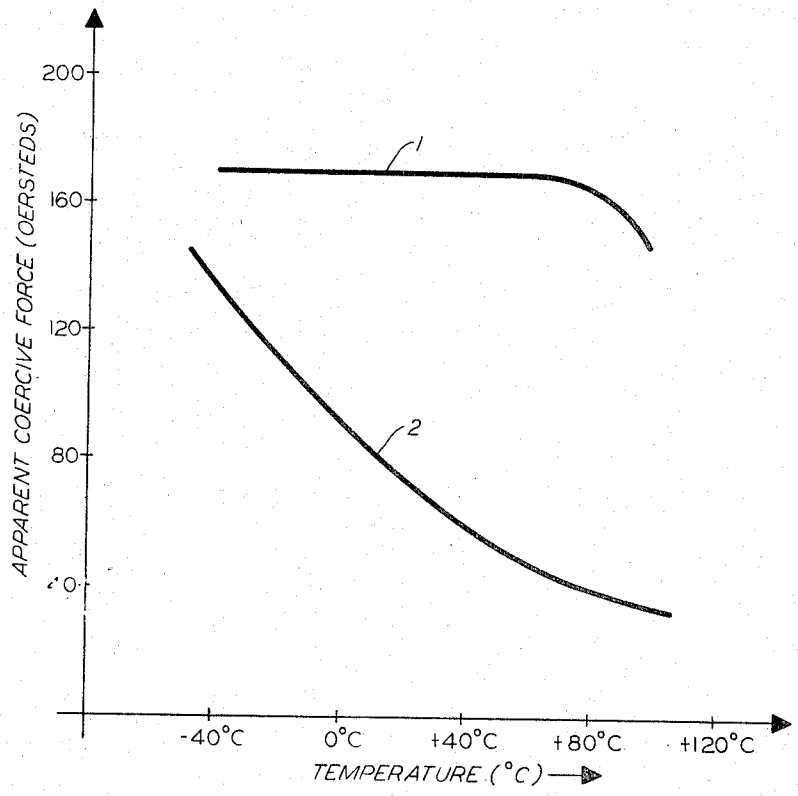
Jan. 16, 1968 H. L. B. GOULD ET AL 3,364,449

MAGNETICALLY ACTUATED SWITCHING DEVICES

Filed Dec. 18, 1963 3 Sheets-Sheet 1

FIG. 1



INVENTORS H. L. B. GOULD
D. H. WENNY, JR.

BY George C. Sughrue

ATTORNEY

FIG. 2

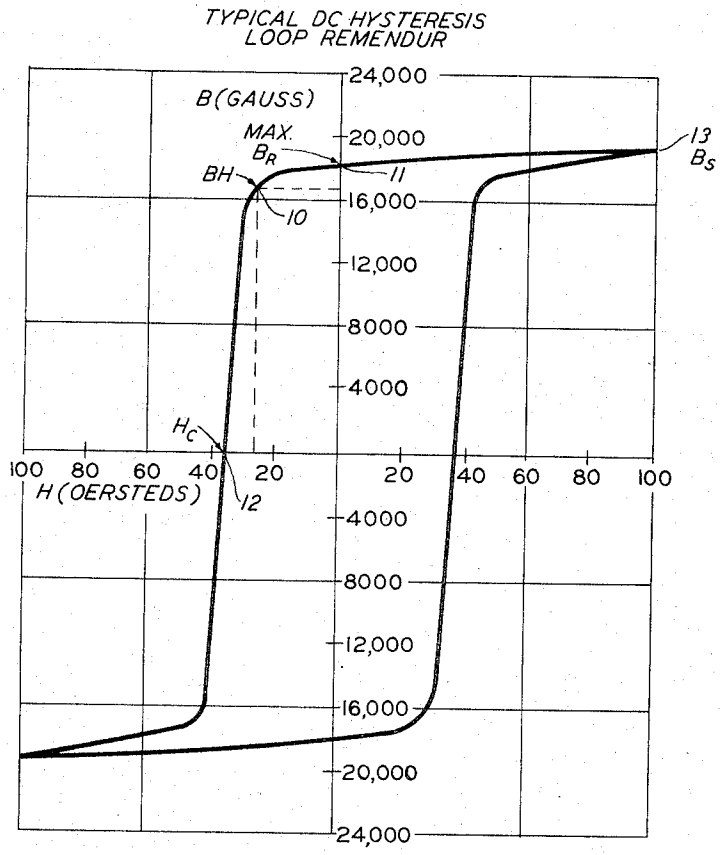
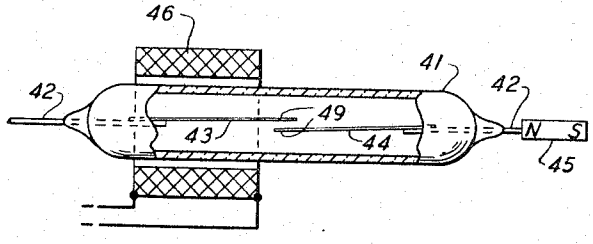

