March 7, 1967 G. R. CURTIS ET AL 3,308,412

TEMPERATURE COMPENSATED MAGNETIC TRANSDUCER

Original Filed April 19, 1960

Fig. 1

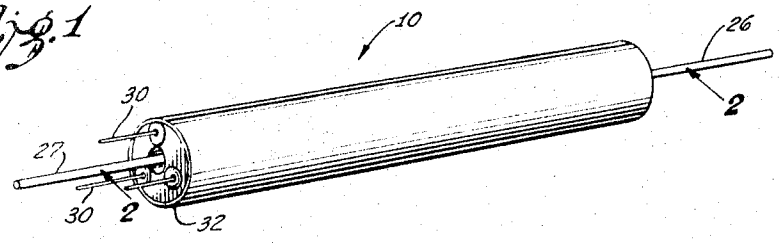


Fig. 2

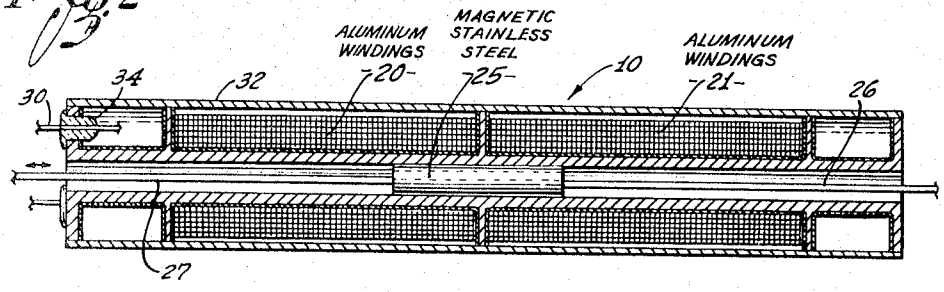


Fig. 3

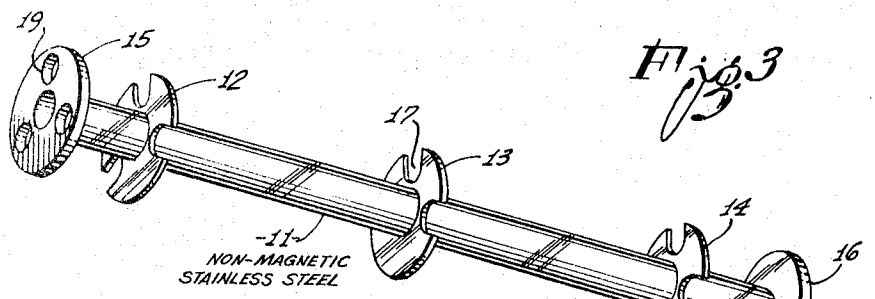
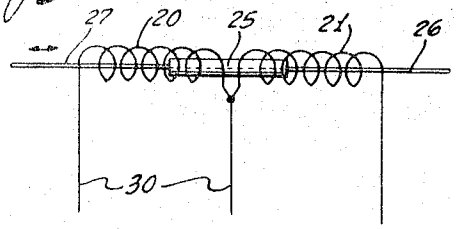


Fig. 4



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TEMPERATURE COMPENSATED MAGNETIC TRANSDUCER

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Original application Apr. 19, 1960, Ser. No. 23,267, now Patent No. 3,183,126, dated May 11, 1965. Divided and this application June 13, 1963, Ser. No. 300,950

8 Claims. (Cl. 336—136)

This is a division application Serial No. 23,267, filed April 19, 1960, and now Patent No. 3,183,126.

This invention relates to magnetic transducers and to methods of making such transducers and, more particularly, this invention relates to high temperature variable permeance transducers and to a method of making such transducers.

There are applications in which it is desirable to accurately measure a physical input such as pressure in a high temperature environment. For example, in a nuclear reactor, measuring instruments and transducers are required for operation in temperature environments up to 1,000 degrees Fahrenheit and in the presence of substantial radiation. In such environments, conventional instruments and transducers become inaccurate and often inoperable.

One conventional transducer utilized to transform a positional input to an electrical signal is a Variable Permeance Transducer. The input movement may be responsive, illustratively, to the action of a diaphram of a pressure sensitive capsule. The Variable Permeance Transducer generally includes a first and a second wound on a non-magnetic tube which encloses a moving element in the form of a core made of high permeability magnetic material. With the core centered in the tube, the permeance of the two windings is the same. As the core is moved toward either end, the permeance of one winding is increased, and it is decreased in the other winding. The result is that an output voltage is produced which is proportional to the displacement of the core.

