Jan. 21, 1964 S. G. WOODWARD 3,118,383

ELECTROMAGNETICALLY ACTUATED DEVICE WITH FEEDBACK CONTROL

Filed Dec. 15, 1961

Fig. 1

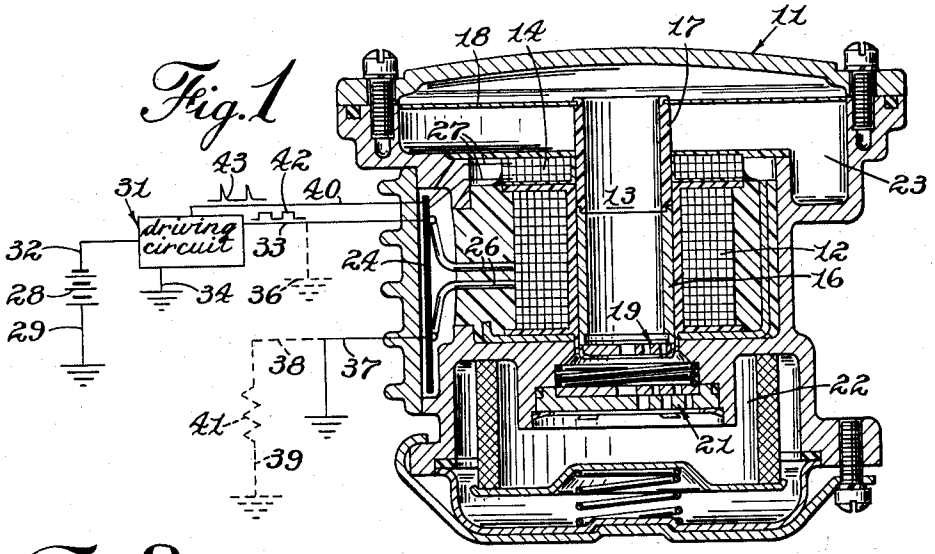
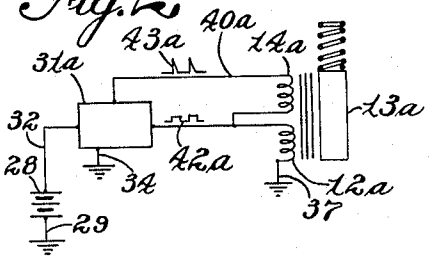


Fig. 2



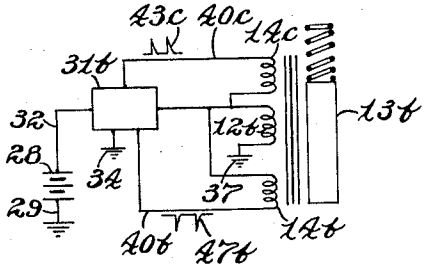


Fig. 3

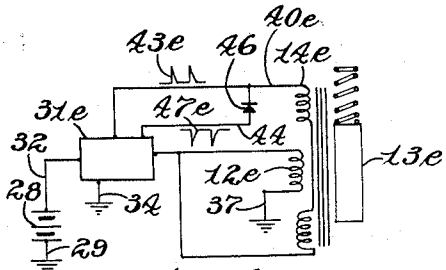


Fig. 4

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ELECTROMAGNETICALLY ACTUATED DEVICE WITH FEEDBACK CONTROL

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The present invention relates to an electromagnet-spring actuated device wherein the energization pulses supplied to the electromagnet are provided by means of an electronic driving circuit whose output pulse duration and off time duration are controllably varied by control pulses generated in means sensing the position of the actuated element of the device. More particularly the invention relates to an electromagnet-spring actuated pump wherein coil means sense the pump plunger position and provided generated control pulses to control and vary the output pulse duration and off time duration of a driving multivibrator energizing the electromagnet.

