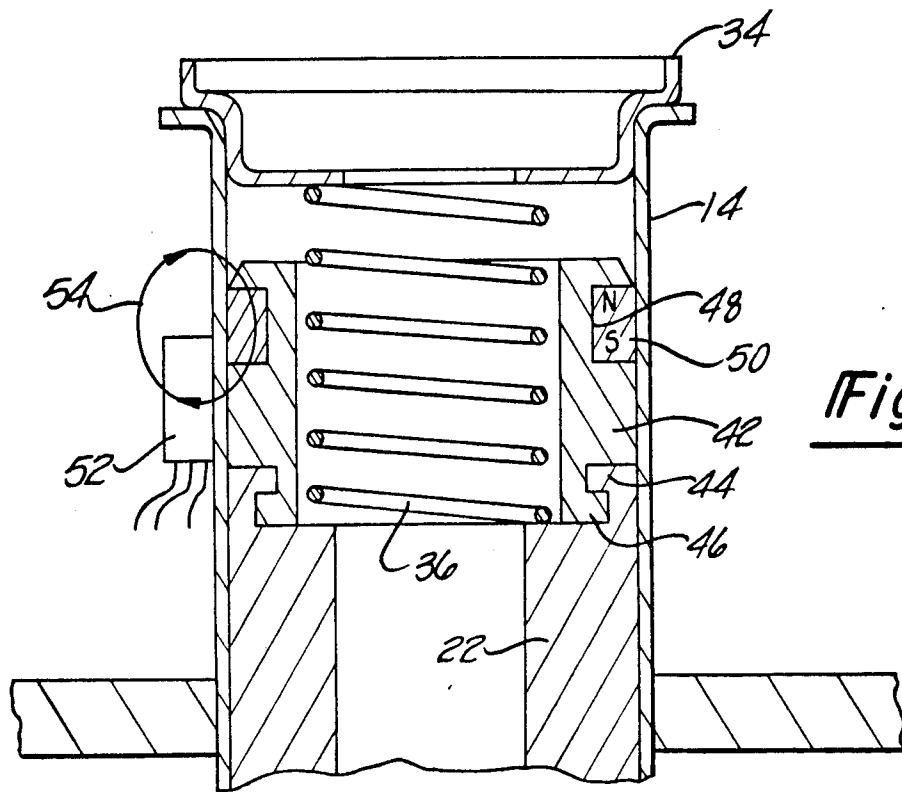


Fig-2

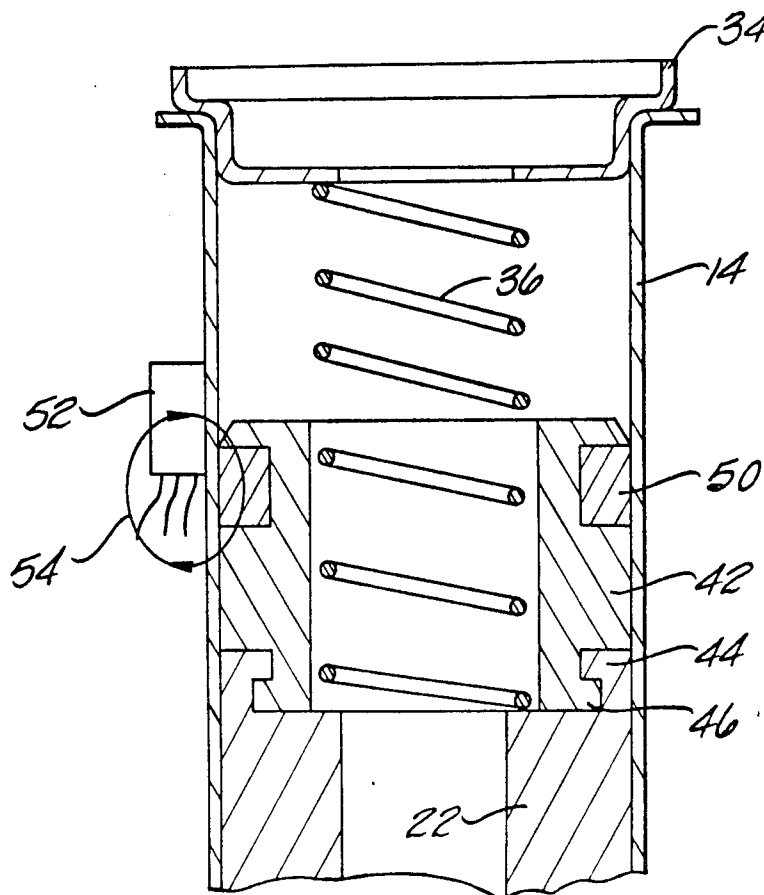


Fig-3

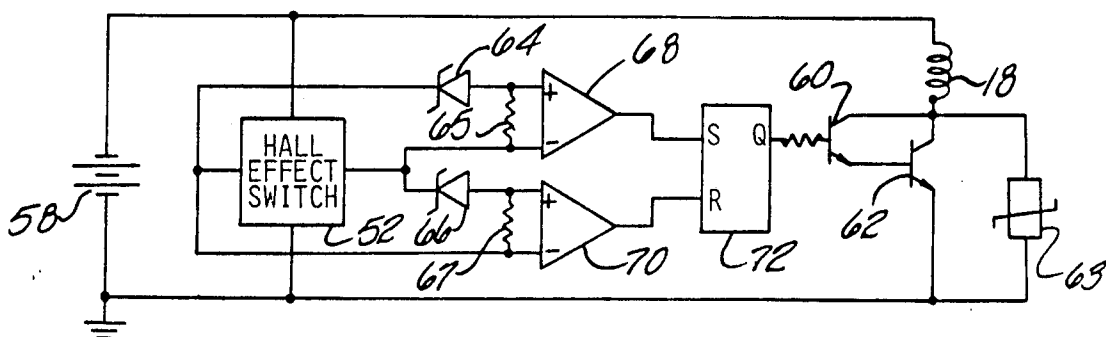


Fig-4

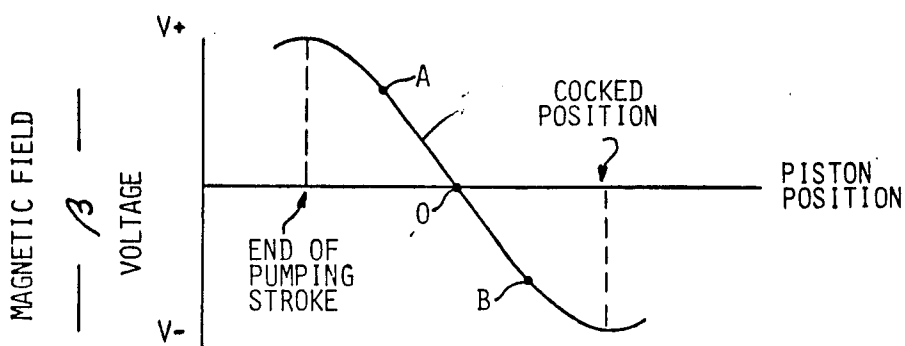


Fig-5

