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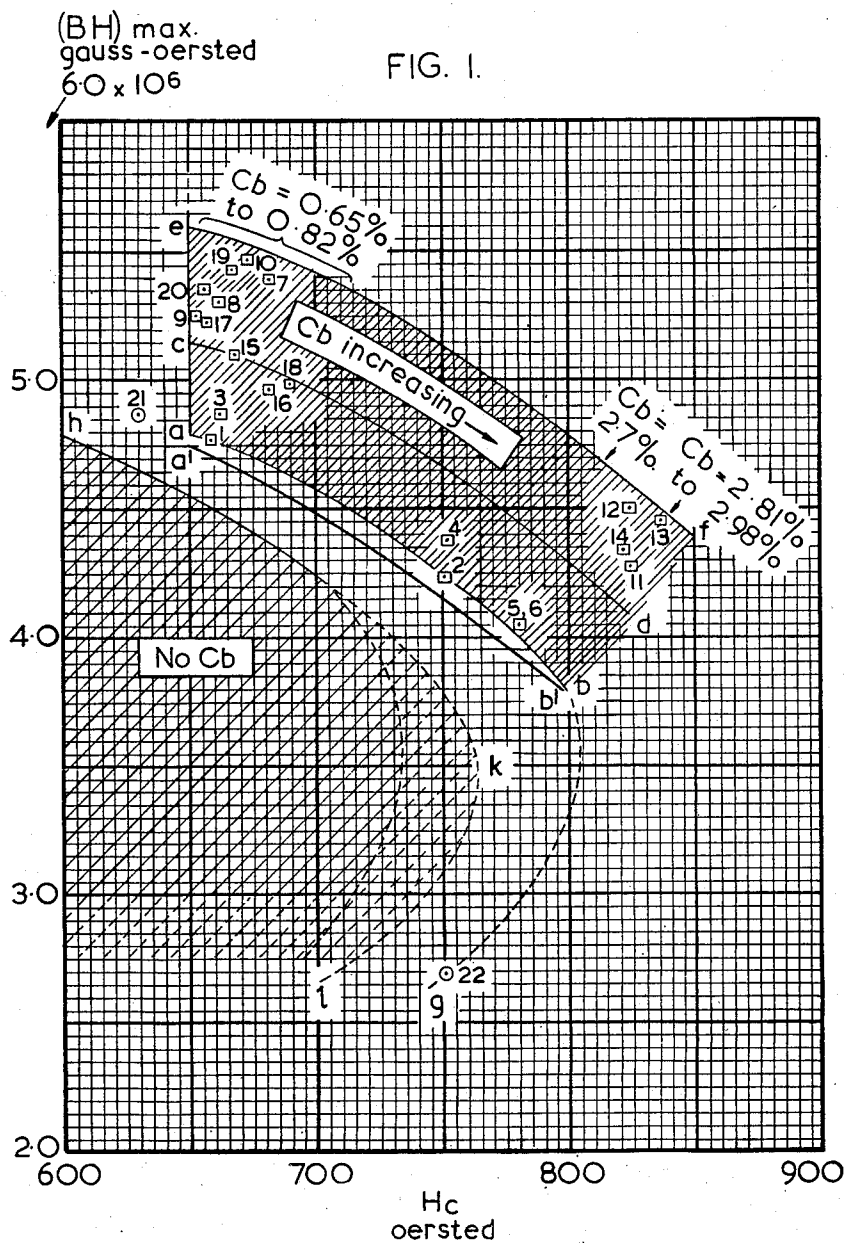
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2,694,166

