June 24, 1930. G. W. ELMEN 1,768,443

MAGNETIC MATERIAL AND APPLIANCE

Filed July 12, 1926 3 Sheets-Sheet 1

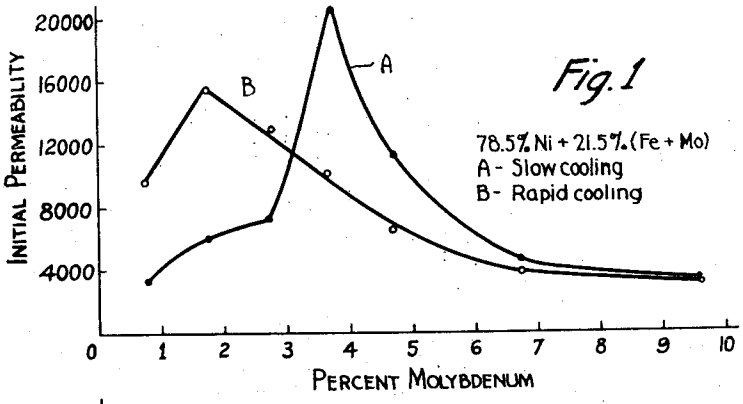


Fig. 1

78.5% Ni + 21.5% (Fe + Mo)
A - Slow cooling
B - Rapid cooling

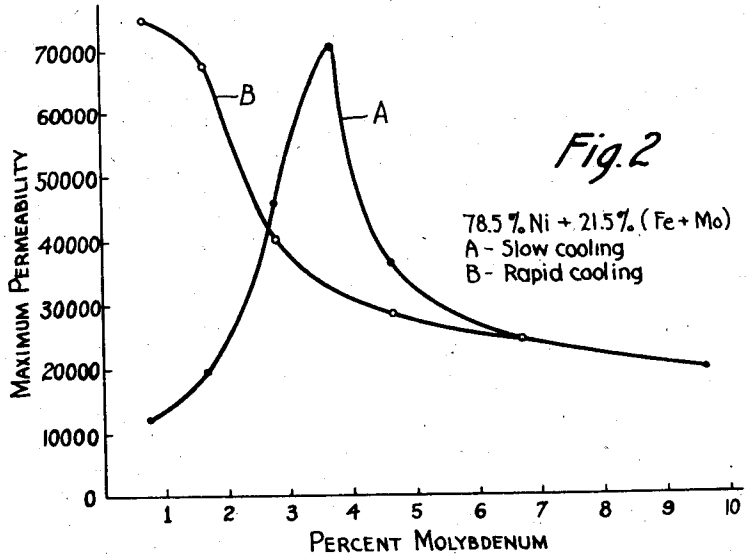


Fig. 2

78.5 % Ni + 21.5 % (Fe + Mo)
A - Slow cooling
B - Rapid cooling

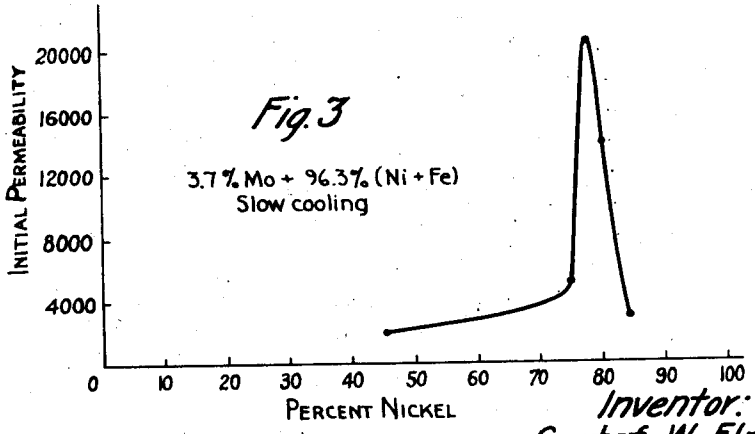


Fig. 3

3.7 % Mo + 96.3% (Ni + Fe)
Slow cooling

Inventor:
Gustaf W. Elmen

by W. Griggs Atty.