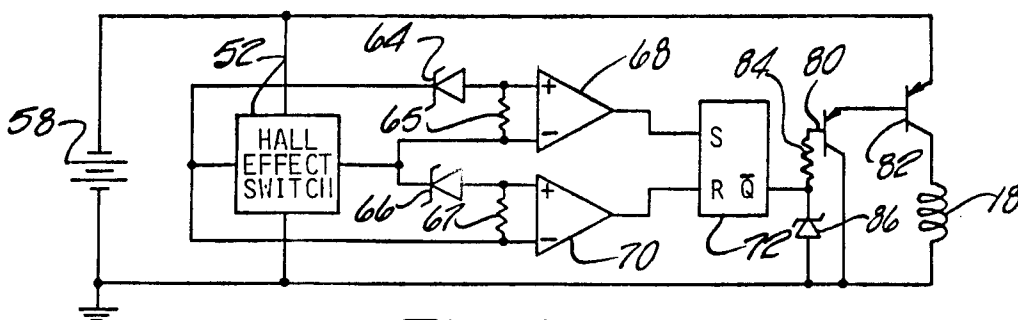


Fig-6

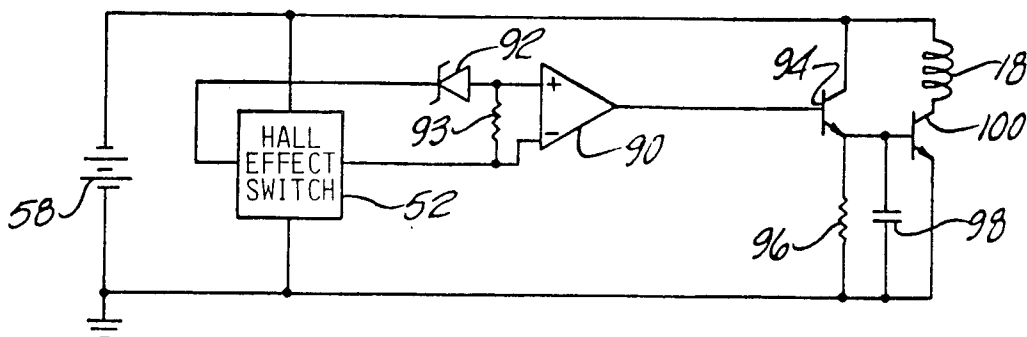


Fig-7

## HALL SWITCH PUMP

This is a continuation, of application Ser. No. 191,055, filed Sept. 25, 1980 now U.S. Pat. No. 4,413,950.

