

[54] **MAGNETIC LATCH AND SWITCH
USING COBALT-RARE EARTH
PERMANENT MAGNETS**

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[58] Field of Search **335/170, 167, 166, 179, 229-230,**
335/78, 79, 80, 81, 82; 148/31.57

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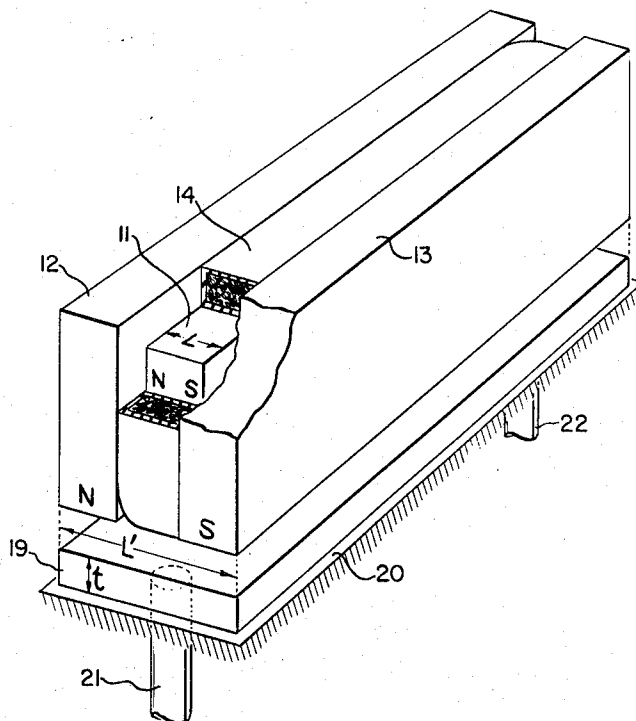
