

Aug. 4, 1942.

W. H. BRANDT ET AL
FERROMAGNETIC MATERIAL

2,292,191

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3 Sheets-Sheet 1

Fig. 1.

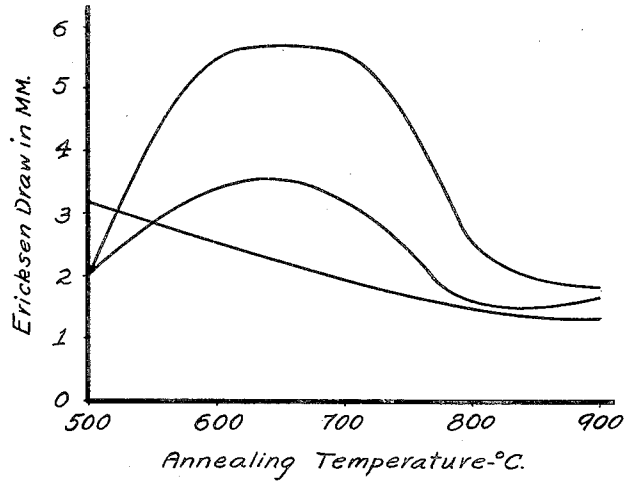
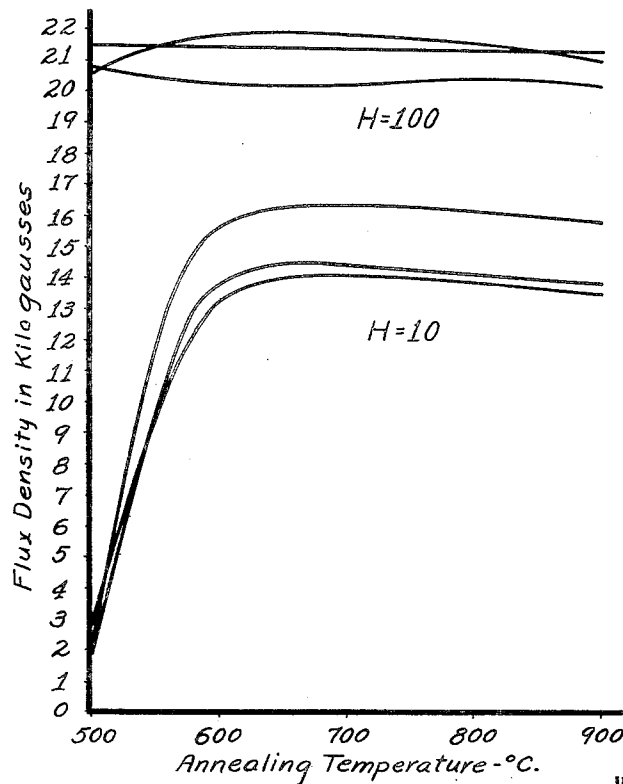


Fig. 2.



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Fig. 3.

