United States Patent

[11] 3,629,678

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[21] Appl. No. 884,958
[22] Filed Dec. 15, 1969
[45] Patented Dec. 21, 1971
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[54] **PROXIMITY SWITCH**
21 Claims, 5 Drawing Figs.

[52] U.S. Cl. 318/558, 317/DIG. 2
[51] Int. Cl. H02p 1/08
[50] Field of Search 318/558; 317/DIG. 2

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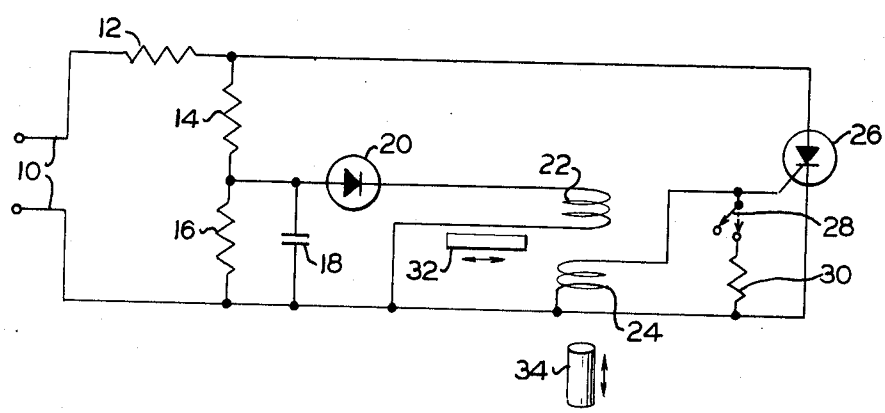
ABSTRACT: A proximity switch operable in response to the position of a movable object and including a pulse-forming circuit for generating a series of pulses in a first coil, and a detecting network including a second coil for energizing a load whenever a pulse from the first coil is induced in the second coil. The first and second coils are positioned such that the degree of coupling therebetween is responsive to the proximity of the object for controlling the energization of the load.