The core is, of course, made of ferromagnetic materials and, therefore, is an alloy composed essentially of one or a combination of three elements, iron, cobalt and nickel which are the only three elements ferromagnetic at room temperature. The manufacture of a ferromagnetic alloy is generally a detailed process designed to enhance the desirable magnetic characteristic of the alloy. The magnetic properties of a single crystal of iron or nickel depend upon the crystallographic direction, in which they are measured. The crystal of grain orientation is effective in enhancing certain magnetic characteristics, and two methods are generally utilized to orient the crystals; cold rolling, and annealing, both in the presence of a magnetic field.

A core made of a conventional ferromagnetic alloy must be handled carefully because magnetic or thermal shocks or deformations degrade the magnetic properties of these special alloys. Even without shock, a variation of temperature changes the magnetic characteristic of the material. Conventional core materials such as Deltamax Orthonal, 48 Alloy, Hypernik-V, Hy-Mu 80, 4–79 Mo-Permalloy and Super-Permalloy (all U.S. trademarks) change as much as 10 to 15 percent when heated even gradually to 1,000 degrees Fahrenheit. None of the conventional core materials are, accordingly, suitable for use to provide for an accurate magnetic transducer for use in high temperature environments. Moreover, all these conventional core materials are not high temperature materials and, accordingly, they oxidize at high temperatures and tend to fall apart. The oxidation effectively seperates the crystals of the ferromagnetic material. Further, thermal shocks or rapid changes in temperature speed the distintegration of the core materials.

Moreover, conventional magnetic materials are all affected by the radioactivity present in nuclear reactor so that their magnetic characteristics change substantially responsive thereto. More specifically, with changes of temperature, and in the presence of radioactivity, the curie point at which the material loses its ferromagnetic properties decreases, the saturation flux density and rectangularity of the hysteresis loop changes; and the coercive force also is changed. These changes are not readily predictable and, therefore, cannot readily be compensated for by components external to the transducer. Because of these various factors, suitable transducers for use in nuclear reactors have not heretofore been provided.

In a specific illustrative embodiment of this invention, a variable permeance transducer is provided including two matched impedances in the form of windings of a suitable material such as aluminum. Aluminum in effectively transparent to radioactive particles. The aluminum is coated with a particular ceramic material which maintains its insulating properties at temperatures in the range of 1,000 degrees Fahrenheit and in the radioactive environment in the reactor. The inductive balance of the transducer is varied by means of the movement of a slug or core made essentially of a high temperature chromium-iron alloy. Features of this invention relate to a method of removing stresses from the core material and for magnetically stablizing the core material so that neither the stresses nor the magnetic characteristics of the material effectively change with substantial variations of temperature. The stresses are removed and the stability of the material is improved by repeatedly thermoshocking the material to randomly orient the alloy crystals and to lock them in the random orientation. In one embodiment of the invention, a ferromagnetic stainless steel material is subjected to a number of different thermal shocks to stabilize the material both dimensionally and magnetically. The thermoshocks increase the modulus of elasticity of the material and increase its hardness. The permeability of the material is somewhat less than that of the conventional core materials but, due to the fact that the output voltage is derived by the magnetic unbalance of the two windings, he sensitivity of the transducer is maintained.

Other features of this invention pertain to the provision of means for compensating for any small changes of the magnetic characteristics of the core at the elevated temperatures. The compensating means is in the form of the resistivity of the aluminum windings which increases with temperature as does the magnetic flux developed by the core. The change of magnetic characteristics of the core of this invention is quite small, illustratively 0.001 percent per degree Fahrenheit compared to 10 percent per degree Fahrenheit for the conventional core materials.

Further advantages and features of this invention will become apparent upon consideration of the following description when read in conjunction with the drawing wherein:

FIGURE 1 is a pictorial view of the variable permeance transducer of this invention;

FIGURE 2 is a sectional view of the variable permeance transducer of this invention;

FIGURE 3 is a pictorial view of the tube utilized in the variable permeance transducer of this invention; and

FIGURE 4 is an electrical representation of the variable permeance transducer of this invention.