TYPICAL DC HYSTERESIS LOOP REMENDUR
B(GAUSS)
24,000
20,000
16,000
12,000
8000
4000
MAX. B_R
BH
11
10
13
B_S
H_C
12
100 80 60 40 20
H(OERSTEDS)
20 40 60 80 100
4000
8000
12,000
16,000
20,000
24,000

FIG. 5


46
41
42
42
49
43
44
N
S
45

MAGNETICALLY ACTUATED SWITCHING DEVICES

Filed Dec. 18, 1963 3 Sheets-Sheet 3

FIG. 3

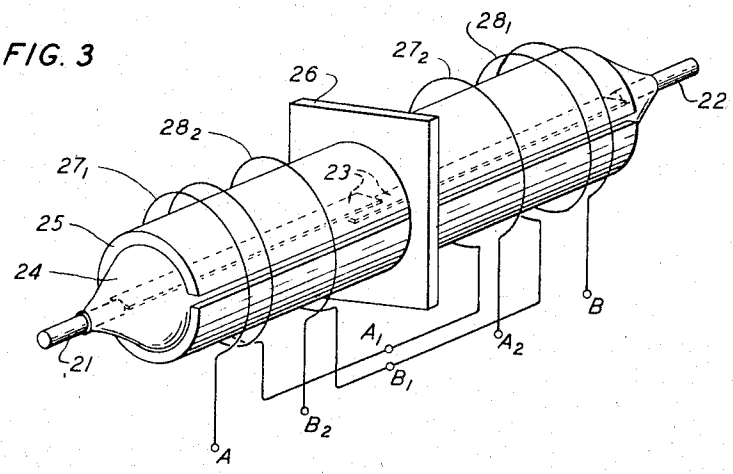
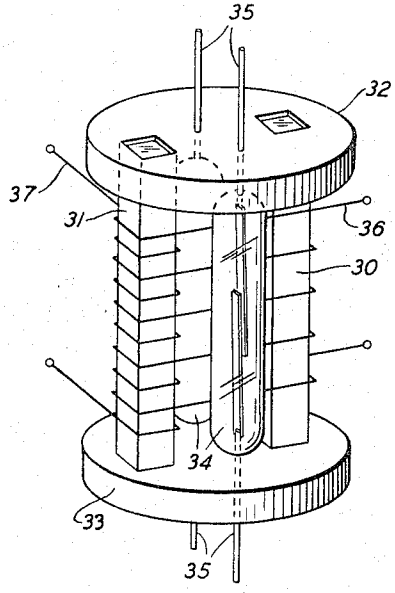


FIG. 4



United States Patent Office 3,364,449 Patented Jan. 16, 1968

3,364,449

MAGNETICALLY ACTUATED SWITCHING DEVICES

Harold L. B. Gould, Kinnelon Borough, and Daniel H. Wenny, Jr., Morris Township, Morris County, N.J., assignors to Bell Telephone Laboratories, Incorporated, New York, N.Y., a corporation of New York

Filed Dec. 18, 1963, Ser. No. 331,434
1 Claim. (Cl. 335—153)

This invention relates to a class of electromagnetically controlled switching devices employing remanently magnetic members, and more particularly to such devices employing alloys of vanadium, cobalt, and iron in such remanent members.

In the Bell System Technical Journal for January 1960, at pages 1 et seq., there is described a class of switching devices designated "ferreeds." These devices, characterized by the provision of sealed metallic contacts while being controllable at electronic speeds, are so designed that they can be left switched without holding power being required. They have control times in the microsecond range and are capable of selection by the use of coincident currents.

