May 7, 1968 H. P. WERTHEIMER ET AL 3,381,616

ELECTROMAGNETIC FLUID PUMP

Filed July 13, 1966 2 Sheets-Sheet 1

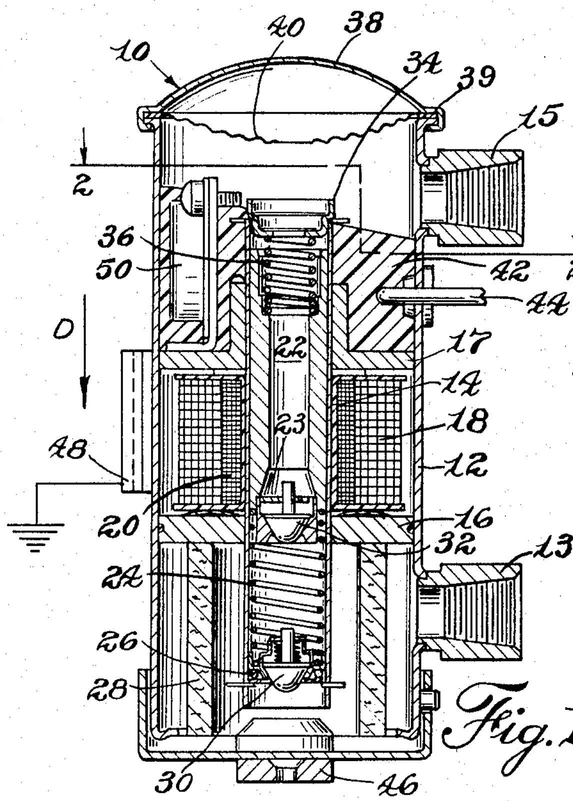

Fig. 1

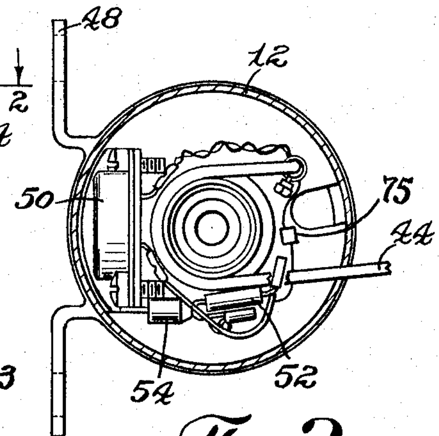

Fig. 2

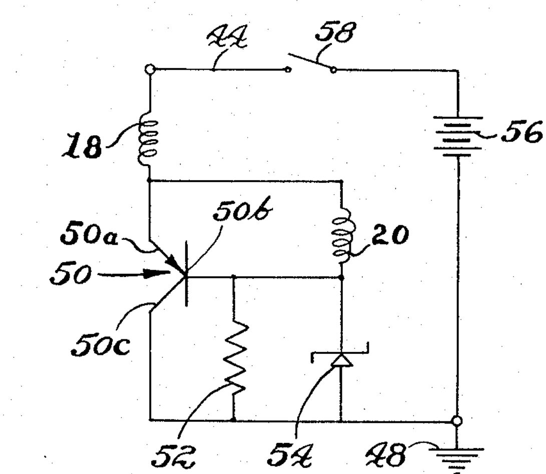

Fig. 3

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ELECTROMAGNETIC FLUID PUMP

Filed July 13, 1966 2 Sheets-Sheet 2

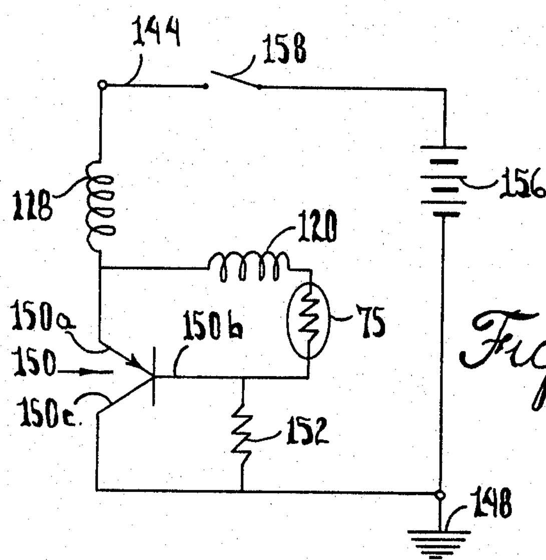

Fig. 4

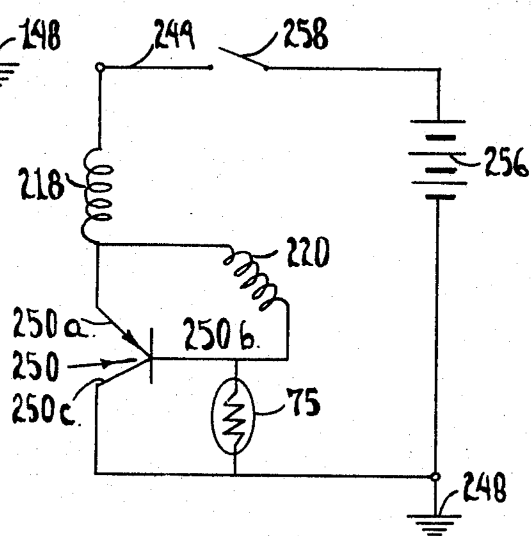

Fig. 5

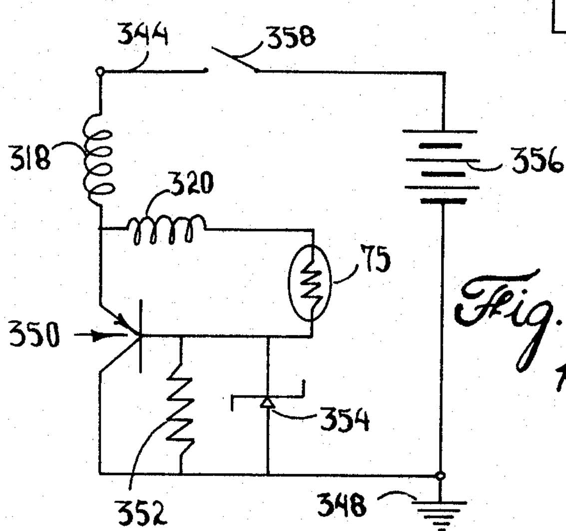

Fig. 6

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ELECTROMAGNETIC FLUID PUMP

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ABSTRACT OF THE DISCLOSURE

A reciprocating plunger electromagnetic fluid pump in which plunger motion is controlled by solid state circuitry and electromagnetic coils. A switching transistor, alternately in the conducting and non-conducting states, drives the plunger against a spring when the transistor is conducting and when the transistor is in the non-conducting state the field in the main pump coil collapses and the spring drives the plunger back. The transistor is held in the non-conducting state during the back-travel of the piston by a second coil which is magnetically linked to the plunger. Transistor protection is provided by any of a variety of voltage limiting devices to control the base-to-collector voltage.

The present invention relates to electromagnetic fluid pumps and, more particularly, to electromagnetic fluid pumps having solid state circuitry for reciprocating a plunger.

It is an object of the present invention to provide a solid state circuit and electromagnetic fluid pump combination having a low-cost transistor-oscillator circuit.

It is an object of the present invention to provide an electromagnetic fluid pump having solid state circuitry in which electric transient times are low.

It is an object of the present invention to provide a solid state circuit for an electromagnetic piston fluid pump in which piston travel is assured to be the maximum allowed by the mechanical circuit.