### CROSS REFERENCE

The invention is related to commonly assigned U.S. Pat. No. 4,413,950, issued Nov. 8, 1983, entitled "Reciprocating Fluid Pump Having a Hall Switch" by Ralph V. Brown which also discloses the use of a hall effect switch to detect the position of a reciprocating piston.

### BACKGROUND OF THE INVENTION

#### 1. Field of the Invention

The present invention relates to the filed of reciprocating electromagnetic devices, and in particular to a solenoid driven pump having a magnet attached to the reciprocating piston activating a hall effect switch to produce a signal having a magnitude and polarity indicative of the position of a reciprocating piston.

#### 2. Description of the Prior Art

Reciprocating piston electromagnetic fluid pumps as disclosed in the patents to Parker U.S. Pat. No., 2,994,792, and Wertheimer, U.S. Pat. No. 3,381,616, have obtained wide commercial acceptance, but in a highly competitive field, improvements are very important. The earlier models of these pumps, as represented by Parker, include an electrical switch in circuit relationship with a solenoid which is either mechanically or magnetically actuated by the piston at the end of the pumping stroke. Closing the switch energizes the solenoid retracting the piston to its cocked position. When the piston reaches the cocked position, the switch opens, deenergizing the solenoid and the pumping stroke is carried out under the force of a compressed spring. Although these types of pumps function very satisfactorily and have a reasonable operating life, the electrical switch is subject to failure and is determinative of the pump's operating life.

To increase the life of the pump, blocking oscillators were subsequently introduced such as taught by Wertheimer and Brown in U.S. Pat. No. 3,629,674. Blocking oscillators eliminated the electrical switch and increased the operating life of the pump.

Disclosed herein is a reciprocating piston electromagnetic fluid pump in which the mechanical switch is replaced by a hall effect switch generating a signal having a magnitude and polarity indicative of the piston's position.

### SUMMARY OF THE INVENTION

The invention is an electromagnetic fluid pump having a magnet attached to a piston reciprocated in response to the periodic energizing of a solenoid coil. A hall effect switch generates a signal which reverses polarity in response to a change in the direction of the magnetic field through the hall effect switch as the magnet is reciprocated with the piston. An electronic switch circuit responsive to only a signal of a predetermined polarity energizes a solenoid coil which retracts the piston against a resilient force. As the piston is retracted, the magnetic field across the hall effect switch is reversed causing the polarity of the generated signal to reverse. The electronic switch circuit responds to the reversal of the signal from the hall effect switch and

deenergizes the solenoid coil. The piston is then moved by the resilient force in the opposite direction.

An object of the invention is to provide an electromagnetic fluid pump having a hall effect switch detecting the position of a reciprocating piston. Another object of the invention is an electromagnetic fluid pump having a solenoid coil energized by an electronic switch circuit responsive to a reversal in the polarity of the signal generated by a hall effect switch. A further object of the invention is an electromagnetic pump in which the position of the reciprocating piston is detected by a solid state device having no movable parts or electrical contacts. Another object of the invention is an electromagnetic fluid pump having an increased operating life.

These and other objects of the invention will be understood from the detailed description read in conjunction with the accompanying figures.

### BRIEF DESCRIPTION OF THE FIGURES

FIG. 1 is a cross-sectional view of an electromagnetic fluid pump incorporating the disclosed invention.

FIG. 2 is a partial cross section of the fluid pump showing the position of the magnet relative to the hall effect switch at the end of the pumping stroke.

FIG. 3 is a partial cross section of the fluid pump showing the position of the magnet relative to the hall effect switch with the piston in the cocked position.

FIG. 4 is a circuit diagram of the electronic switch circuit.

FIG. 5 is a graph showing the output of the hall effect switch as a function of the piston's position.

FIG. 6 is a circuit diagram of an alternate configuration of the electronic switch circuit shown in FIG. 5.