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MAGNETIC MATERIAL AND APPLIANCE

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Fig. 4

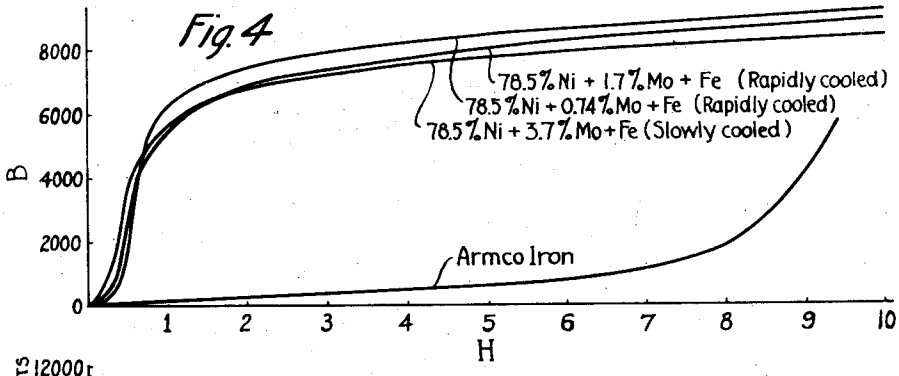
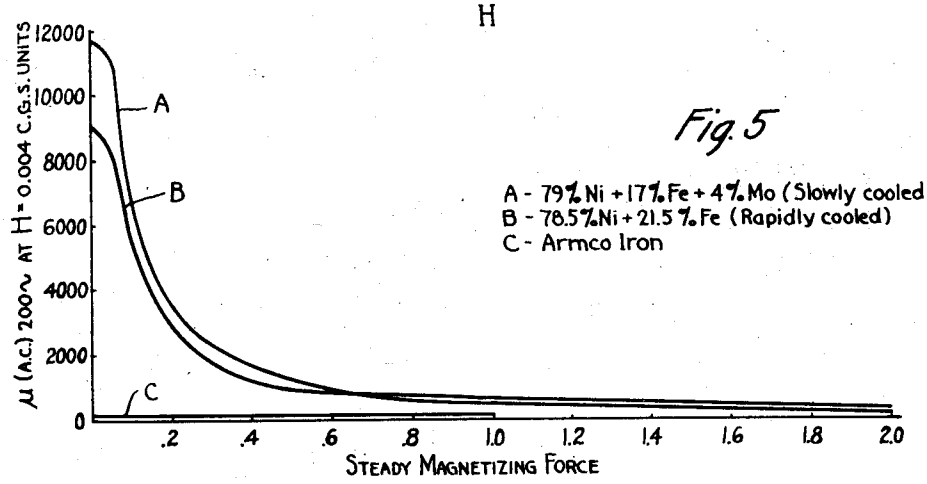
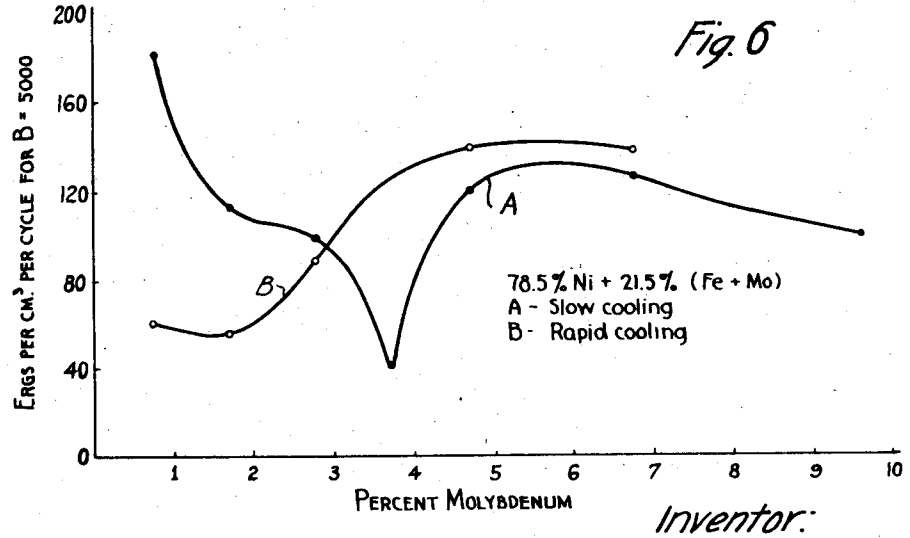


Fig. 5



A - 79% Ni + 17% Fe + 4% Mo (Slowly cooled)
B - 78.5% Ni + 21.5% Fe (Rapidly cooled)
C - Armco Iron

Fig. 6



Inventor:
Gustaf W. Elmen

by E. W. Griggs Atty.

