United States Patent [19]

Bratkowski et al.

[11] B **3,919,676**

[45] **Nov. 11, 1975**

[54] **PERMANENT-MAGNET TYPE RELAY**

[75] Inventors: **Walter V. Bratkowski**, McKeesport; **Metro Spewock**, Export, both of Pa.

[73] Assignee: **Westinghouse Electric Corporation**, Pittsburgh, Pa.

[22] Filed: **Feb. 4, 1974**

[21] Appl. No.: **439,168**

[44] Published under the Trial Voluntary Protest Program on January 28, 1975 as document no. B 439,168.

[52] **U.S. Cl.** **335/179**; 335/79; 335/234

[51] **Int. Cl.**² **H01H 51/27**

[58] **Field of Search** 335/179, 170, 174, 78, 335/79, 229, 234, 236, 237

[56] **References Cited**

UNITED STATES PATENTS

3,441,883	4/1969	Alletru	335/234
3,534,307	10/1970	Spewock et al.	335/170
3,783,422	1/1974	Taylor	335/229

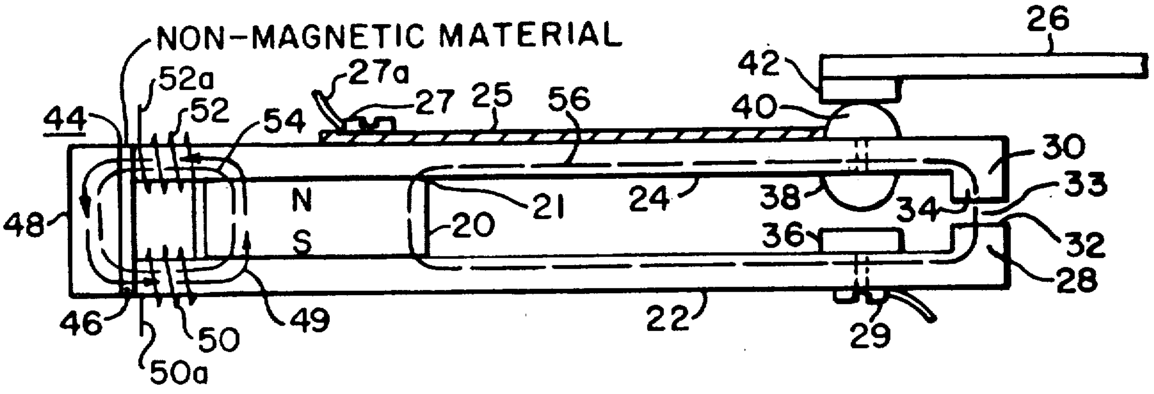
Primary Examiner—Harold Broome

Attorney, Agent, or Firm—W. A. Elchik

[57] **ABSTRACT**

A relay has a flux transfer device including a permanent magnet interposed between two ferromagnetic cantilevers, at least one of which is free to flex between two stable positions. The relay has two separate magnetic paths. A winding means encircles one of the paths and, when energized, causes the permanent magnet flux to transfer from one path to the other path, thus causing one of the cantilevers to flex in a snap action fashion from one stable position to the other stable position which connects or disconnects a set of electrical contacts. The relay remains magnetically latched in a stable position even after deenergization of the winding means.

