June 19, 1928. 1,673,790

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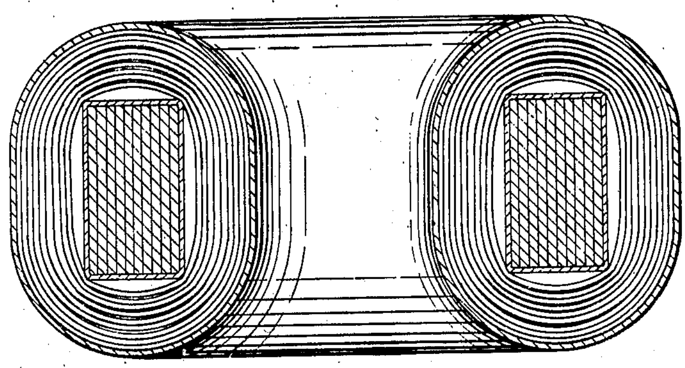
MAGNETIC MATERIAL, PROCESS OF PRODUCING IT, AND ELECTROMAGNETIC DEVICE INCORPORATING SUCH MATERIAL

Filed Dec. 13, 1924 2 Sheets-Sheet 1

Fig. 1.



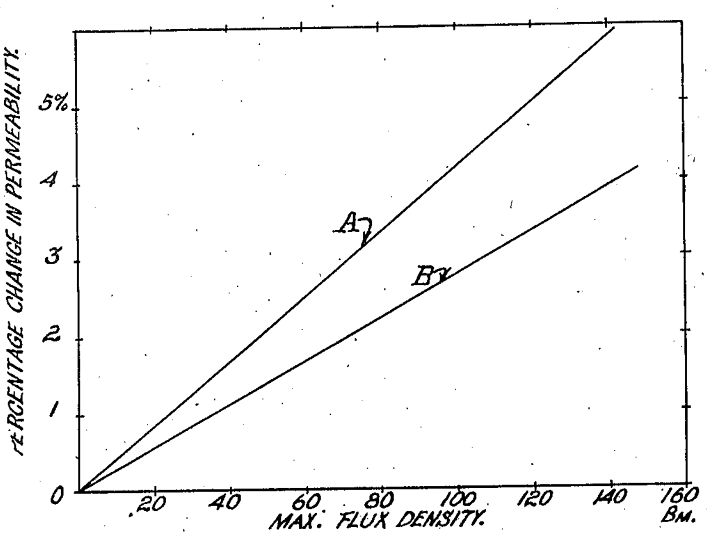



Fig. 2.

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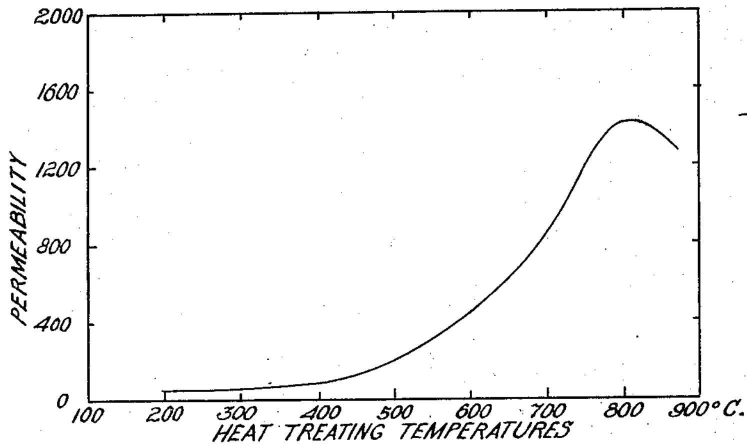
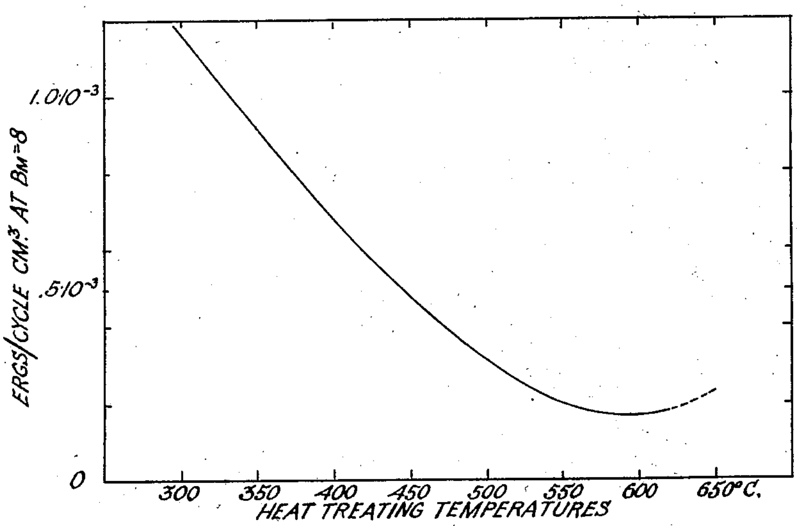