In the past, attempts have been made to provide a pump effectively combining an electromagnet and a resonant spring actuated pump plunger with the electromagnet being driven by a fixed cycle electronic driving circuit tuned to the period of resonance of the spring. The developed devices were found to have definite limitations because the resonance of the spring is of little value when pumping fluid under a pressure head and this is particularly so when the pump is used to meet varying pressure head requirements. The resonance of such a system can not be varied since the spring has a fixed period of resonance and this period of resonance must be continually matched and synchronized with the fixed duration of energization output pulses of the electronic driving means. Failure to attain the aforesaid matching and synchronistic requirements results in a rapid decrease in fuel delivery or pump output especially when the output pressure requirements imposed on the pump are increased. The decrease in pump output has been determined to be primarily the result of a diminishing plunger or piston stroke. The diminished stroke in turn has been determined to result from an inadequate output pulse duration applied to the electromagnet. The resonant spring characteristics are also detrimentally affected under such conditions. It is therefore the primary object of the invention to provide a pumping device including means for overcoming the aforesaid deficiencies.

It is a further object of the invention to provide a pump which is relatively simple, economical to manufacture and fabricate, efficient and dependable in operation and durable in construction.

It is another object of the invention to provide an electromagnet-spring actuated pump which is driven by multivibrator means having controllable and variable off and output pulse durations with said durations being controlled by means sensing the positions of the pump piston.

It is still another object of the invention to provide a pumping device which is driven by a multivibrator means of either the astable or monostable variety and in which the sensing means includes coil means in which induced energy pulses are caused to exist responsive to piston reciprocations into and out of the coil with the induced pulses being applied to the multivibrator to provide control pulses for terminating or initiating the multivibrator operation.

With the above and other objects in view which will appear as the description proceeds, this invention resides in the novel combination and arrangement of elements substantially as hereinafter described and more particularly defined by the appended claims, it being understood

that such changes in the precise embodiments of the herein disclosed invention may be made as come within the scope of the claims.

The accompanying drawing illustrates several complete examples of the physical embodiment of the invention constructed according to the best mode so far devised for the practical application of the principles thereof, and in which:

FIGURE 1 is a view, partly in section and partly in diagrammatic form, of a pump embodying the invention;

FIGURE 2 is a schematic representation of the embodiment illustrated in FIGURE 1 wherein the driving circuit is a monostable multivibrator and the sensing means in which the control pulse is generated comprises a single coil positioned adjacent the piston actuated position;

FIGURE 3 is a schematic representation of another embodiment of the invention wherein the driving circuit is an astable multivibrator and the sensing means in which the control pulses are generated comprises a pair of coils positioned one adjacent the piston actuated position and the other adjacent the rest position; and

FIGURE 4 is a schematic representation of still another embodiment of the invention wherein the driving circuit is an astable multivibrator and the sensing means includes diode means for distinguishing and directing generated control pulses to the multivibrator.

Referring now more particularly to the accompanying drawing in which like numerals indicate like parts, in FIGURE 1 the numeral **11** generally designates a pump housing supporting a solenoid **12** fixedly secured within the pump housing coaxially surrounding the pump-plunger or piston **13**. A sensing coil **14** is also fixedly secured in the pump housing in coaxial relation with the pump piston. The piston, which consists of a hollow metal cylindrical plunger portion **16** and a hollow non-magnetic cylindrical extension **17** of nylon or a similar material, is supported by a spider-like spring **18** and is adapted to be reciprocally movable between a rest position (illustrated in FIGURE 1) and an actuated or cocked position. In the actuated position the plunger portion **16** is attracted upwardly by the electromagnetic forces of the energized solenoid **12** and to a slight degree projects into the magnetic field of the coil **14**.

The lower extremity of the plunger supports a valve mechanism generally designated as **19** which cooperates with other valve means generally designated as **21** supported by the pump housing. The valve **21** communicates with the inlet cavity **22** of the pump. The hollow piston and valve **19** communicate with the outlet cavity **23**. The description, to this point, is intended only to define broadly the pump and not to specifically define or limit the pump structure. It is important only that the pump device comprises as its principal elements a solenoid for creating an electromagnetic field, a piston reciprocally movable within the solenoid between an actuated or energized position and a rest or deenergized position, with the piston motivating force being supplied by the electromagnetic field generated by the energized solenoid for attracting the piston to one of the positions, and a spring member for biasing the piston to the other position.

