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[15] **3,683,239**

[45] **Aug. 8, 1972**

[54] SELF-LATCHING SOLENOID ACTUATOR

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[22] Filed: **June 17, 1971**

[21] Appl. No.: 153,939

[52] U.S. Cl. 317/150, 317/154, 317/157,
335/170, 335/179, 335/234

[51] **Int. Cl.**.....H01h 9/20, H01h 47/04

[58] **Field of Search** 317/150, 154, 157; 335/170,
335/179

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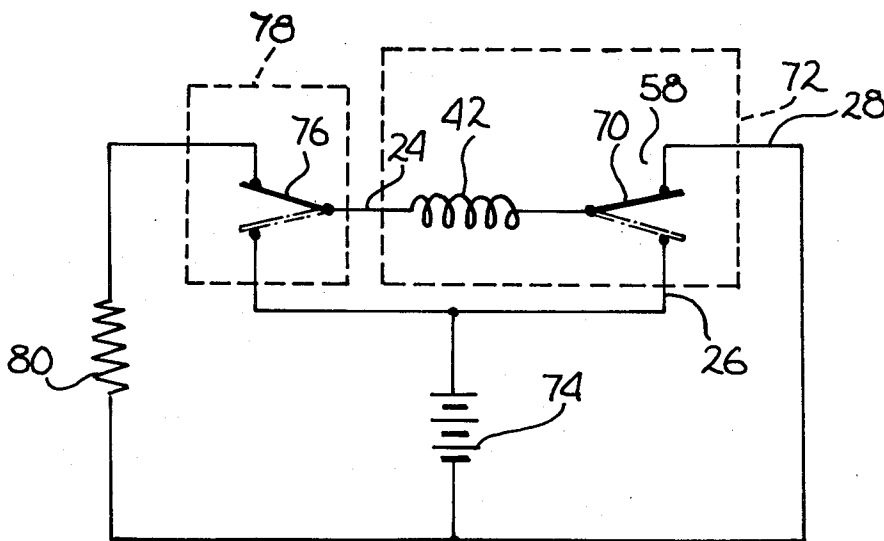
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[57] **ABSTRACT**

A self-latching solenoid actuator having a low power consumption and an internal switching arrangement whereby latching and unlatching may be accomplished by such means as a simple single-pole, double-throw remote switch. The solenoid has a permanent magnet in the magnetic circuit thereof so that an actuating current in a first direction will actuate the solenoid and charge the permanent magnet, and a smaller current in the opposite direction will de-magnetize the permanent magnet and allow a return spring to force the plunger to the fully extended position. A single-pole, double-throw switch electrically coupled to the solenoid coil is disposed adjacent the magnetic circuit and mechanically coupled to the solenoid plunger. The switch is coupled in the circuit so as to be operative to turn off the actuating current and the unlatching current as the plunger approaches the latched and unlatched positions respectively, and to re-connect the solenoid coil in preparation for the next operating signal.