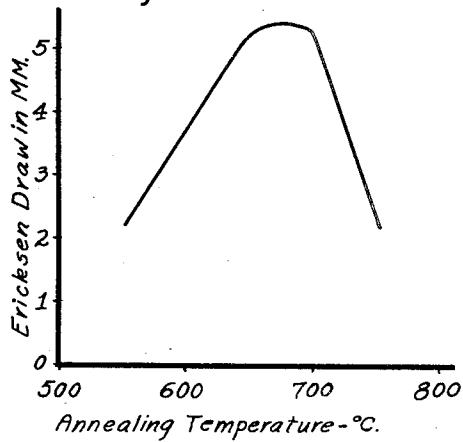
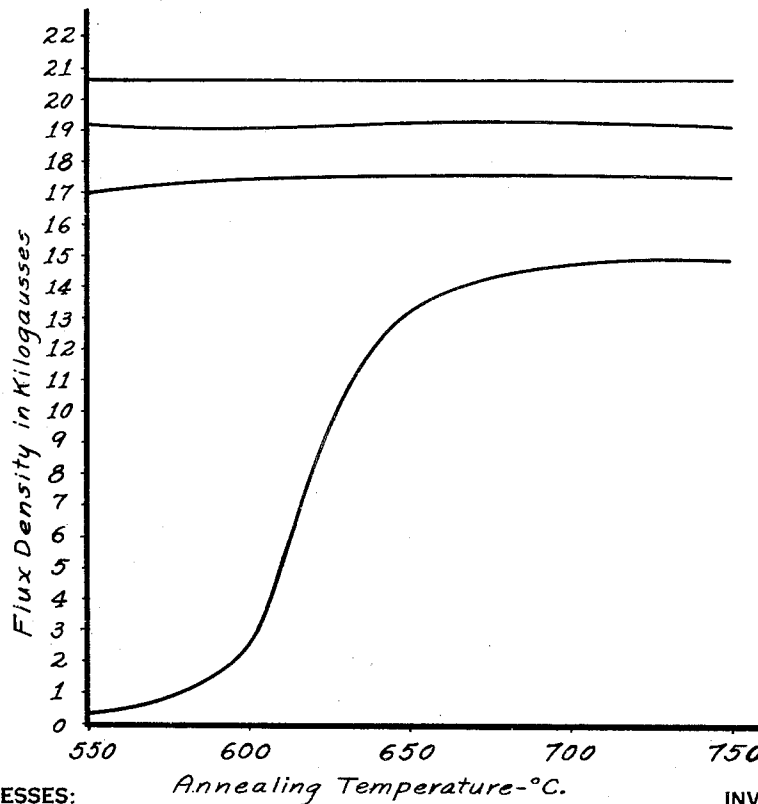
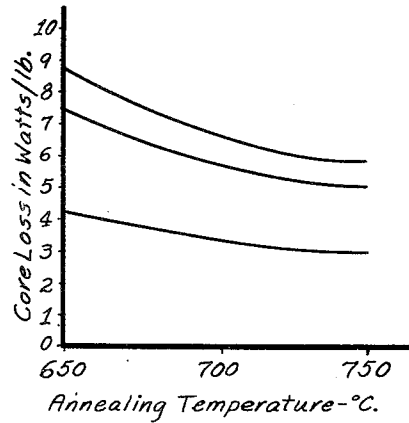


Fig. 4.



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Fig. 5.

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Fig. 6.

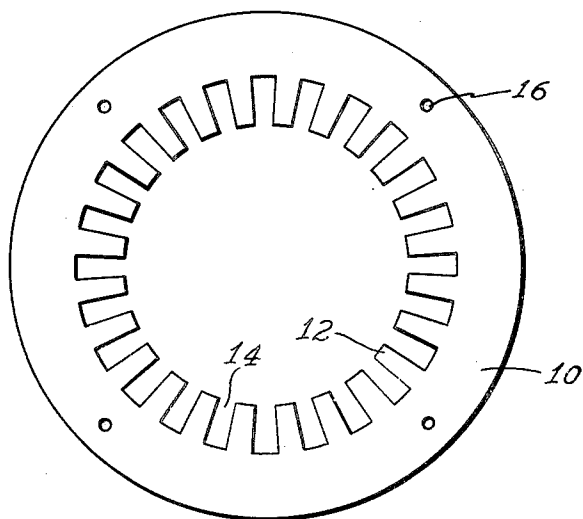
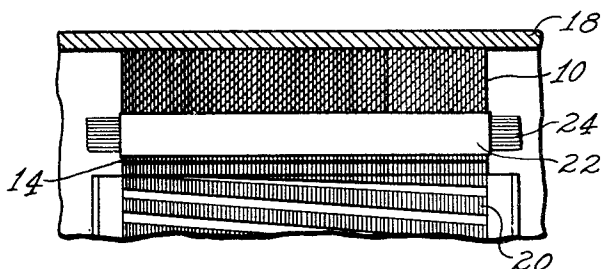


Fig. 7.