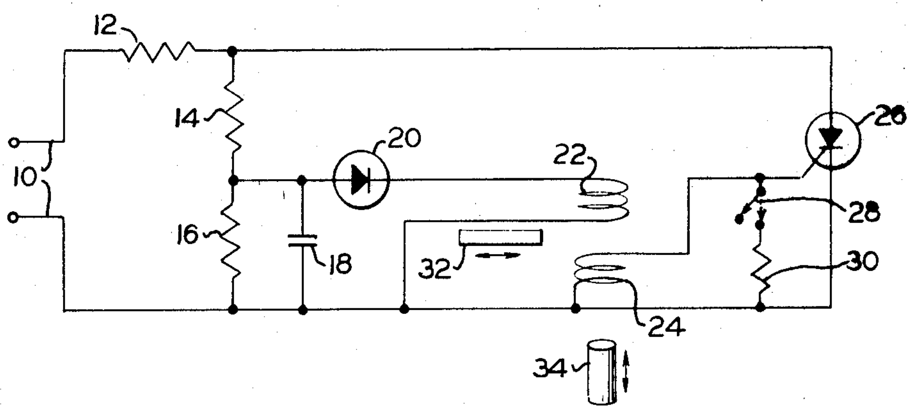


Fig. 1

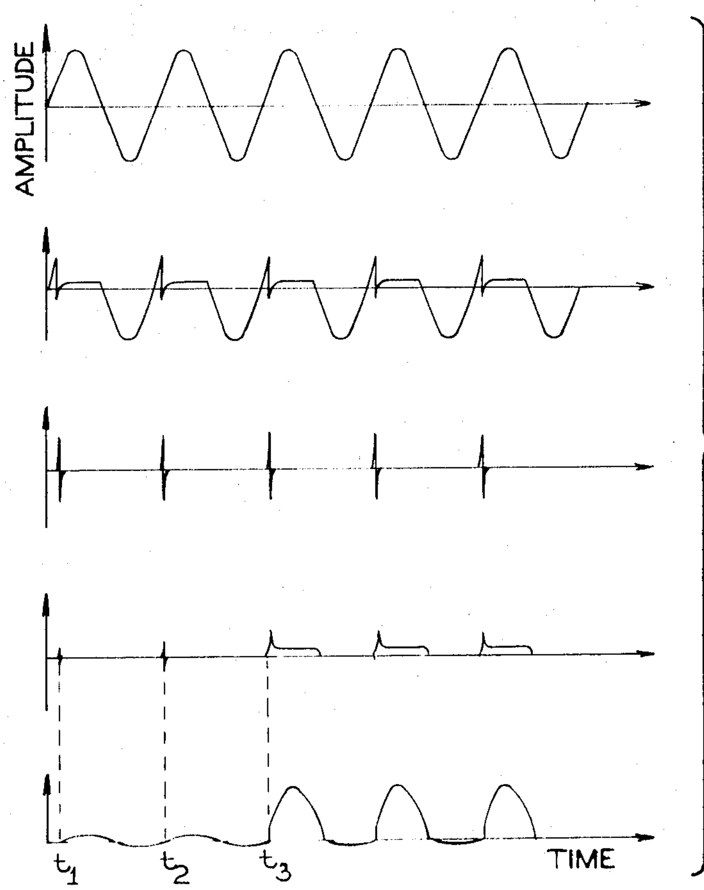


Fig. 2

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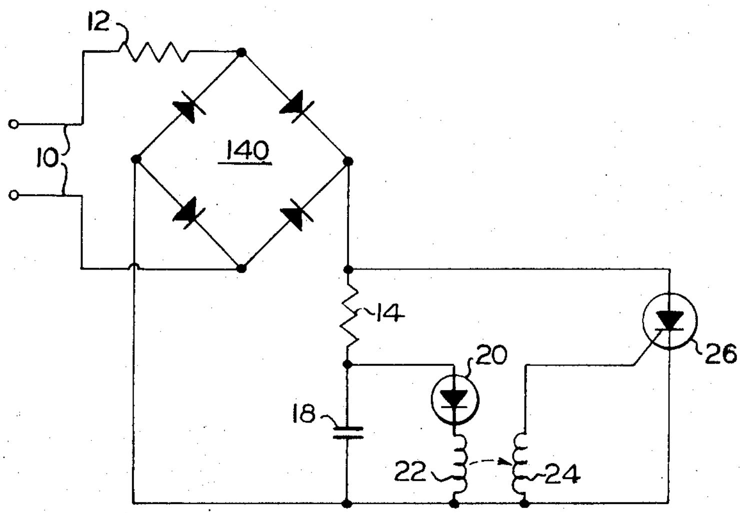

