

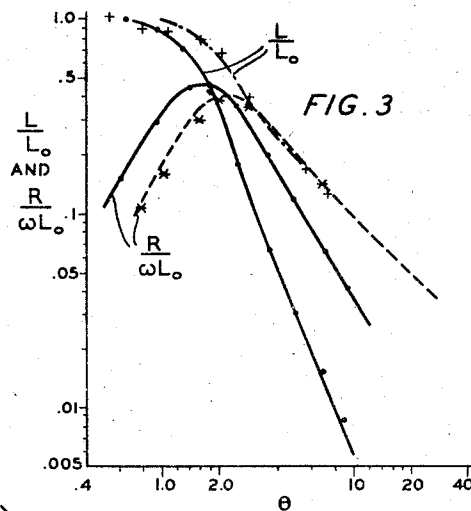
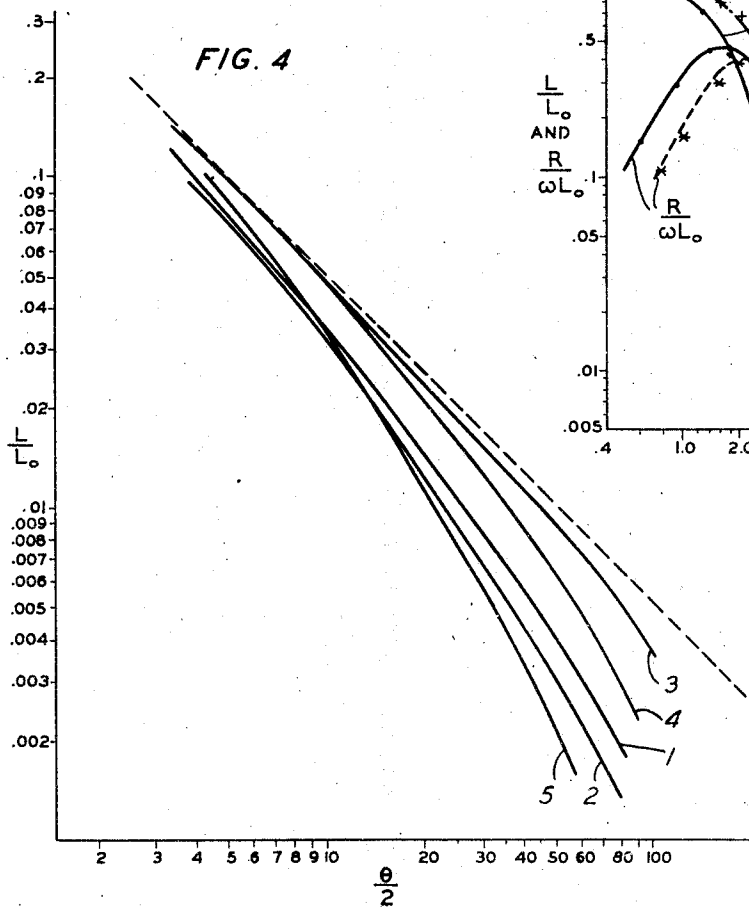
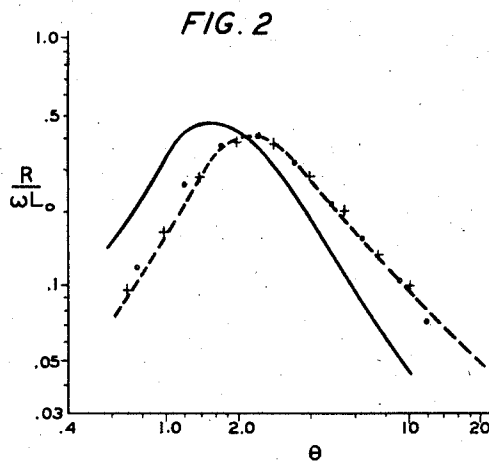
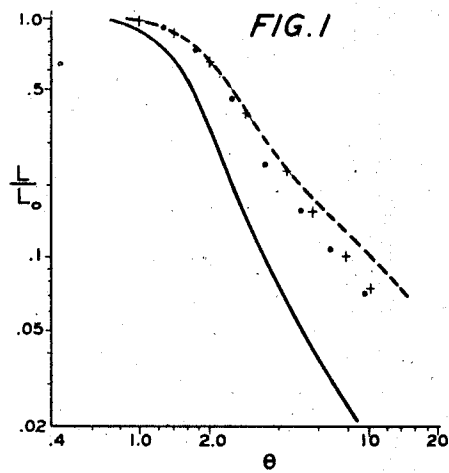
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MAGNETIC MATERIAL AND METHOD OF TREATMENT THEREOF.

