Aug. 15, 1950

E. A. NESBITT ET AL

MAGNETOSTRICTIVE DEVICE AND ALLOY AND METHOD OF PRODUCING THEM

Filed Jan. 15, 1947

2,519,277

FIG. 1

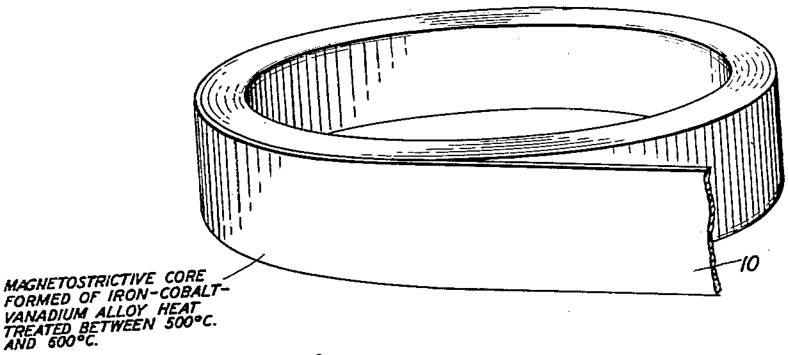


FIG. 2

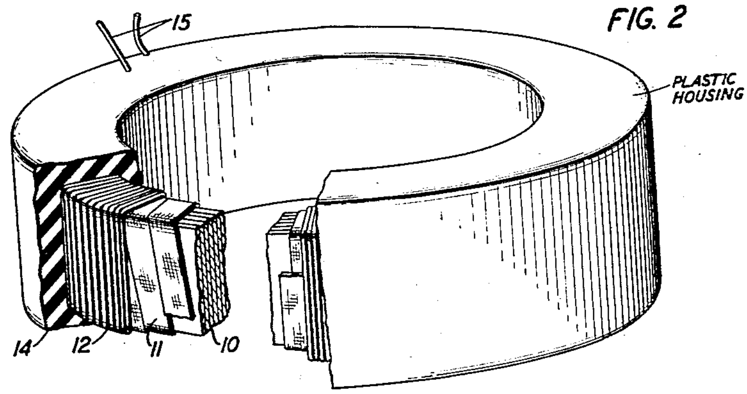
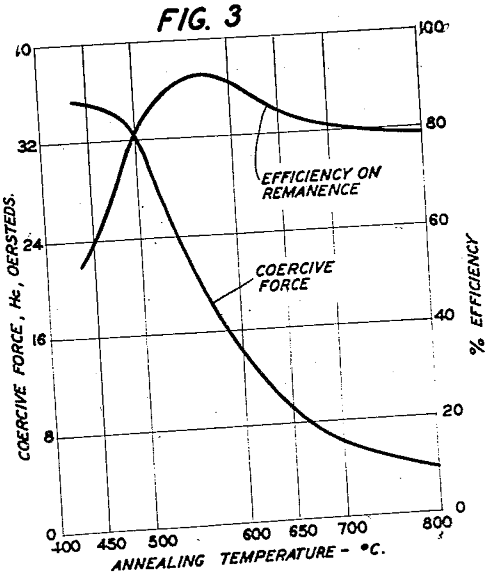


FIG. 3



INVENTORS: E. A. NESBITT
H. J. WILLIAMS

BY Edwin B. Cave

ATTORNEY

Patented Aug. 15, 1950

2,519,277

UNITED STATES PATENT OFFICE

2,519,277

MAGNETOSTRICTIVE DEVICE AND ALLOY AND METHOD OF PRODUCING THEM

Ethan A. Nesbitt and Howell J. Williams, Chatham, N. J., assignors to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

Application January 15, 1947, Serial No. 722,242

10 Claims. (Cl. 175—21)

This invention relates to magnetostrictive devices and to materials suitable for use in such devices and to methods of producing such devices and such materials.

In particular, this invention relates to magnetostrictive devices in which the magnetostrictive element is made of a permanently magnetized body of an alloy comprising cobalt and iron, preferably with a small amount of vanadium added, which has been subjected to a special treatment comprising working and heating. Such a treatment gives a sufficient coercive force to the alloy so that a magnetostrictive element made from it may be efficiently operated entirely on remanence without the aid of an external polarizing device.

In using magnetostrictive devices having magnetostrictive elements which vibrate mechanically under the influence of a magnetic winding supplied with an alternating current, it has been found that the greatest degree of magnetostriction is obtained when the vibrating element is magnetically polarized. This polarization is also necessary in order to bring the total flux density within the element to a point at which there will be no reversal of magnetic flux direction in the magnetostrictive device throughout the alternating current cycle, and at which the change in dimensions of the element will be substantially proportional to the change in flux density so that the wave form of the mechanical vibrations of the magnetostriction element will conform as nearly as possible to the wave form of the alternating current applied to it.