It is an object of the present invention to provide an electromagnetic fluid pump in which circuit reliability is greatly increased and transistor failure significantly decreased.

It is an object of the present invention to provide a novel circuit design for an electromagnetic fluid pump employing a transistor oscillator in which the transistor is protected from excessive voltage transients.

It is a further object of the present invention to provide a one-piece, fully-enclosed electromagnetic fluid pump having a solid state circuit.

It is a further object of the present invention to provide a transistor oscillator circuit for an electromagnetic fluid pump having a Zener diode disposed between the base and collector of the transistor to protect the transistor against breakdown voltage surges.

It is a further object of the present invention to provide a transistor oscillator circuit for an electromagnetic fluid pump which assures that plunger travel will be the maximum mechanically permissible over the full range of pump operating temperatures.

It is a still further object of the present invention to provide a transistor oscillator circuit for an electromagnetic fluid pump which provides a greater design flexibility in selecting the transistor base drive and in selecting and varying transistor turn-on current.

It is a still further object of the present invention to provide a temperature compensated, transistor oscillator electromagnetic fluid pump which has greater fluid output in its pressure range than prior art pumps.

The foregoing and other additional objects and advantages of the present invention will appear more fully hereafter from a consideration of the detailed description which follows, taken together with the accompanying drawing wherein an embodiment of the present invention is illustrated. It is to be expressly understood, however, that the drawing is for the purpose of illustration and description and is not to be construed as defining the limits of the invention.