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MAGNETIC MATERIAL AND METHOD OF
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This invention relates to a method of treating magnetic materials for use in transformers, loading coils, inductances and for the continuous loading of communication cables.

The object of the invention is to improve the magnetic properties of these materials by removing a surface layer from the completely formed and heat treated material. It also relates to magnetic material so treated and more particularly to alloys of nickel and iron comprising several per cent of a metal of the chromium-molybdenum-tungsten group so treated.

It is well known that due to eddy currents the apparent permeability of magnetic materials decreases while the apparent resistance of a coil surrounding the material increases as the frequency of the alternating current magnetic field to which the material is subjected is increased. A description of an eddy current theory which accounts for some of these changes may be found in "The Theory of Alternating Currents" by A. Russel starting on page 490 of the second edition published in 1914 by the Cambridge University Press. However, in many materials the permeability decreases faster and the resistance increases faster than accounted for by this theory.

A feature of this invention resides in the discovery that the magnetic properties of the material on the surface of magnetic sections made from these alloys are inferior to the magnetic properties of the material in the remainder of the sections.

A further feature resides in the discovery that the magnetic properties of the section are improved by removing the surface layer having the inferior magnetic properties.

Still another feature of the invention is that the magnetic properties of the magnetic materials at high frequencies may be controlled by changing or altering the surface layer of these materials.

In a specific embodiment of the invention, a magnetic alloy of iron and nickel comprising several per cent of a metal of the chromium-molybdenum-tungsten group are worked into final form and heat treated after which the surface layer is removed, preferably by etching off with chemicals.

In another specific embodiment of the invention, the magnetic properties of ferro-magnetic material in high frequency alternating current fields are controlled by applying other materials to the surface of the ferro-magnetic material. A very convenient and effective way of changing

the surface of these materials is to electroplate them with some other metal.

This invention may be more fully understood from the following description of several specific embodiments of the invention when read with reference to the attached drawing in which:

Fig. 1 shows the variation of the inductance as a function of frequency for a coil surrounding magnetic materials treated in accordance with this invention;

Fig. 2 shows variation of the apparent resistance of a coil surrounding magnetic materials treated in accordance with this invention;

Fig. 3 shows variation of both resistance and inductance of a coil surrounding a core of magnetic material treated in another manner in accordance with this invention; and

Fig. 4 shows variation of inductance as a function of frequency variation for these materials when treated in different manners.

The variation of the apparent magnetic property of magnetic material with frequency has been the subject of much study and investigation due to its importance in the various fields of electrical engineering. The variations of these properties cause variations in the apparent inductance and resistance of inductance coils having these materials for cores, as well as constants of continuously loaded communication cables which have these magnetic materials wound about them. These variations also affect the constants of transformers and other electrical apparatus employing cores and magnetic structures of these materials.

