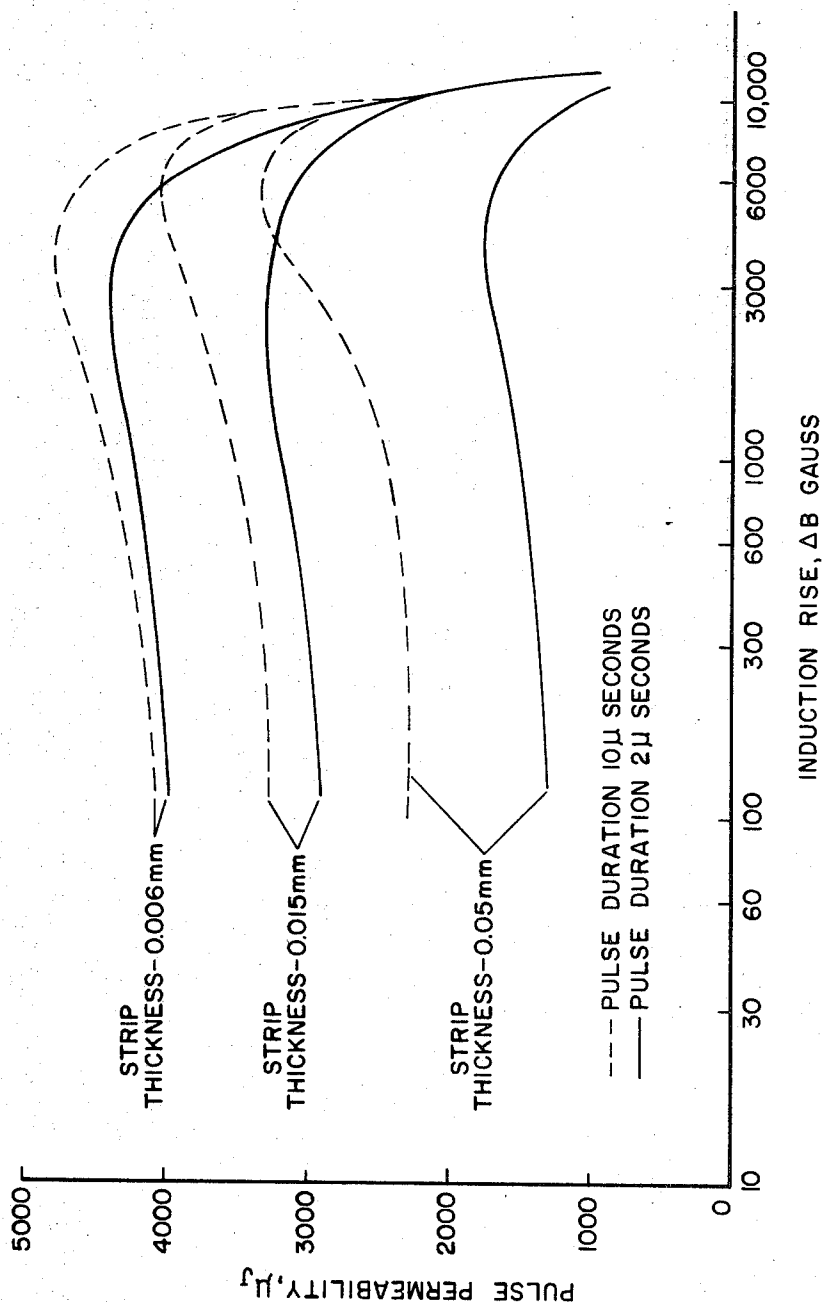


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PROCESS FOR TREATING NICKEL-IRON-MOLYBDENUM ALLOY TO
INCREASE INDUCTION RISE AND PULSE PERMEABILITY
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WITNESSES

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3,546,031

PROCESS FOR TREATING NICKEL-IRON-MOLYBDENUM ALLOY TO INCREASE INDUCTION RISE AND PULSE PERMEABILITY

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5 Claims

ABSTRACT OF THE DISCLOSURE

Nickel-iron-molybdenum alloy strip which has been previously subjected to an annealing treatment at a temperature between 950° C. and 1,220° C., is reheated to a temperature above the Curie point and then rapidly cooled to 200° C. or below. The alloy strip is then subjected to a final anneal at a temperature of about 400° C. to 500° C. This final anneal may be carried out on the alloy strip in a magnetic field wherein the lines of force are transverse to the direction in which the magnetic flux will travel in the strip when it is in use in a magnetic core.