FIG. 7 is a circuit diagram of a third embodiment of the electronic switch circuit.

### DETAILED DESCRIPTION OF THE INVENTION

Referring to FIG. 1, the numeral 10 indicates generally an electromagnetic fluid pump having a cylindrical housing 12 with a fluid inlet 13 and fluid outlet 15. Contained within the housing 12 is a nonmagnetic guide member or cylinder member 14 which is supported within the housing by pole members or annuli 16 and 17. Disposed intermediate the pole members 16 and 17 is a solenoid coil 18 circumscribing guide member 14. A hollow magnetically permeable piston 22 is disposed inside the guide member 14 and is free to reciprocate therein. A one way valve 20 is disposed at the inlet end of the piston 22. Another one way valve 30 is disposed at the inlet end of the guide member 14. The action of one way valves 20 and 30 combine in a known way to provide a unidirectional fluid flow through the guide member 14 from the inlet 13 to the outlet 15 as the piston 22 is reciprocated. A spring 24 is compressively disposed within the guide member 14 between the piston 22 and the one way valve 30. A lock ring 26 restrains the movement of the one way valve 30 in a direction away from the piston 22. A filter member 28 may be disposed in the housing 12 between the fluid inlet 13 and the lower end of the guide member to filter out contaminants which could foul the operation of the pump.

An abutment member 34 is fixedly attached to the upper end of the guide member 14 and compressively confines a spring 36 between itself and the upper end of piston 22. Spring 36 provides for storage of the piston's kinetic energy over part of the flow range. This energy

is returned to the piston during the reverse travel. Resonant operation will then be achieved with an increase in efficiency and capacity. A cap member 38 is clamped or otherwise fitted over the top of the housing 12 as shown at 39 to provide a fluid tight seal. A flexible diaphragm 40 is rigidly attached to the cap member 38 to suppress peak fluid pressure pulses generated by the reciprocating piston. The pump configuration described thus far is identical to the pump illustrated and described in U.S. Pat. No. 4,080,552, entitled "Hybrid Blocking Oscillator for an Electromechanical Pump" and represents a basic configuration of an electromagnetic fluid pump.

FIGS. 2 and 3 are enlarged cross sections of the pump above the pole member 17. Referring to FIGS. 1 and 2, piston 22 is shown at the end of its pumping stroke. A nonmagnetic annular bushing 42 is attached to the top of piston 22 by means of a pair of interlocking dogs 44 and 46 formed in the piston 22 and bushing 42, respectively. An annular magnet 50 is captivated in an annular groove 48 formed at the upper end of the bushing 42. The annular magnet 50 is axially polarized with its poles arranged parallel to the axis of guide member 14. The bushing 42 and annular magnet 50 reciprocate with the piston 22 inside of guide member 14.

Disposed on the external surface of the guide member 14 adjacent to the path of the reciprocating piston 22 is a hall effect switch 52. The hall effect switch 52 is located with respect to the annular magnet 50 such that when the piston 22 approaches the end of its stroke, the magnet flux lines 54 flowing externally about the annular magnet 50 pass through the hall effect switch 52 in a direction as indicated by the magnetic flux lines 54. This causes the hall effect switch 52 to generate an output signal having a first polarity.

Referring now to FIG. 3, the piston 22 is shown in its retracted or cocked position. In this position, the annular magnet 50 has been moved downwardly with reference to the hall effect switch 52, and now the magnetic flux path 54 passes through the hall effect switch in the opposite direction as indicated by the arrows. When the direction of the flux lines through the hall effect switch are reversed, the polarity of the signal generated by the hall effect switch 52 reverses.

Returning back to FIG. 1, the signal generated by the hall effect switch 52 is received by an electronic switch circuit 56. The electronic switch circuit 56 responds to the signal from the hall effect switch 52 having the first polarity to energize the solenoid coil 18. The electronic switch circuit 56 receives electrical power from an external source, such as a battery 58, through an insulated feedthrough 59 passing through the housing 12. The opposite pole of battery 58 is connected to housing 12 through an intermediate common ground. The hall effect switch 52 and the electronic switch circuit 56 may be encapsulated within housing 12 above pole member 17 using a conventional electronic potting material 61 as is known in the art.