PERMANENT MAGNET ALLOY

Filed July 10, 1951

2 Sheets-Sheet 1



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2 Sheets-Sheet 2

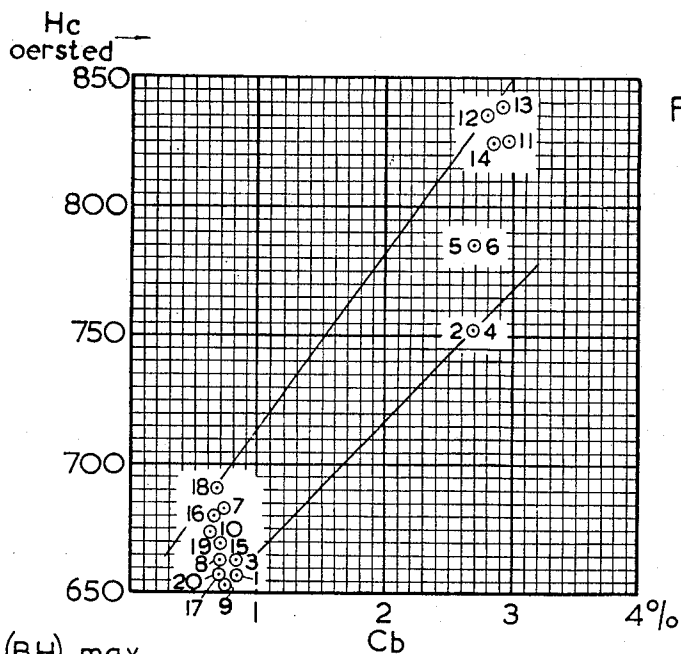


FIG. 2.

(BH) max.
gauss-oersted
 $6 \cdot 0 \times 10^6$

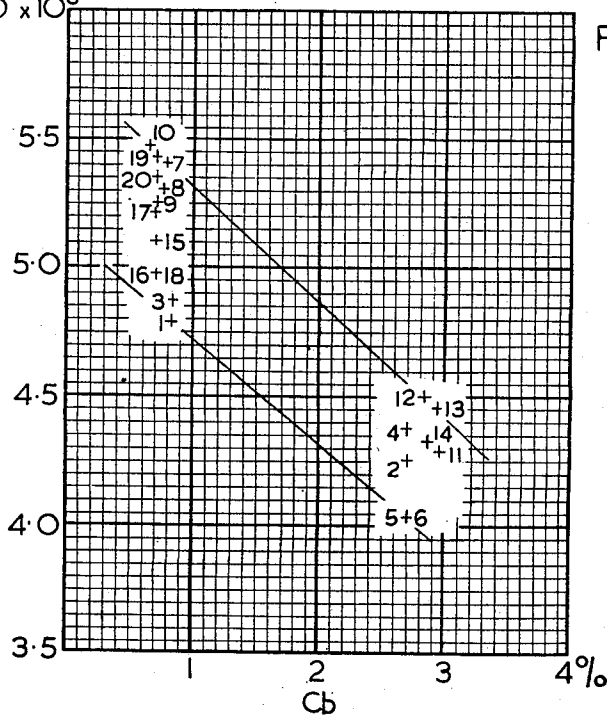


FIG. 3.

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2,694,166

PERMANENT MAGNET ALLOY

Dennis Hadfield, Sheffield, England, assignor to William Jessop & Sons Limited, Sheffield, England

Application July 10, 1951, Serial No. 236,052

9 Claims. (Cl. 317-202)

This invention relates to permanent-magnet alloys of the Alnico type (Fe-Ni-Al-Co-Cu) to which anisotropic characteristics have been imparted, and is a continuation-in-part of U. S. patent application Serial No. 59,183, filed November 9, 1948, now abandoned.

The method of producing anisotropic permanent magnets as now largely practised has its basis in work by D. A. Oliver and J. W. Shedden, who, as they set out in a letter published in the issue of "Nature" dated July 30, 1938 (p. 209), subjected a permanent magnet alloy of the Alnico type to the action of a magnetic field whilst cooling from a high temperature such as, for example, 1200° C. Since that date, such treatment has been applied on a large scale to magnet alloys capable of attaining anisotropic characteristics, and, although various additions—notably of titanium—to the basic Fe-Ni-Al-Co-Cu alloy have been proposed in endeavours to achieve still better magnetic properties, practice for some years past has been largely confined to this basic alloy, since it appeared that that alloy yielded the best results in the present state of knowledge.