BACKGROUND OF THE INVENTION

Alloys having a large induction rise and a large pulse permeability are required in electrical applications, as for use in choke coils, employing bias with DC fields, as well as in pulse transformers which operate in a unipolar fashion. For example, the larger the induction rise from the remanence for a transformer material and the greater the pulse permeability, the smaller the number of windings required for a given iron cross-section in order to transmit a specified voltage-time area.

The high permeability nickel-iron alloys and ferrites which are employed in the manufacture of unipolar pulse transformers have not been entirely satisfactory with regard to the requirement for a short rise time and a small pulse slope coupled with large modulability, and thus are not suitable for transformers with a large bandwidth. In this regard, according to H. Stegmeier ("Archiv der Elektrischen Übertragung" 1965 (5) page 257) a tape-wound core made from a nickel-iron-copper-molybdenum alloy strip of thickness 0.03 mm. possesses, without bias, an induction rise of only 2,000 gauss, and a tape-wound core of the same alloy but having a strip thickness of 0.003 mm. exhibits an induction rise of only 400 gauss. Also, according to H. Stegmeier, the most favorable induction rise value exhibited ferrites is merely 3,000 gauss. However, these induction rise values characterizing the prior art materials are inadequate for high quality pulse transformers to be employed in the new low-leakage uncut magnetic circuits.

SUMMARY OF THE INVENTION

The invention is directed to a process for manufacturing a soft magnetic nickel-iron alloy having a large induction rise, and a large pulse permeability or, the equivalent, a high incremental permeability up to the highest possible modulating fields or induction values.

In accordance with this invention, the desired characteristics are obtained subjecting a known soft magnetic nickel-iron-molybdenum alloy to a high temperature heat treatment between about 200° C. and the Curie point (below about 600° C.) of the said alloy, after which the alloy is subjected to an additional heat treatment or a combined heat treatment and magnetic treatment (magnetic anneal).

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Following the teachings of this invention, the induction rise of a nickel-iron-molybdenum alloy consisting of 61 to 67% nickel, 2 to 4% molybdenum, balance iron and containing the usual deoxidizing and processing additions, and small amounts of incidental impurities is increased from the usual value of 2,000 to 3,000 gauss to more than 5,000 gauss and, in some cases, to more than 8,000 gauss. In carrying out the process of the invention, a magnet core made from the nickel-iron-molybdenum alloy defined above, is annealed for several hours in a preliminary treatment for from 4 to 6 hours at a temperature for from 4 to 6 hours at a temperature between 950 and 1,220° C., after which the said alloy is heated to a suitable temperature above the Curie point, for example to about 750° C., and then rapidly cooled from this temperature to 200° C. or below, the said cooling being effected, for example, in about 5 minutes. Thereafter the said alloy is subjected to a final anneal of several hours duration, about 3 to 5 hours, for example, in the temperature range 400 to 500° C., and preferably from 450° C. to 500° C. This final heat treatment is particularly beneficial when carried out in a magnetic field the lines of force of which, in the hot alloy, run transverse to the subsequent direction of the magnetic flux.

The heat treatment which such a nickel-iron-molybdenum alloy is subjected in accordance with the invention and prior to its use may also be put into effect following somewhat different procedures. Thus, the alloy strip material or the magnet core made from it, which has already been subjected to a high temperature anneal at a temperature of from 950 to 1,220° C. in an atmosphere, having a low partial pressure of oxygen, can first be cooled to about 200° C. or to a temperature below 200° C. and thereafter heated to a prescribed temperature above the Curie point, for example, to 750° C. The said alloy is then cooled in a few minutes to about 200° C. and finally annealed for a number of hours at a temperature below the Curie point, preferably in the range 450 to 500° C., this latter annealing being preferably carried out in a magnetic field whose lines of force in the hot sample run transversely to the subsequent direction of the magnetic flux. It has also been found feasible to cool at a desired rate subsequent to the high temperature anneal and then to subject the alloy, or the magnet core made from it, to a transverse magnetic field for several hours at a temperature below the Curie temperature.