12 Claims, 7 Drawing Figures



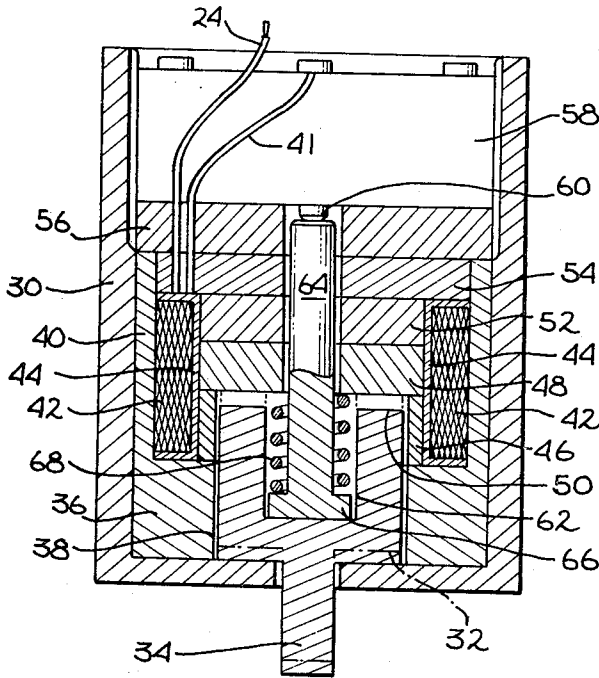


Fig. 2

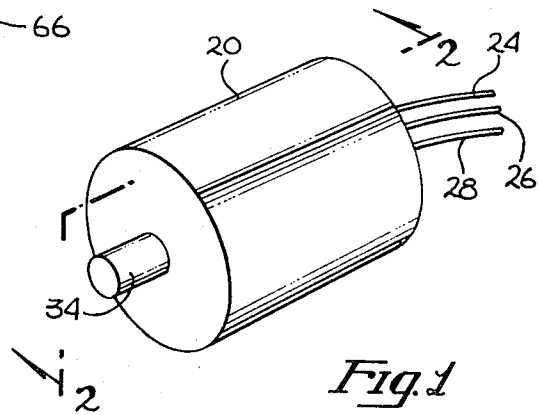


Fig. 1

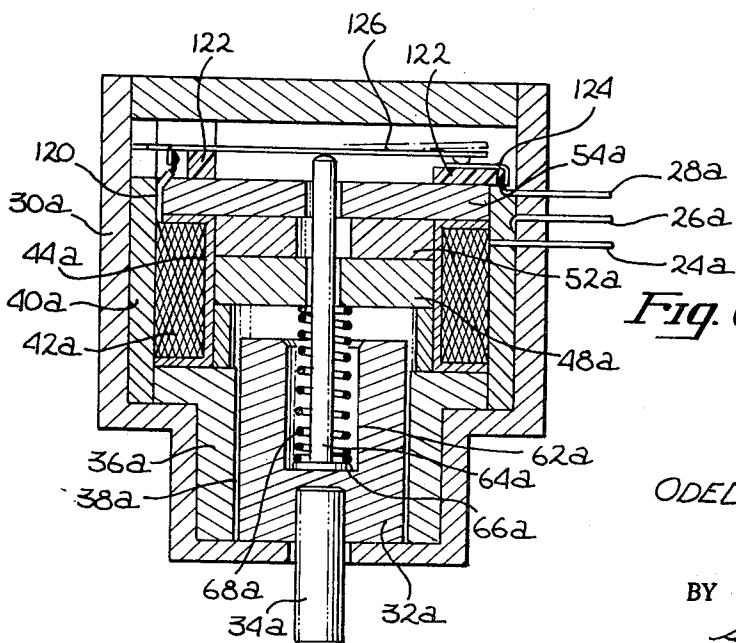


Fig. 6

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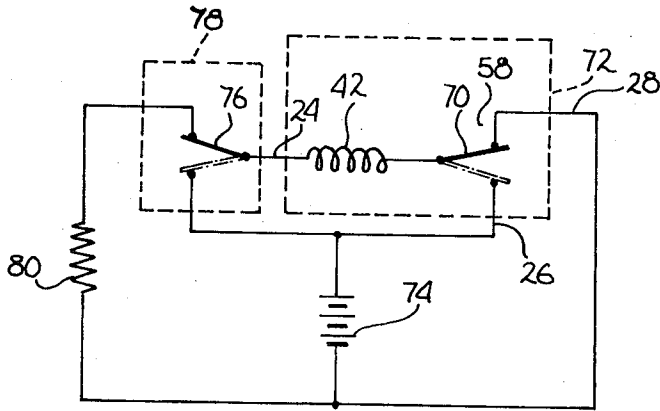


Fig. 3

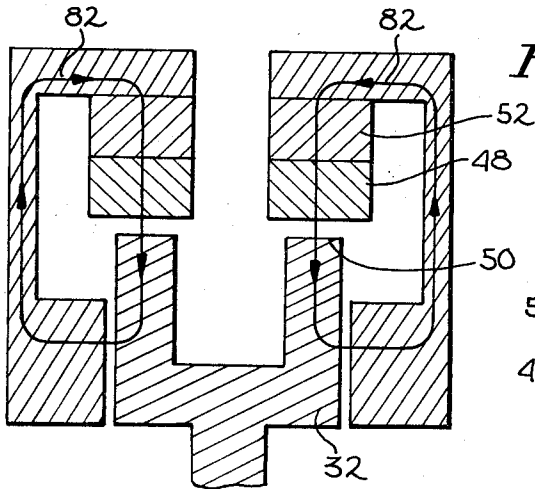


Fig. 4a

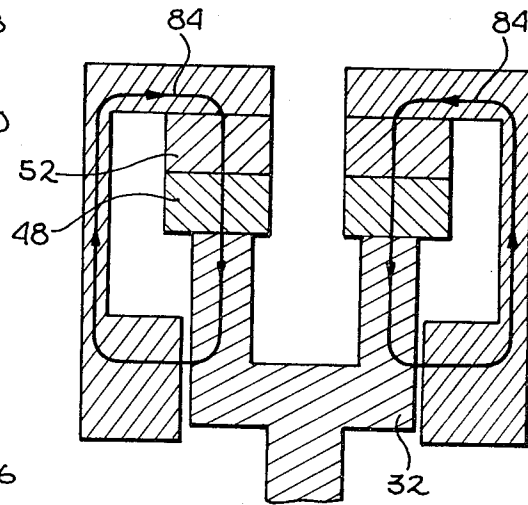


Fig. 4b

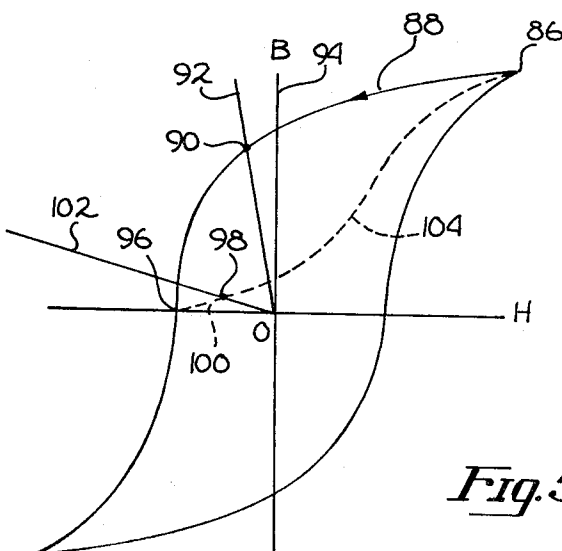


Fig. 5

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SELF-LATCHING SOLENOID ACTUATOR

BACKGROUND OF THE INVENTION

1. Field of the Invention.

This invention relates to the field of solenoid actuators and the method of actuation thereof.