FIGURE 1 shows a sectional view of an electromagnetic fluid pump embodying the present invention;

FIGURE 2 is a view taken along the section lines 2—2 of the pump shown in FIGURE 1; and

FIGURES 3, 4, 5 and 6 are electrical diagrammatic views of embodiments of the solid state circuitry of the present invention.

Turning now to FIGURE 1, the numeral **10** indicates generally an electromagnetic fluid pump having a generally-cylindrically housing **12** with a fluid inlet **13** and fluid outlet **15**. Contained within the housing **12** is a guide 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** are a first winding **18** and a second winding **20** which are disposed coaxially with the guide member **14** and with a reciprocal piston member **22** which moves reciprocally relative to the guide member **14**. A spring member **24** is compressively confined between a lock ring **26** at one end of the guide member **14** and one transverse end of the piston member **22**.A filter member **28** is disposed intermediate the fluid inlet **13** and the inlet **23** to the piston member. A plurality of valves **30** and **32** are disposed in the fluid path through the guide member **14** to prevent fluid flow other than unidirectional fluid flow from the inlet to outlet through the reciprocal piston member **22** in the well known manner.

At the upper end of the piston member **22** is disposed an abutment member **34** which compressively confines a spring member **36** intermediate the piston **22** and the abutment member **34** for providing a cushion for the piston member when it reaches the top of its stroke. A cap member **38** is clamped or otherwise fitted around the housing **12** as shown in **39** to provide a fluid-tight seal. A diaphragm **40** is rigidly attached to the rim of the cap **38** as also shown at **39** so that the interior of cap **38** constitutes a hermetically-sealed chamber.

An epoxy or other moldable material **42** aids in holding the various pump parts in position and is further useful in holding various electrical components, shown in FIGURE 2 in place. Electrical components which are housed within the housing **12** include a transistor member **50**, a Zener diode member **54** and a resistor member **52**. The coils **18** and **20** are electrically connected to the transistor **50**, Zener diode **54**, and resistor as shown in FIGURE 3 and an external source **56** such as a battery, also shown in FIGURE 3. Returning now to FIGURE 1, the electrical input from the battery is shown by lead wire **44**, the other electrical lead being supplied by the grounded mounting bracket **48** of the pump which is fastened to the housing member **12**. A bolt or nut member **46** is fastened to the bottom cap **47** to enable servicing of the filter **28**.

Turning now to the electrical circuit shown in FIGURE 3, a transistor member **50** having an emitter lead **50*a***, a base lead **50*b***, and a collector lead **50*c*** has the emitter lead **50*a*** connected to the main coil or first winding **18** which is connected to the voltage source which is shown as a battery **56**. The collector lead **50*c*** is connected to the ground side of the voltage source **56**. The second coil or second winding **20** is interconnected between the emitter lead **50*a*** and the base lead **50*b*** of the transistor. A resistor member **52** is connected between the base lead

50*b* and ground lead **48** and a Zener diode member **54** is connected between the base lead **50*b*** and the collector lead **50*c*** and which is also grounded at **48.** The second coil **20** may be considered to be a signal or detection coil.

It can readily be appreciated that the voltage source **56** might be a battery or some other source such as a rectified AC source. It should be further appreciated that the transistor **50,** while shown as a PNP transistor, might as well be an NPN transistor and that the polarity of the elements would be reversed. If an NPN transistor were used, the Zener diode **54** would be reversed, that is, it would have its anode connected to the base of the transistor rather than to the ground or low side of the voltage source **56.** If an NPN transistor were used, current and voltage directions would be reversed from those in the description of the circuit operation which follows. When switch **58** is closed, the source **56** voltage appears on the emitter **50*a*** of the transistor **50.** This voltage causes a current to flow through the second coil **20** and resistor **52.** This current flow causes a voltage drop across the second coil **20** which, in turn, causes the base **50*b*** of the transistor **50** to be at a lower voltage than the emitter **50*a*,** initiating "turn on" or conduction in the forward direction of the transistor **50.** As the transistor **50** reaches "turn on," current will start to flow in the first coil **18.** The first coil **18** and the second coil **20** are magnetically linked such that current in the first coil generates a current in the second coil **20** which flows toward the emitter **50*a*** of the transistor **50.** As current builds up in the coil **20,** the transistor **50** is driven toward saturation, that is, resistance to current flow from the emitter **50*a*** to the collector **50*c*** is minimized, causing current through the coil **18** to drive the plunger or piston member **22** in a downward direction, as shown by arrow "D" in FIGURE 1 and to cause compression of the spring **24.** The current which builds up in first coil **18** may cause the magnetic circuit, which includes the first and second coils and the pole pieces, to approach saturation. When magnetic saturation is approached or when the current in coil **18** approaches a steady state value, the bias of the transistor **50** in the forward direction, due to the magnetic linking of the coils **18** and **20,** becomes insufficient to support the transistor **50** in an "on" or forward conducting mode. The transistor is then caused to turn "off" and the coil **18** to discharge its energy very rapidly, largely through the Zener diode **54** by way of the coil **20.** Turn-off of the transistor **50** enables the spring **24** to propel the plunger back toward its initial position and closes the valve member **32,** causing fluid to be carried by the piston and pushed out of the outlet **15,** completing a pumping cycle.