A terminal board **24**, preferably of the printed circuit variety, is supported within the pump housing. Paired leads **26** and **27** in any convenient manner connect the solenoid **12** and the sensing coil **14**, respectively, to one face of the terminal board while other leads hereinafter described externally connect the electrical and electronic components comprising the power source, the driving means and ancillary control elements to the opposite face of the terminal board.

A battery **28** provides a source of power and is con-

nected by lead 29 to ground which provides the reference potential. A multivibrator generally designated as 31, providing the driving circuit means, is connected by lead 32 to the battery and by lead 33 to the terminal board. The multivibrator is preferably connected to the reference potential as at 34 while the lead 33 may optionally be grounded as illustrated in phantom at 36. One of the leads in each of the paired leads 26 and 27 is connected to the lead 33 via terminal board circuits. The remaining lead of the pair 26 connects the solenoid 12 via terminal board circuits to an external grounding lead 37, shown in full lines. The grounding lead 37 can be wholly replaced for a purpose hereinafter described by leads 38 and 39 and resistive means 41, all of which are illustrated in phantom. The remaining lead of the pair 27 connects the sensing coil 14 to the terminal board circuits which in turn is connected by lead 40 to the multivibrator 31.

Operation of the aforesaid generally described pump device of FIGURE 1 has the multivibrator operate in a known manner to provide an output pulse 42 which is schematically illustrated as a square wave. The output pulse is transmitted via lead 33 to the solenoid 12 to energize the solenoid and create an electromagnetic field adapted to attract the plunger portion 16 of the piston 13 into its electromagnetic field. The resulting reciprocal movement of the piston from its rest position to the actuated position causes the spring 18 to be deflected and stressed, and, as the plunger approaches a centralized position within the electromagnetic field, which position is termed the activated position, a portion of the uppermost extremity of the plunger portion 16 will project into and be encompassed temporarily by the sensing coil 14 thereby entering into its electromagnetic field. The sudden entry of portion 16 of the plunger into the area surrounded by the sensing coil will induce or generate a current pulse within the sensing coil in a known manner. The induced pulse in the sensing coil provides a control pulse 43 schematically illustrated as a spike-shaped wave, which is coupled to the multivibrator 31 by the leads 27, 33, and 40. The applied control pulse 43 terminates the multivibrator output pulse 42 causing the solenoid 12 to become deenergized and causing its electromagnetic field to collapse. The spring 18 thereupon asserts its biasing force and returns the piston to its rest or deenergized position.

The pumping action of the piston 13 and the valve mechanisms 19 and 21 is such that when the piston is attracted to its actuated position, the valve mechanism 19 will operate to close off the hollow piston with the consequential result that a suction is created in the pump inlet cavity 22 through the valve 21. The suction is of sufficient magnitude to draw fluid from a reservoir (not shown) and fill the cavity 22 and the area between the valves 19 and 21. The subsequent collapse of the magnetic field upon termination of the multivibrator output pulse by the control pulse allows the spring to bias the piston 13 to its rest or deenergized position and in so doing, the valve mechanisms 19 and 21 will operate to open and close, respectively, and cause fluid to flow into the hollow portion of the piston. Any fluid previously entrapped in the hollow piston will be expelled by the incoming fluids into the outlet cavity 23 in the known manner.