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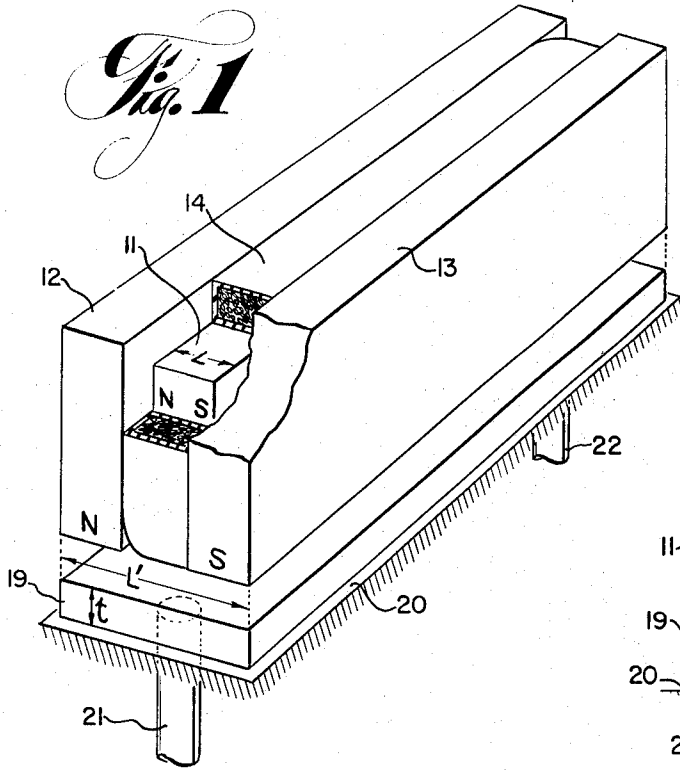
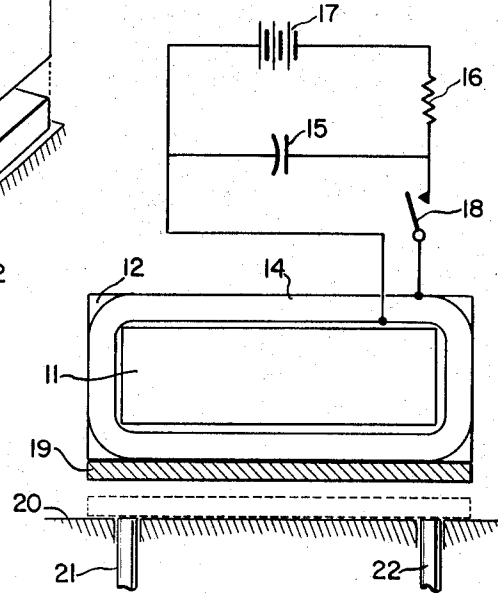
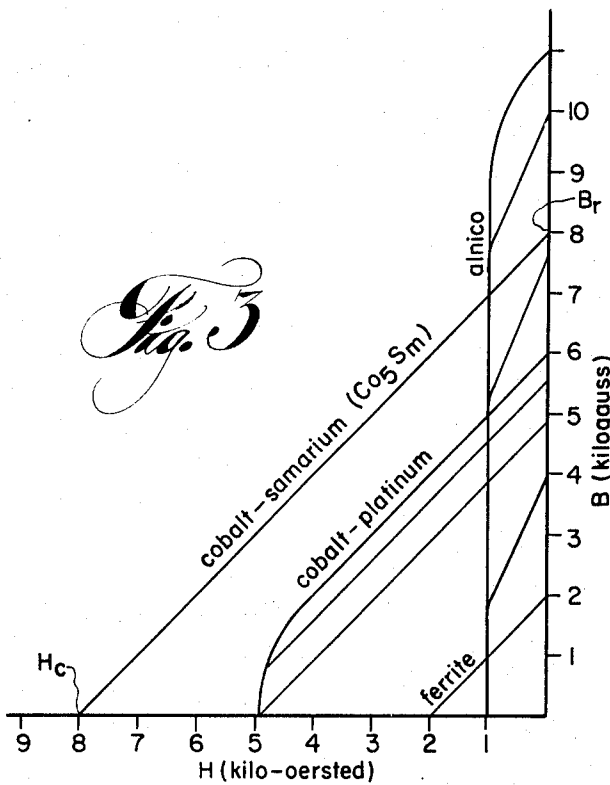
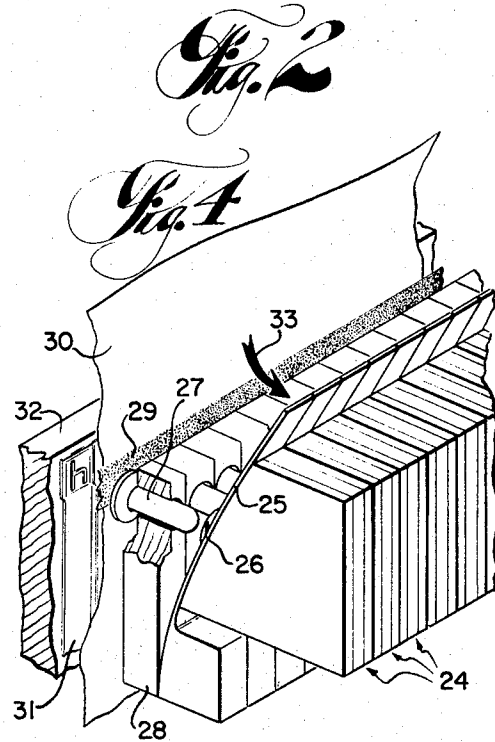
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[57] **ABSTRACT**