The prototype device, as described in that publication, constitutes a magnetically hard ferrite member in combination with a magnetic reed switch utilizing two soft magnetic reeds. The reed switch and ferrite member are so arranged as to form a series magnetic circuit, magnetization of the ferrite member by passage of current through an enveloping coil bringing about closure of the reeds. Ferrite compositions are chosen so as to have a sufficient remanent field to maintain closure after current flow is discontinued.

While ferrite compositions utilized in the devices described in the publication have appropriate coercivity, remanence, and squareness to permit efficient operation, subsequent development work revealed a strong temperature dependence of coercivity, either requiring close temperature control or the use of greater drive currents, most serious in coincident current operation.

In accordance with this invention, it has been discovered that a series of vanadium-cobalt-iron alloys represented by the exemplary composition 3.5% vanadium, 48% cobalt, 48% iron, and 0.5% manganese, when processed in accordance with a specific range of conditions here set forth, manifests substantial temperature insensitivity of coercivity over a broad range of operating temperatures while being possessed of coercivity, remanence, and squareness values well adapted to the operation of ferreed devices. Persons familiar with this development have already adopted the term "Remendur" as encompassing the compositions processed in accordance with the conditions set forth herein. The term "Remendur," as used herein, refers to the entire range of compositions and processing conditions herein described as suitably adapted to the ferreed devices of this invention.

In the course of this description, the use of the term "ferreed" has reference to the prototype devices as originally described in the Bell System Technical Journal. As applied to this description, such devices utilize not ferrite elements but metallic alloy elements of the compositions set forth. In addition to overcoming the most serious drawback of the ferrite element, i.e. temperature dependence of coercivity, the use of these metallic elements has obvious structural advantages, e.g. ease of fabrication, shock resistance, etc. A further characteristic, a thermal coefficient of expansion approximating that of a commercially used sealing alloy, makes possible a new class of ferreed devices in which the reeds are themselves constructed of the remanent material, so eliminating the need for any external magnetic structures.

Compositions of concern for the uses described herein are known to be useful for their magnetic properties. For example, the nominal composition in its soft state is known as "Supermendur," which manifests one of the highest permeability values of the known alloys. A partially worked material of this compositional range is disclosed in United States Patent 2,519,277, issued Aug. 15, 1950, to E. A. Nesbitt et al. The device which is the subject of this patent is a self-biased magnetostrictive sonic generator, use being made of the remanent and coercive characteristics of the alloy.

It has been noted that the devices of this invention utilize the nominal composition 3.5% vanadium, 48% cobalt, 48% iron and 0.5% manganese. The manganese inclusion serves the well-known function of minimizing the deleterious effect of any sulfur inclusion. The amount of manganese is not critical and can be eliminated entirely if precautions are taken to avoid sulfur inclusion. While amounts as great as 1 percent or more may be used, one-half of 1 percent usually suffices, with no further advantage accruing with greater inclusion. It is well known that any of several other elements including cerium, magnesium, beryllium, and calcium may be utilized.

Vanadium is included to improve cold-workability of the resultant alloy. The major ingredients, cobalt and iron, are, of course, mainly responsible for the magnetic properties of the alloy. A preferred range on a 100 part basis for the total of these two ingredients is from 45 parts cobalt to 65 parts cobalt, with a broader range extending from 40 to 75 parts of this ingredient. It is seen that greater freedom exists for increasing cobalt inclusion, and it is this ingredient which is chiefly responsible for increased coercivity and for workability. In general, increasing cobalt content results in decreasing saturation and remanence, however such values being adequate for any of the devices herein at levels far above the maximum inclusion indicated. Fullness ratio, and this discussion is largely in terms of this quantity, $BH_{max.}/B_rH_c$ (where $BH_{max.}$ is the second quadrant product of flux in gauss and applied field in oersteds yielding the largest numerical value, and B_r and H_c are the values of flux and applied field in the same units for zero field and zero flux, respectively), increases for increasing cobalt from a value of about 62 percent at 40 parts to about 80 percent for 50 parts. The ratio decreases slightly for greater cobalt inclusion and is at a value of about 75 percent for 75 parts. For the uses herein a value of 0.60 is considered a preferred minimum.