The details of the electronic switch circuit 56 which energizes the solenoid coil 18 are shown on FIG. 4. The positive pole of a source of electrical power, such as battery 58, is connected to the positive terminal of the hall effect switch 52 and one end of the solenoid coil 18. The negative terminal of the battery 58 is connected to the negative input to the hall effect switch 52, to the emitter of a transistor 62 and to a common ground. One output of the hall effect switch 52 is connected to the cathode of a zener diode 64 and to the negative input of a comparator 70. The anode of zener diode 64 is con-

nected to the positive input of a comparator 68 and to the negative input of comparator 68 through a resistor 65. The other output of the hall effect switch 52 is connected to the cathode of a zener diode 66 and to the negative input of comparator 68. The anode of zener diode 66 is connected to the positive input of a comparator 70 and to the negative input of comparator 70 through a resistor 67.

The outputs of comparators 68 and 70 are connected to the set (S) and reset (R) inputs of a bi-stable switch such as R.S. flip flop 72. The  $\bar{Q}$  output of flip flop 72 is connected to the base of a transistor 60, the emitter of which is connected to the base of transistor 62. The collectors of transistors 60 and 62 are connected to the other end of solenoid coil 18. The transistors 60 and 62 are arranged in the familiar Darlington amplifier circuit. A metal oxide varistor (MOV) 63 is connected in parallel with the collector and emitter terminals of transistor 62.

The operation of the electronic switch circuit 56 shall be described with reference to FIGS. 4 and 5. FIG. 5 shows the differential output voltage of the hall effect switch as a function of the strength and direction of the magnetic field and as a function of the position of the piston 22. Referring first to FIG. 5, when the piston 22 is at the end of its stroke, the differential voltage between the two outputs of the hall effect switch has a maximum positive potential  $V_1$  which varies as the piston 22 is moved to its cocked position to a maximum negative potential as indicated by curve 74. The crossover potential of zener diode 64 is selected at the potential designated "A" on curve 74 and the crossover potential of zener diode 66 is selected at the potential designated "B" on curve 74. Referring now to FIG. 4, when the piston 22 is at the end of its pumping stroke, the positive potential difference between the two output electrodes of the hall effect switch is greater than the crossover potential of zener diode 64. This makes the potential applied to the positive input of comparator 68 more positive than the potential applied to its negative input. At the same time the potential applied to the negative input to comparator 70 is more positive than the potential applied to its positive input. Comparator 68 generates an output signal which sets flip flop 72. In its set state, flip flop 72 generates a high signal at its  $\bar{Q}$  output which is applied to the base of transistor 60 causing it to conduct. The conductance of transistor 60 supplies base current to transistor 62 making it conductive. Conduction of transistor 62 energizes solenoid coil 18 to attract piston 22 towards its cocked position. After the piston 22 passes the point designated 0 the polarity of the signals applied to the inputs of comparator 68 reverse, terminating its output. Flip flop 72 remains in its set state until the piston passes point "B" at which the differential potential generated by the hall effect switch 52 exceeds the crossover potential of zener diode 66. The potential at the positive input to comparator 70 now exceeds the potential applied to its negative input. This causes comparator 70 to generate an output signal which resets flip flop 72 terminating the high signal at its  $\bar{Q}$  output. The termination of high signal at the  $\bar{Q}$  output of flip flop 72 back biases transistors 60 and 62 deenergizing solenoid coil 18. The momentum of the piston 22 will carry it beyond point "B". At some point beyond "B" the force of spring 24 will overcome the piston's momentum. The piston 22 will then reverse its direction motion and begin its pumping stroke moving back toward point "A". Maximum efficiency is ob-

tained by placing point "A" as close to the end of pumping stroke as possible so that the magnetic force does not oppose the piston's motion.

Flip flop 72 will remain in its reset state until piston 22 passes point "A" as indicated on FIG. 5. After the piston passes point "A" the differential potential generated across the outputs of the hall effect switch 52 will again exceed the crossover potential of zener diode 64 and the output of comparator 68 will again set flip flop 72. Solenoid coil 18 will be energized retracting the piston 22 towards the cocked position once more. The above described cycle will be repeated, with the momentum of piston 22 carrying it somewhat beyond the points designated "A" and "B" during each cycle. The piston 22 will, therefore, oscillate between the points designated "end of pumping stroke" and "cocked position" as indicated on FIG. 5. Obviously, the selection of points "A" and "B" can be selected to lengthen or shorten the pumping stroke as desired.