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FERROMAGNETIC MATERIAL

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6 Claims. (Cl. 148—21.5)

This invention relates to a ferromagnetic material, more particularly to alloys comprising iron, vanadium and cobalt which have magnetic properties rendering them suitable for cores of electromagnetic apparatus.

Heretofore, alloys of iron and cobalt have been available for use as magnetic material in the manufacture of electrical apparatus. These alloys when heat treated may be operated at high flux densities but in the process of heat treating they are rendered exceedingly brittle. No prior art process is known which produced a material from this type of alloy which was sufficiently ductile for the moving parts of electrodynamic apparatus.

The object of this invention is to provide for a ductile, high permeability, iron-cobalt-vanadium magnetic material having low energy losses when subjected to alternating flux.

The invention, accordingly, comprises the several steps and the relation and order of one or more of such steps with respect to each of the others and the article possessing the features, properties and the relation of elements which are exemplified in the following disclosure and the scope of the application of which will be indicated in the appended claims.

For a fuller understanding of the nature and objects of the invention, reference may be had to the following detailed description taken in connection with the accompanying drawings, in which:

Figure 1 is a graph of the Erichsen draw plotted against annealing temperature for various cobalt vanadium alloys;

Fig. 2 is a graph of flux density plotted against annealing temperature for various cobalt vanadium alloys;

Fig. 3 is a graph similar to Fig. 1;

Fig. 4 is a graph plotting core losses against annealing temperature for the alloy of Fig. 3 at various strength fields;

Fig. 5 is a graph plotting the flux density against annealing temperatures for the cobalt alloy of Fig. 3;

Fig. 6 is a plan view of a single core lamination; and

Fig. 7 is a view partly in section of a fragmentary portion of a motor embodying a plurality of laminations.

The purpose of this invention is the production of a magnetic alloy which has the following characteristics.

(a) It must have a permeability in excess of 200 at $H=100$, together with high saturation induction. Preferably the material should also have a permeability in excess of 1200 at $H=10$.

(b) It must be feasible to work the alloy in sheet, rod or strip form of any predetermined shape to thicknesses of 0.010 inch or less by forg-

ing and/or hot rolling and by cold working; and

(c) The manufactured sheets of the alloy should possess these good magnetic properties after an annealing treatment which provides sufficient ductility to permit assembly and safe operation of moving electrodynamic apparatus

The cobalt alloys of iron as heretofore known in the art would meet one or more of the above desired characteristics, but not all three. In particular, the iron-cobalt alloys available were extremely brittle after annealing to develop their optimum magnetic characteristics. Sheets of such iron-cobalt material were somewhat similar to sheets of glass in their fragility. It was necessary to handle sheets of the alloy with care in assembling electrical apparatus. Vibration and unintentional mishandling could cause the annealed prior art iron-cobalt material to fracture.

It has been discovered that a ferromagnetic material having from 25 to 32% cobalt will satisfy the first requirement hereinabove specified as to magnetic characteristics. If the cobalt alloy is modified with from $\frac{1}{2}\%$ to 3% of vanadium, and from $\frac{1}{4}\%$ to 1% manganese, it may be forged, hot rolled and cold worked into thin plates of the order of 0.010 inch as set forth in the second requirement. In order to impart satisfactory ductility to the material, it has been discovered that a critical heat treatment for this iron-cobalt-vanadium alloy will result in a material having substantially peak magnetic characteristics and impart a considerable improvement in ductility over the available cobalt ferromagnetic material.