5 Claims, 18 Drawing Figures



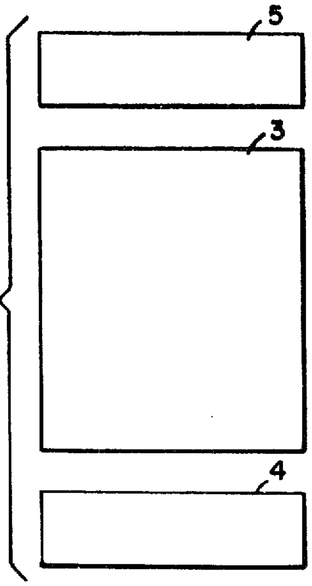


FIG. I
PRIOR ART

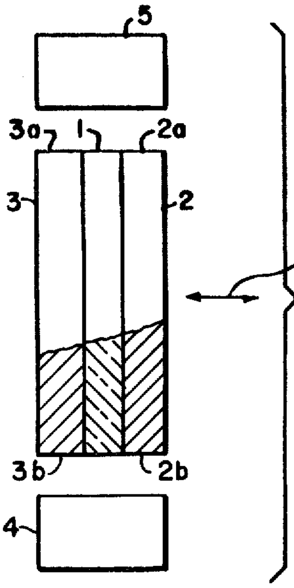


FIG. 2
PRIOR ART

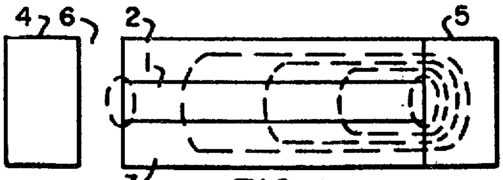


FIG. 3. PRIOR ART

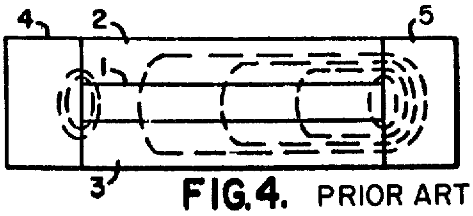


FIG. 4. PRIOR ART

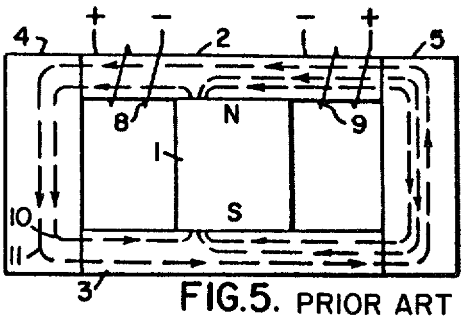


FIG. 5. PRIOR ART

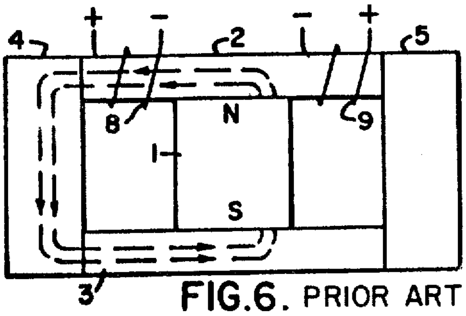


FIG. 6. PRIOR ART

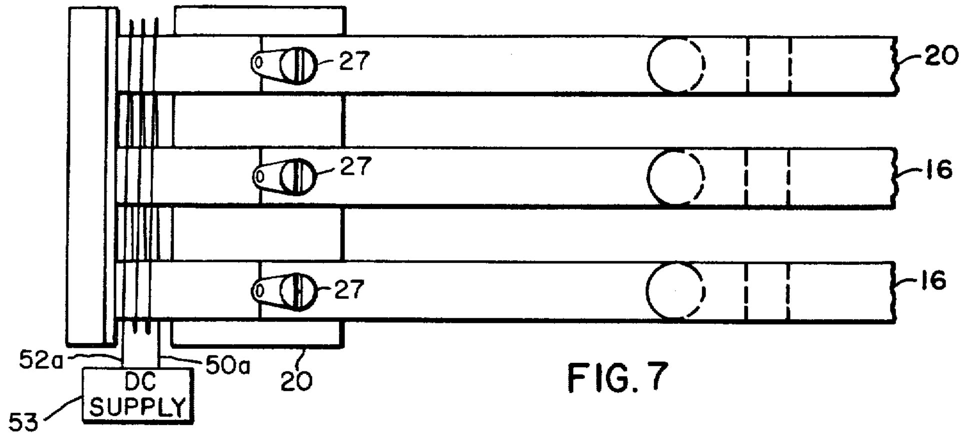


FIG. 7

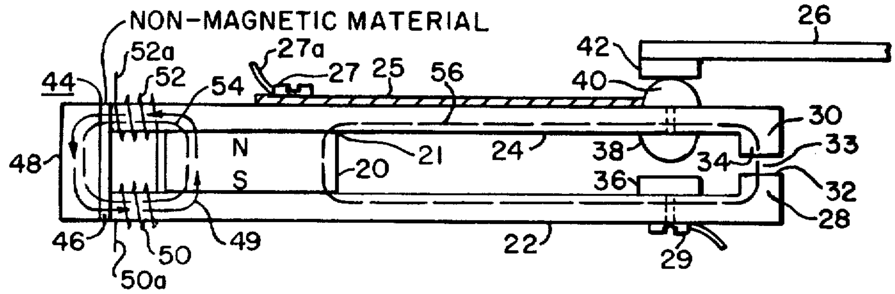


FIG. 8

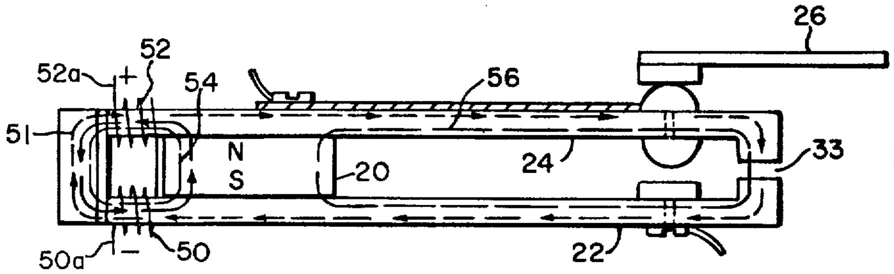


FIG. 9

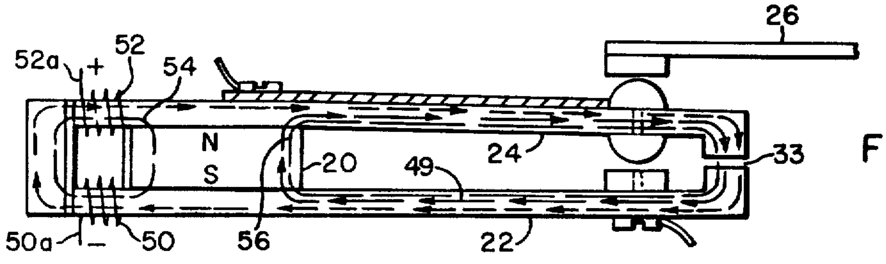


FIG. 10

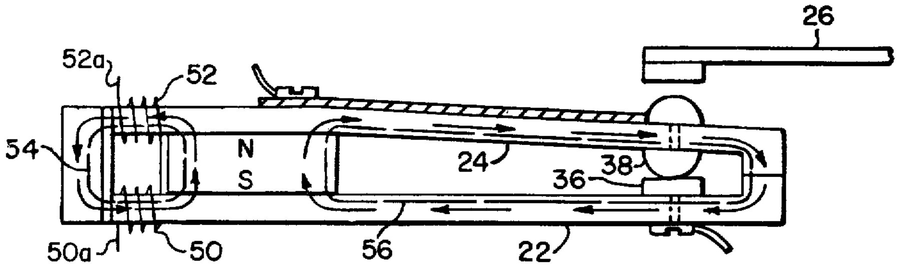


FIG. 11

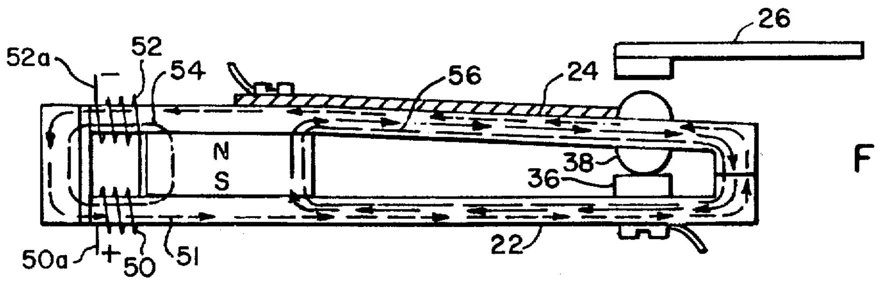


FIG. 12

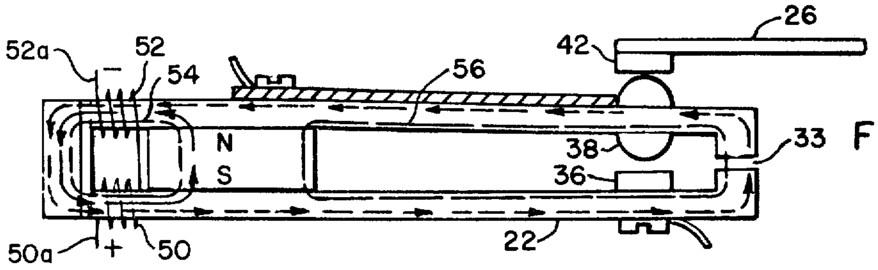


FIG. 13

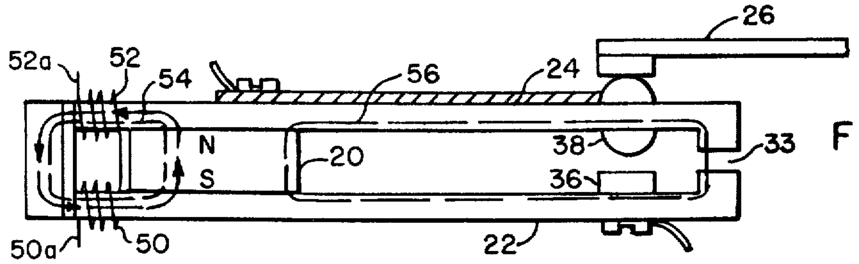


FIG. 14

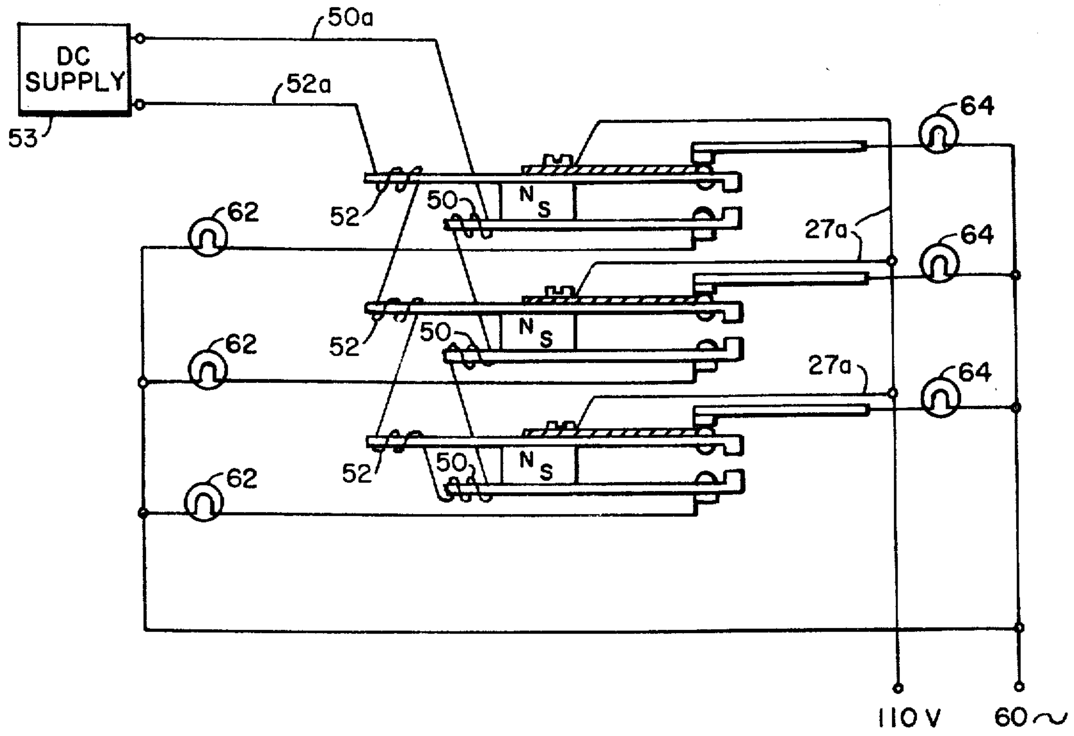


FIG. 15

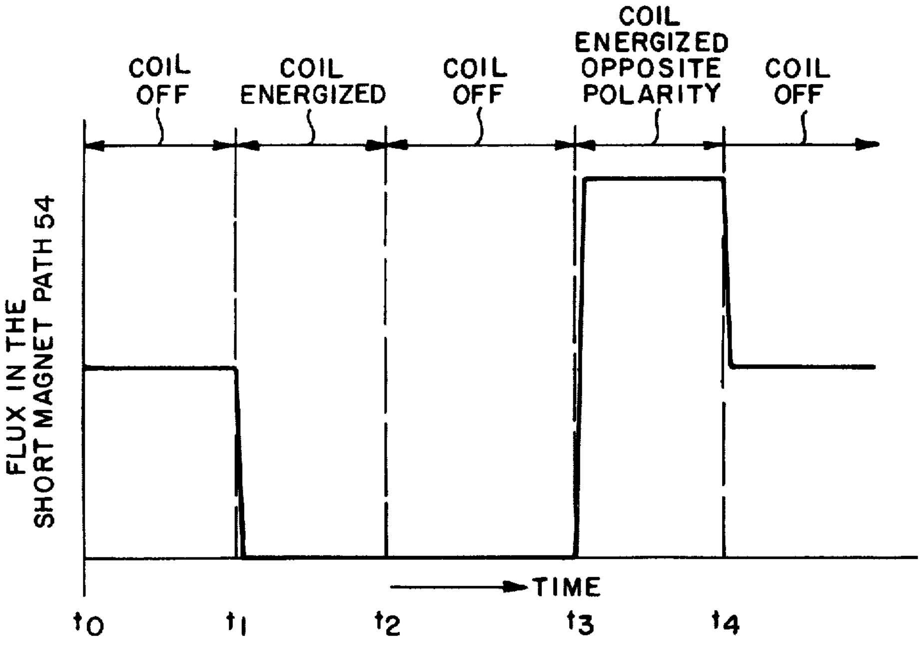


FIG. 16

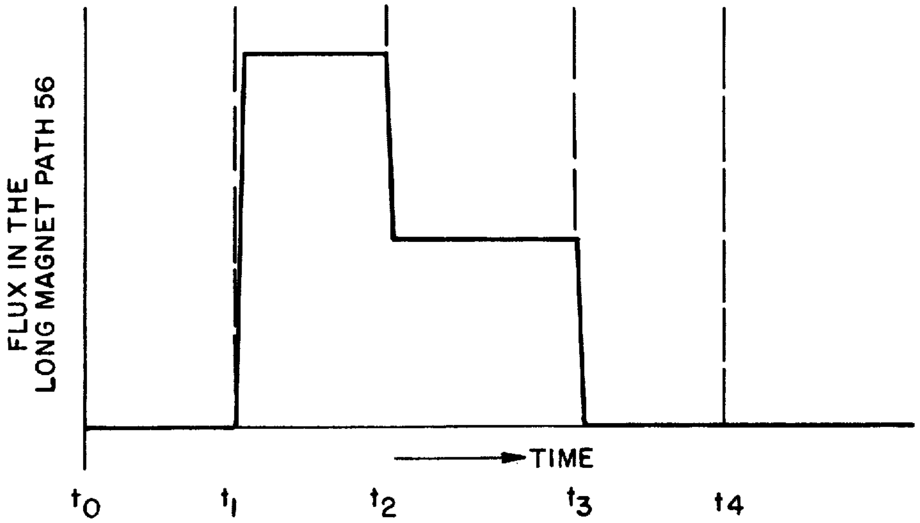


FIG. 17

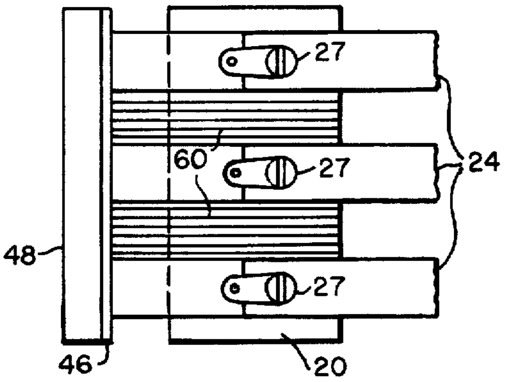


FIG. 18

PERMANENT-MAGNET TYPE RELAY