Fig. 3

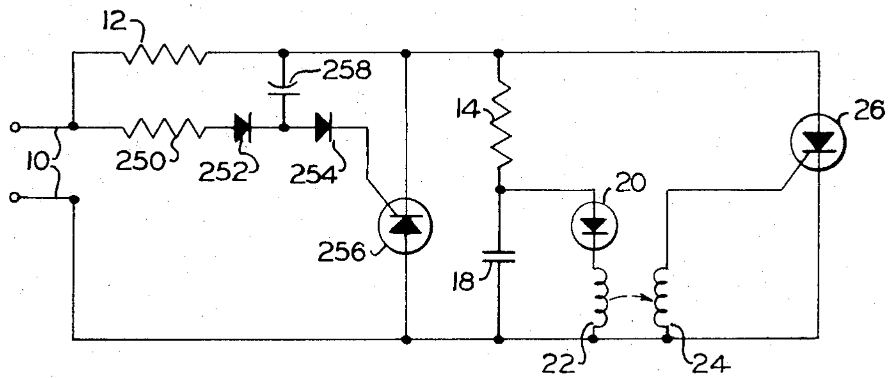

Fig. 4

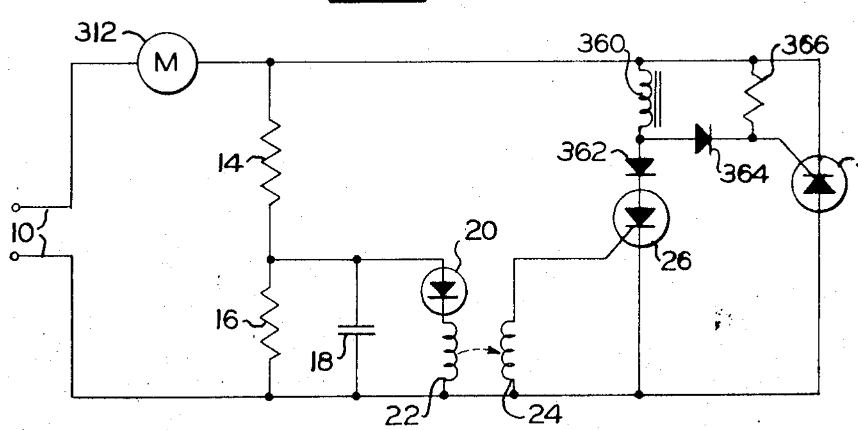

Fig. 5

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PROXIMITY SWITCH

BACKGROUND OF THE INVENTION

1 Field of the Invention

The present invention relates generally to electrical switching circuits and more particularly to such circuits responsive to the proximity of a movable object.

2. Description of the Prior Art

Conventional electrical switching devices include a number of moving parts and have a tendency to wear or become corroded, require considerable mechanical force in operation, and frequently become inoperative due to the mechanical or electrical breakdown of various insulating materials used therein. For these reasons, among others, conventional switches cannot be effectively used for a number of commercially important applications. For example, it is often desired to operate various electrical apparatus, such as heating or air conditioning units, in response to the position of the pointer of a sensitive electrical meter. Of course, any mechanical resistance to the free movement of the meter would have a detrimental effect on the overall operation of the system, and thus, prohibits the use of mechanical switches. Another example is where a bimetal or similar heat-responsive material directly actuates a switch in response to temperature. As in the previous example any mechanical resistance to the movement of the bimetal would seriously limit the degree of accuracy which could be expected from the operation of the system. In addition, where the bimetal forms one contact of a two-contact switch and thus avoids the mechanical resistance problem associated with the operation of a separate switch, the contacts are exposed to the same environmental conditions which are being measured and often will be contaminated or rapidly corroded so as to require frequent maintenance.

A number of electrical switches have been developed in an attempt to avoid some of the problems associated with mechanical switches and to increase reliability. Proximity-type switches, which control current flow in response to the position of an object not in physical contact with the switch itself, fall into this category. Various proximity switches have been developed in the past; however, they have not proven entirely satisfactory under all conditions of service since they typically require expensive and complex regulated power supplies, stable oscillators and stable high-gain detection circuits. In addition, many prior art proximity switches are extremely sensitive to variations in temperature, humidity, static electricity and stray capacity and often fail to define a single positive switching point.

SUMMARY OF THE INVENTION

The present invention is summarized in that a proximity switch operable in response to the position of a movable object includes a pulse generator network for generating a series of pulses, a load, a detecting circuit connected to the load and responsive to pulses from the pulse generator network to energize the load, and a coupling circuit connected to the pulse generator network and the detector circuit and positioned adjacent the movable object for selectively enabling electromagnetic coupling of the pulses from the pulse generator network to the detecting circuit in response to the position of the movable object whereby energization of the load is controlled by the movable object.

It is an object of the present invention to construct an electrical switch operable in response to the proximity of an object.

The present invention has a further object in the construction of an electrical switch having a switching point which is independent of supply voltage.

Another object of the present invention is to provide a proximity switch constructed to positively switch between its off and on positions with no modulation or throttling.

A further object of the present invention is the construction of an economical solid-state proximity switch which will not corrode or deteriorate with time or use.

The present invention is advantageous over prior art devices in the provision of solid-state electronic switching to eliminate contact wear and corrosion, smooth actuation exhibiting no mechanical resistance to the movement of a controlling member, and positive switching independent of supply voltage variations.

Further objects and advantages of the present invention will become apparent from the following description of the preferred embodiments when taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic diagram of an embodiment of a proximity switch according to the present invention;

FIG. 2 is a set of amplitude vs. time curves for the circuit of FIG. 1;

FIG. 3 is a schematic diagram of another embodiment of the proximity switch of the present invention;

FIG. 4 is a schematic diagram of a modification of the embodiment of FIG. 3; and

FIG. 5 is a schematic diagram of a further embodiment of the proximity switch of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

A proximity switch according to the present invention is illustrated in FIG. 1 and includes a convention AC power source, represented by input leads **10**, connected across a series network formed by a load resistor **12** and high-resistance voltage-divider resistors **14** and **16**. Resistor **16** is connected in parallel with a capacitor **18** and is further connected in parallel with a series network formed by a breakdown diode **20** and a coil **22**.