The iron, cobalt, and vanadium alloy may be given an improved ductility with the required magnetic properties by subjecting it to a heat treatment ranging from 550° C. to 800° C., in a non-carburizing and non-oxidizing atmosphere such as hydrogen. Referring to Figure 1 of the drawings, there are three curves illustrating the critical effect of such a heat treatment on three different alloys of this type. The 27% cobalt, 2% vanadium and $\frac{1}{2}\%$ manganese alloy curve shown in Fig. 1 discloses a ductility which reaches a peak of $5\frac{1}{2}$ millimeters as measured by an Erichsen draw test for the annealing heat treatment temperatures ranging from 600° C. to 700° C. However, beneficial results are obtained by employing heat treatments ranging from 550° C. to 800° C. The lowest ductility curve plots ductility against various annealing temperatures for a 27% iron-cobalt alloy containing no vanadium. The improvement secured by adding 2% vanadium and annealing in the given range is approximately threefold in some instances. The curve for an alloy containing 30% cobalt and 2% vanadium illustrates an increase in ductility within the 550° C. to 800° C. temperature range. It should be noted that the alloys of iron and

cobalt become more brittle as the amount of cobalt is increased and that the improvement obtained for 30% cobalt ferro-alloy by the heat treatment within this range of 550° C. to 800° C. is quite marked. Similar critical ductility curves may be secured for cobalt-vanadium ferro-alloys ranging from 25% to 32% cobalt plus amounts of vanadium ranging from ½% to 3%.

Referring to Fig. 2 of the drawings, duplicate sets of curves for the alloys of Fig. 1 are plotted for magnetizing forces of $H=10$ and $H=100$ oersteds. The three upper curves illustrate the effect of heat treatment on the three cobalt alloys when $H=100$. As will be noted, the addition of vanadium decreases the permeability of the 27% cobalt alloy. However, the permeability reducing effect of 2% vanadium is approximately compensated for by increasing the cobalt from 27% to 30%. The effect of the various annealing temperatures, however, is not pronounced at these higher flux densities. It is at magnetizing forces of $H=10$ that the effect of heat treatment becomes particularly critical. It will be noticed in the three lower curves of Fig. 2 that the effect of the annealing temperature is extremely critical between temperatures of 500° C. and 600° C. The flux density for practically all of the three examples shown rises from about two kilogausses at 500° C. to well above 13 kilogausses at 600° C. The optimum permeability is reached at temperatures just over 600° C. for $H=10$ oersteds and the curves flatten out thereafter. As will be noted, the effect of vanadium is to cause a decrease in the permeability of the iron-cobalt alloy.

In order to secure the two characteristics set forth in (a) and (c) previously outlined above, it will be seen that the annealing temperatures should exceed 550° C. in order to obtain the desired magnetic characteristics. In order to achieve the maximum possible ductility, the annealing temperatures should range from 600° C. to 700° C.

A complete set of experimental test data on a particular iron-cobalt vanadium alloy is shown in Figs. 3, 4 and 5. In Fig. 3, the ductility as determined by an Erichsen draw test for various annealing temperatures is plotted in a smooth curve. In this particular alloy the vanadium content is approximately 0.95%, with 28% cobalt, 0.3% manganese, and 0.1% silicon. The sheets were approximately 0.015 inch thick. The peak ductility was obtained by annealing at temperatures of from 650° C. to 700° C.

In Fig. 4 is plotted a series of loss curves for the alloy of Fig. 3 for various flux densities at 60 cycles. It will be noted that the core losses increase with flux density as is common with most magnetic materials. It will also be noted that the core loss decreases as the annealing temperature is increased up to 750° C. It is therefore, desirable to anneal at temperatures of about 700° C. to 750° C. in order to achieve minimum core loss where the material is to be used in an alternating current field. Fig. 5 illustrates the magnetic flux density for various magnetizing forces for the alloy of Fig. 3, annealed at different temperatures. As will be noted, when $H=10$, the heat treating temperature is extremely critical below 650° C. Above 650° C., only slight changes take place with change in temperature of anneal. At magnetizing forces of $H=25$ and $H=100$, the effect of the annealing temperature is not very significant.

From curves 3, 4 and 5, it will be seen that

an annealing temperature of approximately 700° C. will give maximum ductility, low core loss and substantially peak flux density for $H=10$.