Referring to FIGURES 1 through 4, the variable permeance transducer **10** is cylindrically shaped, and includes a tube or shell **11** made of a non-magnetic material. The material may illustratively be a non-magnetic steel. The tube **11** supports two windings **20** and **21** made of a material such as aluminum which is effectively a window for radioactive particles. Copper, which is conventionally utilized for transducer windings, becomes somewhat radioactive and changes its characteristics in the presence of the radiation. The aluminum wire of winding **20**, coated with an insulating material, is wound on the tube **11** between two baffles **12** and **13** of the tube **11**, and the aluminum winding **21**, also coated with an insulating material, is wound on the tube **11** between two baffles **13** and **14**. The baffles **12**, **13** and **14** are shown particularly in FIGURE 3 together with two end baffles **19** and **16** positioned at the respective ends of the tube **11**. The baffles **12**, **13** and **14** hold the windings **20** and **21** in place, and each includes a number of peripheral slots **17** for connecting leads between the windings **20** and **21** and for connections to external components, not shown. The windings **20** and **21** may be made of aluminum conductors 10 mils in diameter and approximate gage of 30.

As illustrated in FIGURE 4, the two windings **20** and **21** have one common terminal **30**. The three terminals **30**, including the common terminal, are connected through circular openings **19** in the end baffle **15** of the tube **11**. The terminals, or pins, **30** are supported by small ceramic insulator bushings, or beads, **34** in the openings **19** and may be made of non-magnetic stainless steel such as AISI 304. The tube **11** is coated with an inorganic ceramic material to fully insultate it from the windings **20** and **21**. The ceramic material coating may be similar to the material of the ceramic bushings **34** and the insulator coating on the windings **20** and **21**.

As indicated above, the aluminum windings **20** and **21** are also coated with a ceramic material which may be similar to that of the beads **34** and the coating of the tube **11**. A suitable method for coating aluminum with a ceramic material which maintains its insulating properties at temperatures in a range of 1,000 degrees Fahrenheit is disclosed in the copending patent application Serial No. 847,081 filed on October 19, 1959, by John A. Earl, and now abandoned. As described in the copending patent application, the coating may consist of a mixture by weight of lead oxide from 70 to 76 percent silicon dioxide, from 10 to 14 percent bismuth trioxide, from 7 to 14 percent, and from 4 to 6 percent of any one of barium oxide, lanthium trioxide, magnesium oxide, calcium oxide and zinc oxide. The coating is substantially unaffected by nuclear flux because it has a low thermoneutron capture cross section of the order of only 30 barns. Moreover, as indicated above, the coating maintains its electrical insulation at temperatures on the order of 1,000 degrees Fahrenheit. The various ingredients of the mixture are thoroughly mixed and then smelted until homogenized at a temperature of approximately 2,100 degrees Fahrenheit. After being homogenized, the mixture is quenched in water and then ground through a fine mesh screen. The mixture then is coated on the aluminum and fired to a suitable firing temperature between 1,000 degrees Fahrenheit and 1,200 degrees Fahrenheit to cure the coating. The resistivity of the coating at room temperature is on the order of 1×10^{14} ohms, and the resistivity at 1,000 degrees Fahrenheit is on the order of 4×10^{7} ohms. As indicated above, the ceramic coating of the tube **11** and the ceramic beads **34** may be made of similar material. The windings **20** and **21** are enclosed by a cylindrical tube **32** which may be made of steel such as the non-magnetic stainless steel having the AISI designation of 304. The tube **11** may be made of a similar material. The tube **32** may also be coated with the ceramic insulating material.

The tube **11** encloses a slug or core **25** which is made of magnetic material and which is movable longitudinally in the tube **11**. Two leads **26** and **27** are affixed respectively to the core **25** and extend through the end baffles **16** and **19** of the tube **11**. The inductance presented by each of the two windings **20** and **21** and the coupling therebetween is determined by the longitudinal position of the core **25**. With the core **25** centered, the inductance of the two windings **20** and **21** is identical so that a null or minimum signal is provided at the common terminal **30**.

As described above in the introduction, the magnetic characteristics of the core **25** must remain substantially constant throughout a temperature range up to 1,000 degrees Fahrenheit and in the presence of radiation. In order to magnetically stablize the material of the core **25**, the various crystalline stresses of the core **25** are removed. The material is so stabilized as to have a variation of magnetic characteristics only 0.001 percent per degree Fahrenheit throughout a temperature range from minus 320 degrees Fahrenheit to 1,000 degrees Fahrenheit. Moreover, the curie point temperature of the material is increased and the material is not effectively susceptible to the radioactive environment.