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates, generally, to relays and more particularly to an improved permanent magnettype relay in which the operation is highly effective and reliable to remain in one of its two bistable positions.

2. Description of the Prior Art

Electromagnetic relays have been widely used in the past. One of the most extensive early uses for magnetic relays was in communication applications. They were first used in the telegraph industry and later in the development of the telephone. A variety of assorted applications in other fields grew slowly until relays are now a commonplace component in electrical systems, especially in such applications as automated assembly lines and protective electrical systems. The failure of a relay can cause expensive shut-downs of equipment or even loss of life. A major requirement of industry for these applications is trouble-free performance over a large number of operations. Such units have a large application in industrial and space industries.

The present invention is particularly concerned with a new relay utilizing magnetic snap action and a magnetic flux transfer principle. The magnetic flux transfer principle is broadly set forth in U.S. Pat. No. 3,228,013 issued to R. D. Olson et al, and assigned to the assignee of the instant application. As set forth more fully hereinafter, the permanent-magnet flux transfer type of relay offers considerable simplicity in design. The control power may be AC or DC. Such a relay offers increased reliability with a substantial reduction in cost.

A relay utilizing the flux transfer principle was described in U.S. PAT. NO. 3,534,307 issued to the present applicants and assigned to the assignee of the instant application. The present invention, however, provides a much different structure and is especially suited to reed type relays and other applications requiring miniaturization or a closed system.

The present invention is particularly concerned with magnetic memory characteristics, and utilizes an electromagnetically controlled magnetic memory device which takes advantage of the inherent characteristics of soft ferromagnetic material.