The iron-cobalt-vanadium alloys having from ½% to 3% vanadium and 25% to 32% cobalt respond markedly to the heat treatment of from 550° C. to 800° C. to give a ductility which is extremely desirable for the making of laminations for moving electrodynamic machinery. The ductility curves, such as are disclosed in Figs. 1 and 3, disclose ductility characteristics which are satisfactory as far as use of this type of alloy for electrodynamic apparatus subject to rotational and vibratory stresses is concerned. The material may be bolted or clamped in building the machinery without fracturing. When in service vibratory stresses or accidental rough handling will not be liable to cause physical failure or fracture of laminae of the alloy.

In producing thin sheets of material of the alloy suitable for laminations such as are shown in Fig. 6, it has been found that the following procedure may be successfully followed. The base material comprises a pure iron such as Armco iron or electrolytic iron which is melted in a refractory pot. Cobalt used for alloying is in the form of rondules which have preferably been pre-annealed in hydrogen for 24 hours to remove carbon and other impurities. The cobalt rondules may contain small traces of nickel which will be carried over into the final product. The cobalt and the desired amount of vanadium is added to the molten iron and the whole is heated until a homogeneous melt is produced.

It has been found that in order to deoxidize the melt and to effect good forgeability and hot rolling, approximately ½ of 1% of manganese should be added to the melt. The manganese may be introduced as ferro-manganese. From ¼% to 1% of manganese may be introduced in order to secure beneficial hot forging properties in the magnetic alloy. Approximately 0.2% silicon may also be added to the melt as an additional deoxidizer. However, the final silicon content of the alloy should be less than 0.1% to achieve the best ductility. The difference in the percent of silicon added and the percent found on analysis is due to the oxidation of the silicon during melting.

It is desirable to maintain the carbon in the alloy as low as possible. By hydrogen annealing the raw materials such as the pure iron and the cobalt rondules before melting, the carbon content thereof may be reduced. The use of good melting practice to prevent contamination of the melt assists in keeping the carbon low. The heat treatment of the laminations of alloy in a hydrogen atmosphere may further eliminate carbon. It is believed that with these precautions the carbon content may be maintained at 0.035% or less.

The melt is cast in metal molds. After cooling, the cast bars are reheated to temperatures of preferably about 1000° C. to 1150° C. and thereafter forged and hot rolled. The hot rolled material possesses sufficient cold workability so that it may be finish-rolled to a smooth surface by cold rolling. The material is cold rolled to final gauge and is thereafter ready for stamping and shaping into the desired type of structure for use. It is slightly cold workable at this stage.

Referring to Fig. 6 of the drawings, there is shown a lamination 10 of the type which may be

readily cut out from a sheet of cold rolled material. The lamination 10 comprises a circular punching having winding slots 14 defined by teeth 12. Apertures 16 are provided for the clamping bolts.

A fragmentary portion of a motor embodying the laminations of Fig. 6 is shown in Fig. 7. The motor comprises an outer casing 18 in which the laminations 10 are placed. The slots 14 hold a slot insulating liner 22 within which a winding 24 is located. A rotor 20 comprises a plurality of other laminations.

The laminations such as shown in Fig. 6 are annealed within a temperature range of 550° C. to 800° C. after stamping but before assembly into the rotor and stator portion of the apparatus of Fig. 7. The annealing treatment will produce the predetermined magnetic characteristics of permeability and low loss and also impart a certain amount of ductility to the laminations of material.

The processed laminations may be heat treated in several ways to bring out their high magnetic permeability and good ductility. A successful heat-treatment was accomplished by loading the laminations into a sealed container which was placed in an annealing furnace. A protective gas atmosphere was secured by introducing hydrogen to the sealed container after the furnace reached 550° C. In some instances other atmospheres which are neutral or reducing may be employed. Cracked ammonia gas is an example. Such atmosphere insures that the laminations come out of the furnace with a clean surface and proper low carbon content.