These characteristics are achieved by a thermoshocking process utilizing a ferromagnetic high temperature material. The material illustratively may be a magnetic stainless steel material or alloy consisting mainly of chromium and iron. One particular illustrative embodiment of the material includes by weight, 12 to 14 percent of chromium, 0.5 percent nickel, 1.25 percent manganese, 1 percent silicon, 0.15 percent carbon and the rest of iron. Such a stainless steel is conventionally designated AISI 416. The stainless steel is readily machinable and may also include a minimum of 0.07 percent by weight of phosphorous, sulfur or selenium; or a maximum of 0.06 percent by weight of zirconium or molybdenum. Any one of the AISI 400 series of stainless steels may be magnetically stabilized. The particular stainless steel 416 is selected because it is also readily machinable. The AISI 300 are not magnetic and cannot be heat treated. The magnetic characteristics of the 400 series stainless steels are generally deleterious in conventional applications of such steels.

One specific illustrative process for magnetically stabilizing the material to form a suitable core **25** for the variable permeance transducer **10** includes the following steps:

(1) The stainless steel material is heated to 1,550 degrees Fahrenheit and maintained at that elevated temperature for 8 to 10 hours;

(2) The heated material is then cooled to room temperature;

(3) The material is dropped into liquid nitrogen at −320 to −325 degrees Fahrenheit and maintained in the liquid nitrogen for aproximately 15 minutes;

(4) The cooled material is then warmed back to room temperature;

(5) The material is then heated to approximately 1,100 degrees Fahrenheit for 1 hour;

(6) The heated material is again returned to room temperature;

(7) The material is then dropped back into liquid nitrogen at approximately −320 degrees Fahrenheit for another 15 minute interval;

(8) The material is then returned to room temperature;

(9) The material is again heated to 1,100 degrees Fahrenheit for one hour;

(10) The material is returned to room temperature;

(11) Again, the material is thermally shocked to −320 degrees Fahrenheit in the liquid nitrogen for an interval of 15 minutes;

(12) The cooled material is then returned to room temperature;

(13) The substantially stabilized material is then cut and turned down to ¼-inch diameter to remove surface

impurities and stressed areas generally at the periphery of the material;

(14) The cut material is then again heated to 1,100 degrees Fahrenheit for 1 hour to remove stresses in the material due to the machining operation;

(15) The heated material is returned to room temperature;

(16) The material is then thermally shocked to —320 degrees Fahrenheit in the liquid nitrogen for 15 minutes;

(17) The material then returned to room temperature;

(18) The piece of material is then turned down to 0.125 inch which is just slightly larger than that required for the particular magnetic core;

(19) A cylindrical hole 0.0509 inch in diameter is drilled through the core along its longitudinal axis;

(20) The drilled material is then heated up again to 1,100 degrees Fahrenheit for 15 minutes, returned to room temperature, and dropped into the liquid nitrogen to remove the stresses in the material due to drilling;

(21) The material is then returned to room temperature;

(22) Finally, the piece of magnetic material is centerless ground to correct its external diameter to 0.116 inch ±0.003 inch and to a length of 1.250 inches ±0.0005 inch. The last step is essentially a surface cleaning operation.

The particular dimensions are, of course, merely illustrative and are given to illustrate the feature of machining the material to approximate size then thermoshocking the material again to remove machine stresses. Any of the conventional core materials would oxidize at the elevated temperatures and would fall apart during the repeated thermoshocks. The particular selected material for the core is a high temperature material which does not oxidize at the elevated temperatures. Moreover, the material is readily machinable so that only small stresses are introduced to the material by the machining operation.

The initial thermoshock cycles stabilize the dimensions of the core material. The machining operations are provided after the dimensions have been stabilized to accurately provide the desired core dimensions.

A core **25** produced in accordance with this method is very stable and provides for minute changes of magnetic characteristics for temperatures up to 1,000 degrees Fahrenheit. Even the small change in magnetic characteristics, however, is compensated for by an opposite small change in the resistance of the aluminum wire with changes of temperature. The resistivity of the aluminum wire increases with changes of temperature to decrease the effective flux density developed by the core. The resistivity illustratively increases from approximately 20 ohms per circular mil foot to approximately 60 ohms per circular mil foot. The curie point of the core **25** is quite high, at approximately 1,580 degrees Fahrenheit.

Although this invention has been disclosed and illustrated with reference to particular applications, the principles involved are susceptible of numerous other applications which will be apparent to persons skilled in the art. The invention is, therefore, to be limited only as indicated by the scope of the appended claims.