Even prior to the publication of the work by Oliver and Shedden, numerous additions had been proposed to Alnico alloys to improve their properties (then, of course, isotropic) and/or to facilitate their manufacture; and, since the present invention is based on the discovery that very advantageous results may be achieved with anisotropic alloys of the type in question by the addition of columbium in amounts lying within a well-defined range, it is relevant to mention that British patent specification No. 496,774 (dated November 5, 1937, and accepted December 6, 1938) described the addition of columbium to an isotropic Alnico permanent magnet alloy for the purpose of reducing the harmful effects of contamination by carbon to the magnetic properties of the alloy.

Since 1937, the general adoption of induction furnaces for melting magnet alloys has much reduced carbon contamination, so that 0.05% carbon would rank as a high amount of this impurity; 0.02% to 0.03% is the maximum now found in the best commercial alloys. It is, therefore, very doubtful if this smaller amount of carbon has any noticeable depressing effect on the magnetic properties, but British specification No. 496,774 shows that as little as 0.2% to 0.3% columbium would be ample to neutralise it.

As indicated above, the present invention makes use of a definite amount of columbium in anisotropic permanent magnet alloys of the Fe-Ni-Al-Co-Cu type, and the object of the invention is to obtain permanent magnets of this type having a high coercive force in the preferred direction, and particularly having a combination of high coercive force and high (BH)_{max.} better than has hitherto been obtainable in magnets of such high coercivity.

When a permanent magnet "alloy" is mentioned in the present specification, it is to be understood that this term applies alike to a casting produced by melting the constituent elements together and to a sintered mass produced by subjecting a powdered mixture of those elements to pressure in a mould and heating the compact, it having been found that such a sintered mass behaves very similarly to a casting of like composition when both have been subjected to similar thermo-magnetic, thermal, and magnetic treatments required to achieve anisotropic characteristics.

According to the present invention, a magnetically anisotropic permanent magnet consists of an alloy of the

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Fe-Ni-Al-Co-Cu type containing about 12.5% to 14.5% nickel, 7.5% to 8.5% aluminum, 23.5% to 25.5% cobalt, 2.9% to 3.3% copper, less than 0.05% carbon, and columbium within the range of 0.5% to 3.25% (all within the usual manufacturing tolerances), with the balance mainly iron, said magnet having in a preferred direction a coercivity of at least 630 oersted increasing approximately linearly with the amount of columbium selected from the said range and a (BH)_{max.} in gauss-oersted in accordance with the approximate mutual relationship, valid for (BH)_{max.} of at least 3.8×10^6 ,

$$(BH)_{\max.} = (P \times 10^6) - Q(H_c - 600)^{3/2} \quad (1)$$

where P is at least 4.9 and Q has a maximum of 400.

It is a result of the stated relationship between coercivity and (BH)_{max.} that the latter decreases as the former is increased, but the combination of the two properties in any magnet having its columbium selected from the range 0.5% to 3.25% always has high values for both properties, and in general includes coercivity materially, or even substantially in excess of 650 oersted. Thus at the minimum value of coercivity of 630 oersted obtainable with columbium selected from about the bottom of the range, the corresponding (BH)_{max.} is in excess of 4.75×10^6 gauss-oersted, with the product $H_c \times (BH)_{\max.}$ at least 3.08×10^9 ; with a coercivity of about 700 oersted obtained with columbium approaching 1%, the (BH)_{max.} is in excess of 4.50×10^6 gauss-oersted and may approach 5.50×10^6 gauss-oersted, $H_c \times (BH)_{\max.}$ being at least 3.15×10^9 . Again with a coercivity of about 750 oersteds, the (BH)_{max.} still has the high value of at least 4.25×10^6 gauss-oersted ($H_c \times (BH)_{\max.} = 318 \times 10^9$) and does not fall below 4.00×10^6 gauss-oersted with increase of coercivity to about 800 oersted or even higher ($H_c \times (BH)_{\max.}$ at least 3.20×10^9). Magnets are obtainable according to the invention with coercivity of at least 825 oersteds and an accompanying (BH)_{max.} of 4.25 to 4.5×10^6 gauss-oersteds ($H_c \times (BH)_{\max.}$ at least 3.5×10^9).