Fig. 3.

Fig. 4.



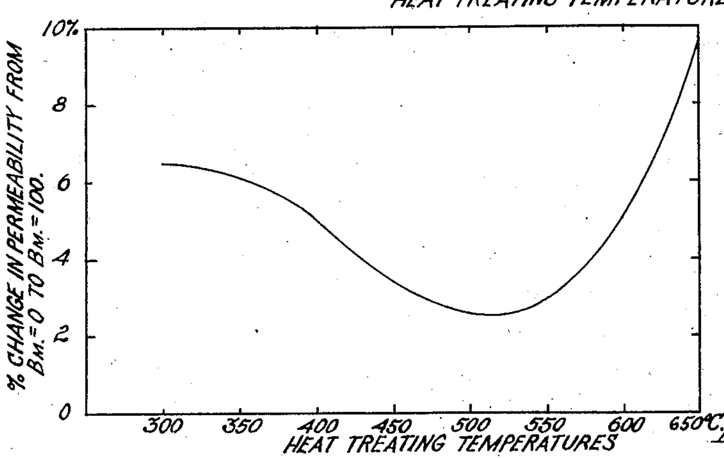




Fig. 5.

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# UNITED STATES PATENT OFFICE.

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## MAGNETIC MATERIAL, PROCESS OF PRODUCING IT, AND ELECTROMAGNETIC DEVICE INCORPORATING SUCH MATERIAL.

Application filed December 13, 1924. Serial No. 755,613.

This invention relates to magnetic materials, processes of producing them, and electromagnetic devices in which such materials may be used to advantage.

The principal object of the invention is to secure constancy of operating characteristics of magnetic material used in signaling apparatus and for other apparatus employing low field strengths; examples of signaling apparatus being inductive loading, transformers, relays, filter coils, and balancing and wave-shaping networks.

An object of the invention in a different aspect is to reduce, in magnetic material used in signaling apparatus, variations in those magnetic characteristics the variability of which introduces distortion in the signaling currents. Two such characteristics are permeability and variable flux due to hysteresis. Another object is to secure relative constancy of the variable operating characteristics in magnetic material used in signaling apparatus and for apparatus employing low field strengths, and at the same time to secure a high value of permeability. Another object is to obtain in a magnetic material those characteristics which peculiarly adapt it for use as inductive loading material for signaling lines. Other objects of the invention will become apparent on consideration of the following specification.

Wherever magnetic material is subjected to magnetic fields set up by signaling currents, these currents are distorted because there is no known magnetic material which does not have some characteristic which varies within the operating range. Such distortion is variously characterized as modulation, Morse flutter, etc., depending upon the conditions under which it is produced. Permeability ordinarily varies with the field strength or with the resultant flux density. Likewise, when fields due to a complete cycle of alternating signaling current are set up, the flux density is different for equal positive and negative values of the field strength because of the hysteresis of the magnetic material. The resistivity may likewise vary somewhat with field strength which introduces variable losses with consequent distortion of the signaling current, but this effect is ordinarily small. It is highly desirable to have high resistivity to avoid excessive eddy current losses and also to have high permeability to enable a given inductance to be obtained with a minimum amount of the material.