An alternate configuration of the electronic switch circuit 56 is shown in FIG. 6. This circuit is basically the same as the one shown in FIG. 4 except that the npn transistors 60 and 62 are replaced with pnp transistors 80 and 82. This permits one end of the solenoid coil to be connected directly to the common ground. The operation of the circuit shown on FIG. 6 is identical to the operation of the circuit shown on FIG. 4 except that the base of transistor 80 is connected to the  $\bar{Q}$  output of flip flop 72 through a resistor 84. The resistor 84 and a zener diode 86 perform the same basic function as the metal oxide varistor 63 of FIG. 4, i.e., protection of transistor 82 from voltage spikes on the voltage supply. The  $\bar{Q}$  output of flip flop 72 is also connected to ground through zener diode 86. When flip flop 72 is set by the output of comparator 68, the  $\bar{Q}$  output of flip flop 72 goes low forward biasing transistor 80. The conductance of transistor 80 forward biases transistor 82 energizing solenoid coil 18.

A third embodiment of electronic switch circuit 56 is shown in FIG. 7. Referring to FIG. 7, the positive terminal of the battery 58 is connected to the positive input of the hall effect switch 52, the collector of a first transistor 94 and to the collector of a second transistor 100 through the solenoid coil 18. The negative terminal of the battery 58 is connected to the negative input to the hall effect switch, to the emitter of transistor 94 through a resistor 96, to the emitter of transistor 100 and to a common ground. The emitter of transistor 94 is also connected to the base of transistor 100 and is coupled to ground by a capacitor 98 in parallel with a resistor 96.

One output of the hall effect switch 52 is connected to the cathode of a zener diode 92 which has a crossover potential equal to the potential designated "A" on curve 74 of FIG. 5. The anode of zener diode 92 is connected directly to the positive input of a comparator 90 and to the negative input of comparator 90 through the resistor 93. The other output of the hall effect switch 52 is connected directly to the negative input of comparator 90. The output of comparator 90 is connected to the base of transistor 94.

The operation of the circuit shown on FIG. 7 is as follows: When the piston 22 is at the end of its pumping stroke, the output of the hall switch is greater than the crossover potential of zener diode 92 making the potential applied to the positive input of comparator 90 more positive than the potential applied to its negative input. The comparator 90 generates a signal forward biasing transistor 94 causing it to conduct. The conductance of

transistor 94 forward biases transistor 100 energizing solenoid coil 18 and charges capacitor 98. The energizing of the solenoid coil 18 as before retracts piston 22 towards its cocked position. When the piston 22 passes the point designated 0 on FIG. 5, the potential on the outputs of the hall effect switch reverse polarity terminating the signal from comparator 90 to the base of transistor 94. This back biases transistor 94 and it ceases to conduct. Transistor 100 continues to be forward biased by the discharge of capacitor 98. The impedance values of resistor 96 and capacitor 98 are selected to maintain transistor 100 forward biased until the piston reaches point "B". As previously described, the momentum of piston 22 will carry it a short way beyond point "B" to the cocked position. The spring 24 will then urge the piston forward on its pumping stroke until it reaches point "A" where the differential output of the hall effect switch 52 exceeds the crossover potential of zener diode 92. At this point, comparator 90 will again produce an output signal forward biasing transistors 94 and 100 to energize solenoid coil 18 and charge capacitor 98. The cycle will repeat oscillating the piston between its cocked position and the end of its pumping stroke.

It is submitted that persons skilled in the art will be able to devise other circuits responsive to the change in polarity of the hall effect switch to periodically energize a solenoid coil to oscillate a movable member without departing from the spirit of the invention. It is not intended that the invention be limited to controlling the oscillation of a piston in a pump as described and illustrated but may also be used to oscillate a movable member in other types of devices.

What is claimed is:

1. An electromagnetic fluid pump comprising:

- an enclosed housing having an inlet port and an outlet port;
- a cylindrical guide disposed in said enclosed housing defining a fluid flow path through said enclosed housing, said cylindrical guide having one end proximate said inlet port and an other end proximate said outlet port, said cylindrical guide further having an axis;
- a magnetically permeable piston member disposed in said cylindrical guide and free to reciprocate therein;
- valve means for providing a unidirectional fluid flow through said cylindrical guide in response to the reciprocating movement of said magnetically permeable piston member;
- biasing means for urging said magnetically permeable piston member towards said other end of said cylindrical guide proximate said outlet port;
- solenoid coil means disposed concentrically about said cylindrical guide for moving said magnetically permeable piston member towards said one end of said cylindrical guide proximate said inlet port against the force of said biasing means;
- a magnet attached to said magnetically permeable piston member for reciprocating therewith to define a reciprocating path of motion, said magnet having its magnetic poles disposed parallel to the axis of said cylindrical guide;
- Hall-effect means disposed intermediate the extremities of said reciprocating path of motion of said magnet for generating a predetermined signal, said predetermined signal varying from a first magnitude and polarity when said magnet is at one ex-

tremity of said reciprocating path to a second magnitude of reversed polarity when said magnet is at the opposite extremity of said reciprocating path; and

electronic switch means for periodically energizing and de-energizing said solenoid coil in response to said predetermined signal generated by said Hall-effect means.