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MAGNETIC MATERIAL AND APPLIANCE

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Fig. 7

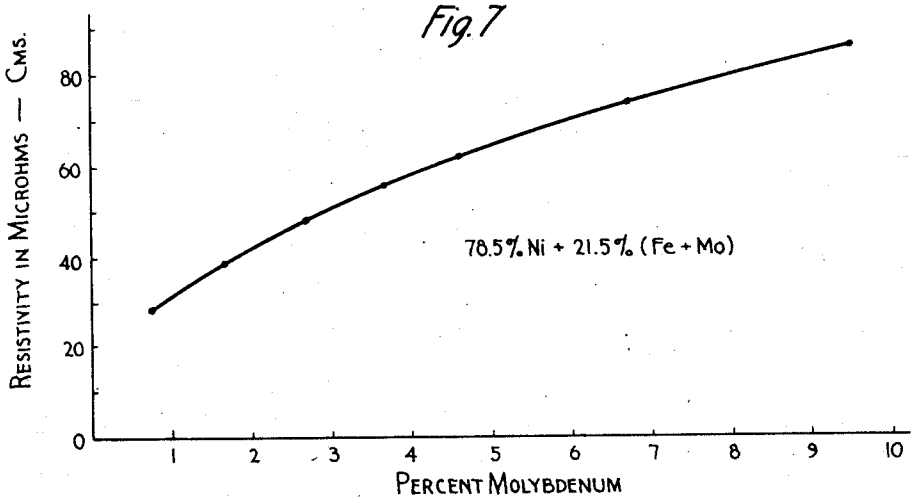


Fig. 8

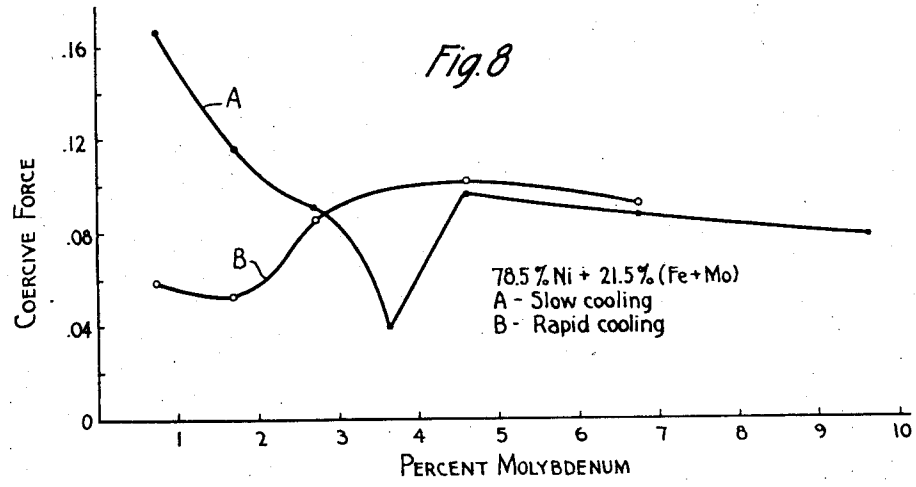
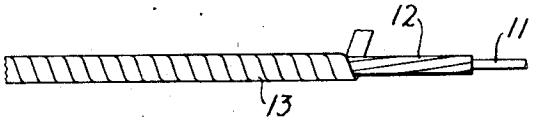


Fig. 9



Inventor:
Gustaf W. Elmen

by W. Griggs Att'y.

Patented June 24, 1930

1,768,443

UNITED STATES PATENT OFFICE

GUSTAF W. ELMEN, OF LEONIA, NEW JERSEY, ASSIGNOR TO WESTERN ELECTRIC COMPANY, INCORPORATED, OF NEW YORK, N. Y., A CORPORATION OF NEW YORK

MAGNETIC MATERIAL AND APPLIANCE

Application filed July 12, 1926. Serial No. 121,830.