2. Prior Art.

Solenoids are well-known electromechanical devices for the conversion of electrical energy into mechanical energy, and particularly into short stroke mechanical motion. These devices are used to actuate valves, clutches and the like upon the application of an electrical signal. In many applications, the efficiency of the solenoid is of little concern since a relatively unlimited source of electrical power is readily available. By way of example, solenoids used in dishwashers for actuating valves, pumps and the like are operated directly from a 115 volt power source for so long as the solenoid is maintained in the actuated position, and power dissipation, except as it effects solenoid size to avoid overheating, is of little concern.

In other applications, the efficiency of the solenoid may be a significant consideration. By way of example, solenoids may be used in applications where the source of power is limited, such as, in applications where the solenoid is to be operated by batteries. To decrease the power dissipation by the solenoid, particularly in applications where the solenoid is to be retained in the actuated position for significant time periods, latching systems are used in conjunction with the solenoids so that the solenoids may be actuated by a relatively short term pulse to the solenoid coil and latched in the actuated position without requiring further electrical power application to the solenoid. Later, upon application of a short unlatching signal, the latching system is released and a return spring returns the solenoid plunger to the fully extended position. Thus, the solenoid is actuated and latched for an indefinitely long period by the application of only a short duration pulse of electrical energy and may be unlatched for an indefinite period by a similar unlatching pulse of electrical energy.

In the prior art, one form of latching mechanism is comprised of a permanent magnet forming part of the magnetic circuit of the solenoid. The permanent magnet is thus subject to the magnetizing and de-magnetizing forces of the solenoid coil and provides a form of magnetic memory to retain either a high flux density, as characteristic of the actuation conditions, or a low flux density (approaching zero) characteristic of the unlatching condition. Thus, to actuate and latch the solenoid, a high current pulse is applied to the solenoid coil. This causes a strong magnetic field between the stationary portion of the solenoid and the solenoid plunger, with the magnetic field in the stationary portion also passing through the permanent magnet. The magnetic forces on the plunger attract the plunger into the fully actuated position and the magnetizing force on the permanent magnet causes the permanent magnet to be strongly charged. Thus, when the actuating current pulse is removed, the permanent magnet maintains a substantial portion of the magnetic field, thereby retaining the solenoid plunger in the actuated position. To unlatch the solenoid so that the return spring may move the solenoid plunger back to the fully extended position, a current pulse is passed through the solenoid coil in the opposite direction. This current

pulse is selected to be substantially less in magnitude than the actuating and latching current pulse so that the permanent magnet is substantially de-magnetized and the field in the solenoid reduced to a very low level.

In this condition, the return spring force is much greater than the magnetic force and the solenoid plunger is returned to the fully extended position by the return spring.

Prior art solenoids of the latching variety as hereabove described are highly efficient as compared to the non-latching solenoids since power is not required to maintain the solenoid in the actuated position after actuation has occurred. However, the current pulses required to actuate the solenoid are not easily generated and considerable additional complexity in the associated circuitry is required in order to make the hereabove described latching solenoids operate properly. The primary difficulty arises from the fact that the current pulses for latching and unlatching must be controlled (and different) in amplitude, of opposite polarity and of timed duration. Consequently, timing circuitry, polarity reversing circuitry and current determining circuitry must be used with prior art latching solenoids having permanent magnet latching systems therein in order to achieve the desired result. The additional complexity of such circuitry substantially detracts from the otherwise desirable features of such latching solenoids. In this regard, it should be noted that because of the improved efficiency of a latching solenoid over a solenoid of the non-latching variety, smaller solenoids may be used for a specific application without resulting in overheating of the solenoid. Thus, such self-latching solenoids have the potential of being substantially cheaper in a given application because of a substantial reduction in size compared to the size of a non-latching solenoid for the same application. This potential cost reduction, however, is not realized in prior art actuating systems because of the complexity of the circuitry required to provide the required actuating and unlatching signals to the solenoid.