SUMMARY OF THE INVENTION

The present invention is a new and improved permanent magnet type relay providing a magnet structure forming two separate magnetic paths. A permanent magnet is disposed between a pair of longitudinal ferromagnetic cantilevers, intermediate the ends of the cantilevers, with the direction of magnetization of the permanent magnet substantially perpendicular to the pair of cantilevers. A wafer of non-magnetic material abuts one pair of ends of the pair of cantilevers. A keeper of ferromagnetic material is secured to the face of the wafer on the side opposite the ends of the cantilevers. The permanent magnet, portions of the pair of cantilevers, the non-magnetic wafer, and the keeper define the first magnetic path. At least one of the ends of the ferromagnetic cantilevers opposite the non-magnetic wafer is free to flex. The permanent magnet, the portions of the pair of ferromagnetic cantilevers opposite the non-magnetic wafer, the flexing end portions of the ferromagnetic cantilevers, and the air gap between the flexing ends constitute the second magnetic path. Electrical contact means are secured to flexing portions of the pair of ferromagnetic cantilevers intermediate the permanent magnet and the air gap defined by the flexing cantilever ends, so as to make electrical contact when the flexing cantilever ends are in a position of close physical proximity and to break electrical contact when the flexing cantilever ends are in a spaced-apart position. An electromagnetic control winding means is provided encircling at least one leg of the first path and arranged so that upon energization, the control winding means produces flux which "bucks" the flux produced in the first magnetic path by the permanent magnet, and simultaneously auguments the flux produced in the second magnetic path by the permanent magnet. Thus, the normal magnetic flux is deliberately reduced in the first magnetic path, whereas the flux in the second magnetic path is deliberately increased by the energization of the power control winding means. The result is that the flexing ends of the ferromagnetic cantilevers are attracted to one another and assume a stable position of close physical proximity, thus effecting electrical contact between the electrical contact means secured to the cantilevers. By reversing the direct current through the control winding means, the flux produced in the second magnetic path by the permanent magnet is opposed, while the flux produced by the permanent magnet in the first magnetic path is augmented, thus permitting the inherent mechanical stiffness of the flexing ferromagnetic cantilever arms to overcome the reduced magnetic force attracting the cantilevers, and causing the cantilevers to spring to a relatively spaced-apart stable position, breaking electrical contact. Momentary energization of the control winding means is sufficient to effect transfer to a new stable position. As a result, a magnetically-latched bistable relay with two contact positions and low power consumption is provided. No power is needed to hold the relay in either of its stable positions. Power is only used to switch the relay.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention may be more readily understood when considered in view of the following detailed description of exemplary embodiments thereof, taken in conjunction with the drawings, in which:

FIG. 1 is a front elevational view of permanent magnet apparatus which shows the memory principle utilized in the present invention;

FIG. 2 is a right-hand side elevational view of the permanent magnet apparatus shown in FIG. 1;

FIGS. 3 and 4 illustrate flux patterns in the permanent magnet apparatus illustrated in FIGS. 1 and 2;

FIGS. 5 and 6 illustrate the electromagnetic external power control of the magnetic memory phenomena shown in FIGS. 1–4;

FIG. 7 is a plan view of an electromagnetically controlled, magnetically latched relay incorporating principles of the present invention;

FIGS. 8–14 are side elevational views showing the relay of FIG. 7 through various stages of its operation cycle;

FIG. 15 is a schematic view of a control circuit utilizing the relay of FIG. 7 to operate a plurality of electric light bulbs;

FIGS. 16 and 17 are diagrams of the magnetic flux conditions in the closed and open magnetic paths over various conditions of electromagnetic control winding means energization; and

FIG. 18 is a detail elevational view showing the construction of the relay of FIG. 7.

A ferromagnetic material must have atoms whose electron arrangement is such that magnetism is created. The atoms having these magnetic characteristics are grouped into regions called domains. In these domains it is equally probable that magnetism will occur in any one of six directions. In the iron crystal, for example, the atoms are at the corners of the cube-shaped crystal with one atom at the center. This arrangement is called a bodycentered cubic lattice. The grouping in a nickel crystal differs from this by having an atom in the center of each face but none at the center of the cube; this is called a facecentered cubic lattice. The domain in an iron crystal in the absence of an external magnetizing force has its atomic magnetic moments all lined up in a single direction, the direction of one of the edges of a cubic lattice. In a face centered cubic lattice, such as nickel, the atomic magnetic moments are in the direction of a diagonal of the cube. In unmagnetized ferromagnetic materials, the domains are randomly oriented and neutralize each other. However, the magnetic forces are present. Applications of an external magnetic field causes magnetism in the domains to be aligned so that their magnetic moments are added to each other and to that of the applied magnetic field.

With soft magnetic materials, such as iron, small external magnetic fields will cause great alignment but, because of the small restraining force, only a little of the magnetism will be retained when the external magnetic field is removed. With hard magnetic materials, a greater external force must be applied to cause orientation of the domains, but most of the orientation will be retained when the field is removed, thus creating a stronger permanent magnet, which will have one north pole and one south pole.

Materials which may be grouped as soft range from cast iron, which is one of the poorest, to the ironnickel alloys, which rank among the best. Alnico and barium ferrite are examples of hard magnetic materials.

The present invention utilizes the above-mentioned characteristics of soft magnetic materials by providing two ferromagnetic paths, each having a portion common to the other path. A permanent magnet is used to supply flux to each of the paths. If one path has less reluctance than the other path, the majority of the domains in the above-mentioned common portion will align themselves in the direction of the path having the least reluctance and the majority of the permanent magnet flux will flow in that path. The domains will remain so aligned until some external energy is applied to realign them in a different direction causing transfer of the permanent magnet flux to the second path. Control of the external energy required to rotate the domain orientation and indicate the flux transfer is obtained through the use of electromagnetic control windings associated with each of the ferromagnetic paths. This characteristic of assuming and maintaining either of two stable conditions in response to a momentary input-signal defines a type of digital memory. It is desirable to use this memory characteristic to allow a relay to maintain either of its two stable positions without the application of external power.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

In FIG. 2 there is shown a ceramic permanent magnet of barium ferrite 1 used as a source of magnetomotive force sandwiched between two soft ferromagnetic bars 2 and 3. The permanent magnet 1 is magnetized in the direction perpendicular to the soft magnetic bars 2 and 3, as indicated by the arrow in FIG. 2. Two keepers 4 and 5, also made of soft magnetic materials, are placed so that they may complete separate ferromagnetic paths through the common portion consisting of bars 2 and 3 and permanent magnet 1. The device comprises the ceramic magnet 1 and the soft magnetic bars 2 and 3. It is capable of holding a cold-rolled low-carbon steel keeper against the pole faces with a pull of approximately 26 pounds. The high coercive force of the barium ferrite material 1 permits the magnetic length to be shorter for the same pole face area than magnets of other materials. In addition, the flux density at the pole faces 2*a*, 2*b*, 3*a*, 3*b* of the device, shown in FIG. 1, can be raised to five times the flux density in the magnet 1 by making the area of the pole face smaller than the magnetic area. The combination of these two design features yields a relatively small magnet, which has a high flux density at the pole faces, but which has very little "reach-out" power. As previously stated, the device can hold one keeper, for instance, keeper 4, with a pull of approximately 26 pounds. If another keeper were placed upon the magnetic structure in FIG. 1, such as keeper 5, it would not be held with much force (i.e., less than 26 pounds); that is, it would be held with less force than the keeper 4 only if it were placed on the structure after keeper 4 had been placed on the device.