The remanence of the magnets is likewise high; as is necessary with (BH)_{max.} values of the order previously exemplified.

Various examples will now be given of different compositions of alloy, the thermo-magnetic, thermal, and magnetic treatments used with them, and the resultant magnetic properties in the preferred direction. All the alloys were prepared as castings.

Two castings were prepared with the following check analyses (which indicate the kind of departure that may be expected from the intended "round-figure" analysis):

Cast No.	Ni, Per-cent	Al, Per-cent	Co, Per-cent	Cu, Per-cent	Ob, Per-cent
1.....	13.30	8.08	24.60	3.19	0.82
2.....	13.62	8.58	24.72	3.15	2.70

the balance being iron and the usual carbon (less than 0.05%) and impurities.

Test pieces were prepared, all being of the same size, 40×35×10 mm., and all heated to a high solution-temperature of 1250° C. and then cooled in a magnetic field directed along their 40 mm. dimension at an average rate of 1.5° C. per second down to 600° C. according to the now well understood practice for producing anisotropic magnets. The test pieces were then subjected to the usual kind of ageing process in which they were tempered for one hour at 680° C. and furnace cooled to 400° C. over a period of 22 hours, followed by further ageing at 560° C. for 16 hours. The pieces were ground on their contact ends only. The magnetic properties were:

Table II						
Cast No.	Cooling rate	Remanence gauss	Coercivity oersted	(BH) _{max.} gauss-oersted	H _c ×(BH) _{max.}	Ref. No.
1.....	1.5° C./sec.....	12,200	658	4.78×10 ⁶	3.14×10 ⁹	1
2.....	do.....	10,950	752	4.25×10 ⁶	3.19×10 ⁹	2

The test pieces were then re-tested after being ground on all faces as is necessary to obtain a really true comparison between test pieces. These gave re-tested, the following characteristics, showing a slight improvement:

Table III

Cast No.	Cooling rate	Remanence gauss	Coercivity oersted	(BH) _{max.} gauss-oersted	H _c ×(BH) _{max.}	Ref. No.
1-----	1.5° C./sec-----	12,200	661	4.86×10 ⁶	3.21×10 ⁹	3
2-----	do-----	11,170	752	4.38×10 ⁶	3.29×10 ⁹	4

Further castings were also prepared with the following compositions—generally resembling that of Cast No. 2

(Table I), but with rather more columbian:

Table VII

Cast No.	Ni, Per-cent	Al, Per-cent	Co, Per-cent	Cu, Per-cent	Cb, Per-cent	Fe etc., Percent
7-----	13.52	7.56	24.96	3.24	2.98	Balance.
8-----	13.52	7.74	25.20	3.30	2.81	Do.
9-----	13.36	7.48	25.08	3.12	2.94	Do.
10-----	13.44	7.58	25.08	3.30	2.86	Do.

All further test pieces referred to below were ground 20 on all faces.

Further samples of Cast No. 2 were cooled from the solution temperature at 1.0° C./sec. and 0.5° C./sec. respectively, but otherwise treated exactly as before, when the following characteristics were obtained:

Table IV

Cast No.	Cooling rate	Remanence gauss	Coercivity oersted	(BH) _{max.} gauss-oersted	H _c ×(BH) _{max.}	Ref. No.
2-----	1.0° C./sec-----	10,900	784	4.04×10 ⁶	3.15×10 ⁹	5
2-----	0.5° C./sec-----	10,940	785	4.05×10 ⁶	3.16×10 ⁹	6

This indicates that a slower cooling rate than 1.5° C./sec. improves coercivity, at the expense of some reduction in (BH)_{max.} but that there is negligible difference between cooling rates of 1.0° C./sec. and 0.5° C./sec. At any of the variations in cooling rate that are known to be acceptable, the magnet alloys according to the invention have characteristics superior to any 50 shown in the prior art.