BRIEF SUMMARY OF THE INVENTION

A self-latching solenoid actuator having a low power consumption and an internal switching arrangement whereby latching and unlatching may be accomplished by such means as a simple single-pole, double-throw external switch and the like. The solenoid has a permanent magnet in the magnetic circuit thereof so that upon actuation by a high current in a first direction in the solenoid coil, the plunger is pulled into the actuated position and the permanent magnet is charged, thereby magnetically retaining the plunger in the actuated position. When a smaller current is passed through the solenoid coil in the opposite direction, the magnetic field holding the solenoid in the actuated position is reduced to approximately zero so that a return spring may force the plunger to the fully extended position. A switching means is disposed adjacent the solenoid stationary member and a member actuated by the plunger extends through the end of the stationary member so as to engage the switching means. The switch is a single-pole, double-throw switch with the moving contact attached to one end of the coil and each of the two remaining contacts attached to each of the power supply terminals. By attaching the other end of the solenoid coil

to the equivalent of the moving member of an external single-pole, double-throw switch and attaching the equivalent of the two stationary contacts of the external switch to the power supply terminals, the solenoid may be caused to be actuated and unlatched in response to the condition of the external switch. The internal switch limits the power drain to that required for actuation and unlatching and maintains the steady-state power drain at zero. Two embodiments of the invention are disclosed.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective view of one embodiment of the self-latching solenoid actuator of the present invention.

FIG. 2 is a cross-section of the solenoid actuator of the present invention taken along lines 2—2 of FIG. 1.

FIG. 3 is a schematic diagram showing the electrical connection of the solenoid actuator of the present invention to a source of electrical power and remote control of the actuator.

FIG. 4a is a schematic diagram representing the cross-section of the magnetic circuit of the solenoid actuator of the present invention, illustrating the relatively weak magnetic field in the magnetic circuit when the solenoid is in the unlatched condition.

FIG. 4b is a schematic diagram representing the cross-section of the magnetic circuit of the solenoid actuator of the present invention, illustrating the strong magnetic field in the magnetic circuit holding solenoid actuator in the latched position.

FIG. 5 is a B-H curve typical of permanent magnet materials illustrating the magnetic field density and magnetizing force for various points throughout the operation of the solenoid actuator of the present invention.

FIG. 6 is a cross-section of an alternate embodiment of the solenoid actuator of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

First referring to FIG. 1, a perspective view of the present invention solenoid may be seen. The solenoid of this embodiment is characterized by a cylindrical body 20, a plunger rod 34 extending outward from the cylindrical body, and three wires 24, 26 and 28 extending outward generally from the top of the solenoid.

Now referring to FIG. 2, a cross-section taken along lines 2—2 of FIG. 1 may be seen. The various components of the solenoid are housed within housing 30 (forming cylindrical body 20) which provides an outer protective case and may be adapted as desired for mounting of the solenoid. A plunger 32 is disposed adjacent one end of the case, with an integral plunger rod 34 projecting through an opening in the end of the case for attachment to the mechanism to be actuated by the solenoid. A soft iron inner case member 36 has an inner diameter 38 forming a loose slip fit with the outer diameter of the plunger 32, and has an integral, upward projecting cylindrical member 40 forming a portion of the magnetic circuit and providing an inner diameter for location of other components of the solenoid. Fitting within the upward projecting member 40 is a solenoid coil 42 wound on a plastic bobbin 44. A non-magnetic spacer 46 fits within the inside diameter of plastic bobbin 44 and spaces a soft iron pole piece 48

above the inner end 50 of the plunger 32. Located above the pole piece 48 is a permanent magnet 52, the top surface of which is substantially flush with the top of the plastic bobbin 44. A soft iron upper frame member 54 fits within the upward projecting member 40 so as to complete the magnetic circuit and to retain the various components of the solenoid in cooperative disposition.

Located above the upper frame member is a non-magnetic spacer 56, and located thereabove at the top of the outer case member 30 is a single-pole, double-throw switch 58 having a centrally disposed actuating member 60. The switch 58, of the type often referred to as microswitches, is retained in position by cementing the switch in place in the case member 30 (as are the other parts of the solenoid).

The plunger 32 has a cylindrical depression 62 extending downward from the top face 50 of the plunger and adapted to receive the switch actuating pin 64. The switch actuating pin 64, which is a non-magnetic pin, has an enlarged head 66 at the lower end thereof fitting within cylindrical depression 62 in plunger 32, and extends upward through clearance holes in pole piece 48, magnet 52, upper frame member 54 and the spacer 56 to a position adjacent switch actuating member 60. A coil spring 68 disposed between pole piece 48 and the enlarged head 66 on switch actuating pin 64 urges the switch actuating pin and plunger 32 into the downward position shown in FIG. 2. This position shall be referred to herein as the fully extended position.

The various parts of the solenoid are assembled by merely slipping them in the proper order into the top of case member 30 and cementing various of the parts to the case member so as to retain the assembly in position. The two leads for solenoid coil 42 may be brought out through appropriate openings in the side of member 40 and case member 30, or, as is done in the preferred embodiment, may be brought upward through appropriately placed grooves in pole piece 54 and cooperative holes in spacer 56 to positions adjacent switch 58. This last specified manner of bringing out the two solenoid coil leads is preferred because it disposes the leads adjacent the switch and, as shall be subsequently seen, one of such leads is connected to one of the switch terminals.