What is claimed is:

1. An electromagnetic transducer having stable characteristics when exposed to variable radioactive and fluctuating high temperature environments, the transducer comprising:

a tube made of non-magnetic material;

at least one winding formed from an elongated material coated with a boron-free ceramic disposed on the tube and having a temperature-resistance characteristic effectively immune to variations in radioactivity over an extended range of temperatures to approximately 1000° F.;

a coating of boron-free ceramic on the peripheral surface of the tube and having a temperature-resistance characteristic effectively immune to variations in radioactivity over an extended range of temperatures to approximately 1000° F.; and

disposed within the tube, a core having a temperature-permeability characteristic counteracting the effect of the temperature-resistance characteristic of the winding and having substantially constant magnetic characteristics through an extended range of temperatures to approximately 1000° F. and having characteristics effectively immune to variations in radioactivity.

2. An electromagnetic transducer having stable characteristics when exposed to variable radioactive and fluctuating high temperature environments, the transducer comprising:

a tube made of non-magnetic material;

at least one winding formed from aluminum coated with a boron-free ceramic disposed on the tube, and having a temperature-resistance characteristic effectively immune to variations in radioactivity over an extended range of temperatures to approximately 1000° F.;

a coating of the boron-free ceramic on the peripheral surface of the tube; and

disposed within the tube, a magnetic core consisting mainly of chromium and iron and having a temperature permeability characteristic counteracting the effect of the temperature-resistance characteristic of said winding and having substantially constant magnetic characteristics even when subjected to radioactivity and having substantially constant magnetic characteristics over an extended range of temperatures between approximately —320° F. and approximately 1000° F.

3. An electromagnetic transducer having stable characteristics when exposed to variable radioactive and fluctuating high temperature environments, the transducer comprising:

a tube made of non-magnetic material;

at least one winding formed from aluminum coated with a boron-free ceramic disposed on the tube and having a temperature-resistance characteristic effectively immune to variations in radioactivity over an extended range of temperatures to approximately 1000° F.;

a coating of boron-free ceramic on the peripheral surface of the tube; and

disposed within the tube, a core having a temperature-permeability characteristic counteracting the effect of the temperature-resistance characteristic of the winding, said core comprising a piece of magnetic stainless steel including by weight 12 to 14 percent chromium, 0.5 percent nickel, 1.25 percent manganese, 1 percent silicon, 0.15 percent carbon, and the rest iron with characteristics of providing substantially a constant permeability when subjected to radioactivity and over an extended temperature range between approximately —320° F. and 1000° F.

4. The electromagnetic transducer set forth in claim **1** wherein the boron-free ceramic consists of a mixture by weight of lead oxide from about 70 percent to 76 percent, silicon dioxide from about 10 percent to 14 percent, bismuth trioxide from about 7 percent to 14 percent and from about 4 percent to 6 percent of a material selected from a group consisting of the oxides of barium, magnesium, calcium and zinc.

5. The electromagnetic transducer set forth in claim **1** wherein the core consists of 12 percent to 14 percent of chromium, 0.5 percent nickel, 1.25 percent manganese, 1 percent silicon, 0.15 percent carbon and the remainder of iron.

6. The electromagnetic transducer set forth in claim **2** wherein the core includes 12 percent to 14 percent of chromium and approximately 83 percent to 85 percent of iron.

7. The electromagnetic transducer set forth in claim 6 wherein the boron-free ceramic consists of a mixture by weight of lead oxide from about 70 percent to 76 percent, silicon dioxide from about 10 percent to 14 percent, bismuth trioxide from about 7 percent to 14 percent and from about 4 percent to 6 percent of a material selected from a group consisting of the oxide of barium, magnesium, calcium and zinc.

8. The electromagnetic transducer set forth in claim 3 wherein the boron-free ceramic consists of a mixture by weight of lead oxide from about 70 percent to 76 percent, silicon dioxide from about 10 percent to 14 percent, bismuth trioxide from about 7 percent to 14 percent and from about 4 percent to 6 percent of a material selected from a group consisting of the oxides of barium, magnesium, calcium and zinc.

References Cited by the Examiner

UNITED STATES PATENTS

3,052,576	9/1962	Josso	148—135 X
3,060,353	10/1962	Shansky et al.	336—213 X
3,089,081	5/1963	Brosh	336—30 X
3,119,897	1/1964	Coper	174—110

OTHER REFERENCES

Radiation Shielding: Price, Horton and Spinney 1957.

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Dedication

3,308,412.—*Gerald R. Curtis*, Duarte, *James C. Kyle*, Glendora, and *Glen Robinson*, Pasadena, Calif. TEMPERATURE COMPENSATED MAGNETIC TRANSDUCER. Patent dated Mar. 7, 1967. Dedication filed June 3, 1970, by the assignee, *Physical Sciences Corporation.*

Hereby dedicates the entire term of said patent to the Public.

[*Official Gazette November 10, 1970.*]