2. The fluid pump of claim 1 further comprising an axis of the magnetic field sensitivity of said Hall-effect means disposed normal to the axis of said cylindrical guide.

3. The fluid pump of claim 1 wherein said solid state switch means comprises at least one transistor having its collector and emitter electrodes connected in series with said solenoid coil means.

4. The fluid pump of claim 3 wherein said solid state switch means comprises a Darlington amplifier connected in series with said solenoid coil means.

5. The fluid pump of claim 1 wherein said electronic switch means comprises:

polarity sensitive means for generating a biasing signal in response to said predetermined signal generated by said Hall-effect means having said first polarity and for terminating said biasing signal in response to said predetermined signal having said reversed polarity; and

solid state switch means for energizing said solenoid coil means in response to said biasing signal.

6. The fluid pump of claim 5 wherein said polarity sensitive means comprises:

a first comparator for generating a SET signal in response to said predetermined signal generated by said Hall-effect means having said first magnitude and polarity;

a second comparator for generating a RESET signal in response to said predetermined signal generated by said Hall-effect means having said second magnitude of reversed polarity; and

bi-stable switch means for generating said biasing signal in response to said SET signal, and for terminating said biasing signal in response to said RESET signal.

7. The fluid pump of claim 5 wherein said solid state switch means comprises:

a first transistor forward biased by said biasing signal; a second transistor having an emitter, base and collector electrode, said collector and emitter electrodes being connected in series with said solenoid coil means and a base electrode being connected to the emitter electrode of said first transistor; and

delay means connected to said base electrode of said second transistor for forward biasing said second transistor for a predetermined time after the termination of said biasing signal to said first transistor.

8. The fluid pump of claim 7 wherein said delay means is an R-C time constant network comprising:

a resistor connected between said base electrode and said emitter electrode of said second transistor; and a capacitor connected in parallel with said resistor.

9. A method for reciprocating a magnetically permeable piston member along a predetermined path in an electromagnetic device between first and second extreme predetermined positions, said electromagnetic device having a resilient member urging said magnetically permeable piston member in one direction along said predetermined path and a solenoid coil for pulling said magnetically permeable piston member in the op-

posite direction against the force of said resilient member, said method comprising the steps of:

reciprocating a magnet attached to said magnetically permeable piston member along said predetermined path, the magnetic poles of said magnet being arranged parallel to the direction of motion of said magnetically permeable piston member along said predetermined path;

sensing the magnetic field generated by said magnet with a Hall-effect switch disposed intermediate said first and second extreme predetermined positions along said predetermined path of said magnet as said magnet is reciprocated, said Hall-effect switch being sensitive to the direction of the magnetic field generated by said magnet passing there-through to generate a differential signal having a first magnitude and a forward polarity indicative of said magnet being near said first extreme predetermined position of said predetermined path and a second magnitude and reverse polarity indicative of said magnet being near said second extreme predetermined position of said predetermined path;

activating an electronic switch circuit to energize said solenoid coil in response to said differential signal having said first magnitude and forward polarity indicative of said magnetically permeable piston member being pushed to a position near said first extreme predetermined position of said predetermined path under the influence of said force generated by said resilient member; and

activating said electronic switch circuit to deenergize said solenoid coil in response to said differential signal having said second magnitude and reverse polarity indicative of said magnetically permeable piston member being pulled to a position near said second extreme predetermined position of said predetermined path under the influence of said force generated by said energized solenoid coil.

10. The method of claim 9 wherein said Hall-effect switch produces a first signal at a first output terminal and a second signal at a second output terminal, said differential signal being the difference between said first and second signals.

11. The method of claim 9 wherein said electromagnetic device is an electromagnetic fluid pump and said magnetically permeable piston member is a reciprocating piston.

12. The method of claim 9 wherein said step of activating an electronic switch circuit to energize said solenoid coil comprises the steps of:

detecting when said differential signal has said first magnitude and forward polarity to generate a SET signal;

switching a bi-stable means to a first predetermined state in response to said SET signal to generate a biasing signal;

connecting a transistor means in series with said solenoid coil to control the current flow therethrough; and

forward biasing said transistor means to its conductive state with said biasing signal to energize said solenoid coil.