This invention relates to magnetic materials and electromagnetic systems. It has wide application and is especially useful where the impressed magnetizing forces are small, as in signaling systems.

Among the important characteristics of the material of this invention are high permeability, especially at low magnetizing forces, small hysteresis and high resistivity.

As a material the invention has its embodiment in magnetic compositions containing molybdenum, preferably with nickel and iron. The proportions of the ingredients and the treatment of the material may be varied to emphasize one or more of its characteristics.

This application is in part a continuation of application Serial No. 48188, filed August 5, 1925.

Magnetic materials have been variously employed in electrical systems for such purposes as the cores of loading coils, transformers, magnetic modulators, etc., for tractive electromagnets, dynamos, motors, telephone receivers, telegraph relays, etc. Magnetic materials have also been employed for the continuous loading of signaling conductors, but, until recently, this use has been limited to relatively short cables for telephone purposes. Heretofore the magnetic materials generally used for these purposes have been soft iron and silicon steel. Recently, however, alloys consisting chiefly of nickel and iron have been employed to great advantage, particularly in connection with signaling systems and apparatus, in which the magnetic forces involved seldom exceed .2 gauss. Such alloys and the method of producing them are disclosed in U. S. Patent 1,586,884, issued June 1, 1926, and in applicant's copending application, referred to above.

The magnetic materials of this invention are peculiarly suitable for loading signaling conductors and more especially long submarine telegraph cables.

The invention will be more clearly understood by reference to the accompanying drawings in which:

Fig. 1 indicates the change in initial permeability of alloys containing nickel, iron and molybdenum when the molybdenum content and the iron content are varied and the nickel content is kept at 78½% of the nickel-iron-molybdenum content;

Fig. 2 indicates the change in maximum permeability of alloys containing nickel, iron and molybdenum when the molybdenum content and the iron content are varied and the nickel content is kept at 78½% of the nickel-iron-molybdenum content;

Fig. 3 shows the change in initial permeability of alloys containing nickel, iron and molybdenum when the molybdenum content is 3.7% of the nickel-iron-molybdenum content, and the nickel and iron are present in varying proportions;

Fig. 4 gives B—H curves for various nickel-iron-molybdenum alloys and for Armco iron;

Fig. 5 indicates the permeability of various alloys of this invention for a small constant alternating magnetizing force when a steady force, varied in steps, is superimposed thereupon;

Fig. 6 shows the variation in hysteresis loss with varying molybdenum content at an induction of 5000 for certain alloys of this invention in which the nickel content is 78½% of the nickel-iron-molybdenum content;

Fig. 7 indicates the specific resistance of certain alloys of this invention in which the nickel content is 78½% of the nickel-iron-molybdenum content;

Fig. 8 shows coercivity curves for various nickel-iron-molybdenum alloys.

Fig. 9 is a side elevation of a signaling conductor loaded with the magnetic material of this invention in the form of tape.

In Fig. 1 of the drawings the curves indicate the effect on the initial permeability of a magnetic alloy comprising 78½% nickel and 21½% (iron-plus-molybdenum) when the molybdenum content is increased from a very small initial value and the iron content is correspondingly decreased. The heat treatment to which each alloy is subjected controls the characteristics of the resulting

product to a large measure. Thus curve A represents the change in initial permeability with change in molybdenum content of this series of alloys after having been heated to a temperature of 1100° C. and then cooled slowly. Curve B is a similar curve for the same alloys given a heat treatment which consists in annealing at 1100° C. and subsequently reheating to a temperature of approximately 600° C. and then cooling rapidly. If desired, the equivalent of this heat treatment may be obtained by heating to 1100° C., cooling slowing to 600° C. and cooling rapidly to room temperature.