A second coil **24** is spaced from coil **22** and has one terminal connected to power source **10** and another terminal connected to the gate of a silicon-controlled rectifier (SCR) **26**. The cathode of SCR **26** is connected directly to power source **10** so that the gate-cathode path of the SCR is coupled in parallel with coil **24**. A series network formed by a two-position switch **28** and a resistor **30** is also coupled in parallel with the gate-cathode path of SCR **26** which has its anode returned to the junction of resistors **12** and **14**.

As illustrated in the drawings, coils **22** and **24** may be axially aligned and are spaced apart by a preselected distance. An electromagnetically shielding vane **32** is located between the two coils and is adapted to move in a direction transverse to the coil axis, as shown by the arrow. Similarly, a magnetic core **34** is positioned adjacent the coils and is adapted to move axially through the center of the coils as illustrated.

The operation of the circuit of FIG. 1 will be explained with the aid of the curves of FIG. 2. On positive half-cycles of the AC supply voltage shown in curve A of FIG. 2, current will flow through load **12** and resistors **14** and **16** to charge capacitor **18**. Breakdown diode **20** is a unidirection conducting device having a predetermined breakdown voltage in the forward direction, such as a four-layer or Shockley diode. Thus, when the voltage across capacitor **18** increases to the predetermined breakdown voltage of diode **20**, the diode will be rendered conductive to discharge the capacitor and provide a sharp positive pulse to coil **22**. The heavy surge current through coil **22** tends to shock it into oscillation with capacitor **18**; however, capacitor **18** has a small value of capacitance causing the frequency of the shock-induced oscillations to be high. For this reason, the negative pulse which follows the initial positive pulse is too short in duration to turn off diode **20** which remains conducting and prevents capacitor **18** from charging more than once during each positive half-cycle. The oscillations thus continue and rapidly decay, the net result being the generation of a single major pulse in coil **22** at the start of each positive half-cycle of the AC supply.

Referring to FIG. 2, curve B represents the variation in voltage across capacitor **18** with time and shows the initial charge produced on the positive half-cycle upswing, and the rapid discharge which occurs when diode 20 fires. Since diode remains conducting during the remainder of the positive half-cycle, only a small residual voltage will appear across the capacitor, as illustrated. As seen in curve C, the initial voltage surge produced by the discharge of capacitor 18 developes a single large spike across coil 22 at the beginning of each positive half-cycle.

On the negative half-cycle of the AC input signal, diode 20 will be reverse biased and thus will not permit the flow of current through coil 22. Furthermore, since capacitor 18 is small, it effectively acts as an open circuit for the relatively low frequency 50 to 60 cycle AC input signals used with the present invention. It is noted that voltage divider resistor 14 has a high value of resistance as compared with that of load 12 so that negligible voltage will appear across load 12 during both positive and negative half-cycles of the input signal, as can be seen in curve E of FIG. 2 from time t_1 to time t_3. The high value of resistor 14 also protects diode 20 and maintains the diode within the maximum ratings.

The initial pulse or spike through coil 22 during the positive half-cycles is air coupled to 24 to place a positive pulse on the gate of SCR 26. The magnitude of the pulse on the gate of SCR 26 (i.e., whether the amplitude of the pulse is above or below the firing level of the SCR) depends upon the degree of coupling between coils 22 and 24 so that the conducting state of SCR 26 when forward biased can be selectively controlled. In other words, and referring to curves D and E of FIG. 2, when the degree of coupling is low, a low-level pulse will appear across coil 24 and will be insufficient to prime the SCR. Such a condition is illustrated at time t_1. At time t_2, the degree of coupling has increased, but is still insufficient to prime the SCR; however, at time t_3 and thereafter, the pulse developed at the gate of the SCR is large enough to render it conductive to provide a low-impedance current return path for energizing load 12. The SCR thus acts as a detector for controlling the energization of the load when air-coupled pulses are detected at coil 24. Of course, the SCR will cease conduction on the negative half-cycle of the input voltage and the SCR must be primed once again at the beginning of each positive half-cycle.