Further castings were prepared with the following compositions—generally resembling that of Cast No. 1 (Table I), but with rather less columbium and with the cobalt including value approximately 1% above and below the general average of 24.5%:

Table V

Cast No.	Ni, Per-cent	Al, Per-cent	Co, Per-cent	Cu, Per-cent	Cb, Per-cent
3-----	13.1	8.04	23.76	3.16	0.76
4-----	12.5	8.30	25.56	3.18	0.74
5-----	13.08	8.1	24.36	3.2	0.72
6-----	13.12	8.06	24.24	3.17	0.65

the balance being iron and the usual carbon and impurities.

Test pieces, of the same size as before, were heated to a solution temperature of 1250° C., cooled at 1.4° C./sec. in a magnetic field to 600° C., and subjected to an ageing process: 590° C. for 32 hours, followed by 560° C. for 32 hours. The pieces were then ground all over, magnetized, and tested. The magnetic properties were:

Table VI

Cast No.	Remanence gauss	Coercivity oersted	(BH) _{max.} gauss-oersted	H _c ×(BH) _{max.}	Ref. No.
3-----	12,650	683	5.39×16	3.68×10 ⁹	7
4-----	12,800	661	5.30×16	3.50×10 ⁹	8
5-----	12,450	653	5.25×16	3.43×10 ⁹	9
6-----	12,650	674	5.48×16	3.69×10 ⁹	10

Cooling from a solution temperature of 1250° C. was at 0.6° C./sec. and the ageing process was 595° C. for 48 hours, followed by 560° C. for 48 hours. The pieces were ground all over, magnetized, and tested. The magnetic properties were:

Table VIII

Cast No.	Remanence gauss	Coercivity oersted	(BH) _{max.} gauss-oersted	H _c ×(BH) _{max.}	Ref. No.
7-----	11,300	825	4.28×10 ⁶	3.53×10 ⁹	11
8-----	11,300	835	4.50×10 ⁶	3.75×10 ⁹	12
9-----	11,060	838	4.45×10 ⁶	3.72×10 ⁹	13
10-----	11,160	824	4.32×10 ⁶	3.56×10 ⁹	14

Further castings were also prepared with the basic composition:

Table IX

Ni, Percent	Al, Percent	Cu, Percent	Cu, Percent	Cb, Percent	Fe etc.
13.5	8.0	24.5	3.0	0.7	Balance.

Each cast was cooled from a solution temperature of 1250° C. at a rate of 1.4° C./sec. and then subjected to alternative two-stage ageing treatments:

- A. 590° C. for 32 hours followed by 560° C. for 32 hours
B. 640° C. for 2 hours followed by 560° C. for 16 hours

The magnetic properties were:

Table X

Cast No.	Ageing Treatment							
	A				B			
	Brem. gauss	H _c oersted	(BH) _{max.} gauss-oersted	Ref. No.	Brem. gauss	H _c oersted	(BH) _{max.} gauss-oersted	Ref. No.
11-----	12,480	670	5.20×10 ⁶	-----	12,550	680	5.25×10 ⁶	-----
12-----	12,230	681	5.00×10 ⁶	-----	12,270	680	5.12×10 ⁶	-----
13-----	12,490	668	5.10×10 ⁶	15	12,500	676	5.18×10 ⁶	-----
14-----	12,700	675	5.16×10 ⁶	-----	12,250	679	5.11×10 ⁶	-----
15-----	12,320	684	5.01×10 ⁶	-----	12,060	690	4.97×10 ⁶	18
16-----	12,430	684	5.09×10 ⁶	-----	12,250	680	5.10×10 ⁶	-----
17-----	12,430	683	5.05×10 ⁶	-----	12,320	684	5.01×10 ⁶	-----
18-----	12,700	682	5.24×10 ⁶	-----	12,350	678	5.23×10 ⁶	-----
19-----	12,430	681	4.96×10 ⁶	16	12,300	690	5.17×10 ⁶	-----
20-----	12,520	670	5.11×10 ⁶	-----	12,540	668	5.22×10 ⁶	17