FIG. 3 shows what occurs when one keeper is placed on the device. In this Figure it can be seen that the domains of the soft magnetic material in the bars 2 and 3 have aligned themselves in the direction of a flux path including permanent magnet 1, bar 2, keeper 5 and bar 3. Very few lines of flux are present in the air gap 6 between the keeper 4 and the device. In FIG. 4 there is shown what happens when the keeper 4 is placed against the device. Though there now appears to be two separate ferromagnetic paths which are physically and magnetically equal, the flux does not divide equally between the two paths. The first path mentioned previously includes keeper 5; and the second path includes permanent magnet 1, bar 2, keeper 4, and the bar 3. The domains of the soft magnetic material in bars 2 and 3 have aligned themselves in a direction of the path including the keeper 5. Therefore, this is still a low-reluctance path for the flux applied by the permanent magnet 1, and very little flux will be supplied to the path including the keeper 4. This device can be used to distinguish between four possible states, and for one of these states, there are two alternatives of priority. The four states are: (1) no keepers; (2) keeper 4 in contact with the device, keeper 5 not in contact with the device; (3) keeper 5 in contact with the device, keeper 4 not in contact with the device; and (4) keepers 4 and 5 both in contact with the device. Two alternatives of priority for state 4 are: (a) keeper 5 placed before keeper 4, and (b) keeper 4 placed before keeper 5.

The above description defines a memory device or storage element for digital information, that is the device remembers which keeper was placed on it first. In FIG. 4, if the keeper 5 were removed, the domains would align in the path including the keeper 4 and if the keeper were again placed against the device, it would be held with much less force than the keeper 4.

In order to achieve control over the alignment of the domains in the common portions 2 and 3 without the necessity of physically moving the keepers 4 and 5, an electromagnetic control winding 8 was added to a device similar to the one shown in FIG. 4, whose domains were aligned in the direction of the path including the keeper 5. Such a device is shown in FIG. 5. The control winding 8 has a signal applied to it, which causes flux to be produced in the direction of flux produced by the permanent magnet in the keeper 4. The flux from the permanent magnet 1 is shown by the inner dotted line 10, and the electromagnetic flux from control winding 8 is shown in the outer dotted line 11. This superposition of the electromagnetic field upon the permanent magnet field is such that the value of the electromagnetic field causes the effective reluctance of the path, including the keeper 4 and the permanent magnet 1, to be lower than the effective reluctance of the path including the keeper 5 and the permanent magnet 1. The domains in the common portion of the bars 2 and 3 become aligned in a direction of the path including the keeper 4. When the electromagnetic control windings no longer supply magnetomotive force to the device, as shown in FIG. 6, the path including the keeper 4 continues to have a lower reluctance than the path including the keeper 5, and therefore most of the lines of flux continue to stay in this path. Thus, it can be seen that a pulse, or short time duration signal, applied to the control winding 8, can be used to switch the lines of flux emanating from the permanent magnet 1 from one path to another. It is most important to note that the magnetic fields attain the equilibrium, or stable state, after each flux transfer. Stability is not destroyed if the electromagnetic field is removed. One important feature is that with proper choice of magnitude of electromagnetic fields, virtually complete transfer of permanent magnet fields can be achieved as shown in FIG. 6.

The relay of FIGS. 7–14 includes a permanent magnet 20, which may be of barium ferrite or strontium ferrite, for example, having a polarity as indicated in the drawings. Each pole of the relay comprises three cantilevers 22, 24, 26. Cantilevers 22 and 24 are of a magnetic material such as that known commercially as Hipernik 50–50, and are in a position longitudinally across the pole faces of the permanent magnet 20. Cantilever 26 is of copper or other non-magnetic material. The ends of the canntilevers 22 and 24 closest to cantilever 26 contain projecting members 28 and 30 whose faces 32 and 34 define an air gap 33. Mounted on cantilevers 22 and 24 near the projecting members 28 and 30 are cooperating electrical contacts 36 and 38. The contact 38 is electrically connected by a conductor in the cantilever 24 to a contact 40 which cooperates with a corresponding contact 42 mounted on the cantilever 26. A thin strip 25 of copper or other electrical conductor is bonded to the cantilever 24 and electrically connected to contacts 38 and 40. A terminal 27 is provided to connect the common leg 27a of a circuit to be controlled by the relay. Other controlled circuit connections are made to the cantilever 26 and a terminal 29 which is electrically connected to the contact 36. Affixed to the ends of all ferromagnetic cantilevers is a laminated structure 44 consisting of a thin wafer 46 of non-magnetic material such as polystyrene secured to a keeper member 48 of ferromagnetic material.

Thus, two magnetic paths 54 and 56 are defined, as indicated by the broken lines. Magnetic path 54 is defined by the permanent magnet 20, the cantilever 24, the keeper member 48 and the cantilever 22. The magnetic path 56 is defined by the permanent magnet 20, the cantilever 24, the air gap 33 and cantilever 22.