Magnetic latches and switches based on the flux cancellation or flux diversion principle use the high coercive force of cobalt-rare earth permanent magnets such as cobalt-samarium. These permanent magnets are not demagnetized by a flux cancellation coil and can be made thin in the field direction. Devices with thin magnetic circuits and low volume armature achieve high unlatching speeds.

4 Claims, 8 Drawing Figures





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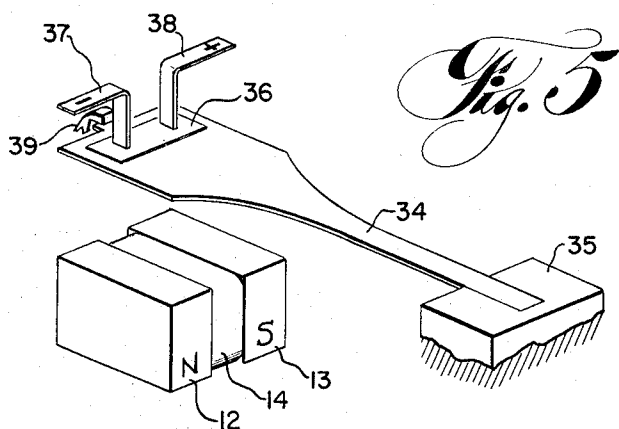


Fig. 6

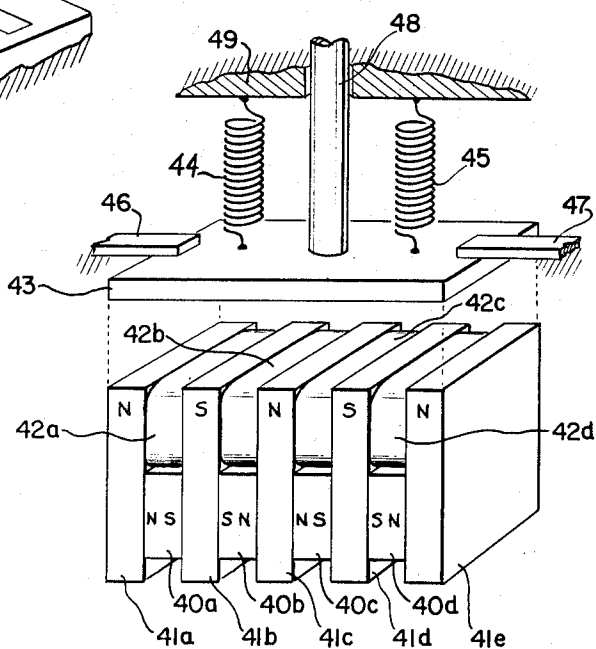
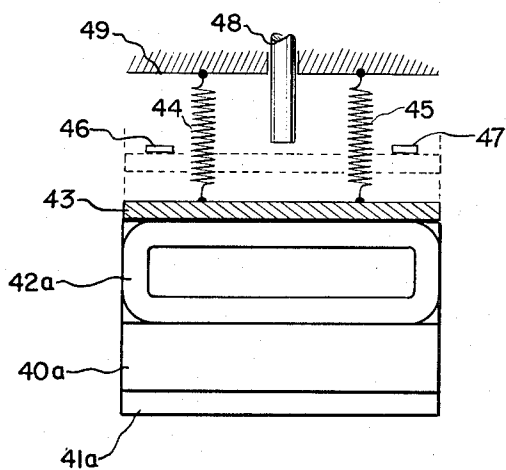
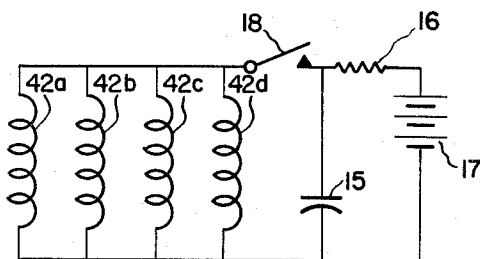


Fig. 7

Fig. 8



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MAGNETIC LATCH AND SWITCH USING COBALT-RARE EARTH PERMANENT MAGNETS

BACKGROUND OF THE INVENTION

This invention relates to magnetic latches and switches made with cobalt-rare earth permanent magnets such as the cobalt-samarium magnet, and more particularly to new constructions made possible by the special properties of these rare-earth permanent magnets.