Vanadium content is critical. Its range extends from 1 percent up to about 5 percent. Its minimum value for optimum properties is somewhat dependent on cobalt content, with the low value indicated corresponding with the greatest cobalt inclusion. Minimum vanadium content is about 2 percent for equal amounts of cobalt and iron and about 1 percent at 75 parts cobalt. Vanadium inclusion improves workability, increases resistivity, improves fullness ratio, increases magnetic saturation, and increases coercivity. Increasing vanadium above the maximum indicated results in a decrease in remanent magnetization. Remendur compositions within the ranges discussed, and when processed according to the teaching herein, are magnetically isotropic up to a vanadium content of about 3½ percent. While suitable device properties may be obtained in the anisotropic compositions contained herein, isotropy may facilitate the adaptation of these materials to a variety of devices. Ease of fabrication of certain ferreed elements requires bending in the direction of cold-working and the utilization of magnetic properties

in a normal direction. While it is possible to develop desired properties in such a normal direction, in an anisotropic material such may require a different processing schedule than that used for the processing of material in which magnetic properties parallel to the direction of working are of consequence. Accordingly, it is expedient to maintain vanadium content at a maximum value of 3.5 percent. This value is therefore considered to be a preferred maximum.

While composition may be varied over relatively long ranges, at least with regard to the major ingredients, the magnetic properties of the final material are extremely sensitive to processing conditions. It is an absolute requirement that the final processing step be a partial anneal following a cold reduction. While there should be no treatment intermediate final cold working and anneal such as to affect magnetic properties, it is at this stage that the parts are punched and shaped. Where reference is made to directly following working by final anneal it should be so construed. The cold reduction, which may be effected by rolling, drawing, swaging, etc., must be at least 60 percent in accordance with the equation

$$Z=\text{Percent Cold Reduction}=\frac{A_0-A_1}{A_0}\times 100$$

where Z equals cold reduction in percent, A_0 equals original cross section area, and A_1 equals final cross section area. A preferred figure is 90 percent on the same basis such reduction resulting in a fullness ratio of at least 65 percent.

The partial anneal may be carried out over the temperature range of from 400° C. to 675° C. Optimum time of anneal ranges from about one-half hour at 675° C. to about twenty hours at 400° C. Some increase in heating time is permissible, maximum times ranging from 1 hour to 25 hours, the lower value again corresponding with the higher temperature of 675° C. Minimum values may range from ¼ hour to 15 hours, the lower value corresponding with the higher temperature. Minimum heating time is somewhat dependent on the cross-section of the body being treated. While this is not a primary consideration for the sections adaptable to the devices herein, which do not generally exceed 0.05 inch, with appreciably larger sections, heating time should be sufficient to heat the inner portion of the body. Some of the specific examples herein are concerned with elements which were heat treated for from one to three hours at a temperature of from 550 to 575° C., and this range of conditions is therefore to be considered optimum.

Partial anneal as well as any process (lead) anneals are desirably carried out in a protective atmosphere over the temperature range down to 350° C. to prevent oxidation of vanadium although air is permissible for processing of thicker sections (60 mils and up). Suitable atmospheres are hydrogen, forming gas, argon, helium, nitrogen, etc.

Some of the physical properties of Remendur are briefly set forth. The processing conditions discussed are for the two terminal steps. Previous history has little effect and may consist of the usual sequential cold-working and dead anneals as applied to many materials in the course of producing the fine wire ribbon or rod structures suitable for use in switching elements of the type discussed herein.

Workability.—The alloy is quite hard mechanically and in the annealed state has a Rockwell hardness of C–20 while possessing a persistent malleability and ductility. It has been rolled to sheet and foil as thin as .2 mil, drawn to wire 1 mil in diameter, and been flattened to ribbons ranging from .5 mil to 8 mils in thickness and 5 mils to 65 mils in width.

Temperature coefficient of expansion values average 10.26 times 10^{-6} per degree C. over the temperature range 30° C. to 550° C. This value is about the same as that of the commercial 52 percent nickel-iron glass sealing alloy now used in dry reed and mercury switches. In addition, the alloy seals readily to glass.

Plating characteristics.—Remendur has been plated with up to .5 mil thick layers of copper, silver and gold, which platings adhere well with or without a bonding heat treatment and resist cold reduction.

Some of the magnetic properties are set forth:

Magnetostriction.—$\Delta l/_1=40\times 10^{-6}$ at $H=100$.

Permanent magnet properties include coercive forces up to about 60 oersteds and residual inductions (remanent fields) up to about 21,500 gauss.

Temperature stability.—As discussed in conjunction with FIG. 1, the coercive force is stable over a temperature range of from −60° F. to +130° F.