In British Patent 189,410 is described an invention of G. W. Elmen pertaining to nickel-iron alloys which in many respects are more suitable for inductive loading than iron. Such alloys may contain from 25% or 30% to around 80% or more of nickel, the preferred proportions being nickel 78½% and iron 21½%. A heat treatment suitable for obtaining high permeability, low hysteresis loss and high resistivity is there described.

The present invention is the outgrowth of an extension of the investigation leading to the invention disclosed in the British Patent 189,410. It is based upon the discovery that when nickel-iron alloys containing from 30% to 60% of nickel are given a special treatment hereinafter described, the permeability becomes relatively constant over a very wide range of low flux densities—the range ordinarily employed in signaling—and, as compared with iron, the permeability is high, the hysteresis loss very low, and the resistivity very high. The material is better than iron in all of these important respects.

Heretofore, aside from the work of Elmen, various investigators have independently investigated some of the properties of certain nickel-iron alloys falling within the range from 30% to 60% nickel but not at flux densities with which this invention is concerned.

The treatment of nickel-iron alloys employed to obtain the properties described above may be outlined as follows: The alloy ingot, after casting, is worked by being rolled and occasionally annealed as found necessary until thin sheets or strips about .002 inch thick are obtained. This process produces a certain moderate degree of hardness in the metal. It is then subjected to a temperature lower than that which would ordinarily be employed to anneal it and the heat is applied for a shorter time than is usual in annealing processes. When employing an alloy containing 36% of nickel and 64% of iron, the temperature employed is from 425° C. to 750° C. and the time of application about fifteen minutes. The same result may be obtained within limits by simultaneously increasing one of these factors and decreasing the other. The proper values of temperature and time may be determined by trial in each case. The rate of cooling is preferably more rapid than that ordinarily employed in annealing but has no critical value. Cooling in air at ordinary room temperature is satisfactory. The process of subjecting a material, as just described, to a temperature and for a time insufficient to secure maximum softness is herein characterized as partially annealing.

In the alloy just mentioned containing 36% of nickel when treated as described, permeability will lie in the range from 125 to 1000 and the variation of permeability over a range of flux densities from 0 to 100 c. g. s. units is from 2% to 5%. The hysteresis loss at a maximum flux density of 8 c. g. s. units may be as low as $1.5 \cdot 10^{-4}$ ergs per cycle per $cm^3$, being about 1/15th that of hard drawn iron wire. The resistivity is about 80 microhms per $cm^3$.

Inductive loading of signaling lines is a suitable use of magnetic material to serve as an illustration of the uses and manner of preparation of the new material, and has therefore been chosen for that purpose in the following specification.

Heretofore the material which has been generally used for loading telephone lines is iron, the most suitable form being specially prepared compressed iron dust. Another form is that in which the core is a coil of fine iron wire. Such loading coils are described, for example, in an article by Buckner Speed and G. W. Elmen, entitled "Magnetic properties of compressed powdered iron", Journal of the A. I. E. E., July, 1921.

In the construction of loading coils for telephone lines in which the cores are of iron wire, it has been found possible to obtain a semi-hard drawn wire which has an initial permeability approximately 125, the permeability varying by not more than 2% or 3% over a range of flux densities from 0 to 30 c. g. s. units. Its hysteresis loss is $2.25 \cdot 10^{-3}$ ergs per cycle per $cm^3$ at a maximum flux density of 8 c. g. s. units, and its resistivity is 9 microhms per $cm^3$.

In a standard design of loading coil, the magnetizing force corresponding to a telephone current of five milliamperes is of the order of .05 gauss. At a permeability of 100 the corresponding flux density is 5 c. g. s. units. Ordinarily, however, loading must be designed to serve either near the terminals of lines or cables where the currents are large or at mid-line where the currents have been reduced by attenuation. In many installations, moreover, telephone and telegraph currents are composited so that the flux in the coils at any given point on the line varies over a wide range. In many other uses of magnetizing material designed to operate at flux densities up too 100 c. g. s. units, the flux varies over a large part of this range, as for example in transformers employed to interconnect stages of amplifiers in public address systems and in filter coils for similar systems.