Electromagnetic control windings 50 and 52 encircle cantilevers 22 and 24, respectively. These control windings are connected electrically in series so as to produce magnetic flux in phase through keeper member 48 when connected to reversible current supply means, such as DC supply 53, connected through leads 50*a* and 52*a* .

Cantilever 24 is free to flex between an open position wherein contact 40 and 42 are engaged as in FIG. 8 and FIG. 9 and a closed position wherein contacts 36 and 38 are engaged as in FIGS. 11 and 12.

The position of the permanent magnet 20 in relation to the ends of the cantilevers 22 and 24, the thickness of the non-magnetic wafer 46, and the size of the air gap 33 are chosen such that the reluctance of magnetic path 54 is less than the reluctance of magnetic path 56 when the cantilever 24 is in the open position, and the reluctance of the magnetic path 54 is greater than the reluctance of the magnetic path 56 when the cantilever 24 is in a closed position. Since the reluctance of magnetic path 54 is less than magnetic path 56 in FIG. 8, most of the flux produced by permanent magnet 20 flows through magnetic path 54 as shown by the solid arrows 49. When the control coils 50 and 52 are energized as in FIG. 9, through leads 50*a* and 52*a* by DC supply 53 (not shown) they produce flux in magnetic path 54, shown by dashed arrows 51, which bucks the flux produced by the permanent magnet in the same path 54. This increases the effective reluctance of magnetic path 54 and causes the flux 49 produced by the permanent magnet 20 to transfer to magnetic path 56, as shown in FIG. 10. The flux produced in magnetic path 56 by the permanent magnet 20 and the control coil windings 50 and 52 are additive. This increased flux causes the cantilever 24 to flex toward the cantilever 22, closing electrical contact 36 and 38 and eliminating the air gap 33. The elimination of the air gap 33 and the alignment of the domains in path 56 decreases the reluctance of the magnetic path 56. Thus, even when the control coil windings are deenergized, the reluctance of magnetic path 56 is still less than magnetic path 54 and the flux from the permanent magnet 20 remains in magnetic path 56, as shown in FIG. 11, a small leakage flux remains in path 54.

When the control winding coils 50 and 52 are energized in the opposite direction as shown in FIG. 12 through leads 50*a* and 52*a* by DC supply 53 (not shown), they produce flux as represented by the dashed arrows 51 in FIG. 12. As can be seen, this flux bucks the flux produced in magnetic path 56 by the permanent magnet. The domains in the path 56 become less completely aligned, increasing the effective reluctance of magnetic path 56, and causing the flux from permanent magnet 20 to transfer from magnetic path 56 to magnetic path 54 as shown in FIG. 13. With the decrease in flux through magnetic path 56 the stiffness of cantilever 24 overcomes the force produced by flux in path 56 causing the cantilever 24 to return to an open position, opening contacts 36 and 38, closing contacts 40 and 42, and restablishing the air gap 33. The air gap 33 increases the reluctance of magnetic path 56. Thus, even after deenergization of the control coil windings, the flux from permanent magnet 20 remains in magnetic path 54 and the cantilever 24 remains in the open position as shown in FIG. 14. In this manner, the relay assumes either of two bistable positions.

The relay described in the present invention does not require the continual application of voltage to the control coil windings **50** and **52** through leads **50***a* and **52***a* to operate the relay. Application of voltage to the coils **50** and **52** is required only when switching from one stable state to the other. A relay of this type can be operated with very low power, and therefore is highly desirable for telephone switching systems, automation, and the like. The relay can have any combination of normally closed or normally open contacts. For purposes of simplicity, the use of the relay with three normally closed and three normally open contacts has been described. As indicated, the relay comprises three contact poles, each having a double throw, and a flux transfer device for operation. The double throw feature is optional. The relay can be operated on an AC or DC voltage. When using AC power, an AC to DC converter is used with a DC relay. The contacts can be plated with silver or other suitable material.

A relay of this design may be operated in air, vacuum or gas. The operation of the cantilever in vacuum or gas would significantly reduce the contact oxidation and greatly extend the operating life of the relay.

FIGS. **16** and **17** illustrate the magnetic flux relationship in the paths **54** and **56** as the various states of control winding energization cause the relay to go through its operational cycle. At time t_o, the flexing cantilever **24** is in the open position and no current is flowing in the control winding. At this time the short magnetic path **54** has the lower reluctance of the two paths and the flux from the permanent magnet is flowing through this path. At t_1 the coil is energized so as to produce a magnetic flux in the short magnetic path opposite to the flux produced by the permanent magnet. This increases the effective reluctance of the magnetic path **54** and causes the permanent magnet flux to transfer to the long magnetic path **56.** The flux produced by the control winding coils is in phase with the permanent magnet flux in the long magnetic path **56.** At time t_2, the coil is deenergized, causing a reduction in total flux through the long magnetic path **56.** However, the flexing cantilever is now in its closed position, causing the long magnetic path **56** to exhibit a smaller reluctance than the short magnetic path **54.** Thus, the permanent magnet flux remains in the long magnetic path **56** as is shown in FIG. **17** between time t_2 and t_3. At time t_3 the coils are energized in a direction producing flux in the long magnetic path **56** opposite to that produced by the permanent magnet. This increases the effective reluctance of the magnetic path **56** causing the permanent magnet flux to transfer back to the short magnetic path **54.** The flux produced by the permanent magnet in magnetic path **54** and that produced by the control winding coils in magnetic path **54** are additive, producing a high total value of flux in this short magnetic path **54.** The absence of flux in the long magnetic path **56** allows the elastic stiffness of cantilever **24** to return the relay to its open position increasing the reluctance of path **56** even more. Thus, when the coil is deenergized at the time t_4, the reluctance of path **54** will be less than the reluctance of path **56** and the permanent magnet flux will remain in the short magnetic path **54,** allowing the relay to remain in its open position.