Description of the invention is expedited by reference to the drawings, in which:

FIG. 1, on coordinates of apparent coercive force in oersteds on the ordinate and temperature in degrees C. on the abscissa, is a plot showing the temperature sensitivity of coercive force for two samples, one of Remendur and the other a typical ferrite;

FIG. 2 is a typical D-C hysteresis loop for a Remendur sample plotted on the usual ordinates of B in gauss on the ordinate and H in oersteds on the abscissa;

FIG. 3 is a perspective view of one ferreed configuration utilizing Remendur elements;

FIG. 4 is a perspective view of a different type of ferreed also utilizing a Remendur element; and

FIG. 5 is a front elevational view, partly in section, of a ferreed structure in which a reed is itself constructed of Remendur.

Referring again to FIG. 1, curve **1** shows the variation in coercive force with temperature for an alloy of the invention, while curve **2** shows the variation in coercive force with temperature for a ferrite composition otherwise possessed of the requisite magnetic characteristics for use in a ferreed device. Comparison of the curves readily indicates the relative temperature insensitivity of coercivity of the Remendur sample.

FIG. 2 shows a conventional hysteresis loop for an alloy of the invention having the nominal composition 3.5% vanadium, 48% cobalt, 48% iron, and 0.5% manganese.

The significance of the fullness factor, BH_{max}/B_rH_c is seen from this figure. The point in the second quadrant corresponding with the maximum value of the product BH occurs at the knee **10** of the curve. This is compared with the product B_r, the remanent field, taken at point **11**, and the coercive force H_c at **12**. This is a more meaningful term than the usual squareness ratio ordinarily considered as the ratio B_r to the flux value at saturation B_s (taken at point **13**). The fullness factor for the hysteresis loop shown is 71.5%, which compares favorably to the minimum value of 50% which is usually specified for devices of the nature discussed herein.

The device of FIG. 3, the prototype of which is described in United States Patent 3,075,059, issued Jan. 22, 1963, is sometimes called the series ferreed. The device depicted includes a pair of magnetizable reeds **21** and **22** constructed of a soft magnetic material enclosed within a glass envelope **24**. Overlapping portions of reeds **21** and **22** serve as contact areas **23**, which are normally separated. Surrounding envelope **24** there is a split or "C" sleeve **25** of an alloy herein. Disposed about the sleeve, in the vicinity of the contact areas **23** of the reeds **21** and **22**, is a shunt plate **26** of a permeable soft magnetic material.

Wound about the sleeve **25** on both sides of the shunt plate **26** are two sets of windings 27_1, 27_2 and 28_1, 28_2 the pair of **27** and **28** windings terminating at A, A_2 and B, B_2, respectively. Each of the windings 27_1 and 28_1 has twice the number of turns of each of the windings 27_2 and 28_2 to permit differential operation, as discussed in United States Patent 3,075,059. The A windings are interconnected at terminal A_1, while the B windings are interconnected at terminal B_1.

A complete description of the operation of the device of FIG. 3 or of the other devices herein is not appropriately included in this disclosure and may be obtained by reference to the Blaha patent, supra, or to the Bell System Technical Journal reference. Very briefly, switch closure is accomplished so passing current through the windings creating a magnetic path such that flux closure is accomplished through the reeds 21 and 22 at contact areas 23. The remanent field to maintain closure must, of course, be of sufficient strength to overcome the stiffness of the reeds. This condition obtains in the device of FIG. 3 when pulses applied at A and B are such as to produce the same direction of magnetization through the portions of sleeve 25 on either side of shunt 26. Reversing the direction of magnetization of either of the two halves of sleeve 25 results in a flux path through shunt 26, so eliminating any substantial flow of flux through either of the reeds.

In the device of FIG. 4, two bistable, remanently magnetic members constructed of an alloy herein control two reed switches. The device shown is one type of parallel ferreed.

This device is described in United States Patent 2,995,-637, issued on Aug. 8, 1961.

The device of FIG. 4 includes a pair of Remendur rods 30 and 31, suspended between a pair of soft magnetic disks 32 and 33. Also suspended between the disks 32 and 33, adjacent to the rods 30 and 31, are two reed switches 34 having individual terminals 35 which protrude through and are electrically insulated from the disks 32 and 33. Reed switches 34 may be identical to that enclosed within tube 24 of FIG. 3. A winding 36 encircles both of the rods 30 and 31. A winding 37 is shown wound about the rod 31 alone.

