Dec. 28, 1965 A. C. LYNCH ETAL 3,225,421

METHOD OF MAKING A MAGNETIC CORE FOR A MAGNETIC SWITCH

Filed April 15, 1964 3 Sheets-Sheet 1

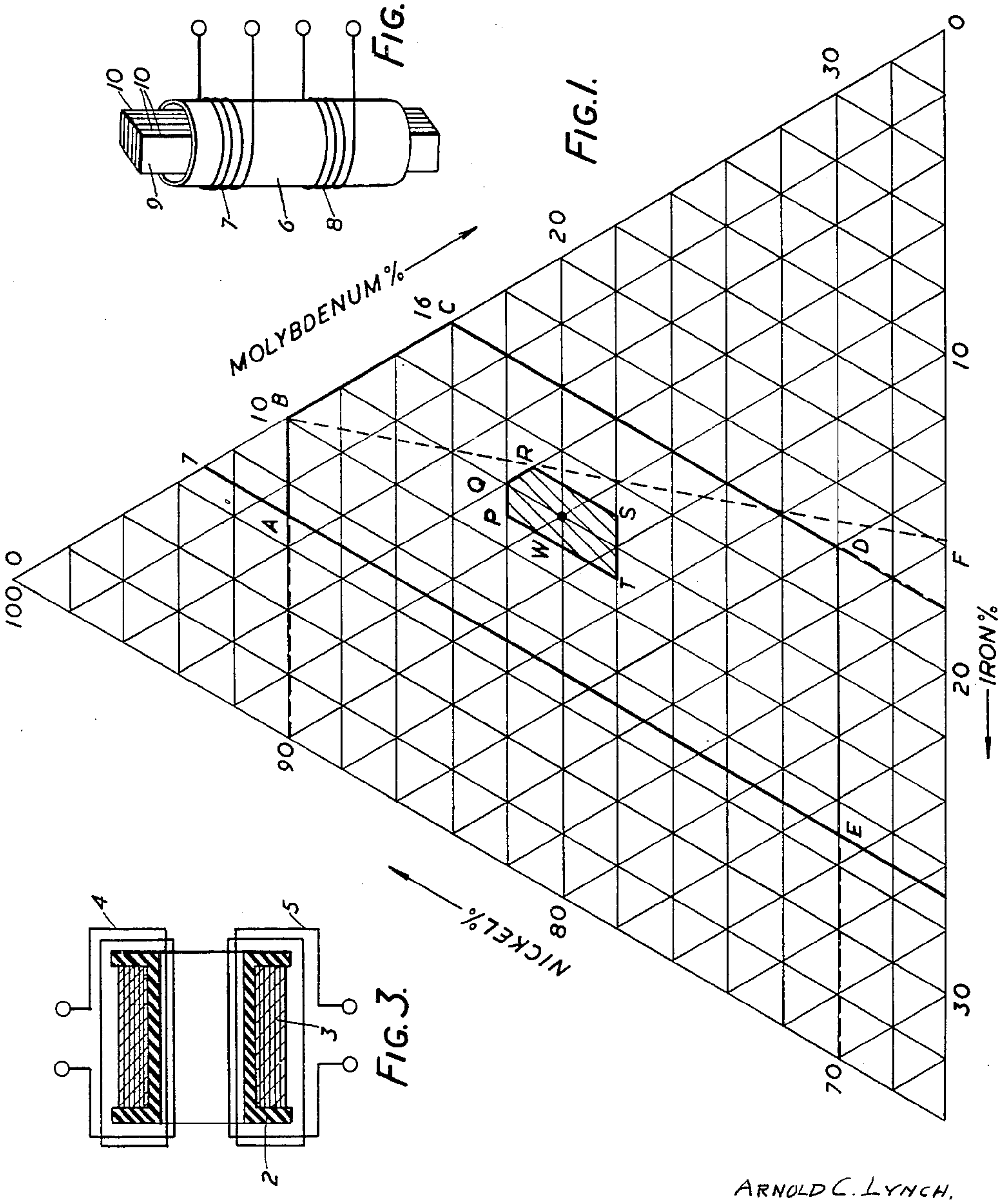

FIG. 4. FIG. 1. FIG. 3.