In equipment of many different types a desirable component is a frictionless latch that is easily and dependably released by an electrical signal. Magnetic or electromagnet latches are commonly employed to accomplish this function. Basically, the magnetic latch comprises an armature held by magnetic forces against the pole faces of a magnetic circuit. The magnetic field is temporarily cancelled or reduced, allowing the armature to move away from the pole pieces under the influence of a mechanical force, usually a spring or gravity. Two elementary approaches used to neutralize temporarily the magnetic field of the magnet are flux cancellation and flux switching. In flux cancellation systems, the holding flux is provided by an electromagnet whose field is momentarily cancelled by an opposing field generated by a control electromagnet. The holding field in practical devices presently known usually is not provided by a conventional permanent magnet because the cancelling field would de-magnetize it. In flux switching systems, the holding flux provided by a permanent magnet or an electromagnet is diverted from the armature by establishing in a shunt magnetic path a flux which subtracts from the armature flux but reinforces the magnet flux. Although there is no demagnetization of the permanent magnet, if used, the diverting shunt path is space consuming.

The present invention recognizes that the unique properties of the relatively new cobalt-rare earth permanent magnets make possible new and improved magnetic latch constructions, and that these concepts have general utility in similarly constructed switches and relays. The cobalt-rare earth permanent magnets were first described to the public in 1967, and subsequent interest in them has generally been with regard to their preparation and properties rather than with regard to their applications.

SUMMARY OF THE INVENTION

The cobalt-rare earth permanent magnets are characterized by a high coercive force, H_c , and medium values of magnetic induction, B . These permanent magnet materials, of which cobalt-samarium is the most common, are more specifically comprised substantially of Co_xR , where R is a rare earth metal. The demagnetization curve of Co_xSm is linear with a typical H_c of 8,000 oersted and a remanent magnetization, B_r , of 8,000 gauss. These unique properties of the cobalt-rare earth permanent magnets, principally the high coercive force, are utilized in the construction of new and improved magnetic latches and electrical switches based on either the flux cancellation or flux diversion principle.

In one embodiment, a magnetically operated device of this type includes a magnet assembly comprising a cobalt-rare earth permanent magnet and a flux cancellation coil, preferably wound about the magnet, that selectively produces a magnetic field opposed to that of the permanent magnet. A ferromagnetic armature normally is in latched position magnetically attracted to the magnet assembly but is movable to released position under the influence of a biasing force, such as spring force or gravity. A circuit energizes the coil at least temporarily to cancel the magnet flux completely or partially, to thereby reduce the magnetic force acting on the armature and release it for movement to the released position. The permanent magnet is not demagnetized and the armature is relatched upon return by a restoring means. Built with thin magnetic circuits and a relatively thin armature, the device has high unlatching speed with modest electrical requirements and has application for example as a print actuator in a high speed printer. The construction has general application, however, without size and speed limitations.

In a second embodiment, a multipole device based on the flux diversion principle is similar but utilizes coils, not wound on the magnets, that each selectively produces a magnetic field with the same polarity as the associated cobalt-rare earth permanent magnet. The principal value of this embodiment is the low volume, high speed armature made possible by the use of thin magnetic circuits.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a diagrammatic perspective view of a high speed latch based on the flux cancellation principle and constructed in accordance with the invention with a cobalt-samarium permanent magnet and an encircling flux cancellation coil;

FIG. 2 is a schematic cross-sectional view of FIG. 1 illustrating in full lines the latched position of the armature attracted against the pole faces of the magnetic circuit and in dotted lines the released position, further showing a schematic circuit diagram of the flux cancellation coil pulsing circuit;

FIG. 3 shows the demagnetization curves of several permanent magnet materials including that of cobalt-samarium to illustrate the superiority of this new material;