Surprisingly it has been found that heat treatment in a transverse magnetic field is beneficial both in obtaining a high induction use and in obtaining a relatively high pulse permeability.

The primary object of the invention is a process for manufacturing a soft magnetic alloy material which, over the entire thickness range from 0.1 to 0.003 mm., displays an induction rise from the remanence (B_r) which is greater than 3,000 gauss and, more especially, one of 5,000 to 12,000 gauss and which, in addition, possesses a high pulse permeability.

BRIEF DESCRIPTION OF THE DRAWING

The figure presents a series of curves in which pulse permeability μ_J is plotted against induction rise, ΔB , for a series of nickel-iron-molybdenum alloy strips of three different strip thicknesses, each at two values of pulse duration.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The improvements effected by using the process of this invention can be seen from the following examples. In the data given for these examples, the induction rise, ΔB , denotes the difference between the induction, measured ballistically at 10 oersteds, and the remanence. The perme-

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ability set forth in Table II by μ_a was determined by means of a Maxwell bridge at 0.5 mce and 70 Hz.; it is essentially the same as the initial permeability. In addition, as to practical working characteristics, the pulse permeability

$$\mu_j = \mu_0 \frac{\Delta B}{\Delta H}$$

was measured for a number of samples, with varied induction, ΔB , while keeping the pulse duration t_d constant and in the region of 1 to 50 μ sec. (In the equation for the pulse permeability μ_j , μ_0 denotes the permeability of empty space and ΔH the change in field strength.)

EXAMPLES

Four Ni-Fe-Mo ingots A, B, C and D, whose compositions in wt. percent are given in Table I below, were hot rolled to 7 mm. in thickness and then cold-rolled, with intermediate anneals, to a final thickness of 0.05, 0.03, 0.015 and 0.006 mm. respectively.

TABLE I

Alloy	Nickel	Molybdenum	Manganese	Iron
A.....	64.95	2.58	0.6	Balance.
B.....	64.95	2.57	0.52	Do.
C.....	64.60	2.59	0.56	Do.
D.....	64.90	2.59	0.49	Do.

Tape-wound cores made from the alloys of Table I are annealed for 5 hours at 1,000 to 1,200° C. in hydrogen, furnace cooled to about 200° C., and finally reheated to 750° C., after which they are cooled in about 5 minutes from 750° C. to about 200° C. by inserting them into a water-cooled container. After making room-temperature measurements of the magnetic characteristics (which appear in columns 6 and 7 of Table II below), a subsequent series of treatments is given in the temperature range 400 to 500° C., both in the absence of an external magnetic field and in the presence of a magnetic field provided by an alnico permanent magnet, the said magnetic field being transverse to the subsequent magnetization direction of the samples. The values of induction rise and of the permeabilities evaluated at the conclusion of this tempering treatment are presented in the last two columns of Table II. The data obtained in these tests is summarized in Table II hereafter.

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field. It can be seen from the shapes of the curves that, over the whole range of measurement, as a result of the heat treatments and magnetic annealing carried out in accordance with the invention, almost the same value is obtained for the maximum induction variation, and, further, that the thinner strips are characterized by having a higher pulse permeability.

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The benefits to be obtained via the procedures carried out in accordance with the invention do not reside only in the great improvement in the induction rise at a favorable pulse permeability, but also in the fact that, by a suitable choice of heat treatment or heat treatment combined with a magnetic anneal, it is possible to attain a desired induction rise combined with a suitable pulse permeability, or to produce a desired pulse permeability in association with a satisfactory induction rise. As may be seen from Table II, the heat treatment at a temperature more remote from the Curie point leads to a larger induction rise than does a temperature nearer to the Curie point.

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The nickel-iron-molybdenum alloy strip produced in accordance with the invention is suitable for chokes having D.C. bias as well as being suitable for chokes and pulse-transformers which have unipolar operation. The advantage to be gained by the use of such alloy strip for unipolar pulse transmission lies mainly in the fact that its very large induction rise, in combination with the satisfactory pulse permeability, serves to transmit appreciably larger voltage-time areas (integrated voltage-time pulses) than hitherto, and in a still shorter time.