To this point the generally designated multivibrator 31 has not been identified specifically as to type nor has the sensing means for terminating or initiating the multivibrator output pulses been fully disclosed. Each of the FIGURES 2, 3, and 4 discloses a specific embodiment of the present invention and more particularly describes these elements. FIGURE 2 illustrates an embodiment of the invention wherein the multivibrator 31*a* is monostable. As such, the multivibrator has an off time of a fixed duration and has an on or output pulse 42*a* which is of a variable duration with the output pulse duration being determined by the sensing means 14*a* and its generated or induced control pulse 43*a*. Once the output pulse is initiated it is internally controlled by a calibrated time constant which is set for a maximum time duration. Normally the time constant is calibrated to meet the longest time interval requirement for the solenoid 12*a* energizing output pulse. This calibrated time duration is sufficiently long to insure that the piston 13*a* will always be attracted to the fullest extent of its actuated position. If the piston attains the actuated position in a time interval of less than the calibrated time constant, then the control pulse 43*a* applied to the multivibrator time constant through lead 40*a* from the sensing coil 14*a* will act to terminate prematurely the multivibrator output pulse and thereby initiate the multivibrator off time cycle. It can be appreciated that, as the fluid outlet pressure increases, the time duration of the solenoid energizing output pulse will of necessity lengthen and approach in duration the time duration established by the internally calibrated time constant.

FIGURE 3 illustrates the invention wherein the multivibrator 31*b* is astable. As such, the multivibrator has an off time duration having an established maximum time duration and also has an on or output pulse time having an established maximum time duration both of which are determined by internally controlled and calibrated time constants. The durations of both the output pulse and the off time can be controllably shortened. To achieve a shortened off time a sensing coil 14*b* is positioned adjacent the rest position of the piston 13*b*. When the piston is biased to the rest position, its movement into the electromagnetic field of coil 14*b* will induce or generate a control pulse 47*b*, schematically illustrated as a negative spike-shaped wave. Pulse 47*b* is applied to the multivibrator through lead 40*b* to terminate prematurely the off time cycle and/or to initiate the output cycle. To achieve a shortened output pulse a second sensing coil 14*c* is positioned adjacent the actuated or cocked position of the piston 13*b*. When the piston is attracted to its actuated position by solenoid 12*b* its movement into the electromagnetic field of coil 14*c* will induce or generate a second control pulse, schematically illustrated as a positive spike-shaped wave 43*c*, which is applied to the multivibrator through lead 40*c* to initiate the off time cycle and/or to terminate the output pulse cycle.

In FIGURE 4 the invention is illustrated as including an astable multivibrator 31*e* also having an established maximum off time and an established maximum output pulse time, both of which are determined by an internally and calibrated time constant. The duration of both the output pulse and the off time can be controllably shortened. To achieve a shortened interval a sensing coil 14*e*, schematically illustrated as a single coil, but actually comprising a single coil having a portion of its turns positioned adjacent the rest position of the piston 13*e* and having the balance of its turns positioned adjacent the actuated position of the piston, is utilized. Each group of turns of the coil is so positioned that the movements into and out of the electromagnetic field of the coils will induce or generate a control pulse of either a positive characteristic or a negative characteristic both of which are schematically illustrated as 43*e* and 47*e*, respectively. The internal structure of the multivibrator when supplied the pulse 47*e* by lead 40*e* will inherently act as a diode and refuse actuation by this negative control pulse. Depending upon the electronic structure of the multivibrator the control pulse 43*e* when applied will either prematurely initiate or terminate the multivibrator output pulse. A second lead 44 is connected between lead 40*e* and a second connecting point in the multivibrator 31*e* and includes therein the diode 46. The diode will pass the control pulse 47*e* and will operate in a blocking fashion to the control pulse 43*e* thus either prematurely terminating or initiating the multivibrator off time cycle.

In each of the embodiments of FIGURES 2, 3, and 4

the solenoids **12***a*, **12***b*, or **12***e*, respectively, has one of its leads connected directly to the reference potential. In each embodiment this direct grounding lead can be wholly replaced by the counter-parts of the leads **38**, **39**, and the resistive element **41** generically described above. The resistive element **41** is intended to be variable and operatively responsive to the pump outlet pressure. Variations of the value of resistance in the solenoid circuit by resistor **41** will then vary the output pulse energy level applied to the solenoid during the pulse on cycle and will thereby affect the maximum pressure obtainable, or control pressure output to a desired maximum value.