With the heat treatment for which the data for curve A were obtained, the highest initial permeability attained was over 20,000. This value was obtained in an alloy containing about 3.7% molybdenum, 78.5% nickel and 17.8% iron. Curve B, representing alloys which are given the heat treatment with rapid cooling, shows that the highest initial permeability obtainable with this particular treatment occurs with an alloy containing about 1.5% molybdenum, 78.5% nickel and 20% iron. It is seen from the curves that those alloys of this series having from about 1% to 5% molybdenum and 78½% nickel were given an initial permeability of over 10,000. Furthermore, a higher initial permeability was attained with alloys containing from approximately 1% to 3% molybdenum when given a heat treatment with rapid cooling, whereas slow cooling produced higher initial permeability in alloys containing approximately 3% or more of molybdenum. The initial permeability of over 20,000, obtained with the alloy containing 3.7% of molybdenum is higher than has heretofore been attained with any magnetic material known and approximately forty times that of good grades of silicon steel or sixty times that of soft iron such as is now commonly employed for electromagnetic purposes.

The heat treatments used in obtaining data for curves A and B of Fig. 1 will now be discussed. The same treatments were used for obtaining the data upon which the curves of the other figures are based.

A preliminary investigation indicated that the highest initial permeability obtainable in this series of alloys could be obtained with about 3.5% of molybdenum when given the heat treatment involving slow cooling; that the rate of cooling when slow could be varied within quite wide limits without greatly affecting the characteristics, and that, as the molybdenum content is decreased below about 3.5%, the optimum rate of cooling increases. A more thorough investigation of the optimum rate of cooling with about 3.5% of molybdenum was made, which verified the results earlier obtained. It was found that, except when the rate of cooling is very slow, such as that used in obtaining data for curve A of Fig. 1, the optimum rate should be determined in each case, curve B representing but one rapid rate which may be used (the one which gives highest initial permeability in an alloy comprising nickel and iron alone in the ratio of 78½% nickel to 21½% of iron). In general, the optimum rate is a slower rate than that used to obtain curve B. It varies not only with the composition but with the size and form of the sample. While less variation is present with slow cooling rates, the very best results can be obtained only by determining the optimum rate in each case.

The heat treatment involving slow cooling was performed as follows. The sample of the alloy, prepared in the form hereinafter described, was placed in an annealing pot, and, after the usual precautions were taken to prevent oxidization during annealing, was heated in an electric furnace to a temperature around 1100° C. and was maintained at that temperature for about one hour. The furnace with the annealing pot therein was then allowed to cool to about 70° C. before removing the sample. This cooling required approximately 16 hours. Measurements with a thermocouple in contact with the annealing pot indicated that about 3 hours were required for the pot to cool from 1100° C. to 350° C.

The heat treatment involving rapid cooling was that developed for obtaining high initial permeability in nickel-iron alloys containing 78½% nickel and 21½% iron. See the paper entitled "Permalloy" by H. D. Arnold and G. W. Elmen, Journal of the Franklin Institute, May, 1923, and an application of G. W. Elmen, Serial No. 41,490, heat treatment of magnetic material, filed July 6, 1925. In accordance with this treatment the samples were heated at about 1100° C. for about one hour and allowed to cool slowly, being protected from oxidization throughout these processes; then reheated to around 600° C., quickly removed from the furnace and laid upon a copper plate which was at room temperature.

The magnetic properties of the materials of this invention are, like those of many of the alloys containing nickel and iron alone, subject to change under the influence of mechanical strains. Due precautions must therefore be taken in the utilization of these alloys to avoid excessive strains and stresses. Likewise, when rapid cooling is employed, internal stresses great enough to vary the magnetic properties may be introduced. For this reason uniform results may be more easily obtained with heat treatments involving slow cooling. As the molybdenum content of this series of alloys is increased from zero up to around 3½% the rate of cooling necessary to develop the magnetic properties

which are ordinarily desired decreases, as is indicated by the curves of several of the figures. The addition of molybdenum to nickel and iron in high permeability alloys therefore not only improves the magnetic properties of the material but enables a more uniform product to be obtained without the introduction of costly refinements in the process of manufacture.

Fig. 2 shows graphically the change in maximum permeability of an alloy containing 78½% nickel and 21½% (iron-plus-molybdenum) when the molybdenum content was increased and the iron content correspondingly decreased, curves A and B indicating heat treatments involving slow cooling and rapid cooling respectively, as in Fig. 1. It will be noted that higher maximum permeability was obtained with the heat treatment involving rapid cooling for alloys having about 3% or less of molybdenum whereas a heat treatment employing slow cooling gave higher maximum permeability for alloys having higher percentages of molybdenum. As indicated by the curves, an alloy containing 1% of molybdenum had a maximum permeability of either 12,000 or 75,000 depending upon which of the two heat treatments was employed. In the alloy containing about 3.7% molybdenum a maximum permeability of over 71,000 was attained at a field of about .06 gauss.