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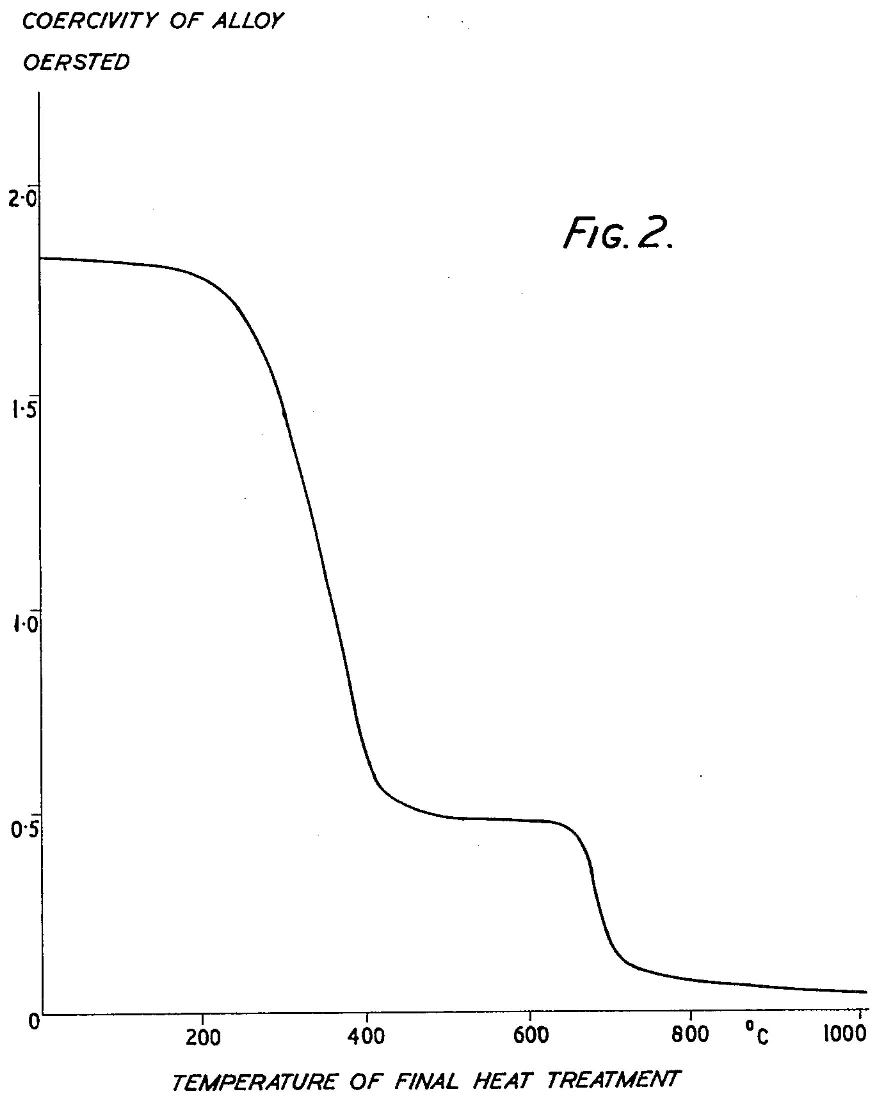

FIG. 2.

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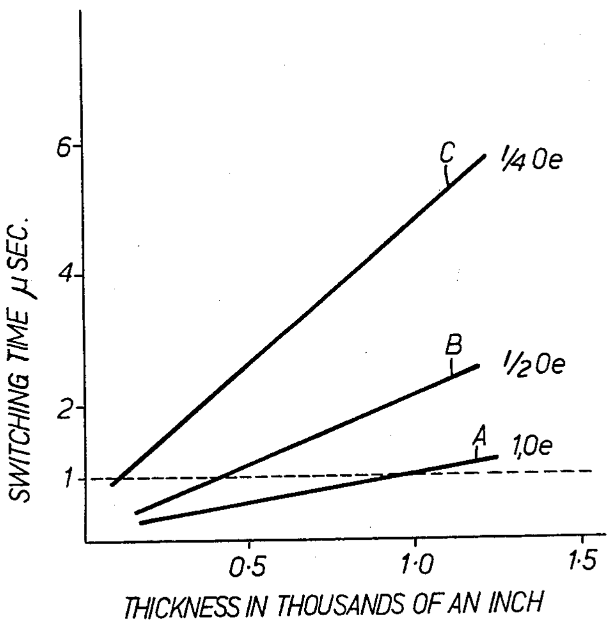

FIG.5.