	A	B
Average H _c ×(BH) _{max.} -----	3.45×10 ⁹	3.48×10 ⁹

Further castings were also prepared in the same cast with the basic composition as in Table IX, one being subjected to cooling slowly from a high solution temperature, with long two-stage ageing, and another to slower cooling from a low solution temperature, with shorter three-stage ageing:

Table XI

Cast No.	Solution Temp., °C.	Cooling Rate	Ageing
21-----	1,250	1.4° C./sec.-----	590° C. for 32 hours and 560° C. for 32 hours.
21-----	950	0.5° C./sec.-----	590° C. for 9 hours, 560° C. for 15 hours, and 520° C. for 24 hours.

The magnetic properties were:

Table XII

Cast No.	Remanence gauss	Coercivity oersted	(BH) _{max.} gauss-oersted	H _c ×(BH) _{max.}	Ref. No.
21-----	12,640	668	5.42×10 ⁶	3.62×10 ⁹	19
21-----	12,560	657	5.35×10 ⁶	3.51×10 ⁹	20

Figure 1 of the accompanying drawings shows graphically the field in which (BH)_{max.} is plotted against coercivity (H_c) for most of the results cited above as Reference Nos. 1 to 20. In the case of Table X (which shows the substantial consistency of properties attainable by the invention in ten pairs of casts), only four of the twenty sets of results have been selected for inclusion in Figure 1. The plots are correspondingly identified as 1 . . . 20 in Figure 1, and it will be seen that all lie on a line *a*¹*b*¹ or to the upper right hand side of that line, i. e., in an area (shown heavily shaded) in which both H_c and (BH)_{max.} tend to increase above the combination of those values represented by points on the line *ab* itself.

The *a*¹*b*¹ (not quite an arc of a circle) is represented by the equation

$$(BH)_{\max.} = (4.9 \times 10^6) - 400 (H_c - 600)^{3/2} \quad (1)$$

as may be checked from the following values of (BH)_{max.} calculated from the equation:

H _c -----	650	700	750	800 oersted.
(BH) _{max.} -----	4.76	4.50	4.17	3.78×10 ⁶ gauss-oersted.
H _c ×(BH) _{max.} -----	3.09	3.15	3.13	3.02×10 ⁹ .

The minimum points, 1, 2, 5, 6, plotted lie on the line *ab*, which is above the line *a*¹*b*¹. The lines *cd* and *ef* are approximately concentric with line *a*¹*b*¹ and still

further above that line. They have the approximate equations.

Line *cd*:

$$(BH)_{\max.} = (5.3 \times 10^6) - 350 (H_c - 600)^{3/2} \quad (2)$$

Line *ef*:

$$(BH)_{\max.} = (5.7 \times 10^6) - 300 (H_c - 600)^{3/2} \quad (3)$$

Line *ef* completes with lines *ab* an area in which lie the above cited results of magnets according to the invention (i. e. with H_c of 650 oersted or substantially more), and line *cd* represents an approximate mean across the area between the lines *ab* and *ef*. In the area, any movement in the direction of the arrow, i. e., approximately normal to these three lines, shows simultaneous increase of H_c and (BH)_{max.}

It follows that a movement in the opposite direction shows a simultaneous decrease of H_c and (BH)_{max.}; and, when the line *ab* has been crossed in this reverse direction, some substantial distance has to be covered before the line *hk* is reached. This line forms the boundary of an area (shown lightly shaded) in which lie corresponding values of H_c and (BH)_{max.} of anisotropic permanent magnets of the Alnico type heretofore known, none of these having any content of columbium. There being the distinct gap between the two areas, it is evident that no magnet belonging to the lightly shaded area and having any particular value of H_c can have a value of (BH)_{max.} as high as a magnet having that same value of H_c and belonging to the heavily shaded area, i. e., in the area relating to the present invention. And likewise no magnet belonging to the lightly shaded area and having any particular value of (BH)_{max.} can have a value of H_c as high as a magnet in the heavily shaded area.