FIG. 4 is a fragmentary perspective view, with portions broken away, of an illustrative application of the new magnetic latch of FIGS. 1 and 2 in the hammer actuator of a high speed printer;

FIG. 5 is a diagrammatic perspective view of a normally open switch, illustrated with the armature released to close the circuit, which is based on the principles of the permanent magnet flux cancellation latch of FIGS. 1 and 2;

FIG. 6 is a diagrammatic perspective view of a multipole latch based on the flux switching principle and constructed in accordance with the invention with thin magnetic circuits employing cobalt-samarium magnets;

FIG. 7 is a schematic cross-sectional view of FIG. 6, with the armature shown in full lines in latched position attracted to the magnetic circuit pole faces and in dotted lines in the released position; and

FIG. 8 is a schematic circuit diagram of a coil pulsing circuit for the device of FIGS. 6 and 7.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The single pole magnetic latch shown in FIGS. 1 and 2 comprises essentially a rectangular cobalt-samarium permanent magnet 11 mounted between a pair of similarly shaped but larger soft ferromagnetic pole pieces 12 and 13. A flux cancellation coil 14 is wound directly about permanent magnet 11 in the remaining peripheral space between the two pole pieces. Flux cancellation coil 14 is connected to a suitable pulsing circuit such as the capacitor discharge circuit in FIG. 2, which includes a capacitor 15 charged through resistor 16 from a battery 17 or other low energy source, coil 14 being connected across the capacitor through a switch 18. The light-weight, relatively thin armature 19 is also made of a soft ferromagnetic material, such as soft iron or cobalt-iron. Armature 19 is normally attracted against the pole faces of pole pieces 12 and 13 (FIG. 2), but upon operation of the latch drops by gravity to its released position supported on plate 20. To reset the latch, push rods 21 and 22 extending through plate 20 are elevated to restore armature 19 to its normal position attracted toward pole pieces 12 and 13. The showing of the magnetic latch in FIGS. 1 and 2 is, of course, highly schematic and many other arrangements are possible. In general, armature 19 after release moves away from the pole pieces 12 and 13 under the influence of a biasing mechanical force, commonly gravity or a spring force. The restoring force for the armature is also usually mechanical, and push rods 21 and 22 can be replaced by a bar, cams, cogs, and the like.

The principle of operation of a magnetic latch based on the flux cancellation scheme is simple. In the latched position, armature 19 is held by the forces of magnetic attraction against pole pieces 12 and 13 and completes a magnetic circuit for the flux from permanent magnet 11. The poles of magnet 11 and pole pieces 12 and 13 have the polarity indicated. When the

flux in the air gap between the armature and the poles is reduced, the magnetic force decreases according to the square of the flux and the armature is released. The flux reduction is obtained by momentarily pulsing flux cancellation coil 14 by closing switch 18 to discharge capacitor 15 through the coil. The magnetic field produced by coil 14 is opposite in polarity to the field of permanent magnet 11 and partially or completely cancels the magnet field so that armature 19 is released. An important feature of the invention is that, due to the high coercive force of the cobalt-samarium magnet material, permanent magnet 11 is not permanently demagnetized by the oppositely poled flux cancellation coil field.

Another important feature of the invention is that cobalt-samarium permanent magnet 11 can be made relatively thin in the direction of the field. That is, the dimension L can be made small, in the order of mils. The unique property of cobalt-samarium that permits the use of extremely thin magnetic circuits in the field direction is again the high coercive force of the cobalt-rare earth permanent magnets, in combination with their medium flux density capability. Pole pieces 12 and 13 can also be made relatively narrow in the same direction, depending on the flux, and the important consequence follows that the armature can have a relatively small thickness t . A small, low volume armature has the advantage of high speed unlatching operation. As one illustration of the small size that can be attained, the length L of cobalt-samarium magnet 11 is 20 mils, while the over-all length L' of the magnet and pole pieces is 90 mils. For these dimensions the thickness t of armature 19 is on the order of 20 mils. For a given area of magnet 11, the cross section of pole pieces 12 and 13 is made sufficiently large to obtain the required flux density in the pole pieces. For the example given, the area coordinates are that the height of the pole pieces is about 100 mils while the depth is about 1 inch, and armature 19 is 90 mils by 1 inch. The power requirements for flux cancellation coil 14 are modest and consistent with the integrated circuit approach. Furthermore, a small width pulse can be used to energize coil 14 since, due to the small dimensions of pole pieces 12 and 13 in the order of tens of mils, armature 18 is released after a few mils of travel away from the pole faces. For the example given, the capacitor 15 is a 25-volt, 50 μ F, capacitor.