When the proximity switch of the present invention is on and the degree of coupling between coils 22 and 24 is subsequently decreased, the gate voltage of SCR 26 correspondingly decreases until it is once again insufficient to prime the SCR. The switch thus reverts to its off state and no operating potential appears across the load.

It should be understood that since capacitor 18 is small, it charges rapidly and causes diode 20 to fire early in the positive half-cycle. The priming pulse on the gate of SCR 26 therefore causes the SCR to conduct while the AC input voltage is near its zero-crossing. In this manner, low-current or zero-voltage switching is provided by the present invention to reduce radiofrequency interference and provide load 12 with operating potential for nearly full half-cycles of the AC input signal.

The degree of coupling between coils 22 and 24 can be controlled in any number of ways such as by physically moving them closer together or farther apart from each other. In other words, if coils 22 and 24 are moved far enough apart, the degree of coupling becomes low and the circuit turns off; i.e., the load 12 is deenergized. The proximity switch can then be turned on by increasing the coupling between the two coils by moving them closer together until the coupling is sufficient to fire the SCR. In the embodiment illustrated in FIG. 1, the two coils are mechanically fixed at a spacing which is sufficient to fire the SCR when switch 28 is open, as illustrated. Since the coils are fixed, the entire unit is adaptable to potting or other suitable insulating techniques to reduce the possibility of electrical shock from exposed wires.

With switch 28 open, the circuit is in its "normally-on" mode; i.e., the degree of coupling of the two coils is normally sufficient to prime SCR 26 which then conducts current through the load during each positive half-cycle. The load current is turned off by reducing the degree of coupling between the two coils so as to cut the electromagnetic force lines therebetween to thereby reduce the amplitude of the induced voltage spike in coil 24. As vane 32 is thereafter removed, the coupling will increase and eventually SCR 26 will again receive adequate priming potential on its gate electrode to cause its conduction during successive positive half-cycles.

When switch 28 is closed, as shown by the dotted line in FIG. 1, resistor 30 is placed across coil 24 and the gate of SCR 26 to convert the circuit to its "normally-off" mode. Resistor 30 has a relatively small value of resistance and thus loads down the gate of the SCR so that a larger priming signal is required to turn it on than is normally supplied by coils 22 and 24 at their fixed spacing. To turn on the circuit, a magnetic core 34, which may be constructed from a ferrite material, for example, is axially inserted through the coils to increase the degree of electromagnetic coupling therebetween. As the core 34 is inserted the coupling will increase until it produces a sufficiently large positive pulse on the loaded gate of SCR 26 to render the SCR conductive and apply power to load 12. Conversely, when core 34 is thereafter removed, the coupling between coils 22 and 24 will decrease until the priming voltage is once again insufficient to render the SCR conductive.

It is noted at this point, that coils 22 and 24 may be wired such that they are either similarly or opposingly polarized; i.e., current in the two coils may flow in either the same direction or in opposite directions, while the overall operation of the switch will remain primarily the same.

A second embodiment of the present invention is illustrated in FIG. 3 wherein component parts identical to those in FIG. 1 are identically labeled while the remaining parts are numbered with 100 added thereto.

The proximity switch of FIG. 3 includes a full-wave diode rectifier 140 having its input side connected in series with load 12 across the AC input source 10 and its output side connected between the junction of resistor 14 and the anode of SCR 26 and the junction of capacitor 18, coils 22 and 24, and the cathode of SCR 26. It is noted that loading resistor 30 as well as voltage divider resistor 16 are not shown in the circuit of FIG. 3 but may be added, if desired, in a similar manner to that described with respect to the embodiment of FIG. 1.