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METHOD OF MAKING A MAGNETIC CORE FOR A MAGNETIC SWITCH

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4 Claims. (Cl. 29—155.5)

The present invention relates to material for constructing magnetic cores for use in magnetic devices such as for example magnetic switches. The present application is a continuation-in-part of our application Serial No. 704,764, filed December 23, 1957, for Magnetic Cores.

It is an object of the invention to provide an improved method of making a material for constructing magnetic cores.

It is a further object of the invention to provide an improved method of making a magnetic core for a magnetic device.

It is a still further object of the invention to provide an improved method of making a magnetic core for a magnetic switch in which the switching time is less than one microsecond when the magnetic field is less than one oersted.

These and other objects of the invention are achieved by the practice of the method of the invention according to which method a material for use in the manufacture of a magnetic core is produced by forming an alloy containing nickel and molybdenum in the proportions by weight of from 70% to 90% nickel, from 6% to 16% molybdenum, and the remainder if any iron; reducing the alloy into strip having a thickness of less than 0.001 inch and subjecting the strip to heat treatment at a temperature in excess of 750° C. It is preferred, however, that the molybdenum should be present in a percentage not less than 7%.

Conveniently the constituents are in powdered form and the alloy is formed by throughly mixing the powdered constituents together, compressing the powder mixture into a solid block, and sintering the block in a protective atmosphere for example hydrogen so that the constituents are alloyed by diffusion one into another.

The invention will now be described in further detail with reference to the accompanying drawings in which:

FIG. 1 illustrates in graphical form the inter-relation of the proportions of nickel, molybdenum and iron,

FIG. 2 is a graph showing how the coercivity of a core constructed with material according to the invention varies with the temperature of heat treatment,

FIGS. 3 and 4 illustrate respectively alternative forms of magnetic devices embodying the invention, and

FIG. 5 illustrates in graphical form results obtained experimentally and relating the thickness of lamination with switching time.

Within the limits of the previously mentioned proportions, the resulting alloy may have a low Curie point and at ordinary room temperature may be non-magnetic. Thus and referring to FIG. 1 of the drawings alloys lying to the right of the line BF have low Curie points and are non-magnetic at ordinary room temperatures. The area marked ABCDE on FIG. 1 encloses the alloys coming within the preferred proportions mentioned and it will be seen that a part of this area lies to the right of the line BF and therefore the alloys included in this part of the area are non-magnetic at room temperatures.

Although such alloys may be useful in some applications for example for constructing the cores of thermoresponsive magnetic devices, when it is necessary that the alloy should be magnetic at room temperature as for example when used in the construction of cores for magnetic switches, the alloy should lie within the smaller area PQRST representing a range of proportions of 78–82% nickel, 11 to 13% molybdenum and from 6% upwards of iron. The preferred composition of alloy is indicated at W and consists of 80% nickel, 12% molybdenum and 8% iron.

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The coercivity of a core constructed of strip material prepared in accordance with the invention varies with the temperature at which the final heat treatment is effected, and FIG. 2 of the drawings is a graph illustrating the variation of coercivity with the temperature of final heat treatment of an alloy of the preferred composition, i.e., 80% nickel, 12% molybdenum and 8% iron. The graph shows that over two temperature ranges, the coercivity remains substantially constant. Thus at temperatures from approximately 400° C. to 650° C. the coercivity is substantially constant and at temperatures in excess of 750° C. the coercivity is substantially constant at a reduced value.

However, it is found that heat treatment at the first range of temperatures does not yield a material having the aforementioned properties for use in a magnetic switch, i.e., a switching time of less than 1 microsecond when the magnetic field is less than 1 oersted. Heat treatment in the second temperature range on the other hand gives the required properties, as will be apparent from the following table showing the relation between temperature, coercivity and switching time for cores formed of strip material having a thickness of .0005 inch:

Temperature of heat treatment, ° C.	Coercivity H_o, oersted	Switching time, μ sec. at 1 oersted
400	0.55	5.0
500	0.50	1.8
600	0.50	1.5
675	0.18	0.8
800	0.05	0.6
1,050	0.021	0.36

The rate of cooling after the heat treatment is not critical and no variation in the characteristics of the material has been observed as a result of variation in the cooling rate.