A large proportion of the change has been found to be due to eddy current shielding, the theory of which takes forms varying widely in complexity, depending upon the shape of the material in which the eddy current is induced, and the nature of the impressed magnetic field, as well as the electrical and magnetic properties of the material in which these eddy currents are induced. The theory assumes a comparatively simple form in the particular case of a homogeneous flat plate of magnetic material in the form of a sheet having a constant permeability and subjected to a sinusoidal magnetizing force. The results of computation based upon this theory, to be more fully explained hereinafter, may be closely approximated in the magnetic cores of ordinary transformers, inductance coils, and the loading material applied to communication cables where the ratio of lamination width is small. In the case of cores made up of an-

nular rings it is necessary, in addition, that the ratio of lamination width to core radius be small. In addition, the magnetizing force to which the material is subjected must be sufficiently small to render non-linear effects negligible.

Details of the comparatively simple theory mentioned above may be found in Russel as previously pointed out or in an article by K. L. Scott published in "Proceedings of the Institute of Radio Engineers", vol. 18, pp. 1750-1764, October 1930 where equations similar to the following ones are developed

$$\frac{L}{L_0} = \frac{1}{\theta} \cdot \frac{\sinh \theta + \sin \theta}{\cosh \theta + \cos \theta} \quad (1)$$

and

$$\frac{R}{\omega L_0} = \frac{1}{\theta} \cdot \frac{\sinh \theta - \sin \theta}{\cosh \theta + \cos \theta} \quad (2)$$

and the parameter θ is given by

$$\theta = 2\pi \cdot 2\delta \sqrt{\mu \gamma f}$$

where L and R are the apparent inductance and resistance, respectively, of a coil due to the laminated core about which the coil is wound, L_0 is the inductance of the coil due to the core at zero frequency, 2δ is the thickness of the core laminations in centimeters, γ is the conductivity in micromhos per cubic centimeter, and f is the frequency in kilocycles which is equal to $\omega/2\pi \cdot 10^3$. θ is also equivalent to the term $2a/S$ employed by Scott.

The broken curves of Figs. 1 to 4 show the variation of the apparent inductance and resistance of a coil due to the laminated core about which it is wound which is in accordance with Equations 1 and 2. It is to be noted that as the frequency increases, that is, as θ exceeds a value of say 2, the inductance and resistance rapidly decrease. As hereinafter referred to "high frequency" means that the value of θ exceeds a value of about 2.

In general the magnetic properties of ferromagnetic materials may or may not vary in accordance with these equations and curves. The magnetic properties of some laminations may vary in accordance with these curves while in other laminations having substantially the same composition the magnetic properties may not vary in accordance with this theory. The previous working and heat treatment seem to alter the variations in most materials. For example, in some specimens of silicon steel the variations in the magnetic properties seem to follow these equations while in other specimens they do not. In certain tests of some materials such as silicon steel; hydrogenized silicon steel; nickel; alloys comprising approximately 45% nickel, 25% cobalt, and 30% iron; and other alloys comprising approximately 78% permalloy and 22% iron, when worked and heat treated in the usual manner the magnetic properties varied in accordance with these curves and with this theory, within the limits of experimental errors.

In other tests the magnetic properties of other materials including soft iron; and alloys comprising 45% nickel, 55% iron; approximately 78% nickel, 3.8% molybdenum and the remainder iron; and approximately 78% nickel, 3.8% chromium and the remainder iron when worked and heat treated in the usual manner vary much more rapidly with frequency than shown by these broken curves which are drawn in accordance with the simple theory. The alloy comprising approximately 78½% nickel, 3.8% chromium and the remainder iron, exhibited a much larger

discrepancy than any of the other materials. The manner in which the inductance and resistance vary with frequency for this particular alloy is shown by the solid curves in Figs. 1 and 2. In Fig. 2 it should be noted that a comparatively low frequency, that is for values of θ less than say 2, the apparent resistance is almost twice as high as expected from the theory.