The lower limit of columbium according to the invention is 0.5%, which is the approximate minimum quantity necessary to achieve H_c of at least 650 oersted (note the line *ace*), with accompanying high (BH)_{max.}—at least 4.75×10⁶ gauss-oersted. As a check, the point 21 is shown in Figure 1, representing H_c of 630 oersted and (BH)_{max.} of 4.86×10⁶ gauss-oersted obtained with a cast substantially identical with Casts Nos. 1 and 2 (Table I) but with columbium of 0.49%.

The point 22 is also shown in Figure 1, representing H_c of 751 oersted and (BH)_{max.} of only 2.7×10⁶ gauss-oersted obtained with a further similar cast, but with columbium of 5.3%. This indicates a curving back of the line *ab* through a point *g*, corresponding to the curving back through the point *l* known to exist in the continuation of the line *hk* bounding the lightly shaded area. The upper limit of 3.25% columbium according to the invention produces magnets with H_c and (BH)_{max.} plots lying beyond the line *ab* before it begins to curve back, i. e., before both H_c and (BH)_{max.} decrease simultaneously.

It will be noted that H_c tends to increase with increasing columbium within the 0.5% to 3.25% range of this constituted; (BH)_{max.} on the other hand, tends to decrease.

Figure 2 plots H_c against columbium content, and shows the approximately linear increase of the former with increase of the latter. The points plotted are num-

bered to correspond with the points in the heavily shaded area of Figure 1. They lie in an area, an indication of some departure from a truly linear increase of H_c with columbium content within the stated range. A "spread" of this kind is to be expected with minor variations found in check analyses from the intended "round-figure" analysis, and with variations in the thermo-magnetic, thermal, and magnetic treatments of which indications have been given above.

Figure 3 shows a similar plot of $(BH)_{max}$ against columbium content, with a similar "spread" evident.

Apart from the interdependence of H_c and $(BH)_{max}$, as shown by Equations 1, 2 and 3, the products of H_c and $(BH)_{max}$ given above also demonstrate that the combination of H_c and $(BH)_{max}$ values remains high, a decrease in $(BH)_{max}$ being compensated by an increase in H_c . The products at intervals along the line a^1b^1 have been shown to be in excess of 3.0×10^9 , and it will be evident that all the points 1 to 20 plotted have products in excess of 3.0×10^9 . Points on the line cd , e. g. 15, 18, have products in excess of 3.4×10^9 ; and points nearer the line ef , e. g. 10, 7, 12, 13, have products about 3.7×10^9 or even greater.

Columbium is rarely, if ever, obtainable on a commercial scale free from tantalum, as the separation of the two is difficult. The references to columbium in this specification are to be regarded as including a proportion of tantalum fortuitously present with the columbium. But tantalum alone is incapable of achieving the high combination of H_c and $(BH)_{max}$ values that the invention shows to be possible with columbium. Any content of tantalum with columbium should therefore be limited. Anisotropic permanent magnet alloys containing material quantities of tantalum in addition to columbium are described and claimed in co-pending U. S. patent application Serial No. 236,053 of even date herewith, likewise a continuation-in-part of U. S. patent application Serial No. 59,183.

The columbium is most conveniently introduced in the form of ferro-columbium, the iron content of which must be allowed for in the ultimate composition of the alloy.

Cooling rates of 1.5, 1.0, and 0.5° C./sec. have been mentioned above, and it will be seen that the magnetic properties are not largely influenced by changes in this rate. The alloy not being unduly sensitive in this direction, a wider range of cooling rate than this available, say from 0.2° C./sec. to 5° C./sec.

Generally, the slower the cooling rate the higher the coercivity but the lower the remanence and $(BH)_{max}$, whilst the faster the cooling the higher the remanence and $(BH)_{max}$ but the lower the value of the coercivity. Consequently it is desirable to use the slower cooling rates for very short magnets and to increase the rate for longer magnets.

Further, it is generally advisable to reduce the cooling rate when the nickel content is reduced and to increase it when the aluminum content is reduced and vice versa.