Ordinarily, the polarization of the magnetostriction element has been accomplished by means of an external direct current winding applied to the element, by means of a direct current superimposed upon the alternating current winding or, by a permanent magnet placed in the magnetic circuit of the element. The use of the external winding or superimposed direct current or the permanent magnet to polarize the element presented difficulties since the external winding and the superimposed direct current required a source of power, while if the external permanent magnet was used the device did not operate in a closed magnetic circuit. Also, the use of an external polarizing winding or of an enlarged alternating current winding to carry the extra biasing current together with the required additional power supply, or the use of an external permanent magnet, took up extra space which was undesirable in equipment where available space was at a minimum.

In the device of the present invention the

above-described difficulties are avoided by using, for the magnetostrictive element, an alloy of cobalt and iron (preferably containing a small amount of vanadium) which has been subjected to a special treatment which confers on it a sufficiently high coercive force so that the vibrating element may be operated entirely on remanence for most purposes without being demagnetized by the alternating current required. This does away with the necessity of using the external polarizing winding or magnet with the resulting saving in space and power. Even for uses requiring large values of alternating currents which would, in the absence of a biasing field, tend to demagnetize the magnetostrictive cores of the present invention, such cores are desirable since they reduce considerably the necessary size of supplementary biasing equipment.

It has been known that alloys of cobalt and iron or of vanadium, cobalt and iron are useful as magnetic materials. However, it was not previously known that such alloys, having a certain range of composition if given a special heat treatment, would acquire properties rendering them suitable for use as vibratory magnetostrictive elements without a biasing field. The present invention provides a method of treating such alloys to make them suitable for such use in magnetostrictive devices.

According to the present invention, in its preferred form, vibrating magnetostrictive elements are made from an alloy comprising 2 per cent by weight of vanadium, 49 per cent by weight of cobalt and 49 per cent by weight of iron, which has been cold worked and then annealed at from 450° C. to 650° C. Although this range is the preferred composition, favorable results are also obtained when the alloy comprises from about ¼ per cent to about 4 per cent by weight of vanadium, about 30 per cent to about 70 per cent by weight of cobalt and the remainder iron. Good results are also obtained with alloys having similar proportions of cobalt and iron and containing less vanadium or none at all.

Good results are obtained when these alloys are formed of the purest ingredients with the least inclusion of impurities or modifying ingredients. However, when the alloy is formed of commercial substances, there will ordinarily be small amounts of impurities present but such impurities should ordinarily be kept below about 1 per cent total and preferably below about ½ per cent. Particularly harmful impurities such as carbon and sulphur should be avoided in so far as possible. Carbon is preferably not present in amounts greater than about .1 per cent. Desulphurization by addition of manganese to the melt ordinarily results in an adequate removal of sulphur. The manganese remaining in the alloy as a result of this desulphurization procedure may constitute up to .3 per cent or .5 per cent of the alloy. Other impurities such as nickel and silicon may often be present in amounts up to ½ per cent each.

The first step in the treatment of these alloys to produce the desired magnetic properties upon which the present invention is dependent is a cold working of the alloy. This cold working is usually applied in the form of cold rolling although obviously other common forms of cold deformation of the metal may be employed. This cold working step is essential to the development of the desired coercive force in the alloy.

The full value of coercive force appears to be developed when the alloy is cold rolled to a thickness reduction of at least 50 per cent. When the alloy is to be rolled into thin tapes, as is preferable for the formation of the magnetostrictive devices of the present invention as will be described in more detail below, thickness reductions of the order of 90% or more may be found desirable. There is no limit to the degree to which the thickness may be reduced except for the practical limitation of the inability of available devices to produce a uniform tape at excessively high reductions. An adequate coercive force may be obtained for some purposes with a lesser degree of working, for instance, by cold rolling to a thickness reduction of 30% or 20% or in some instances even less.

The second step in the treatment of the alloy is a heat treatment. The preferred temperature range for heat treating the material is from about 500° C. to about 600° C. The temperature of heating depends partly on the use to which the material is to be put, and on what properties are desired for the finished material, for the properties such as the coercive force and the efficiency vary with the temperature of annealing. For instance, the coercive force after heat treatment is highest when the material is heated at around 450° C., but the efficiency of the alloy when the device is operated entirely on remanence is greatest when it is heated at between about 525° C. and 600° C.

The time of heating is not critical but it should be long enough to insure thorough heating throughout the body. Heating times of ½ hour to 2 hours will be found satisfactory, although at the higher temperatures shorter times, such as about 15 minutes, may be used and at the lower temperature longer times such as 3 to 4 hours or more may be used. The heating may be done in a sealed pot to prevent excessive oxidation, or it may be done in an atmosphere of hydrogen or nitrogen. The cooling rate after heat treatment is not critical.