The deviations from the simple theory were found to depend upon the thickness of the lamination, being larger the thinner the lamination. It was also noted that the initial permeability, as measured at frequencies at which eddy current effects are negligible, of a given material is reduced as the lamination thickness is reduced by the usual rolling process. For this particular alloy which comprises approximately 78½% nickel, 3.8% chromium and the remainder iron the initial permeability of laminations having a thickness of 0.014 inch was over 9000, while for laminations having a thickness of less than 0.001 inch the initial permeability fell to below 1000. The specific resistivity of the material remains practically constant over this range of thicknesses.

These observed facts may be accounted for by assuming a thin layer of low permeability material on the surface of the lamination. Such a layer would have but relatively little effect on the initial permeability of a thick sheet but in the extreme case in which the sheet is rolled down until only the low permeability surface layer remains the initial permeability of the sheet would be reduced to the low permeability of the surface material.

To determine whether or not a surface layer having different magnetic properties actually existed the surfaces of the materials exhibiting the rapid change of apparent magnetic properties with frequency were removed by etching with chemicals. It is to be understood that other methods, such as electrolytic means, for example, can be used to remove the surface layer. In most cases the thickness of the surface layer removed was two mils or more and in every case the initial permeability of the laminations so treated was increased and, in addition, the magnetic properties varied with frequency very nearly in accordance with the broken curves. This is illustrated in Figs. 1 and 2 by the circles which show the variations of the magnetic properties with frequency of the same material as employed to obtain the solid curve, after a layer .002 inch had been etched off the surface of the material. The crosses show the variations of the magnetic properties with frequency after an additional layer .0005 inch had been etched off the surface.

The curves of Fig. 4 illustrate the effects of various methods of treating laminations of an alloy of 78% nickel, 3.8% chromium and the remainder iron on the variation of the magnetic properties with frequency. The broken curve illustrates the relation to be expected from the simple theory. Curve 1 shows the actual variation as the material is received after its final rolling operation. The material was then annealed and the measurements again made which are illustrated by curve 2. A layer of 0.002 inch was then etched off the surface of the material and the magnetic properties again measured. The values of the magnetic constants then coincided rather closely with the theoretical curve as shown by curve 3. The laminations were then again annealed after which the magnetic characteristics is given by curve 4. The laminations were then rolled and again annealed after which the

magnetic properties varied in accordance with curve 5. Thus, it is seen that the constants of the surface material such as its thickness and magnetic properties are materially affected by both heat treating and mechanically working the material. From these curves it may be seen that when these materials are applied to transmission conductors for loading them some improvement may be expected if the surface layer of the loading material is removed and then the material applied to the conductor after which the loaded conductor is heat treated. Thus the material is obtained in the desired form for loading the conductor, the surface layer is removed after which the material is applied to the conductor and then finally heat treated.

It was noted that after approximately 0.002 inch of the surface has been etched off by chemicals, the rate of the chemical action is noticeably increased which indicates that this material has a surface layer having different properties. Since there appears to be no simple way of determining the constants of the two different materials in the laminations, further information relating to such laminations was obtained by taking a material such as silicon steel in which the variation of the magnetic properties with frequency corresponded to the above simple theory and surrounding these laminations with a thin layer of foil or sheet of another material and then observing the variation of the magnetic properties with frequency. Fig. 3 illustrates the variation of the magnetic properties of silicon steel when treated in accordance with this procedure. The broken curves illustrate the variation of the magnetic properties with frequency for the silicon steel alone and correspond very closely with the values derived from Equations 1 and 2. The laminations were then electroplated with a layer of copper 0.0003 thick after which the magnetic properties of these laminations are illustrated by the solid curves of Fig. 3. It should be noted that these curves are very similar to those obtained for any alloy of 78% nickel, 3.8% chromium and the remainder iron as shown in Figs. 1 and 2.

It may be noted that by changing the surface layer of these laminations by electrodepositing some other material upon them or by surrounding them with a metallic foil of some material the magnetic properties may be materially altered, particularly at the higher frequencies. Thus, it is possible to control the magnetic properties of laminations by altering the surface of these laminations. In certain materials if it is desired to increase the permeability at the higher frequencies, a portion of the surface is removed, as illustrated by the curves of Figs. 1 and 2, or if it is desired to reduce the permeability of the laminations at the higher frequencies the surface of the material is electroplated or surrounded in some other manner by a second material which will give the desired magnetic property.