The operation of the circuit of FIG. 3 is similar to that of the circuit of FIG. 1 and thus will not described in detail for the sake of brevity. The circuit of FIG. 3 differs from that of FIG. 1 in that complete cycles of alternating current pass through the load when the SCR has been triggered, rather than only positive half-cycles as provided by the circuit of FIG. 1. In this manner, the embodiment of FIG. 3 can be termed a true AC switch; i.e., depending upon the degree of coupling between coils 22 and 24, and consequently, the conductive state of SCR 26, the application of a true AC signal across load 12 can be controlled. In other words, when sufficient coupling between coils 22 and 24 exists, SCR 26 will be rendered conductive and load 12 will be energized with full cycle AC. Similarly, as the coupling between the coils decreases, SCR will not be triggered and no operating potential will be applied to load 12.

Referring more specifically to the operation of the circuit of FIG. 3, the AC input signal is fed through load 12 in FIG. 3 and is rectified by rectifier 140 as a positive full-wave signal which is applied across the pulse-generating network formed by capacitor 18, diode 20 and coil 22. At the beginning of every positive half-wave swing, capacitor 18 is charged to breakdown the diode 20 and impress a voltage pulse across coil 22. As in FIG. 1, and under proper coupling conditions, the positive pulse is air coupled to coil 24 for firing SCR 26 through its gate. Since a triggering pulse will appear on the gate of SCR 26 at the beginning of every half-cycle, and since the positive full-wave rectified signal is also applied across the anode-cathode path of the SCR, the SCR will be rendered almost continuously conductive when sufficient coupling is provided from coil 22 to coil 24. In other words, since the AC signal impressed across capacitor 18 and SCR 26 in the embodiment of FIG. 3 is positive full-wave rectified, the SCR will be triggered at the beginning of every half-cycle rather than only on the alternate positive half-cycles as in the circuit of FIG. 1.

With SCR **26** nearly always conductive when coils **22** and **24** are within coupling proximity, both the positive and the negative swing of the AC input signal will appear across load **12**. In this manner, various devices such as hysteresis and capacitor-type AC motors may be directly controlled by the present invention. For example, an AC motor wired as load **12** may be energized by the circuit of FIG. 3 by fixing the position of coils **22** and **24** within coupling proximity. The insertion of a conductive vane (similar to vane **32** of FIG. 1) between the coils will thereafter decrease the degree of coupling therebetween until the magnitude of the pulses induced in coil **24** becomes insufficient to prime SCR **26** each half-cycle. The SCR therefore becomes nonconductive and energizing voltage is blocked from passing through the motor (acting as load **12**). If the vane is then removed, the coupling increases between coils 22 and 24 and the SCR will fire to turn the motor on once again. Thus, the application of complete cycles of AC operating potential to load 12 can be effectively controlled by the circuit of FIG. 3 in response to the position of a movable vane or magnetic core adjacent coils 22 and 24, or by the proximity of the coils to each other, as explained with respect to FIG. 1.

A modification of the proximity switch of FIG. 3 is shown in FIG. 4 wherein component parts identical to those in FIG. 3 are identically labeled while the remaining parts are numbered with **200** added thereto.

The circuit of FIG. 4 includes a slave network having a resistor **250** connected between the junction of input source **10** and resistor 12 and the anode electrode of a diode **252** which has its cathode connected to the anode of a second diode **254**. The cathode electrode of diode **254** is connected to the gate of an SCR **256** which has its anode-cathode path connected in inverse parallel relationship with the cathode-anode path of SCR **26**. A capacitor **258** is connected between the junction of diodes **252** and **254** and the junction of resistor **12** and the cathode of SCR **256**.

In operation, as in FIG. **1**, on positive half-cycles current is fed from source **10** through resistors **12** and **14** to charge capacitor **18**. When the capacitor builds up a sufficient voltage thereacross, diode **20** will fire to produce a sharp voltage pulse in coil **22**. If the coupling between coils **22** and **24** is insufficient to fire SCR **26**, very little operating potential will appear across load **12** in view of the high resistance of resistor **14** as compared with the load.

On the negative half-cycle, no current will flow through load **12** since capacitor **18** acts as an open circuit, diode **20** is reverse biased, and SCR **26** is reverse biased. In addition, since SCR **256** has not previously been primed, it is in its nonconductive state and presents an open circuit to block the flow of current through the load **12**. Thus, when the degree of coupling between coils **22** and **24** is insufficient to trigger SCR **26**, negligible current will flow through the load during both positive and negative half-cycles of the AC input supply voltage.