During collapse of the magnetic field, the induced voltage in the coil **20** back biases or reverse biases the transistor **50,** assuring the transistor "turn off." The reverse induced voltage in the coil **20** counter balances the voltage drop across the coil **20,** resulting from the resistivity of coil **20.** Thus the voltage between the emitter and base of the transistor is limited to a level which is safe for the transistor. As the voltage across coil **20** builds up as a result of the collapsing magnetic field, the Zener or avalanche diode **54** reaches its Zener point. At the Zener point, the Zener diode has a very low resistance which permits a large current flow to the series connection of the first coil **18,** the second coil **20,** and the Zener diode **54.** Zener member **54,** however, maintains the base to collector voltage to an acceptable maximum for the transistor.

A relatively large power loss (I^2R) in the second coil **20** allows the Zener diode **54** to dissipate a smaller amount of power, thus reducing the cost of the Zener diode member. Furthermore, the Zener diode member is able to clamp electrically not only the base to collector voltage of the transistor, permitting a lower cost transistor, but also provides a safe limit to the base to the emitter voltage of the transistor because of the use of the second or signal coil member **20** as the conduit for the collapsing field energy stored in the main coil **18.** This latter effect occurs because the collapsing field induces a voltage across coil **20** which opposes the resistively-caused voltage across coil **20** which results from current through coil **20.** This is a distinct advantage over the arrangement of a Zener diode between emitter and collector wherein emitter to collector voltage is limited, but not base to collector voltage. The disclosed use of the Zener respectively limits voltage to all three transistor terminals to a safe level and enables the use of a lower cost transistor member. Further the present circuit design enables the number of signal coil turns, **20,** to be chosen independently of the number of main coil turns, **18,** so that a sufficient value of "turn on" current is possible without exceeding transistor member **50** breakdown voltages upon collapse of the magnetic field generated by coil **18.**

In the embodiments of the electrical circuitry shown in FIGURES 4, 5 and 6, like parts are shown by like numerals in the **100, 200** and **300** series respectively without further explanation; for example, the main coil member bears the numeral **18** in FIGURE 3, **118** in FIGURE 4, **218** in FIGURE 5 and **318** in FIGURE 6.

In the embodiment of the invention shown in FIGURE 4, a negative temperature coefficient resistor member **75** is placed in electrical series relationship with the detector coil **120.** The resistor member **75** may be a thermistor or some other negative temperature coefficient device. A diode (not shown) or a series in combination of a diode and resistor (not shown) may be added in parallel with the main coil member **118** to provide a discharge path for the energy stored in the coil **118** during one part of the pumping cycle.

Turning now to the embodiment of the present invention shown in FIGURE 6, a negative temperature coefficient resistor member **75″** is in electrical series relationship with the detection coil **320** and the emitter-base circuit of the transistor member **350.**

If the pump of the present invention were to be used as a fuel pump for an automobile, it is required that the initial "turn-on" bias for the transistor be sufficient to insure actuation of the pump at temperatures below minus forty degrees Fahrenheit (−40° F). "Turn-on" bias refers to that voltage on the emitter with respect to the base which is required to initiate emitter-collector current flow at the start of the pumping cycle. In FIGURE 6, this bias would be the voltage drop across the series combination of coil **320** and resistor member **75″**. At a given supply **356** voltage, the "turn on" bias will be determined by the relative magnitude of the resistance of the series combination of coil **320** and a resistor member **75″** in comparison with the resistance of resistor member **352,** as well as the transistor's base to collector leakage.

If the resistances of coil **320** and resistor members **75″** and **352** are established to provide the required "turn on" bias at low temperatures, such as minus forty degrees Fahrenheit (−40° F), good pump performance at more normal operating temperatures would necessitate a (premium) transistor with high gain, were it not for the reduced resistance of resistance member **75″**. A low gain (economical) transistor may be used even at −40° F, since the gain of power transistors generally increases at low temperatures. "Turn-on" bias at the more normal temperature. This leakage current flows in a parallel path base to collector leakage current increases with increasing temperature. This leakage current flows in a parallel path to the current in resistor member **352,** causing the current to increase in the series combination of coil **320** and resistor member **75″**. Since the resistance of member **75″** is lower at the normal temperatures, the voltage drop across the series combination, which is the "turn-on" bias, is nearly constant over a wide range of temperature.