As in the case illustrated in Fig. 1, the rapid rate of cooling employed in obtaining the data for curve B is the one which gives highest initial permeability in an alloy containing nickel and iron alone in the ratio of 78½% nickel and 21½% iron. It represents roughly an upper limit to the rate of cooling desirable with alloys of this series. As stated above, the optimum rate of cooling should be determined in each case.

Fig. 3 indicates the initial permeabilities of a series of alloys containing about 3.7% molybdenum with the balance nickel and iron, the nickel content being varied while keeping the molybdenum constant, the heat treatment involving slow cooling as for curve A of Fig. 1. It was found that the alloy containing 78.2% nickel had the highest initial permeability and that within a range of a few per cent increase or decrease of the nickel content the initial permeability decreased rapidly.

Fig. 4 shows the magnetization or B—H curves obtained for samples of several of these alloys together with the corresponding curve for a characteristic sample of Armco iron. It will be seen that the permeability of the alloys at low magnetizing forces is very great as compared with iron, that saturation is approached at relatively low field strengths and that the knees of the curves are sharp. It will be seen also that the curve for the alloy having about 3.7% molybdenum rises more steeply from the origin than those for the alloys having a smaller amount of molybdenum. The heat treatment to which the sample of alloy containing about 3.7% molybdenum was subjected was that in which the material is slowly cooled, as for curve A of Fig. 1, while the heat treatment employed for the other alloy samples was that involving rapid cooling, as for curve B of Fig. 1.

The curves of Fig. 5 are permeability curves for a 200 cycle alternating magnetizing force of 0.004 gauss when superimposed upon a steady force varied in steps from 0 to 2 gauss. Curve A is for a sample of an alloy containing about 4% molybdenum, 79% nickel and the remainder iron, the heat treatment being that involving slow cooling as for curve A of Fig. 1. Curve B is for a nickel-iron alloy having a composition of 78½% nickel and 21½% iron and subjected to a heat treatment involving rapid cooling as for curve B of Fig. 1. Curve C is for Armco iron. From these curves it is seen that the sample of material containing nickel, iron and molybdenum has higher permeability for alternating magnetizing force at low magnetizing forces than the nickel-iron alloy and very much higher than Armco iron.

In Fig. 6 the hysteresis loss of these alloys at an induction of 5000 is shown by curves A and B, the curve A representing alloys given a heat treatment with slow cooling, and curve B representing alloys given a heat treatment with rapid cooling, the respective rates of cooling being those employed in obtaining curves A and B of Fig. 1. While the hysteresis loss in no case exceeds 180 ergs per cycle, per c. c., it may be kept well below 100 ergs for alloys containing approximately 4% or less of molybdenum by properly choosing the heat treatment. In the case of the alloy containing approximately 3.7% molybdenum and slowly cooled, the hysteresis loss at B=5,000 is about 40 ergs, per cycle, per c. c. The curve for the rapidly cooled sample also has a minimum point—that corresponding to a composition of about 1.5% molybdenum.

As indicated in Fig. 7, the resistivity of alloys of nickel, iron and molybdenum is high as compared with that of iron, the specific resistance ranging from 28 to 86 microhm-cms. for alloys containing from 0.75% to 10% molybdenum, 78½% nickel and varying percentages of iron. The resistivity of the 3.7% molybdenum alloy referred to above is 56 microhm-cms. This comparatively high resistivity is characteristic of all nickel-iron-molybdenum alloys which have been investigated.

In Fig. 8 the curves indicate the effect on

the coercivity of a magnetic alloy comprising 78½% nickel and 21½% (iron-plus-molybdenum), when the molybdenum content is increased from a small initial value and the iron content correspondingly decreased, the coercive force readings being taken after a magnetizing force of 100 gauss had been applied, which nearly or quite saturated the material. Curve A is for alloys given a heat treatment with slow cooling and curve B is for alloys given a heat treatment with rapid cooling, the respective rates of cooling being those employed in obtaining the data for curves A and B of Fig. 1. It is seen that the points of these curves representing minimum coercivity correspond approximately to the points representing maximum initial permeability of Fig. 1 and the points representing minimum hysteresis of the curves of Fig. 6. The minimum value of coercive force obtained with the slowly cooled material was less than 0.04 gauss and was obtained with the sample containing 3.7% molybdenum.