Having described the structure of the solenoid of the present invention, the electrical connection of the solenoid and operation thereof shall now be described with the aid of FIG. 3. One end 41 of the solenoid coil 42 is connected to the moving contact 70 of switch 58 in the solenoid (generally indicated by the dashed enclosure 72 of FIG. 3). The other end of the solenoid winding is brought out of the solenoid on line 24 and the two switch contacts for switch 58 are brought out on lines 26 and 28. Thus, the solenoid of the present invention has three electrical connections thereto, rather than simply two electrical connections characteristic of the prior art devices. Leads 26 and 28 are connected to each side of a DC power source 74 and lead 24 is connected to the moving contact 76 of a single-pole, double-throw switch, generally indicated by the numeral 78. One contact of the switch is connected to the power source 74 and the other contact is connected through a resistor 80 to the other side of the power source. It is to be understood that the single-pole, double-throw

switch 78 is schematic only, and in any specific application of the present invention might be comprised of a mechanical switch, an electronic switch or like devices.

With switch 78 in the position shown in FIG. 3, the solenoid plunger will be in the fully extended position, as shown in FIG. 2, and microswitch 58 will also be in the position shown in FIG. 3. Thus, both ends of the solenoid coil 42 are connected to the same side of the DC power source 74. Consequently, the power drain from the power source 74 in this unlatched state is zero. In this condition, there will be a small magnetic field in the solenoid, generally indicated by the field lines 82 in FIG. 4a (which is a schematic representation of the magnetic circuit in the solenoid when in the fully extended position). The strength of the magnetic field at this time is quite low, as shall be subsequently described in detail, being on the order of 5 to 10 percent of the saturation values for the circuit. Since the magnetic force exerted on the end 50 of plunger 32 by the magnetic field between the plunger and the pole member 48 is proportional to the square of the field strength, the magnetic force exerted on the plunger is on the order of 1 percent of the maximum force achievable. The return spring 68, on the other hand, which is under substantial preload, has a force approximately equal to one-half the maximum force of the solenoid, and, therefore, plunger 32 is encouraged to remain in the position shown by the return spring.

When switch 78 is first switched to the position shown in phantom in FIG. 3, line 24 is connected to the positive side of the power source 74 while the other end of coil 42 is connected through line 28 to the negative side of the power source. Consequently, the full voltage of power source 74 is connected to the solenoid coil 42 and a high magnetizing current is caused to flow in the coil. This creates a high magnetizing force in the magnetic circuit, causing a high flux density both through permanent magnet 52 and through the air gap between pole piece 48 and plunger 32. In general, it is desirable for the current in coil 42 to result in a sufficient magnetizing force to nearly saturate the soft iron in the magnetic circuit and to substantially fully magnetize the permanent magnet 52. Under this condition, the solenoid force will be approximately twice the return spring force and the solenoid plunger will move to the position shown in FIG. 4b and as shown in phantom in FIG. 2. This position shall be referred to herein as the fully actuated or latched position for the solenoid. As the plunger approaches the position shown, the switch actuating member 64 (FIG. 1) operates the switch 58, causing the switch to change to the position shown in phantom in FIG. 3. When the switch 58 changes to this position, the current in coil 42 falls to zero, since both ends of the coil are again attached to the same terminal of the power source 74 (in this case the positive terminal). However, since the permanent magnet 52 was substantially fully magnetized by the sharp pulse of current to the solenoid coil, and since the current pulse terminated only as the air gap in the magnetic path approached a very small value, there is little demagnetizing force present to cause a demagnetization of the permanent magnet. Therefore, the field remains at a very high level as indicated by the field lines 84 in FIG. 4b, the magnetic force remains substantially equal to twice the return spring force, and the plunger is latched in the

position shown in FIG. 4b. Thus, the solenoid has been actuated, caused to latch in the actuated position, and has been disconnected from further power drain merely upon a single external switching signal.

The solenoid is changed from the latched condition shown in FIG. 4 to the unlatched and fully extended position as shown in FIGS. 2 and 4a by moving external switch 78 from the position shown in phantom back to the original position. Since microswitch 58 initially remains in the position shown in phantom in FIG. 3, opposite ends of the coil 42 are again connected to opposite poles of the power source 74. However, in this case line 24 is connected to the negative side of the power source and the other end of coil 42 is connected to the positive side of the power source through line 26. Thus, the polarity of the electrical connection to the solenoid coil 42 is reversed over that which initially caused the high field strength 84 as shown in FIG. 4b. Consequently, the current flowing through the solenoid coil 42 causes a substantial de-magnetizing force on the permanent magnet 52. If this current were not limited, the net effect would be to demagnetize and re-magnetize permanent magnet 52 with the opposite polarity, and since magnetic force is proportional to the square of the field, a reversal of field polarity would result in no change in the magnetic force. However, the de-magnetizing current is limited by resistor 80 so that the permanent magnet 52 is not re-magnetized with the opposite polarity as that shown 4b. FIG. 4b. Instead, resistor 80 is chosen so that the de-magnetizing force created by the current flowing in coil 42 is substantially equal to the de-magnetizing force required to reduce the field in the magnetic circuit, and particularly in the permanent magnet, to a value substantially equal to zero. Thus, the magnetic force from the solenoid falls to substantially zero and the return spring returns the solenoid plunger to the position shown in FIG. 4a. As the plunger returns, the switch actuating member 64 allows switch 58 to switch back to its original position as shown in FIG. 3, thus terminating the de-magnetizing current pulse and again connecting both ends of solenoid coil 42 to the same side of power source 74, namely, the negative terminal.