A further advantage of the use of a negative temperature coefficient resistor member such as **75** or **75″** is realized in some embodiments of the present invention. This advantage is the prevention of "premature termination" of the "off" portion (pumping stroke) of the cycle. "Premature termination" will result if the "turn on" bias is large in comparison to what is needed, and if the piston member 22 is retarded in its upward travel. Such "premature termination" may result in loss of pump performance (delivery) at the higher pressures.

In the embodiment shown in FIGURE 5 a positive temperature coefficient resistor member 75' is connected to the base and collector of transistor member 250. The resistor member 75' has its lowest resistance at the lowest temperature. The effect of this on "turn on" bias is the same as previously described for a negative coefficient resistor (75 or 75") placed in the circuit as shown in FIGURES 4 and 6.

It can thus be appreciated that the present invention achieves all of its stated objects and provides a low cost, high performance, highly reliable transistor oscillator circuit in combination with an electromagnetic reciprocating piston pump. The increase in reliability is insured by the use of the Zener diode member which is connected between the base and the collector of the transistor and serves to stabilize not only base and emitter to collector voltage, but emitter to base reverse voltage, permitting a lower cost transistor. Further, this position of the Zener diode member enables a lower cost Zener member since the signal coil or second coil 20 is providing a significant portion of the power loss when the large main coil current is passed through it. The present invention allows the main coil 18 to discharge substantially completely, thereby assuring full pump output volume and pressure per cycle. The present invention significantly reduces main coil discharge time, thus increasing the pump fluid output over its pressure range. In addition, when operation over a wide range of temperature is considered, the combination of Zener diode and thermistor members produces a higher output than any other embodiment of the present invention. Still further, the thermistor member increases fuel output at the higher pressures in the normal pressure range, when compared to an identical fluid pump without such a circuit element, providing both pumps are to be used over the usual range of outdoor temperatures.

It can be appreciated that although coil members 18 and 20 are shown, that any other form of current sheet could be used such as a solid sheet of conducting material.

We claim:

1. A fluid pump powered by an electrical source comprising:
a reciprocating means;
a first coil member;
a second coil member magnetically linked to said first coil member by the reciprocating means;
a transistor member having an emitter, collector and base;
said first coil connected between said electrical source and said emitter;
said second coil connected between said emitter and said base;
a Zener diode member connected between said base and said collector; and
said collector for connection to said electrical source.

2. The pump as claimed in claim 1 including further:
a negative temperature coefficient resistive means connected in electrical series relationship with said second coil.

3. The pump as claimed in claim 1 including further:
a positive temperature coefficient resistive means connected between the collector and base of said transistor.

4. A fluid pump powered by an electrical source comprising:
a reciprocating means;
a first coil member;
a second coil member magnetically linked to said first coil member by the reciprocating means;
a transistor member having an emitter, collector and base;
said first coil connected between said electrical source and said emitter;
said second coil connected between said emitter and said base;
a temperature responsive resistive means connected relative to the transistor member to assure full piston travel over a broad temperature range; and
said collector for connection to said electrical source.

5. The pump as claimed in claim 4 wherein:
said temperature responsive resistive means is connected in electrical series relationship with said second coil.

6. The pump as claimed in claim 4 wherein:
said temperature responsive resistive means is connected between the collector and base of said transistor.

7. A fluid pump powered by an electrical source comprising:
a hollow guide means having a fluid inlet and a fluid outlet;
a piston member slidably disposed in said guide member for reciprocal movement;
an electrical source of magnetic flux for creating a magnetic field having a component substantially parallel to said piston member reciprocal path;
detection means magnetically linked to said electrical source of magnetic flux for generating an electrical signal;
a transistor member having an emitter, collector and base;
said detection means disposed between said emitter and said base;
electrical valve means having a characteristic of passing substantially no current until a predetermined bias level is exceeded and passing relatively large currents at levels slightly exceeding said predetermined bias level, said valve means disposed between said base and said collector; and
said collector connected to said electrical valve means and for connection to the source of electrical potentials.

8. The fluid pump as claimed in claim 7 wherein:
said electrical source of magnetic flux is magnetically linked to said detection means such that a positive current in said electrical source of magnetic flux produces a negative voltage in said detection means.

9. The fluid pump as claimed in claim 8 including further:
a negative coefficient temperature responsive means in electrical series relationship with said detection means.

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ROBERT M. WALKER, *Primary Examiner.*