The special properties of the cobalt-samarium permanent magnet that make it suitable for a high speed, flux cancellation type magnetic latch are better understood by reference to the demagnetization curves shown in FIG. 3 for this permanent magnet material as well as some other common permanent magnet materials. The demagnetization curves are more particularly the B-H characteristics, where B is the magnetic induction in kilogauss and H is the magnetizing force in kilooersted. To enable a comparison the demagnetization curves for alnico, barium ferrite, cobalt-platinum, and cobalt-samarium (Co₅Sm) are shown. Actually, a family of alnico and cobalt-platinum curves are shown, where the particular curve to be used depends upon the proportions of the constituent metals in the magnet. The property of special interest is the coercive force H_c , defined as the magnetizing force required to bring the flux density to zero in a magnetic material that has been magnetized alternately by equal and opposite magnetizing forces. It is the value of H when B is zero, that is, the reverse magnetizing force needed to remove the residual magnetism. It is seen that the demagnetization curve of cobalt-samarium is linear, with a remanent magnetization value B_r of 8 kilogauss and a coercive force H_c of 8 kilooersted. Consequently, cobalt-samarium is characterized by a very high coercive force and medium flux density values. By comparison, the alnico alloys are capable of supporting high flux densities but the material has a low coercive force. The cobalt-platinum alloys are characterized by a medium coercive force and medium flux density. The barium-ferrite curve is also linear like that of cobalt-samarium, which means that these materials can be varied throughout their entire curve without permanent demagnetization, but the considerably higher coer-

cive force and flux density obtainable with cobalt-samarium is obvious. As was previously mentioned, the coercive force is the property that permits the use of flux cancellation coil 14 without demagnetizing the rare earth magnet 11. The relatively high coercive force, in combination with the medium flux density capability, permits the use of thin samples of material since the energy product, BH, has a relatively high value because of the high coercive force.

In addition to the cobalt-samarium permanent magnets, other cobalt-rare earth permanent magnet materials useful in the practice of the invention are cobalt-yttrium and cobalt-misch metal. Misch metal is the most common alloy of the rare earth metals which contains the metals in the approximate ratio in which they occur in their most common and naturally occurring ores. These new permanent magnet materials are described further in an article by Strnat et al., *Journal of Applied Physics* (38), 1967, pp. 1001-2. Also see the copending patent application entitled "Liquid Sintered Cobalt-Rare Earth Intermetallic Products" by Mark G. Benz, Ser. No. 33,347, filed Apr. 30, 1970, and assigned to the General Electric Company. In the latter application it is explained that cobalt-rare earth intermetallic compounds exist in a variety of phases, but the Co₅R intermetallic single phase compounds, where in each occurrence R designates a rare earth metal, have exhibited the best magnetic properties. Consequently, a more specific description of the permanent magnet materials useful in the practice of the invention is a material comprised substantially of Co₅R, where R is a rare earth metal.