Referring to the accompanying drawings,

Fig. 1 is a vertical sectional view of a loading coil for loading signaling conductors in which the core of the coil consists of laminations of the improved magnetic material of this invention;

Fig. 2 is a curve showing the variation of permeability of the new magnetic material over a range of flux densities from 0 to 100 c. g. s. units, compared to the grade of iron having the greatest attainable constancy of permeability over this range;

Fig. 3 is a representative curve showing the initial permeability that will be secured in one form of the improved magnetic material for certain definite heat treating temperatures;

Fig. 4 is a representative curve showing the magnitude of the hysteresis loss that may be secured in a piece of the new magnetic material after being subjected to the several temperatures of heat treatment shown on the graph; and

Fig. 5 shows the percentage change in permeability that occurs when the maximum flux density is changed from 0 to 100 c. g. s. units for the improved alloy after having been subjected to the different heat treatments indicated on the graph.

In preparing the material for use as the core of a loading coil, nickel and iron in the proportion, for example, of about 36% nickel and the balance of iron are fused in an induction or arc furnace. Pure commercial grades of these two metals are suitable for this purpose. The molten alloy is poured into an ingot mold and allowed to solidify. The ingot is then subjected to repeated hot rolling operations followed by cold rolling operations by which it is reduced in thickness and correspondingly elongated to have a final thickness of about .002 inch. The strip is then passed through cutting rolls or discs which trim its edges squarely on both sides to give the strip an exact and uniform width of 1 inch. This tape of nickel-iron composition is then rolled up to form a ring core as shown in Fig. 1, the adjacent convolutions thereof being suitably insulated from each other. In insulating these adjacent turns of the ring core, good results have been secured by subjecting the tape to an oxidizing process prior to wrapping it into the ring in the manner just described. This oxidizing process consists in removing all oil and grease from the tape with alcohol and subjecting it to an atmosphere of oxygen at a temperature above 400° C. and below the final heat treating temperature (to be described hereinafter). The duration of this process depends upon the thickness of the oxide coating desired, but good results have been secured by heating the material to the temperature stated for about 15 minutes.

The core is then heat treated for a period of time and to a temperature less than would be required for completely annealing it and is then cooled. For example, it has been found desirable to heat the core to a temperature of approximately 480° C. and maintain it at this temperature for about 15 minutes, the core then being allowed to cool. Experiments have indicated that the rate of cooling is not critical and good results have been secured by accelerating the cooling by placing the core in a cold air blast.

It has been found desirable to impregnate the core after heat treating by immersing it under partial vacuum in a hot molten insulating compound that solidifies on cooling. The core after immersion is removed from the molten compound and allowed to drain and cool. This provides a rigid and substantial coil. A rosin compound consisting of a mixture of rosin and rosin oil in ratio of three to one has given good results.

For example, to form a loading coil having an inductance of 28 milhenries and an effective resistance of less than 3.0 ohms with a 1800 cycle alternating current of .002 amperes flowing through a winding of approximately 285 turns of number 22 copper wire, ½ pound of the strip prepared in the manner heretofore described is rolled into a tight ring core the interior opening of which has a diameter of about 1.375 inches, the ends of the coil being held in any suitable manner.

The particular value of permeability desired in the material will vary, depending upon the uses to which the material is to be put, and in order to secure any particular value of permeability which will be constant over a wide range of low flux densities, the temperature during the heat treatment is raised to a definite point. Generally stated, the higher the permeability desired the higher the temperature to which the heating is carried.

Fig. 3 shows the initial permeabilities that will be secured for a range of heat treating temperatures of a nickel-iron alloy having 37½% nickel, the heat treatment having a duration of 15 minutes. In this figure, permeabilities are plotted as ordinates and temperatures as abscissæ, it being understood that the shape of the curve will depend somewhat upon the amount and kind of mechanical treatments to which the material is subjected while being worked down to its final dimension. In general the same type of curve will be obtained for other periods of application of the heat treatment, the longer the period the lower the temperature at which the maximum point of the curve will occur. The change thus produced by prolonging the period beyond a few hours is not marked.