FIG. 5 illustrates in graphical form results obtained experimentally with material according to the invention and heat treated at 1050° C. and relating the thickness of lamination with switching time for different magnetic field strengths. Thus at A there is shown a plot of the experimental results employing a field of 1 oersted, at B a plot of results employing a field of ½ orested, and at C a plot of results employing a field of ¼ oersted. These curves clearly demonstrate that the switching time is dependent on the thickness of lamination and as will be seen from plot A, to obtain a switching time of less than 1 microsecond with a field of 1 oersted, the thickness of the lamination should not substantially exceed .001 inch.

The material according to the present invention is especially suitable for the construction of cores for magnetic switches although it will be understood that its use is not limited thereto.

In one construction of magnetic switch employing a magnetic core material according to the invention, powdered nickel, iron and molybdenum in the ratio by weight of 80, 8 and 12 respectively are thoroughly mixed and compressed into a solid block at a pressure of about 30 tons per square inch. The block thus formed is sintered in an atmosphere of hydrogen at 1300° C. for 5 hours during which the component metals are alloyed by diffusing into one another. The block of alloy is then rolled down into strip of the required thickness less than 0.001 inch, with intermediate annealing treatments if necessary, for example whenever the thickness has been reduced to half that at the start of rolling or that at which the previous annealing was effected, and the final thickness of the strip may be, for example, 0.0005 inch, the last annealing treatment bieng effected when the strip is approximately 0.001 inch thick.

Due care must be taken to ensure that the strip is free from notches or similar irregularities which would unfavourably affect the field strength required for reversal of magnetism.

The strip is then wound on to a ceramic bobbin having flanged ends and a bore extending centrally therethrough, the strip being provided with an insulating coating of magnesia by passing the strip through a bath containing a suspension of magnesia prior to winding the strip on the bobbin. The strip is wound on to the cylindrical surface of the bobbin between the flanged ends thereof and may consist, for example, of about 10 turns, and is secured in position on the bobbin by a separate single turn of strip surrounding the said 10 turns and having its ends radially outwardly turned and secured together as by spot-welding for example. The wound core is then heat treated in hydrogen at a temperature of 1050° C. for 3 hours and allowed to cool at a rate of about 100° per hour. As previously stated, this rate of cooling is not critical.

The magnetic switch is completed by applying toroidal winding of insulated copper wire to the bobbin, the number of windings and the number of turns in each winding being adapted to the particular application for which the switch is required.

One such magnetic switch constructed as above described is shown in longitudinal section in FIGURE 3 of the drawings and in which **2** indicates the ceramic bobbin, **3** the wound strip, and **4** and **5** respectively two toroidal windings.

In another form of magnetic switch employing a magnetic core material according to the invention and suitable for use in a ferroresonant circuit, the alloy is prepared in strip form as described above and the strip is then cut into short lengths of, for example, 1 inch long and 1/16 inch wide which are then heat treated in hydrogen at 1050° C. also as described above. The bobbin of the magnetic switch is in the form of a paper tube indicated at **6** in FIGURE 4 of the drawings and upon which two windings **7** and **8** of insulated copper wire are applied and a core **9** formed of a plurality of superposed short lengths **10** of alloy strip is inserted through the tube and secured in place by a small amount of a suitable adhesive.

We claim:

1. A method of using an alloy to make a high-speed magnetic core switching element, said alloy consisting of

between 70 and 90% nickel, between 6 and 16% molybdenum and the remainder, if any, iron, said element being produced by

(1) forming a mass of such alloy,

(2) reducing the thickness of the mass to form a strip substantially free from notches or similar irregularities and having a thickness less than 0.001 inch,

(3) forming the strip into a core,

(4) heat treating the strip at a temperature in excess of 750° C., and

(5) placing a winding about the core in a position for magnetically linking it with the core.

2. A method of using an alloy to make a high-speed magnetic core switching element capable of switching in less than one microsecond under the influence of a magnetic field of less than one oersted, said alloy consisting of between 78 and 82% of nickel, between 11 and 13% molybdenum, and at least 6% iron, said element being produced by

(1) forming a mass of such alloy,

(2) reducing the thickness of the mass to form a strip substantially free from notches or similar irregularities and having a thickness less than 0.001 inch,

(3) fabricating the strip so formed into a multi-layer core element, and

(4) then, heat treating the core element so formed at a temperature in excess of 750° C.

3. A method of using an alloy as defined in claim **2**, said method including the further step of placing a winding around said core element in a position for magnetically linking it with said core element.

4. A method as defined in claim **2** in which the alloy contains 80% nickel, 12% molybdenum, and 8% iron, and the heat treatment is effected at approximately 1050° C.

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