When the de-magnetizing current is switched off as hereinabove described, the permanent magnet will cause a small percentage of the maximum magnetic field to return to the magnetic circuit. However, the extent to which the magnetic field increases when the de-magnetizing current is switched off may be controlled by the proper design of the solenoid and, in general, will not be adequate to prevent the desired unlatching of the solenoid.

The design considerations for the design of a solenoid of the present invention having the greatest latching force and the greatest unlatching ability may be described with the aid of FIG. 5. This figure is a typical de-magnetization curve for a permanent magnet material, the curve shown being generally representative of the grain oriented alnico V materials. It is to be understood, however, that other permanent magnet materials may also be used with the solenoids of the present invention by appropriate design of the solenoid magnetic circuit, though alnico V is used in the preferred embodiment because of its high energy product, its high saturation flux density and its

moderate magnetizing and de-magnetizing force requirements. In FIG. 5, the ordinate is the flux density B and the abscissa is the de-magnetizing force H. When the solenoid is first actuated, the high current in the solenoid winding 42 results in a high magnetizing force in the magnetic circuit. Initially, this magnetizing force is divided, part of it being required to cause a high flux density in the air gap between the plunger and the stationary portion of the solenoid and part of it, for reasons to subsequently become apparent, being required to cause the relatively high flux density in the permanent magnet. As the plunger moves toward the actuated position, the magnetizing force required to sustain the high magnetic field in the air gap reduces proportionately, so that a greater percentage of the magnetizing force is concentrated in the permanent magnet. In order to insure that the permanent magnet is well magnetized without requiring an excessive magnetizing current in the solenoid coil, it is desirable to design the various components of the solenoid so that the switch 58 will turn off the magnetizing current as hereinabove described only as the plunger approaches the latched position. This assures that only a small percentage of the magnetizing force is required to maintain the flux density in the air gap and most of the magnetizing force is impressed on the permanent magnet. This provides the most efficient use of the available magnetizing force which, for a given solenoid design, is a measure of the power dissipation in the solenoid coil. Under these conditions, the permanent magnet will have the flux density and be subject to the magnetizing force indicated by point 86 in FIG. 5.

Typically, the flux density at saturation, that is, at point 86, is somewhat less than the saturation flux density for the soft iron components in the solenoid. Thus, since the magnetic force is proportional to the square of the flux density times the area over which the flux density is distributed, the solenoid force at saturation of the permanent magnet may be increased if the flux between the plunger and the fixed portion of the solenoid is distributed over a smaller area than the flux through the permanent magnet. In general, the plunger iron should saturate at substantially the same total field strength as the permanent magnet. Thus, it may be noted in FIG. 2 that the area of surface 50 of the plunger 32 is substantially smaller than the cross-section of magnet 52, the ratio of these areas being dependent upon the permanent magnet material chosen for magnet 52.

When switch 58 actuates so as to turn off the magnetizing current, the operating point of the permanent magnet will move along line 88 to point 90, determined by the intersection of line 88 and line 92. Line 92 is, in essence, a measure of the air gap in the magnet circuit at the instant that the magnetizing current is terminated and may be approximated by the equation

$$B = HAglm/A_m l_o$$

where B is the flux density in the magnet;

where H is the magnetizing (de-magnetizing) force in the permanent magnet;

where Ag is the cross-sectional area of the air gap between the plunger and the stationary portion of the solenoid (e.g., the cross-sectional area of the plunger face);

where lm is the length of the magnet as measured in the direction of the field through the magnet; where Am is the cross-sectional area of the magnet measured perpendicular to the field; and

where lo is the length of the air gap between the plunger face and the stationary portion of the solenoid.

Thus, it may be seen that when the actuating current is switched off the flux density in the solenoid will drop somewhat depending in part upon the air gap length lo at that time. If the air gap is small, the flux density will remain relatively high and similarly the solenoid force will remain relatively high. The plunger will continue moving to the latched position as a result of the high flux density maintained by the permanent magnet, and at the latched position, since the air gaps in the magnetic circuit are then small, the flux density will approach the value at point 94.

From the above description, it is apparent that the solenoid force is lowest during actuation at the instant that the actuating current is switched off, and this force may be caused to be as high as possible by designing the solenoid so that the actuating current does not switch off until the air gap between the plunger and pole piece 48 is approaching zero.