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We claim as our invention:

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1. A process for producing a nickel-iron-molybdenum alloy strip characterized by a large induction rise having values ranging from 5,000 to 12,500 gauss and a large pulse permeability value, the alloy containing, by weight, 61% to 67% nickel, 2% to 4% molybdenum and the balance iron with small amounts of incidental impurities, the steps comprising, subjecting the alloy strip to a high temperature anneal at a temperature of from 950° C. to 1,220° C. for a period of from 4 to 6 hours, reheating the alloy to a lower temperature range but above the Curie temperature and quenching therefrom to a temperature below about 200° C. and thereafter annealing the alloy strip for a period of hours in a temperature range lying between the Curie point of the alloy and 200° C.

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TABLE II

Heat treatment and combined heat and magnetic treatment (magnetic annealing) of tape-wound cores made from the Ni-Fe-Mo alloy strip material listed in Table I

Example	Alloy	Strip thickness, mm.	High temp. anneal		Magnetic properties after cooling from 750° C.		Annealing without transverse field		Annealing with transverse field		Magnetic values after tempering	
			Temp., ° C.	Time, hrs.	μ_a	ΔB (Gauss)	Temp., ° C.	Time, hrs.	Temp., ° C.	Time, hrs.	μ_a	ΔB (Gauss)
1.....	A	0.05	1,200	5	4,300	9,170	480	4	-----	-----	2,440	10,700
2.....	A	0.05	1,200	5	4,300	9,170	465	4	-----	-----	2,000	11,240
3.....	B	0.05	1,200	5	3,780	9,680	-----	-----	485	4	4,010	11,890
4.....	B	0.05	1,000	5	4,685	3,079	-----	-----	485	4	4,360	11,180
5.....	C	0.05	1,200	5	5,430	7,360	-----	-----	485	4	4,930	10,970
6.....	D	0.05	1,200	5	5,865	6,575	-----	-----	400	4	2,960	12,000
7.....	D	0.05	1,200	5	5,865	6,575	-----	-----	435	4	3,280	12,300
8.....	D	0.05	1,200	5	5,865	6,575	-----	-----	455	4	3,960	12,150
9.....	D	0.05	1,200	5	5,865	6,575	-----	-----	482	4	4,230	11,510
10.....	C	0.03	1,100	5	5,500	4,300	-----	-----	465	4	3,770	11,600
11.....	C	0.03	1,100	5	5,500	4,300	-----	-----	485	4	3,940	11,000
12.....	C	0.015	1,000	5	4,130	2,990	-----	-----	465	4	4,120	11,830
13.....	C	0.015	1,000	5	4,130	2,990	-----	-----	485	4	4,050	9,820
14.....	C	0.006	1,000	5	3,360	2,500	-----	-----	465	4	4,610	10,305
15.....	C	0.006	1,000	5	3,360	2,500	-----	-----	485	4	4,200	6,735

Examples 12 to 15 of Table II and the curves of the figure illustrate the surprisingly large improvement in the induction rise as a result of using the procedures in accordance with the invention, the improvement being evident for very thin samples as well as for the thicker strips. The curves present the measured pulse permeability μ_j as a function of the induction rise ΔB for pulses of duration of 2 and 10 μ sec, for tape-wound cores made from strip of thickness 0.05, 0.015 and 0.006 mm. respectively of alloy C, the said cores having been subjected to a high-temperature anneal of 5 hours duration followed by tempering for 4 hours at 480° C. in a transverse magnetic

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2. A process in accordance with claim 1 in which the final anneal is carried out in the temperature range from 400° C. to 500° C. for a period of from 3 to 5 hours.

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3. The process of claim 1 wherein the temperature above the Curie point to which the alloy strip is heated is about 750° C.

4. The process of claim 1 wherein the final anneal is carried out in a magnetic field in which the lines of force are transverse to the direction which magnetic flux will ultimately flow in the alloy strip in use.

5. The process of claim 3 wherein the final anneal is carried out in a magnetic field in which the lines of force

are transverse to the direction which magnetic flux will ultimately flow in the alloy strip in use.

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