The arrangement shown provides for a coincident drive to operate the switches 34, but achieves release by current in a single winding. Initially, to prepare the device for use, Remendur rods 30 and 31 are magnetically saturated in the same direction (either up or down in the device as depicted) by passage of a current through winding 36. Since the flux associated with either of the Remendur rods 30 or 31 is opposed by that of the other, the flux of both rods seeks a path through reed switches 34, so accomplishing closure. For the particular embodiment depicted, the remanent magnetization state of rod 30 is now established and will be unaffected by future operation.

In normal operation, switches 34 are released by application of a current to winding 37 with a direction and magnitude such that the remanent magnetization of rod 31 is reversed. This establishes a flux pattern, with the flux in opposite directions in the two rods 30 and 31, and with these two rods now defining a closed magnetic circuit, so bypassing switch 34.

Closure is accomplished by coincident drive currents applied simultaneously to windings 36 and 37. Each of these currents is insufficient to reverse the magnetization of rod 31, but the magnetizing force of both coincident currents reverses this state, so restoring the initial flux pattern for closing switches 34. Since only one winding 36 is associated with rod 30, and since the current applied to 36 is, in itself, insufficient to reverse the remanent field, this rod remains unaffected.

The device of FIG. 5 is illustrative of those embodiments in which at least one reed is itself constructed of a remanently magnetic material, as described herein. This figure depicts a reed switch having a glass envelope 41, with terminals 42. A Remendur reed 43 is attached to the left-hand terminal 42. A second reed 44, which may be constructed of a highly permeable soft magnetic material or of an alloy of this invention, is attached to the right-hand terminal 42 so that its free end overlaps the free end of reed 43 to form a contact pair at 49. Also attached to the right-hand terminal 42 is a permanent magnet 45 having a magnetic polarity, as shown. A coil 46 is wound about the envelope 41 on the portion enclosing the reed 43.

Operation of the device is similar to that of those described above, with coil 46 biased in such manner that the magnetization direction of reed 43 corresponds with that of reed 44 (induced by permanent magnet 45) and closure is accomplished. Reversing the direction of magnetization in reed 43 results in two separate flux paths, the one including reed 43, the other, reed 44, in which condition the natural stiffness of the reeds results in release.

The following examples relate to the preparation of a range of alloy compositions in accordance with the processing conditions herein described.

Example 1

A melt was prepared of the following materials:

	Kilograms
Electrolytic cobalt	1.536
Electrolytic iron	1.375
Ferro-vanadium (0.112 kilogram vanadium, 0.161 kilogram iron)	0.273
Electrolytic manganese	.016
	3.200

On reaching a temperature of 1550° C. the melt was held 2 minutes to insure a thorough mixing and solution of the ingredients and was then poured into a mold and solidified to make an ingot. The ingot was heated to a temperature of about 1250° C. for hot rolling to a thickness of 0.060 inch strip or hot swaging to ¼ inch diameter rod. The hot rolling was accomplished in 14 passes with nominal reductions of 0.050 inch per pass and reheating as required. Hot swaging was done in 20 passes with reductions of 0.025 inch per pass. The hot worked strip and rod were prepared for cold working by heating to 900° C. and quenching in ice brine. They were then sufficiently ductile to be cold worked. The strip was finished at 6 mils thickness (an area reduction of 90%), and the wire at 22 mils with anneals at ⅛ and 1/16 inch.

The cold worked alloy was then heat-treated at 1103°± 27° F. (595°±15° C.) for 120±10 minutes in an inert atmosphere such as forming gas, or in an atmosphere of hydrogen. The furnace was allowed to cool to 662–572° F. (350–300° C.) and the atmosphere was then changed to air (the air serving solely to blue the alloy and improve corrosion resistance). This temperature and atmosphere were maintained for 10–15 minutes.

In the heat treated condition, the composition had magnetic characteristics as follows:

Residual induction, B_r (gausses)	18,200
Coercive force, H_c (oersteds)	38
Squareness ratio, B_r/B_{max}	0.92
Fullness ratio, BH_{max}/B_rH_c	0.75

All measurements were D-C measurements at a magnetizing force of $H=100\pm5$ oersteds.