The magnetic properties of these composite laminations may be calculated by starting with the same equations as before and, by assigning appropriate boundary conditions, a complicated answer may be obtained. Also, if desired, the laminations may be considered analogous to a transmission line or filter which may be solved and an equally complex complicated solution obtained. In this connection see the article by Howe in J. I. E. E., vol. 54, No. 258, 1916, for a detailed description of this method of solution in which the laminations are considered similar to a transmission line. Thus by making plausible

assumptions relating to the properties of the two layers suitable equations and curves may be obtained which duplicate experimental curves.

The above description of several specific examples of the invention is for the purpose of illustrating the features, but is not to limit in any way the scope of the invention as defined in the following claims.

What is claimed is:

1. The method of producing magnetic material of improved magnetic properties from material which after heat treatment has a surface layer causing the body of material to have less satisfactory properties than desired which comprises producing the magnetic material in substantially the desired final form, heat treating the material, then removing an appreciable surface layer of the finally formed heat treated material.

2. A method of altering the magnetic properties of ferro-magnetic materials in high frequency magnetic fields, which comprises reducing the material to the desired thickness, heat treating the material and then removing the surface layer of the finally formed and heat treated material.

3. A method of improving the magnetic properties of ferro-magnetic materials which comprises securing the material in the desired form and then etching the surface layer off with chemicals.

4. The method of altering the high frequency magnetic properties of ferro-magnetic materials in the form of thin sections which comprises working the material into the desired sections, heat treating the magnetic sections and then removing the surface layer of the thin sections of the finally formed and heat treated material.

5. A method of improving the magnetic properties of thin sheets of magnetic alloys of the type comprising alloys of iron and nickel with several per cent of a metal of the chromium-molybdenum-tungsten group which comprises working the alloy into the desired form, heat treating the alloy and then etching off a surface layer of the finally prepared and heat treated alloys with chemicals.

6. A method of controlling the high frequency magnetic properties of ferro-magnetic material for loading communication cables which comprises working the material to the desired form for loading the cable, then removing the surface layer of the material, then applying the material to said cable, and finally heat treating the composite structure.

7. A method of improving the magnetic properties of magnetic alloys of the type comprising alloys of iron and nickel with several per cent of the chromium-molybdenum-tungsten group for loading electrical communication conductors which comprises obtaining the alloy in a desired form, removing the surface layer of the finally prepared alloy, then applying the alloy to said conductor, and finally heat treating the composite structure.

8. A method of altering the high frequency magnetic properties of magnetic structures which comprises first producing the magnetic structure in form for use and then removing the surface layer of said magnetic structure.

9. A method of improving magnetic properties of laminated magnetic structures comprising alloys of the type having several per cent of iron and nickel with several per cent of a metal of the chromium-molybdenum-tungsten group, which

comprises securing laminations of the desired composition and structure, heat treating said laminations and then removing a surface layer from each of said laminations.

5 10. Laminations for cores of high frequency magnetic apparatus, the surface layer of which has been removed.

11. A magnetic material in the form of sheets comprising an alloy of nickel and iron with several per cent of a metal of the chromium-molybdenum-tungsten group which has a thin surface layer etched off.

12. Laminations for magnetic cores comprising an alloy of iron and nickel with several per cent of a metal of the chromium-molybdenum-

tungsten group from which a thin surface layer has been removed.

13. Magnetic loading material for a communication cable comprising an alloy of nickel and iron with several per cent of a metal of the chromium-molybdenum-tungsten group which has been finally formed and heat treated and has had its surface layer removed.

14. In methods of preparing magnetic materials the final step which comprises removing the surface layer of said materials.

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