It will be noted that when the electromagnetic flux is directed through the magnetic path **56** the flux density increases rapidly in the air gap **33.** Thus, an attractive force is set up which pulls the cantilevers **22** and **24** together. This action takes place so quickly with a high-permeability material that snap action is obtained in moving the cantilever **24** from one stable position to the other. Since the material known commercially as Hipernik saturates at a high flux density β at less than one oersted, and has a very high initial magnetic permeability, it was chosen for the ferromagnetic cantilever material. The attractive force F_o which exists between the cantilever is given by Maxwell's Law or:

$$F_o = {}^2\mathrm{G}/\mathbf{8}\ wa$$

where:

ϕG = flux in the gap **33**
w = width of the cantilever
a = width of the flux gap.

Since the cantilevers are long compared to the width of the flux gap, the pull is independent of the cantilever length. The permeability of the cantilever material is high enough to have essentially equipotential surfaces near the gap, therefore the magnetic pull F_m can be written as:

$$F_m = \mathrm{F}_{ol}1 + k(\mathrm{x}/\mathrm{a})$$

where

F_o is defined by Maxwell's Law
k = a function of thickness and width of the contacting surfaces
x = length of the gap
a = width of the gap.

Since the flux in the gap between the high permeability cantilever can change rapidly, the magnetic pull force also changes rapidly. Thus, magnetic snap action is obtained on the application or removal of a magnetic field. The major controlling factor in obtaining snap action is the flux-carrying capacity of the cantilever as limited by the saturation density of the cantilever material.

FIG. **15** shows the above-described relay in a circuit used to control the alternate energization of two sets of electric lamps **62, 64.** Reversible pulses of direct current applied through the leads **50***a* and **52***a* to the control windings **50** and **52** by the DC supply **53** cause the relay to apply **110** volts, **60** cycles AC voltage to either of the desired sets of lamps **62** or **64.**

The common leg **27***a* of the controlled circuit, in this case the 110 volts, **60** cycle AC current, is applied to the flexing cantilevers of the relay through the terminals **27.** Electrical separation of the various poles of the relay is maintained as is shown in FIG. **18** by insulation **60** between the flexing cantilevers **24** of each pole and, as is shown in FIG. **8** insulation **21** between the cantilevers **24** and the permanent magnet **20.**

Various configurations of the control winding coils **50** and **52** are possible. The winding **52** may encircle flexing ferromagnetic cantilevers of all poles in common while the other winding **50** encircles the non-flexing ferromagnetic cantilevers of all poles in common, or each cantilever could be individually encircled by a coil with all coils connected in series. The important thing is that magnetic flux produced by the coils will be in the same direction in like cantilevers of each pole and that the flux produced by the various coils will be in phase through the ferromagnetic keeper member **48.**

The relay as described includes a strip of electrically conducting material bonded to the flexing cantilever. However, for low current applications the ferromagnetic cantilever itself could be the conductor. The connections to the controlled circuit could then be made by affixing the controlled circuit leads directly to the cantilevers in any convenient manner.

From the foregoing, it is seen that the present invention has provided a permanent magnet-type relay of simplified construction featuring low-power consumption and snap action.

While the present invention has been shown and described in only one form, it will be obvious to those skilled in the art that it is not so limited, but is susceptible of various changes and modifications without departing from the spirit thereof.

We claim:

1. A permanent magnet type relay including:

a permanent magnet located between a pair of longitudinal ferromagnetic members intermediate the ends of the ferromagnetic members,

a first magnetic path,

said first magnetic path comprising fixed end portions of said ferromagnetic members which extend in one direction from said permanent magnet, a keeper member bridging said fixed end portions to complete the magnetic path, and non-magnetic material interposed between said fixed end portions and said keeper member,

a second magnetic path,

said second magnetic path comprising cantilever end portions of said ferromagnetic members which extend from said permanent magnet in a direction opposite from the extension of fixed first end of said ferromagnetic members, at least one of said cantilever end portions being flexible to move relative to the other of said cantilever end portions,

electrical contact means, operable to produce first and second external circuit conditions,

winding means inductively coupled to at least one of said magnetic paths,

means for energizing said winding means,

reversible current supply means for selectively reversing the flow of current through said winding means to change the relative magnitude of the flux density in said first and second magnetic paths to cause said at least one cantilever end portion to flex, flexing of said cantilever end portion causing said electrical contact means to produce a first external circuit condition when said cantilever end portions are in a position of close physical proximity and causing said electrical contacts to produce a second external circuit conditions when said cantilever end portions are in relatively spaced-apart position.

2. The permanent magnet type relay of claim 1 wherein said reversible current supply means provides momentary pulses of direct current.

3. A permanent magnet type relay as in claim 1 wherein said at least one cantilever end portion is free to flex so as to permit said at least cantilever end portion to move relative to said other cantilever end portion and assume either of two stable positions, the first of said two stable positions of said cantilever end portions being a position of relatively close physical proximity and the second of said two stable positions of said cantilever end portions being relatively spaced-apart position.

4. The permanent magnet type relay of claim 1 wherein said cantilever end portions of said ferromagnetic members remain magnetically latched in a position of close physical proximity constituting a first stable position when the most recent flow of direct current through said winding means was in a direction so as to produce magnetic flux in said cantilever end portions aiding the flux produced in said cantilever end portions by said permanent magnet, and said cantilever end portions of said ferromagnetic members remain latched in a relatively spaced-apart position constituting a second stable position when the most recent flow of direct current through said winding means was in a direction so as to produce magnetic flux in said cantilever end portions of said ferromagnetic members bucking the flux produced in said cantilever end portions by said permanent magnet.

5. A permanent magnet type relay as in claim 4 wherein the change in relative magnitude of the flux in said first and second magnetic paths is effected with such speed as to cause said end portions of said at least one of said cantilever end portions to transfer from one of said two stable positions to the other of said two stable positions with a snap action.

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