In FIG. 4 there is illustrated one application of the new and improved magnetic latch of FIGS. 1 and 2 in the printing mechanism of a high speed printer. A row of character positions each includes a cobalt-samarium magnet assembly including the two pole pieces and encircling flux cancellation coil. A reed spring 25 functions as a combination armature and spring force for moving the armature to released position when the flux cancellation coil is pulsed. Upon being released, a pressure pad 26 on the other side of the reed engages a cylindrical hammer 27 slidable horizontally in a guide block 28. On the other side of guide block 28 are located the ink ribbon 29, the paper 30 being printed, a plurality of parallel print fingers 31 each with a raised print character at the upper end, and a backup plate 32. Upon pulsing the flux cancellation coil in cobalt-samarium magnet assembly 24, reed spring 25 is released and pushes forward hammer 27 to strike the ribbon 29 and paper 30 upon print finger 31, thereby printing a character on paper 30.

The advantages of the hammer actuator in FIG. 4 are the high density of the print positions and the high unlatching speed that contributes to achieving a high speed printer. The spacing of adjacent cobalt-samarium magnet assemblies 24 and reed springs 25, and consequently the print fingers 31, can be as small as 0.1 inch. High speed printing is made possible by the fact that the reed spring armatures 25 have a low mass and are released within a very short interval of time. To return reed springs 25 to the latched position, the base of each reed spring is rotated and the tip of each spring is wrapped against the curved face of magnet assembly 24 by a restoring force such as an elongated bar indicated diagrammatically by arrow 33.

Referring to FIG. 5, another application of the cobalt-rare earth magnetic latch of FIGS. 1 and 2 is as an integral part of a switch or relay. The electrical switch shown in FIG. 5 is a normally open switch, more specifically a switch that is closed in the released position of the armature. As in FIG. 4, the armature is combined with the spring force that moves it to released position. Reed spring 34 is made of a soft ferromagnetic material and is anchored at one end to a stationary support 35. At the free end is a strip 36 of conductive metal, such as copper, that is engageable with a pair of stationary contacts 37 and 38 to complete the circuit for the flow of current. In operation, flux cancellation coil 14 is pulsed when it is desired to close the switch, releasing spring 34 to flex outwardly and engage conductive strip 36 with contacts 37 and 38 as just

described. To reset the switch, a mechanical force as for instance a cam or pawl 39, engages the end of spring 34 and moves the spring back down to the latched position adjacent the pole faces of pole pieces 12 and 13.

The cobalt-samarium magnetic latch is usable in a variety of switch and relay configurations, only one of which is illustrated. The switch shown in FIG. 5 has the particular advantages of high unlatching or switching speed and small size. Normally closed as well as normally opened configurations are possible. Larger sizes of switches and relays are within the scope of the invention, also, limited only by the practical restrictions on the size of the flux cancellation coil needed to cancel temporarily the holding field due to the cobalt-rare earth permanent magnet.

Another embodiment of the invention illustrated in FIGS. 6-8 is a high speed multipole cobalt-rare earth magnetic latch based on the flux diversion principle. A row of spaced cobalt-samarium permanent magnets 40a-40d are sandwiched between a plurality of soft iron pole pieces 41a-41e. Alternate permanent magnets 40a-40d are oppositely poled, so that the pole faces of the pole pieces 41a-41e have opposite polarity. Flux diversion coils 42a-42d are mounted in the space above the permanent magnets between the opposing pairs of pole pieces. For the reasons already given in connection with the magnetic latch construction of FIGS. 1 and 2, cobalt-samarium magnets 40a-40d and pole pieces 41a-41e can be made relatively thin. Although soft iron armature 43 has sufficient area to cover the entire gap surface of the magnet assembly, it can have a small thickness. Consequently, armature 43 has low weight, low mass and inertia, and is capable of high speed unlatching movement. As with the single pole latch, the normal position of armature 43 is latched against the pole faces of pole pieces 41a-41e as shown in FIG. 7. Electrically, the flux diversion coils 42a-42d are preferably connected in parallel branches (FIG. 8), and are connected to be energized by a suitable pulsing circuit such as the capacitor discharge circuit previously explained with regard to FIG. 2. Closure of switch 18 momentarily pulses all four flux diversion coils 42a-42d at the same time.