It is to be understood that the invention is not limited in its application to a pumping device nor to the details of construction and arrangement of parts illustrated in the accompanying drawing since the invention is capable of other embodiments and of being practically carried out in various ways. Also, it is to be understood that the phraseology and terminology employed herein is for the purpose of description and not limitation and it is not intended to limit the invention herein claimed beyond the requirements of the prior arts.

I claim:

1. A device of the character described, comprising:
a pump including a solenoid and a piston reciprocally movable between a rest position and an actuated position;
resilient means biasing the piston to one of its positions, said piston and resilient means having a natural period of resonant vibration, the frequency of which is altered by variations in load of the pump;
a source of power;
a reference potential connected to one side of the source;
multivibrator means connected to the other side of the source adapted to provide an output pulse which is normally of constant frequency and duration;
means connecting the solenoid to the reference potential;
means connecting the solenoid to the multivibrator, said solenoid being energizable by the output pulse adapted when energized to attract the piston to the other of its positions;
means for sensing the piston position adapted when said position is sensed to provide a control pulse; and
means for applying the control pulse to the multivibrator to alter the character of the output pulse to cause it to conform to the prevailing resonant frequency of the pump piston and resilient means.

2. A fluid transfer device of the character described comprising:
a pump including a solenoid and a piston reciprocally movable between a rest position and an actuated position;
spring means biasing the piston to its rest position;
a source of power connected at one side to a reference potential;
a monostable multivibrator connected to the other side of the source adapted to have a fixed off time duration and to provide an output pulse of variable time duration for energizing the solenoid;
means, including variable resistor means operatively responsive to the pump outlet pressure for varying the output pulse energy level applied to the solenoid and for regulating pump pressure, connecting the solenoid between the reference potential and the multivibrator, said solenoid adapted when energized by the output pulse to attract the piston to its actuated position;
coil means for sensing the piston position adapted when the piston position is sensed to provide a control pulse for controlling the multivibrator output pulse, said coil means surrounding the piston so that reciprocation of the piston into and out of the coil means induces an energy pulse therein to provide the control pulse; and
means for operatively connecting the sensing means to the multivibrator.

3. A fluid transfer device of the character described comprising:
a pump including a solenoid and a piston reciprocally movable between a rest position and an actuated position;
spring means biasing the piston to its rest position;
a source of power connected at one side to a reference potential;
an astable multivibrator connected to the other side of the source adapted to have a variable and controllable off time and to provide an output pulse of a variable controllable time duration for energizing the solenoid;
means, including variable resistors means operatively responsive to the pump outlet pressure for varying the output pulse energy level applied to the solenoid and for regulating pump pressure, connecting the solenoid to the reference potential;
means connecting the solenoid to the multivibrator, said solenoid adapted when energized by the output pulse to attract the piston to its actuated position;
coil means for sensing the piston position adapted when the piston position is sensed to provide a control pulse for controlling the multivibrator operation, said coil means surrounding the piston so that reciprocation of the piston into and out of the coil means induces an energy pulse therein to provide the control pulse; and
means for operatively connecting the sensing means to the multivibrator.

4. A fluid transfer device of the character set forth in claim 3 wherein:
the coil means for sensing the piston position comprises a pair of coils positioned one adjacent the piston actuated position and the other adjacent the piston rest position, the induced control pulse of said one coil adapted to terminate the multivibrator output pulse and the induced control pulse of said other coil adapted to initiate the multivibrator output pulse.

5. A fluid transfer device of the character set forth in claim 3 wherein:
the means connecting the sensing means to the multivibrator includes diode means for distinguishing and controllably directing the induced control pulses to the multivibrator.