13. The method of claim 12 wherein said step of activating said electronic switch circuit to deenergize said solenoid coil comprises the steps of:

detecting when said differential signal has said second magnitude and reverse polarity to generate a RESET signal;



switching said bi-stable means to a second predetermined state in response to said RESET signal to terminate said biasing signal; and backward biasing said transistor means with the termination of said biasing signal to its nonconductive state to deenergize said solenoid coil.

14. The method of claim 12, wherein said step of detecting is performed by a comparator circuit.

15. The method of claim 12 wherein said bi-stable means is an R-S flip flop circuit.

16. The method of claim 12 wherein said transistor means is a Darlington amplifier.

17. An electromagnetic switching circuit for reciprocating a magnetically permeable piston member along a predetermined path between a first extreme predetermined position and a second extreme predetermined position in an electromagnetic actuator having a resilient member urging said magnetically permeable piston member in a first direction along said predetermined path and a solenoid coil for pulling said magnetically permeable piston member in a second direction opposite said first direction against the force of said resilient member, said electromagnetic switching circuit comprising:

a magnet attached at one end of said magnetically permeable piston member and operative to reciprocate along said predetermined path with said magnetically permeable piston member, the magnetic poles of said magnet being disposed parallel to said predetermined path;

a Hall-effect switch disposed intermediate said first and second extreme predetermined positions of said predetermined path of said magnet and adjacent said magnet for generating a predetermined signal having a first magnitude and a first polarity indicative of said reciprocating magnetically permeable piston member being near said first extreme predetermined position of said predetermined path and having a second magnitude and a second polarity opposite to said first polarity, said second polarity being indicative of said magnetically permeable piston member being near said second extreme predetermined position of said predetermined path; and

electronic switch means for energizing said solenoid coil in response to said predetermined signal from said Hall-effect switch having said first magnitude and said first polarity indicating said magnetically permeable piston member is approaching said first extreme predetermined position of said predetermined

mined path and deenergizing said solenoid coil in response to said predetermined signal from said Hall-effect switch having said second magnitude and said second polarity indicating said magnetically permeable piston member is approaching said second extreme predetermined position of said predetermined path.

18. The electromagnetic switching circuit of claim 17 wherein said electromagnetic actuator is a fluid pump and said magnetically permeable piston member is a piston, the reciprocating motion of which pumps a fluid through said fluid pump.

19. The electromagnetic switching circuit of claim 18 wherein said electronic switch means comprises:

polarity sensitive means for generating a biasing signal in response to said predetermined signal generated by said Hall-effect switch having said first polarity and for terminating said biasing signal in response to said predetermined signal having said second polarity; and

solid state switch means for energizing said solenoid coil in response to said biasing signal.

20. The electromagnetic switching circuit of claim 19 wherein said solid state switch means comprises at least one transistor having its collector and emitter electrodes connected in series with said solenoid coil.

21. The electromagnetic switching circuit of claim 19 wherein said solid state switch means comprises a Darlington amplifier.

22. The electromagnetic switching circuit of claim 19 wherein said solid state switch means comprises:

a first transistor forward biased by said biasing signal, said first transistor having a first emitter; a second transistor having a collector electrode, a base electrode, and an emitter electrode, said second transistor further having said collector and emitter electrodes connected in series with said solenoid coil and said base electrode connected to said first emitter of said first transistor; and

delay means connected to said base electrode of said second transistor for forward biasing and second transistor for a predetermined time after the termination of said biasing signal to said first transistor.

23. The electromagnetic switching circuit of claim 22 wherein said delay means comprises an R-C time constant network further comprising:

a resistor connected between said base electrode and said emitter electrode of said second transistor; and a capacitor connected in parallel with said resistor.

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UNITED STATES PATENT AND TRADEMARK OFFICE  
CERTIFICATE OF CORRECTION

PATENT NO. : 4,778,353

DATED : October 18, 1988

INVENTOR(S) : Michael V. Wiernicki

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 1, line 17, delete "filed" and insert ---- field ----.

Column 2, line 46, delete "coli" and insert ---- coil ----.

Column 5, line 66, delete "inout" and insert ---- input ----.

Column 5, line 67, delete "generator" and insert ---- generates ----.

In the Abstract

Line 11, after "effect" insert ---- switch ----.

Signed and Sealed this  
Sixth Day of June, 1989

*Attest:*

DONALD J. QUIGG

*Attesting Officer*

*Commissioner of Patents and Trademarks*