When the external switch 78 is switched to the unlatching position, a de-magnetizing current is caused to flow in the solenoid coil. This current is limited by resistor 80 so as to cause a de-magnetizing force approximately equal to that indicated at point 96, which in turn causes the magnetic field in the solenoid to go substantially to zero. In this condition, as hereinbefore described, the return spring 68 urges the plunger 32 toward the fully extended position, and as the plunger approaches the fully extended position causes switch 58 to turn off the de-magnetizing current. When this occurs the flux density in the magnetic circuit will increase to the value existing at point 98, determined by the intersection of line 100 (having a slope approximately equal to the slope of line 88 at point 94 and representing a physical characteristic of the permanent magnet material) and line 102 determined by the same equation as line 92 but having a much shallower slope because of the greatly increased air gap at this time. The flux density at point 98 will result in a small magnetic force opposing the return spring force, thereby reducing the net force urging the plunger to the unlatched position. This force, however, being proportional to the square of the field strength, will be relatively small and may be caused to be a minimum by assuring in the design of the solenoid that the de-magnetizing current causes the flux density in the solenoid to approach zero (e.g., to have a small plus or minus value) and by assuring that the de-magnetizing current remains until the plunger is near the fully extended position, that is, until the air gap lo is near its maximum value. Thus, it may be seen from the above description of the latching and unlatching of the solenoid actuator of the present invention that it is desirable, though not absolutely necessary, that the switch 58 be caused to have a certain amount of mechanical hysteresis as is typical of switches of a suitable type that are commercially available, or, in the alternative, a small time lag so that it will not switch during the travel of the solenoid plunger in either direction until the plunger is near

or at the end of that travel. Such action of the switch assures maximum latching and minimum unlatching forces for a solenoid of a given size.

When the latching current is again applied to the solenoid coil and the magnetizing force increases, the operating point for the magnet will move from point 98 along line 104 to point 86, again substantially saturating the permanent magnet and the solenoid iron, at least in the vicinity of the plunger face.

Now referring to FIG. 6 an alternate embodiment of the present invention solenoid may be seen. In this embodiment, the design of the solenoid is very similar to that of the embodiment illustrated in FIGS. 1 and 2. In particular, the elements of the solenoid, identified by numbers followed by the letter "a," are similar in design and function to the elements identified by the same numbers and described with respect to FIG. 2, and, therefore, a detailed description of the design and function of most of these parts will not be herein repeated. It should be noted, however, that in this design the plunger 32 and plunger rod 34 are not integral, but instead comprise an assembly of two pieces. Similarly, the soft iron inner case member 36a and the upward projecting cylindrical member 40a are not integral members, but again are an assembly of two separate pieces. The upper frame member 54a has a slot, generally indicated by the numeral 120, in which one of the leads of the solenoid coil 42a is disposed. The other solenoid lead is brought out through a slot in the upward projecting cylindrical member 40a and a hole in the housing 30a as lead 24a. Lead 26a passes through a second hole in housing 30a and is electrically attached to the electrically conductive housing so as to provide electrical contact through the various other conductive parts of the solenoid, and particularly through coil spring 68a and actuating pin 64a. An electrically insulative element 122 provides a support for conductive contact surface 124, connected to lead 28a through a third hole in the housing 30a, and also provides a support for a leaf switch member 126. Thus, with the solenoid in the fully extended position, as shown in FIG. 6, the solenoid coil 42a is electrically connected to leads 24a and 28a, but upon actuation of the solenoid the switch actuating pin 64a makes electrical contact with the leaf switch member 126, and simultaneously elastically deflects the switch member so that it no longer makes electrical connection with contact surface 124. Consequently, the solenoid coil 42 is then connected between leads 24a and leads 26a, thereby providing for the operation and switching of the solenoid coil connections as hereinbefore described, particularly with respect to FIG. 3.

Other embodiments, and in particular, other arrangements for the solenoid actuated switching of the solenoid lead connections, will be obvious to those skilled in the art. By way of specific example, the principles of the present invention may be applied to rotary solenoids, using either a cam actuated switch, such as switch 58, or a rotary switch well-known in the art of mechanical switching devices. Similarly, while the schematic representation of FIG. 3 suggests the operation of the solenoid of the present invention directly from an electrical source 74, such as a battery, other sources of electrical power may readily be used with the present invention, such as a capacitor storage

system comprising a battery connected through a resistor to a capacitor so that the solenoid is latched and unlatched by the discharge of the capacitor, thereby providing a higher instantaneous current level than would be possible with a small battery, yet resulting in a very low total energy withdrawal from the battery. Thus, while the invention has been particularly shown and described with reference to preferred embodiments thereof, it will be understood by those skilled in the art that various changes in form and detail may be made therein without departing from the spirit and scope of the invention.

I claim:

1. A solenoid actuator having a stationary member and a moving member adapted for motion between first and second orientations with respect to said stationary member, a solenoid coil having first and second leads, a permanent magnet, and a switch, said stationary member and said moving member forming a magnetic circuit with said permanent magnet in said circuit, said solenoid coil being disposed with respect to said magnetic circuit so as to cause a magnetizing force in said circuit in response to a current therethrough, said stationary member and said moving member being adapted to magnetically urge said moving member toward said first orientation with respect to said stationary member in response to the establishment of a magnetic field in said magnetic circuit, said switch being electrically coupled to said first solenoid coil lead and adapted to switch electrical coupling with said first solenoid coil lead between first and second actuator leads in response to motion between said stationary member and said moving member.