When the degree of coupling between coils **22** and **24** has been increased, either by removing a shielding vane or by inserting a suitable magnetic core, capacitor **18** will charge on positive half-cycles of the input signal to fire diode **20** and generate a triggering pulse for SCR **26**. The SCR then becomes conductive so as to present a low-impedance path to the flow of current from source **10** through load **12**. Since SCR **26** is in its conductive state, a low-impedance charging path is provided for capacitor **258** and SCR **26** back to source **10**. Therefore, when the proper coupling conditions exist between coils **22** and **24**, load **12** will become energized and capacitor **258** will become charged during positive half-cycles of the input signal.

On the negative half-cycles, SCR **26** will become reverse biased; however, the charge across capacitor **258** will be coupled through diode **254** so as to prime SCR **256** which then becomes conductive. In this manner, load **12** is also energized during the negative half-cycle portions by AC from source **10** through SCR **256**. The circuit of FIG. **4** thus acts as a true AC switch for isolating load **12** from input source **10** when the switching circuit if off, and for providing a complete AC signal to the load when the circuit is on, the positive and negative half-cycles being conducted to the load through SCR **26** and SCR **256**, respectively.

A further embodiment of the present invention is illustrated in FIG. **5** wherein component parts identical to those in FIG. **1** are identically labeled while the remaining parts are numbered with **300** added thereto.

While the energization of any number of AC devices may be controlled by the embodiment of FIG. **5**, an AC motor **312** is shown for purposes of illustration. As in FIG. **4**, the circuit of FIG. **5** includes a slave network having an inductor **360** connected between the junction of motor **312** and voltage divider resistor **14** and the junction of the anode electrodes of a pair of diodes **362** and **364**. The cathode of diode **362** is directly connected to the anode of SCR **26** while the cathode of diode **364** is connected to a resistor **366** and the gate electrode of an SCR **368**. The other terminal of resistor **366** and the cathode electrode of SCR **368** are coupled to the junction of motor **312** and resistor **14** while the anode electrode of SCR **368** is directly connected to the cathode of SCR **26**.

In operation, when the coupling between coils **22** and **24** is too low to fire SCR **26**; i.e., the switching circuit is in its off state, motor **312** will receive no energization potential on either positive or negative half-cycles of the AC input signal in a manner similar to that described above the respect to FIGS. **1** and **4**. Since SCR **26** will not be rendered conductive during any portion of the AC input signal, the slave network is passive and thus provides no operating potential to the load. When the coupling between the sensing coils **22** and **24** increases, SCR **26** will be triggered during positive half-cycles of the input signal to provide a low-impedance current flow path for energizing the motor **312**. In addition, since the anode-cathode path of SCR **26** is in its conducting or low impedance state during positive half-cycles, current will flow through inductor **360** and diode **362** so as to activate the slave network.

As the positive half-cycle ceases and the negative swing of the input voltage begins, SCR **26** will be rendered nonconductive and a triggering signal will be coupled from inductor **360** through diode **364** to the gate of SCR **368** which thereafter becomes conductive for the entire negative half-cycle. In other words, when coils **22** and **24** are within coupling proximity SCR **26** will act to provide a low-impedance current path for motor **312** during the positive half-cycle of the AC input signal while slave SCR **368** will similarly act to provide a low-impedance conductive path for the motor **312** during the negative half-cycles. In this manner, as in the circuit of FIG. **4**, complete AC voltage is applied to load motor **312** when the switching circuit is on so that the energization of true AC devices may be efficiently and effectively controlled.

It should be understood that the present invention can be utilized in any number of applications. For example, vane **32** may correspond to a conductive plate affixed to a meter pointer or the end of a bimetal for controlling the energization of heating or cooling apparatus, alarm lamps, or blower units, to name but a few, in response to the proximity of the conductive plate to coils **22** and **24**. In addition, vane **32** or magnetic core **34** may be employed in conjunction with an expanding and contracting humidity sensitive element to control a humidifier. Of course the above examples are not meant to be comprehensive, and the present invention may be used to control any electrical apparatus in response to the proximity of a van or core to coils **22** and **24** or the proximity of the coils to each other, as desired in various particular installations.