Fig. 4 shows the magnitude of the hysteresis loss obtained for a range of heat treating temperatures with a nickel-iron alloy having 37½% nickel, the heat treatment in each case having a duration of 15 minutes. This figure shows hysteresis loss in ergs per cycle per cm³ for a maximum flux density of 8 c. g. s. units as ordinates. The heat treating temperatures are shown as abscissæ.

One of the outstanding characteristics of this improved magnetic material is the small change in permeability that occurs with changes in flux densities below 100 c. g. s. units. By the method of heat treatment herein described it is possible to secure smaller changes in permeability for given changes in flux density below 100 c. g. s. units than when the material is either unannealed or fully annealed. By referring to Fig. 5 it will be apparent the way in which the method of heat treatment herein described reduces the percentage change in permeability. The curve of Fig. 5 is representative and may shift up or down or laterally depending on the previous history of the material.

In Fig. 2 are curves showing the variations of permeability with flux density for the most suitable grade of iron in comparison with the improved magnetic alloy. By referring to curve A which is representative of the form of iron having the most constant permeability over this range, and to curve B representative of the improved magnetic material in the form of nickel-iron alloy, the comparative constancy of permeability of the materials over a wide range of low flux densities is disclosed. Percents of initial permeability are plotted as ordinates and flux densities as abscissæ. Curve B is for a nickel-iron alloy having 37½% of nickel.

A coil such as that above described is about one-third or less the volume of the best loading coils designed for the same purpose now in use.

It is obvious that the material just described is adapted for continuous loading of signaling conductors as well as for loading coils. As compared with loading material in which high permeability is developed by heat treatment after the material, in a form suitable for continuous loading, is placed upon the copper conductor, the material of this invention has the advantage that if heat treatment of the loaded conductor becomes desirable or necessary the temperature required will be relatively low and will not necessitate special precautions to prevent injury to the copper conductor.

This invention is of particular importance in the loading of lines employing high frequency, since distortion known as intermodulation is then large when ordinary materials are used.

It is within the scope of this invention to apply to any magnetic material the treatment herein described, modified to suit the particular material and the degree to which the desired characteristic or characteristics are to be obtained, for the purpose of obtaining the desirable results herein specified. In another aspect, the invention comprehends the material so treated.

The nickel-iron alloys herein mentioned consist essentially of nickel and iron but other elements may be present in small amounts. The range of nickel-iron alloys of this invention from 35% to 38% of nickel is particularly suitable for loading and analogous purposes, 36% nickel being perhaps the best, but the invention is applicable throughout the entire range from 30% to 60% of nickel and may be used to advantage for some purposes in the range from 60% to 80% or 90% of nickel.

What is claimed is:

1. The method of producing a magnetic material of relatively high initial permeability and relatively constant permeability over a selected range of magnetizing forces, which comprises heating the material at a temperature lower and for a period of time shorter than is required to completely anneal the material.

2. The method of producing a magnetic material in accordance with claim 1 characterized in this that the magnetic material is composed of nickel and iron.

3. The method of producing a magnetic material in accordance with claim 1 characterized in this that the nickel content is from 30% to 60% of the nickel-iron content.

4. The method of producing a magnetic material in accordance with claim 1 characterized in this that said material is heat treated at a temperature not to exceed 550° C.

5. The method of producing a magnetic material in accordance with claim 1 characterized in this that the magnetic material is allowed to cool at substantially room temperature.

6. The method of producing a magnetic material having an initial permeability substantially greater than 125 and having a permeability over a range of flux densities from 0 to 30 c. g. s. units within 2% of its initial permeability, which comprises hardening and partially annealing the material.

7. The method of producing a magnetic material in accordance with claim 6 characterized in this that the magnetic material is composed of nickel and iron.

8. The method of producing a magnetic material in accordance with claim 6 characterized in this that the nickel content is from 35% to 38% of the nickel iron content.

9. The method of producing a magnetic material in accordance with claim 6 characterized in this that the material has a greater resistivity than iron.

10. The method of producing a magnetic material having a relatively high initial permeability and having a substantially constant permeability over a range of flux densities from 0 to 100 c. g. s. units, which consists in hardening and incompletely annealing the material.

In witness whereof, I hereunto subscribe my name this 2nd day of December A. D., 1924.

ADOLPH FRANCIS BANDUR.