The material when heat treated and tested to obtain the data given above was in the form of samples prepared as follows:

Good commercial grades of the materials to be used were fused together in a furnace, a fraction of a percent of manganese being added to increase workability. The molten composition was then poured into a mold to form a thick rod. The rod after being taken from the mold was subjected to rapid repeated swaging and annealing operations by which it was reduced in diameter and correspondingly elongated. The long rod thus formed was then drawn out by repeated drawing and annealing operations to a fine gauge wire and formed into a thin tape 0.125" wide and 0.006" thick by passing it between flattening rolls. A length of tape thus prepared was wound on a mandrel about 2½ inches in diameter so as to form a loosely wound, flat, spiral ring of about 40 turns. This ring had an inner diameter of about 2½ inches and an outer diameter of about 3 inches and a thickness of ⅛ inch.

The preferred coompositions of this invention are those described above in detail. An example of compositions in which molybdenum is added to magnetic material other than nickel-iron compositions is: nickel 93.5% and molybdenum 5.27%, with impurities in the form of iron 0.49%, cobalt 0.64% and very small amounts of other elements. When this composition was formed into a ring sample of the form herein described and given a heat-treatment with slow cooling as described above for curve A of Fig. 1, the initial permeability was found to be about 500, the maximum permeability was about 1800, the hysteresis loss for an induction of 2850 was about 290 ergs per c. c. per cycle, the specific resistance was about 33 microhm-cms., and the coercive-force after a magnetizing force of 26 gauss was applied was 0.36 gauss. Thus the addition of the molybdenum to nickel in this sample resulted in an initial permeability about two and one half times and a resistivity about three times that of nickel alone, and considerable improvement over nickel with respect to the other properties mentioned also was effected.

Fig. 9 shows a section of an inductively loaded submarine cable conductor consisting of a stranded conductor No. 5 B. and S. gauge, comprising a central copper strand 11 surrounded by spirally wound copper strands 12 and having a layer 13 of inductive loading consisting of a helically wound tape of the material of this invention. This tape was formed in the same manner as the tape employed in the ring test samples described above and had the same dimensions. On account of the ease with which this material is affected by the earth's magnetic field, it may be desirable in continuous loading to apply it in the form of wire rather than tape. When the loading material is to be used in the form of wire rather than tape, the drawing process is continued until the wire has a desired diameter. The surrounds 12 are six in number and are shaped to fit together closely to form a cylindrical annulus about the central wire.

A loaded conductor of the form shown in Fig. 9 has been heat treated as follows:

The loaded conductor was drawn lengthwise through a furnace of the type described in U. S. patent to G. W. Elmen No. 1,586,884, issued June 1, 1926. This is an electric furnace of the muffle type having a horizontal iron tube extending through the furnace and projecting a considerable distance beyond. This tube has a copper lining the inside diameter of which is somewhat larger than the outside diameter of the loaded conductor. The conductor was passed through the tube at the rate of about ¼ foot per minute with the furnace held at a temperature of 1000° C. Cooling of the conductor took place in part in the projecting end of the iron tube and in part in the air outside the tube, which was at about normal room temperature, that is, about 20° C. This gave a slow rate of cooling of the order of that discussed above in connection with Fig. 1. An effective permeability of the loading material upon the conductor of about 10,000 was obtained. The optimum rate of cooling varies somewhat with the dimensions and the form of the conductor and loading material and for best results should be determined in each case. For further details regarding the loading of submarine signaling conductors, reference is made to the following:

Patents to G. W. Elmen Nos. 1,586,884, 1,586,887, patented June 1, 1926 and patent

to O. E. Buckley No. 1,586,874, patented June 1, 1926.