After the furnace was in operation at a predetermined temperature between 550° C. and 800° C. for a period of time sufficient for the entire container contents to have reached the desired temperature, the heating was stopped. This heating time period has been from 1 to 4 hours. The container was cooled in the furnace until a sufficiently low temperature was reached such that the laminations would not oxidize when exposed to the air. Slow cooling is preferable in order to avoid warping and to prevent strains being set up in the laminations. Other modes of heat treating to secure these results may be used.

Aircraft generators embodying laminations of the alloy of the type above disclosed have been produced with a 10% reduction in weight due to the use of such material. In addition, the non-brittle characteristics of the material produced by this invention have lessened the cost as compared to prior art cobalt alloy laminations. Furthermore the apparatus is less liable to fail under operating conditions. The magnetic characteristics of the material are nearly equal to that produced in the prior art embodying cobalt and vanadium. In addition, the material has an increased ductility which makes the present material more desirable for the intended purpose. The heat treatment is not as critical as that necessitated heretofore.

A series of alloys ranging from 20% cobalt to 55% cobalt and varying proportions of vanadium and manganese have been prepared and tested. It has been found that when the cobalt ranges below 20%, the magnetic properties of the material do not conform to the first requirement (a) above set forth. If the amount of cobalt exceeds 35%, it becomes quite difficult to cold roll and no longer fulfills requirement (b) above set out.

The amount of vanadium has been found to be undesirable if increased over 3%. The perme-

ability characteristics decrease when vanadium reaches over 3%. When the vanadium is under ½ of 1%, the ductility cannot be developed by heat treatment. Another beneficial effect of increased vanadium content is to increase the electrical resistivity of the alloy and thus reduce the eddy current losses when subjected to alternating fields. Therefore, a 2% vanadium alloy is somewhat better for certain uses than vanadium alloys of 1% or lower.

Since certain obvious changes may be made in the above processes and different embodiments of the invention could be made without departing from the scope thereof, it is intended that all matter contained in the above description or taken in connection with the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

We claim as our invention:

1. A high permeability, low loss, cold workable ferrous magnetic material having good ductility composed of 20% to 35% cobalt, ½% to 3% vanadium, ¼% to 1% manganese and the remainder substantially all iron, the material having been heat treated at from 550° C. to 800° C. only after mechanical working to impart predetermined magnetic and ductility characteristics.

2. A high permeability, low loss, cold workable ferrous magnetic material having good ductility composed of 21% to 30% cobalt, ½% to 3% vanadium, ¼% to 1% manganese and the remainder being substantially all iron, the material having been heat treated at from 550° C. to 800° C. only after mechanical working to impart predetermined magnetic and ductility characteristics.

3. A low loss magnetic core having a flux density of over 20,000 gauss at $H=100$, the core comprising laminations of a cold workable ferrous magnetic material composed of 27% to 30% cobalt, ½% to 3% vanadium, ¼% to 1% manganese, and the remainder substantially all iron, the ferrous magnetic material having been heat treated at from 550° C. to 800° C. only after mechanical working to impart the predetermined magnetic properties and to secure good ductility.

4. A low loss magnetic core having a flux density of over 20,000 gauss at $H=100$, the core comprising laminations of a cold workable ferrous magnetic material composed of 20% to 35% cobalt, ½% to 3% vanadium, ¼% to 1% manganese, and the remainder substantially all iron, the ferrous magnetic material having been heat treated at from 550° C. to 800° C. only to impart the predetermined magnetic properties and to secure good ductility.

5. The method of annealing an alloy composed of 27% to 30% cobalt, ½% to 3% vanadium, ¼% to 1% manganese, and the remainder substantially all iron to produce predetermined magnetic characteristics with good ductility and low losses after mechanical working which comprises heat-treating the alloy at temperatures of from 550° C. to 800° C. only in a hydrogen atmosphere.

6. The method of annealing an alloy composed of 20% to 35% cobalt, ½% to 3% vanadium, ¼% to 1% manganese, and the remainder substantially all iron to produce predetermined magnetic characteristics with good ductility and low losses after mechanical working which comprises heat-treating the alloy at temperatures of from 550° C. to 800° C. only in a hydrogen atmosphere.

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