The alloy which has been treated according to this process will, when magnetized, retain the magnetization even when subjected to forces which tend to demagnetize it, such as a properly limited alternating current field or ordinary mechanical shock.

The invention can best be described as illustrated by one particular form of magnetostrictive device shown in the accompanying drawing in which:

Fig. 1 is a perspective view of one form in which the vibrating element of the present invention may be used;

Fig. 2 is a perspective view of a finished unit employing a vibrating element as shown in Fig. 1, portions of the unit being broken away to show the construction thereof; and

Fig. 3 is a chart showing the variation, as the annealing temperature is varied, of coercive force and efficiency of the magnetostrictive device of Fig. 1 when the magnetizing winding is energized with alternating current without a direct current bias.

The beneficial effects obtained by the above-described treatment of the alloy comprising vanadium, cobalt and iron are shown clearly in the graph of Fig. 3 which shows the variation of the coercive force with the annealing temperature and also the variation of the efficiency of the material operating on remanence with the annealing temperature. These results were obtained with an alloy containing substantially equal parts by weight of iron and cobalt and 2 per cent by weight of vanadium, which alloy was rolled into a tape 2 mils in thickness and formed into a magnetostrictive device as shown in Fig. 2 and described more fully below. Analogous results are obtained with devices formed from alloys having different proportions and from alloys containing no vanadium.

As may be seen, the greatest efficiency for the magnetostrictive device is obtained when the material is annealed at about 550° C., while the coercive force of the alloy tends to decrease as the annealing temperature is raised above 450° C. A desirable combination of coercive force and efficiency may be found in the range of 450° C. to 650° C. although ordinarily it is more desirable to remain within the range of 500° to 600° C.

Materials treated in accordance with the present invention may be employed in the form of a spirally wound tape core 10 such as that shown in Fig. 1. In forming such a core 10, the material is first put through a series of cold rolling operations to form a tape. The last cold rolling operation should cause an adequate reduction in thickness as discussed above. Ordinarily, cores have the most efficient operation when they are formed of thin tapes, such as tapes having a thickness of from 5 mils to 6 mils or even less, such as 1 mil or 2 mils. In determining the thickness to be used for the tape, practical considerations such as the matter of fabricating, handling and winding thin tapes and the increased tendency of thinner tape cores to vibrate in parasitic modes must be taken into account in the design of any particular magnetostrictive core. The tape may be insulated by coating it with an insulating material such as an insulating oxide like silica, either cataphoretically or by passing it through a suspension of silica in a volatile liquid. The tape may then be wound on a mandrel in the form of the spiral core 10 shown in Fig. 1. The core 10 is then annealed on the mandrel under the conditions heretofore described.

After annealing, the core 10 is removed from the mandrel and vacuum impregnated with a suitable material, such as a phenolic condensation product like "Bakelite," to make the core rigid so that it will vibrate in a single mode with no parasitic modes of vibration, and to further insulate the core. The impregnated core 10 may be embodied in the unit shown in Fig. 2 which shows the impregnated spiral core 10 having a fabric tape covering 11 thereon, and a coil 12 wound over the covering 11 having leads 15. The combined structure of coil, core and covering is molded or cast in a plastic insulating body 14.

The body 14 in which the core and coil are cast serve to reinforce the core against parasitic vibrations which may occur due to vibration of the core 10 when signal currents are applied to the coil 12. Plastics and particularly phenolic condensation products are suitable for use as materials for the body. Such a method of enclosing the magnetostrictive element as described above is disclosed in the applications of E. E. Mott, Serial No. 549,970, filed August 8, 1944, now Patent No. 2,438,926, and Serial No. 617,001, filed September 18, 1945, now Patent No. 2,497,901. Other convenient methods of insulating the magnetostrictive element may of course be used.

When the magnetostrictive element has been impregnated, it may be subjected to a magnetizing force from an applied current or an external permanent magnet sufficiently strong to magnetize it, preferably to at least its saturation point or near thereto, so as to cause it to be permanently magnetized in one direction.

The alloy treated according to the process of the present invention may be used in the magnetostrictive element in the form of a toroidal spirally wound tape core as described above, as well as in the form of stack-laminated cores made either from circular rings or rectangular plates or in various suitable forms of other types.

The above-described magnetostrictive elements made from alloys of cobalt and iron, with or without vanadium, treated according to the process of the present invention may be used in general as electromechanical transducers in any device in which it is desired to convert electrical current variations into corresponding mechanical variations, or vice versa, or in which it is desired to use natural mechanical vibrational frequencies to control electrical frequencies, as in underwater sound projectors and microphones, frequency-control devices, electromechanical filters, telephone receivers and other devices. In general, the magnetostrictive devices of the present invention may be used in place of piezoelectric crystals in any circuit or device in which such crystals are used. Although specific embodiments of the invention have been shown and described, it will be understood that they are but illustrative and that various modifications may be made therein without departing from the scope and spirit of the invention.