The improved magnetic material of this invention is, of course, useful also for inductively loading signaling conductors employed in land lines and for electrical purposes generally, wherever the magnetizing forces are low. The material may also be employed with high magnetizing forces although its advantages then are, generally speaking, not so great. For the purposes of this specification the magnetic elements are considered to include iron, nickel and cobalt. The expression "initial permeability of iron" as used herein refers to the state of the art at the time of filing the present application in the U. S. Patent Office.

What is claimed is:

1. A magnetic material containing iron, nickel over 40% of the entire iron-nickel contents, and a material amount but less than 10% of molybdenum and having higher initial permeability than iron.

2. A magnetic material comprising iron, nickel and molybdenum as essential elements thereof, at least 40% of the entire iron-nickel content being nickel.

3. A magnetic material comprising at least two elements of the magnetic group of elements and molybdenum as essential elements thereof, the molybdenum being present in such amounts as to give the material higher initial permeability than if it were omitted but being less than 10%, said material being heat treated to reduce the coercive force to not over a few gauss.

4. A magnetic material containing iron, at least 40% of the entire iron-nickel content of nickel, and from 1 to 6% of molybdenum.

5. A magnetic material containing at least 40% of the entire iron-nickel content of nickel, iron, and from 1 to 6% of molybdenum, characterized by higher electrical resistivity than that of the same material containing no molybdenum, and heat treated to develop an initial permeability higher than that of iron.

6. A magnetic material comprising nickel, iron and molybdenum, in which the nickel content is over 70% and the molybdenum content from 1 to 10% of the nickel-iron-molybdenum content, heat treated to develop an initial permeability of over 300 and a coercive force below 5 gauss.

7. A magnetic material comprising nickel, iron and molybdenum in which the nickel content is around 78% and the molybdenum content is from 1 to 10% of the nickel-iron-molybdenum content, heat treated to develop an initial permeability of over 300 and a coercive force below 5 gauss.

8. A magnetic material comprising nickel, iron and molybdenum, in which the molybdenum content is from 3 to 4% of the nickel-iron-molybdenum content, characterized by a coercive force of less than 1 c. g. s. unit.

9. A magnetic material comprising approximately 78½% nickel, 16% to 18.5% iron and 3 to 4% molybdenum.

10. The combination with means for setting up a magnetic field of a few tenths of a gauss or less of magnetic material in said field comprising at least 70% of nickel and from 1% to 10% of molybdenum.

11. A transmission line loaded with a magnetic material containing nickel and molybdenum, said material having a hysteresis loss less than 200 ergs per cycle per cubic centimeter for a loop for which the limiting value of induction is 5000 gauss.

12. A loaded conductor comprising a conducting core and a layer of loading material wrapped helically thereabout, said loading material containing nickel, iron and molybdenum, the nickel comprising 70% or more and the molybdenum from 1 to 10% of the nickel-iron-molybdenum content.

13. Magnetic material containing from 45% to 85% nickel, 1% to 10% molybdenum, and 10% to 50% iron heat treated to have an initial permeability of over 300.

14. Magnetic material containing from 45% to 85% nickel, 1% to 10% molybdenum, and 10% to 50% iron, having developed therein by heat treatment a coercive force of less than 1 c. g. s. unit.

15. Magnetic material in accordance with claim 13, having developed therein by heat treatment a hysteresis loss of less than 200 ergs per cycle per cubic centimeter for a loop, the limiting value of induction of which is 5000 gauss.

16. A magnetic substance comprising at least 90% of material composed of magnetic elements and a quantity greater than an impurity but not to exceed 10% molybdenum, said substance having higher initial permeability than iron.

17. A magnetic composition comprising iron and nickel in such ratios that the nickel is at least 40% of the total nickel-iron content, including molybdenum in amounts greater than an impurity whereby the material possesses a resistivity greater than 30 microhm cms., and having developed therein by heat treatment an initial permeability of at least 500.

18. A magnetic material including at least one element of the magnetic group and having imparted thereto, by the addition of molybdenum and by being coled with sufficient rapidity below 600° C., an initial permeability higher than 300 and higher than the same material without molybdenum treated in the same manner.

19. A magnetic material comprising nickel, iron and molybdenum, characterized

by a higher initial permeability than a similar material without molybdenum, heat treated to have a coercive force not over a few gauss.

In witness whereof, I hereunto subscribe my name this 10th day of July, A. D. 1926.

GUSTAF W. ELMEN.