Inasmuch as the present invention is subject to many variations, modifications and changes in detail, it is intended that all matter contained in the foregoing description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. A proximity switch operable in response to the position of a movable object comprising input means adapted to be connected with a source of power,

pulse generator means connected with said input means for generating a series of pulses,

load means connected with said input means,

detecting means connected to said load means and said input means and responsive to pulses from said pulse generator means to energize said load means, and

coupling means connected to said pulse generator means and said detecting means and positioned adjacent the movable object for selectively enabling electromagnetic coupling of said pulses from said pulse generator means to said detecting means in response to the position of the movable object whereby energization of said load means is controlled by the movable object.

2. The invention as recited in claim 1 wherein said coupling means includes first and second spaced coils and said movable object is movable in the space between said first and second coils.

3. The invention as recited in claim 2 wherein said first coil is connected to said pulse generator means and said second coil is connected to said detecting means.

4. The invention as recited in claim 3 wherein said detecting means includes a first controlled rectifier having a gate electrode connected to said second coil.

5. The invention as recited in claim 4 wherein said pulse generator means includes a breakdown device connected with said first coil to form a series network, a capacitor connected in parallel with said series network, and a resistor connected at one end with said capacitor and said breakdown device and at the other end with said input means.

6. The invention as recited in claim 5 wherein said breakdown device comprises a unidirectionally conducting diode having a predetermined breakdown voltage in its forward direction.

7. The invention as recited in claim 6 wherein said input means supplies an AC voltage, and said diode is poled to conduct on positive half-cycles only.

8. The invention as recited in claim 7 wherein said first controlled rectifier is connected to said input means and is poled to conduct on positive half-cycles only.

9. The invention as recited in claim 8 wherein said coupling means includes a resistor connected in parallel with said second coil.

10. The invention as recited in claim 8 wherein said detecting means includes circuit means connected to said first controlled rectifier, said load means, and said input means, for conducting current to said load means on negative half-cycles of said AC voltage in response to the conducting of said first controlled rectifier during preceding positive half-cycles.

11. The invention as recited in claim 10 wherein said circuit means includes a second controlled rectifier connected in parallel with said first controlled rectifier and poled to conduct on negative half-cycles of said AC voltage only, and capacitive storage means connected to said input means for storing a triggering potential for said second controlled rectifier when said first controlled rectifier is conductive.

12. The invention as recited in claim 11 wherein said capacitive storage means includes a resistor, a first diode and a capacitor connected in series across said load means, said capacitor and said first diode connected with a gate electrode of said second controlled rectifier.

13. The invention as recited in claim 12 wherein said capacitor and said first diode are connected with said gate electrode of said second controlled rectifier by a second diode.

14. The invention as recited in claim 10 wherein said circuit means includes an inductor and a first diode connected in series with said first controlled rectifier, said inductor and said first diode being connected with the gate electrode of a second controlled rectifier connected to said input means and poled to conduct on negative half-cycles of said AC input signal.

15. The invention as recited in claim 14 wherein said inductor and said first diode are connected with the gate of said second controlled rectifier by a second diode, and a resistor is connected between the gate and cathode electrodes of said second controlled rectifier.

16. The invention as recited in claim 15 wherein said load means comprises an AC motor.

17. The invention as recited in claim 1 wherein said pulse generator means and said detecting means are connected to said input means and said load means by rectifier means.

18. The invention as recited in claim 17 wherein said input means supplies an AC voltage, and said rectifier means comprises a full-wave rectifier poled to produce positive half-wave rectified voltage to said pulse generator means and said detecting means.

19. The invention as recited in claim 18 wherein said coupling means includes a first and a second coil and said movable object is movable therebetween.

20. The invention as recited in claim 19 wherein said pulse generator means includes a capacitor connected in parallel with a series network formed by the connection of a breakdown device and said first coil, said breakdown device being poled to conduct a positive half-cycles only whereby a voltage pulse is produced in said first coil during each positive half-cycle of said AC voltage.

21. The invention as recited in claim 20 wherein said detecting means includes a controlled rectifier poled to conduct on positive half-cycles and having a gate electrode connected to said second coil whereby said controlled rectifier is rendered conductive by said voltage pulse produced in said first coil when said pulse is inductively coupled to said second coil.

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