The momentary energization of flux diversion coils 42a-42d results in the creation by each coil of a magnetic field which reinforces the associated magnet flux but subtracts from the flux path to the armature through the associated pole pieces. Therefore, the magnetic forces attracting armature 43 to its latched position are reduced, and the spring forces of springs 44 and 45 move armature 43 to its released position abutting stops 46 and 47. Push rod 48 extends through the support 49 on which the springs are mounted, and supplies the restoring force to return armature 43 from its released position to its latched position. The advantages of low armature mass and high unlatching speed obtained by the new multipole cobalt-samarium magnetic latch have already been mentioned. It is obvious that pole pieces 41a-41e and armature 43 can be made of any suitable soft ferromagnetic material and that other cobalt-rare earth permanent magnets can be substituted for cobalt-samarium.

In summary, new and improved magnetic latches, switches, and relays are made possible by the unique properties of the cobalt-rare earth permanent magnets, which are more particularly described as materials comprised substantially of Co_2R , where R is a rare earth metal such as samarium. Principally because of the high coercive force, high speed devices with low volume armatures, based on either the flux cancellation principle or the flux diversion principle, are constructed with thin magnetic circuits incorporating permanent magnets. They further have modest electrical control power require-

ments. However, similarly constructed devices with more substantial magnetic circuits and power requirements are within the teaching of the invention.

While the invention has been particularly shown and described with reference to several preferred embodiments thereof, it will be understood by those skilled in the art that the foregoing and other changes in form and details may be made therein without departing from the spirit and scope of the invention.

What we claim as new and desire to secure by Letters Patent of the United States is:

1. A high speed magnetically operated device comprising a magnet assembly including a cobalt-rare earth permanent magnet mounted between a pair of pole pieces having oppositely poled pole faces, said permanent magnet and pole pieces having a relatively thin field direction dimension as compared to the area coordinate dimensions, and a flux cancellation coil wound about said permanent magnet that selectively produces a magnetic field opposed to the polarity of said permanent magnet,
- a low volume ferromagnetic armature attracted by magnetic forces to a latched position against the pole faces of said magnet assembly, and movable under the influence of a biasing force to a released position, said armature having a relatively small thickness dimension as compared to the area coordinate dimensions,
- circuit means for temporarily applying only one polarity of direct current to said flux cancellation coil to thereby reduce the magnetic forces acting on said armature and release said armature for movement to the released position, and
- restoring means for returning said armature to the latched position magnetically attracted to said magnet assembly.
2. A device according to claim 1 wherein said armature is a reed spring that supplies the biasing force for movement to the released position.
3. A device according to claim 2 wherein said device is an electrical switch and further includes a pair of contacts engaged by said reed spring armature in the released position.
4. A high speed magnetically operated device comprising a multipole magnet assembly including a plurality of linearly arranged alternating cobalt-rare earth permanent magnets and ferromagnetic pole pieces having alternately oppositely poled pole faces, and a plurality of flux diversion coils each mounted between a pair of adjacent pole pieces that each selectively produces a magnetic field with a polarity to shunt the magnetic flux produced by the associated permanent magnet mounted between the same pair of pole pieces,
- a ferromagnetic armature attracted by magnet forces to a latched position against the pole faces of said magnet assembly, and movable under the influence of a biasing force to a released position, wherein
- said cobalt-rare earth permanent magnets and pole pieces have a relatively thin field direction dimension as compared to the area coordinate dimensions, and said armature is a low volume armature with a relatively small thickness dimension as compared to the area coordinate dimensions,
- circuit means for temporarily applying only one polarity of direct current to said flux diversion coils to reduce the magnetic forces acting on said armature and release said armature for movement to the released position, and
- mechanical restoring means for returning said armature to the latched position magnetically attracted to said magnet assembly.

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