What is claimed is:

1. A method of forming a vibratile magnetostrictive core comprising cold working, to a thickness reduction of at least 20 per cent, an alloy consisting of from 1/4 per cent to 4 per cent vanadium, from 30 per cent to 70 per cent cobalt and the remainder essentially iron, forming said alloy into a laminated core and annealing said alloy in the cold worked state at a temperature of from 450° C. to 650° C.

2. A method of forming an annular radially vibratile magnetostrictive core comprising cold working, to a thickness reduction of at least 30 per cent, an alloy consisting of about 2 per cent vanadium, about 49 per cent cobalt and about 49 per cent iron to form it into a tape no greater than 6 mils in thickness, forming said tape into a spiral core, annealing said alloy in its cold worked state at a temperature of from 500° C. to 600° C. and magnetizing said core to near its saturation point.

3. The method of preparing an alloy having magnetic properties suitable for the formation of a vibratory magnetostrictive core adapted for operation without a biasing field, which method comprises cold working to a thickness reduction of at least 50%, an alloy containing, by weight, about 2% vanadium and the remainder consisting of substantially equal proportions by weight of iron and cobalt together with incidental impurities, and heat treating said cold worked alloy at a temperature between about 500° C. and about 600° C.

4. An annular, radially vibratile, electromechanical transducer comprising a permanently magnetized core of spirally wound tape formed of an alloy consisting essentially of about 49 per cent iron, about 49 per cent cobalt and about 2 per cent vanadium annealed at about 550° C. from a cold worked state produced by a cold thickness reduction of at least 20 per cent.

5. A device which functions through the magnetostrictive action of a magnetic metal element, said device comprising a magnetostrictive element formed of an alloy, consisting of between about 1/4 per cent and about 4 per cent vanadium, between about 30 per cent and about 70 per cent cobalt and the remainder essentially iron, annealed at a temperature between about 450° C. and about 650° C. from a cold worked state produced by a cold thickness reduction of at least 20 per cent.

6. An annular, vibratile, permanently magnetized, magnetostrictive core composed of a plurality of spirally wound turns of a tape having a thickness of about 2 mils, said tape being formed of an alloy consisting of about 49 per cent cobalt, 2 per cent vanadium and the remainder essentially iron, said tape having been heat treated at a temperature of about 550° C. while in a cold worked state produced by a cold thickness reduction of at least 50 per cent.

7. A magnetostrictive core composed of a plurality of laminations, each no greater than 6 mils in thickness and formed by cold working a body of a magnetostrictive alloy to a thickness reduction of at least 20 per cent and heat treating the body in the cold worked state at a temperature between about 500° C. and 600° C., said alloy consisting of between about 1/4 per cent and about 4 per cent vanadium between about 30 per cent and about 70 per cent cobalt and the remainder essentially iron.

8. A magnetostrictive core composed of a plurality of laminations of a magnetostrictive alloy formed by cold working a body of the magnetostrictive alloy to a thickness reduction of at least 20 per cent and heat treating the body in the cold worked state at between 450° C. and 650° C., said alloy consisting of between about 1/4 per cent and about 4 per cent vanadium, between about 30 per cent and about 70 per cent cobalt and the remainder essentially iron.

9. An alloy having magnetostrictive properties and a substantial coercive force consisting of about 2 per cent vanadium, about 49 per cent cobalt and the remainder iron, said alloy having been treated by a process comprising cold working to a thickness reduction of at least 50 per cent and then heat treating in the cold worked state at a temperature of about 550° C.

10. An alloy having magnetostrictive properties and a substantial coercive force consisting of between about 1/4 per cent and about 4 per cent vanadium, between about 30 per cent and about 70 per cent cobalt and the remainder essentially iron, said alloy having been treated by a process comprising cold working to a thickness reduction of at least 20 per cent and then heat treating

in the cold worked state at between 450° C. and 650° C.

ETHAN A. NESBITT.
HOWELL J. WILLIAMS.

REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
1,441,522	Patterson	Jan. 9, 1923
1,586,889	Elmen	June 1, 1926
1,857,215	Ruder	May 10, 1932
1,862,559	White et al.	June 14, 1932
2,160,588	Granfield	May 30, 1939
2,166,359	Lakatos	July 18, 1939
2,298,225	Nesbitt	Oct. 6, 1942
2,317,294	Nesbitt	Apr. 20, 1943
2,317,295	Nesbitt	Apr. 20, 1943

FOREIGN PATENTS

Number	Country	Date
740,051	France	Nov. 12, 1932