2. The solenoid actuator of claim 1 wherein said switch has mechanical hysteresis so that said switch will not switch electrical coupling with said first solenoid lead between said first and second actuator leads until said solenoid plunger is at least approaching the end of its travel between said first and second orientations.

3. The solenoid actuator of claim 1 wherein said switch exhibits a time lag between said motion between said stationary member and said moving member, and its switching of said first solenoid coil lead between first and second actuator leads.

4. The solenoid actuator of claim 1 further comprising a return spring, said return spring being disposed between said stationary member and said moving member so as to yieldably urge said moving member from said first orientation to said second orientation with respect to said stationary member.

5. The solenoid actuator of claim 2 further comprising of a source of direct current having first and second terminals, a current limiting means and a remote switching means schematically representable as a single pole, double-throw switch having a moving contact switchable between first and second fixed contacts, said second solenoid coil lead being coupled to said moving contact of said remote switch, said first and second actuator leads being coupled to first and second terminals of said source of direct current, respectively, said first fixed contact of said remote switch being coupled to said first terminal of said source of direct current and said second fixed contact of said remote switch being coupled through said current limiting means, to said second terminal of said source of direct current.

6. A solenoid actuator comprising a stationary member, a plunger, a permanent magnet, a solenoid coil and a switch means, said plunger and said stationary member forming a magnetic circuit having a minimum air gap when said plunger is in the actuated position and a maximum air gap when in the fully extended position, said permanent magnet being disposed so as to form a portion of said magnetic circuit and to be subject to magnetizing forces in said magnetic circuit, said solenoid coil being disposed so as to cause a magnetizing force on said magnetic circuit 99 when current is passed through said coil, said switch means having first and second terminals and being cooperatively disposed with respect to said plunger and electrically coupled to a first end of said solenoid coil so as to be operative to switch the coupling of said first end of said solenoid coil from said first terminal to said second terminal as said plunger moves toward said actuated position and from said second terminal to said first terminal as said plunger moves toward said fully extended position.

7. The solenoid actuator of claim 6 further comprising a return spring, said return spring being disposed between said plunger and said stationary member and being operative to return said plunger to the fully extended position when the magnetic field in said magnetic circuit is substantially less than the magnetic field required to saturate said magnetic circuit.

8. The solenoid actuator of claim 6 wherein said switch means comprises first and second fixed contacts connected to said first and second terminals and a moving contact connected to said first end of said solenoid coil moveable between said first and second fixed contacts.

9. A solenoid actuator comprising:

- a generally cylindrical housing;
- a magnetic plunger within said housing having an upwardly disposed plunger face defined by a first outer diameter and an inner diameter and adapted for vertical motion between an extended position and an actuated position;
- a plunger rod of a second diameter substantially less than said first outer diameter connected to said plunger and extending through a clearance hole in the bottom of said housing;
- a cylindrical magnetic member disposed around said plunger, having a loose fit with said first outer diameter, and extending upward therefrom;
- a solenoid coil having first and second leads, located within and concentric to said upward extending portion of said magnetic member;
- a magnetic pole piece, having a clearance hole concentric therewith, disposed within said solenoid coil and spaced above the upper end of said

plunger when said plunger is in said extended position;

- a permanent magnet having a clearance hole concentric therewith disposed within said solenoid coil and immediately above said pole piece;
- a magnetic top plate having a clearance hole concentric therewith disposed immediately above said solenoid coil and said permanent magnet, and extending radially outward to a position adjacent said upward extending portion of said cylindrical magnetic member;
- a switch actuating pin disposed within said clearance holes in said pole piece, said magnet and said top plate, and having an enlarged head extending into said inner diameter of said plunger;
- a coil spring disposed between said pole piece and said enlarged head on said actuating pin and yieldably urging said actuating pin and said plunger toward said extended position; and
- a single-pole, double-throw switch mounted above said top plate and adapted for actuation by said actuating pin, said switch being connected to said first solenoid coil lead and adapted to switch electrical coupling with said first solenoid coil lead between first and second actuator leads in response to motion of said plunger.

10. The solenoid actuator of claim 9 wherein said switch has mechanical hysteresis so that said switch will not switch electrical coupling with said first solenoid coil lead between first and second actuator leads until said plunger is at least approaching the end of its travel at said extended position and said actuated position.

11. The solenoid actuator of claim 9 wherein said switch exhibits a time lag between motion of said plunger and the switching of electrical coupling with said first solenoid coil between first and second actuator leads.

12. The solenoid actuator of claim 9 further comprised of a source of direct current having first and second terminals, a current limiting means and a remote switching means schematically representable as a single pole, double-throw switch having a moving contact switchable between first and second fixed contacts, said second solenoid coil lead being coupled to said moving contact of said remote switch, said first and second actuator leads being coupled to first and second terminals of said source of direct current, respectively, said first fixed contact of said remote switch being coupled to said first terminal of said source of direct current and said second fixed contact of said remote switch being coupled, through a current limiting means, to said second terminal of said source of direct current.

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