Example 2

The procedure of Example 1 was repeated, however utilizing the following amounts of the indicated materials:

	Kilograms
Cobalt	1.536
Iron	1.360
Ferro-vanadium (144 kilograms vanadium, 144 kilograms iron)	.288
Manganese	.016
	3.200

After processing, as indicated, the composition had the following magnetic characteristics:

Residual induction B_r	gauss	17,200
Coercive force, H_c	oersteds	48
Squareness ratio, B_r/B_{max}		0.90
Fullness ratio, BH_{max}/B_rH_c		0.74

Example 3

The procedure of Example 1 was repeated, however utilizing the following amounts of the indicated materials:

	Kilograms
Cobalt	1.568
Iron	1.568
Vanadium	.064
	3.200

After processing, as indicated, the composition had the following magnetic characteristics:

Residual induction B_r	gauss	21,500
Coercive force, H_c	oersteds	25
Squareness ratio, B_r/B_{max}		0.95
Fullness ratio, BH_{max}/B_rH_c		.85

Example 4

The procedure of Example 1 was repeated, however utilizing the following amounts of the indicated materials:

	Kilograms
Cobalt	2.240
Iron	.677
Ferro-vanadium (0.112 kilograms vanadium, 0.156 kilogram iron)	.267
Manganese	.016
	3.200

After processing, as indicated, the composition had the following magnetic characteristics:

Residual induction, B_r	gauss	15,000
Coercive force, H_c	oersteds	50
Squareness ratio, B_r/B_{max}		96
Fullness ratio, BH_{max}/B_rH_c		71

The invention has been described in terms of a limited number of illustrative embodiments. As is well known to those skilled in the art, the devices depicted constitute but a limited portion of a vast class of switching devices in which closure is maintained by means of the remanent magnetic field of one or more associated elements. Most of the description has been in terms of a particular class of such devices which have come to be known as ferreeds by reason of the fact that the remanently magnetic material was a ferrite. It is clear from this description that the remanently magnetic materials herein are suitably adapted to all such devices, as well as to any other design in which a remanent field of sufficient strength to overcome the stiffness or other force accomplishing release is of sufficient strength to maintain closure without application of a holding current. The invention is considered to reside in the discovery that the alloys herein are possessed of temperature insensitivity of coercivity, square hysteresis loop, high residual induction, and other such properties as to make them suitable for use in this class of devices.

The magnetic alloy has been discussed in terms of the nominal composition vanadium-iron-cobalt. It is well known that small amounts of various elements including, for example, chromium, zirconium, titanium, nickel, etc. may be incorporated desirably in such alloys for the purpose of altering such properties as switching time, resistivity, etc. Such additional ingredients are considered to be within the scope of this invention, both as described and claimed.

What is claimed is:

1. Device comprising a magnetic circuit including a pair of normally open switch contacts of a magnetic material together with at least two separately magnetizable body portions, each of said portions having a magnetic fullness ratio of at least 50 percent and each of said portions consisting essentially of an alloy containing from 40 to 75 parts by weight cobalt, 25 to 60 parts by weight iron, and 1 to 5 parts by weight vanadium, said body portions having been produced by a series of processing steps terminating in a cold reduction of at least 60 percent, followed by a partial anneal during which anneal the said body portions are maintained at a temperature of from about 400 to 675° C. for a time period of from one-quarter to 25 hours, the shorter times corresponding with the higher temperature, the said body portions being magnetically bistable, the arrangement being such that closure is accomplished by magnetization of both portions in such direction that the lowest reluctance magnetic circuit includes the two portions as well as the said switch contacts, the remanent field of the said portions being of sufficient strength to overcome the normal force maintaining the said switch contacts open so that closure is maintained, and in which release is accomplished by magnetization of one portion in a direction opposite to that resulting in closure.

References Cited

UNITED STATES PATENTS

1,862,255	6/1932	White et al.	75—123
2,190,667	2/1940	Kelsall et al.	335—102
2,298,225	10/1942	Nesbitt	148—102
2,519,277	8/1950	Nesbitt et al.	317—201
2,995,637	8/1961	Feiner et al.	200—87
3,059,075	10/1962	Peek	200—87
3,075,059	1/1963	Blaha et al.	200—87
3,128,418	4/1964	Zupa	200—87

OTHER REFERENCES

Feiner et al.: "The Ferreed, a New Switching Device," The Bell System Technical Journal, vol. XXXIX, No. 1, January 1960, pp. 1–30, pp. 12–14 relied on.

BERNARD A. GILHEANY, *Primary Examiner.*

R. N. ENVALL, JR., *Assistant Examiner.*