6. A device of the character described, comprising:
a pump including a solenoid and a piston reciprocally movable between a rest position and an actuated position;
means biasing the piston to one of its positions;
a source of power;
a reference potential connected to one side of the source;
multivibrator means connected to the other side of the source adapted to provide an output pulse;
means connecting the solenoid to the reference potential;
means connecting the solenoid to the multivibrator, said solenoid being energizable by the output pulse adapted when energized to attract the piston to the other of its positions;
means for sensing the piston position adapted when said position is sensed to provide a control pulse; and
means for applying the control pulse to the multivibrator, wherein:
the multivibrator means is monostable having a fixed off time duration and in which the output pulse provides a variable time length solenoid energizing pulse, said output pulse time duration being controlled by the sensing means control pulse.

7. A device of the character described in claim 6 wherein:

the means sensing the piston position comprises a coil surrounding the piston adjacent its actuated position adapted so that the reciprocation of the piston into and out of the coil induces an energy pulse in the coil, said induced energy pulse providing the control pulse for terminating the multivibrator output pulse.

8. A device of the character described, comprising:

a pump including a solenoid and a piston reciprocally movable between a rest position and an actuated position;

means biasing the piston to one of its positions;

a source of power;

a reference potential connected to one side of the source;

multivibrator means connected to the other side of the source adapted to provide an output pulse;

means connecting the solenoid to the reference potential;

means connecting the solenoid to the multivibrator, said solenoid being energizable by the output pulse adapted when energized to attract the piston to the other of its positions;

means for sensing the piston position adapted when said position is sensed to provide a control pulse; and

means for applying the control pulse to the multivibrator, wherein:

the multivibrator means is astable having a controllable output pulse providing a variable time length solenoid energizing pulse, and having a controllable off time duration; and

the means sensing the piston position further comprises coil means surrounding the piston adaped so that reciprocation of the piston into and out of the coil means induces an energy pulse in the coil means, the induced energy pulse providing the control pulse for controlling the multivibrator.

9. A device of the character described in claim 8 wherein:

the coil means forming the piston sensing means comprises a pair of coils positioned one adjacent the piston actuated position and the other adjacent the piston rest position, the induced control pulse of said one coil adapted to terminate the multivibrator output pulse and the induced control pulse of said other coil adapted to initiate the multivibrator output pulse.

10. A device of the character described, comprising:

a pump including a solenoid and a piston reciprocally movably between a rest position and an actuated position;

means biasing the piston to one of its positions;

a source of power;

a reference potential connected to one side of the source;

multivibrator means connected to the other side of the source adapted to provide an output pulse;

means connecting the solenoid to the reference potential;

means connecting the solenoid to the multivibrator, said solenoid being energizable by the output pulse adapted when energized to attract the piston to the other of its positions;

means for sensing the piston position adapted when said position is sensed to provide a control pulse; and

means for applying the control pulse to the multivibrator, wherein:

the multivibrator means is astable having a controllable output pulse providing a variable time length solenoid energizing pulse, and having a controllable off time;

the means sensing the piston position includes coil means surrounding the piston adapted so that reciprocation of the piston into and out of the coil means induces an energy pulse therein, said induced energy pulse providing the control pulse; and

the means for connecting the sensing means to the multivibrator includes diode means adapted to distinguish and controllably direct the induced control pulse to the multivibrator.

11. A device of the character described, comprising:

a pump including a solenoid and a piston reciprocally movable between a rest position and an actuated position;

means biasing the piston to one of its positions;

a source of power;

a reference potential connected to one side of the source;

multivibrator means connected to the other side of the source adapted to provide an output pulse;

means connecting the solenoid to the reference potential;

means connecting the solenoid to the multivibrator, said solenoid being energizable by the output pulse adapted when energized to attract the piston to the other of its positions;

means for sensing the piston position adapted when said position is sensed to provide a control pulse; and

means for applying the control pulse to the multivibrator, wherein:

the means connecting the solenoid to the reference potential includes variable resistor means operatively responsive to the pump outlet pressure for varying the output pulse energy level applied to the solenoid whereby pump outlet pressure regulation is achieved.

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