For the purposes of the present invention, carbon, chromium, manganese, molybdenum, phosphorous, and silicon, silver, sulphur, titanium, tungsten, vanadium, or zirconium, are regarded as impurities (included, if present, with the balance of "Fe etc." and should not be present in amounts exceeding a total of 1%. Carbon should be (and is, if induction heating is used) kept low—below 0.05%.

What I claim is:

1. A magnetically anisotropic permanent magnet consisting of an alloy of the Fe-Ni-Al-Co-Cu type containing about 13.5% nickel, 8% aluminum, 24.5% cobalt, 3% copper (within the usual manufacturing tolerances) less than .05% carbon, and 0.5 to 3.25% columbium, with the balance mainly iron, said magnet having in a preferred direction a coercivity in the range 630 to at least 780 oersted, a remanence in the range 10,000 to 12,250 gauss, and a $(BH)_{max}$ in the range, 4.04 to 4.86×10^6 gauss-oersted, the product of the coercivity and the $(BH)_{max}$ of the magnet being between about 3.0×10^9 and 3.2×10^9 .

2. A magnetically anisotropic permanent magnet consisting of an alloy of the Fe-Ni-Al-Co-Cu type contain-

ing about 13.5% nickel, 8% aluminum, 24.5% cobalt, 3% copper (within the usual manufacturing tolerances) less than .05% carbon, and 0.5% to 1.0% columbium, with the balance mainly iron, said magnet having in a preferred direction a coercivity in the range 630 to 670 oersted, a remanence of about 12,250 gauss, and a $(BH)_{max}$ in the range 4.25 to 4.86×10^6 gauss-oersted, the product of the coercivity and the $(BH)_{max}$ of the magnet being between about 3.1×10^9 and 3.2×10^9 .

3. A magnetically anisotropic permanent magnet consisting of an alloy of the Fe-Ni-Al-Co-Cu type containing about 13.5% nickel, 8% aluminum, 24.5% cobalt, 3% copper (within the usual manufacturing tolerances), less than .05% carbon, and 1.0 to 3.25% columbium, with the balance mainly iron, said magnet having in a preferred direction a coercivity in the range 670 to at least 780 oersted, a remanence in the range 10,000 to 12,000, and a $(BH)_{max}$ in the range 4.04 to 4.25×10^6 gauss-oersted, the product of the coercivity and the $(BH)_{max}$ of the magnet being between about 3.1×10^9 and 3.2×10^9 .

4. A magnetically anisotropic permanent magnet consisting of an alloy of the Fe-Ni-Al-Co-Cu type containing about 13.5% nickel, 8% aluminum, 24.5% cobalt, 3% copper (within the usual manufacturing tolerances), less than .05% carbon, and about 3.7% columbium, with the balance mainly iron, said magnet having in a preferred direction a coercivity in the range 750 to at least 780 oersted, a remanence of about 11,000 gauss, and $(BH)_{max}$ in excess of 4.0×10^6 gauss-oersted.

5. A magnetically anisotropic permanent magnet, consisting of an alloy of the Fe-Ni-Al-Co-Cu type containing about 13.5% nickel, 8% aluminum, 24.5% cobalt, 3% copper, less than 0.05% carbon, and about 0.8% columbium (all within the usual manufacturing tolerances) with the balance mainly iron, said magnet having in a preferred direction a coercivity in the range 650 to 700 oersted, and $(BH)_{max}$ in excess of 4.5×10^6 gauss-oersted.

6. A magnetically anisotropic permanent magnet, consisting of an alloy of the Fe-Ni-Al-Co-Cu type containing about 13.5% nickel, 8% aluminum, 24.5% cobalt, 3% copper, less than 0.05% carbon, and 0.5% to 3.25% columbium (all within the usual manufacturing tolerances), with the balance mainly iron, said magnet having in a preferred direction a coercivity of between 630 and 840 oersted, a remanence of about 10,000 to 12,000 gauss, a $(BH)_{max}$ of between 3.8×10^6 and 5.5×10^6 gauss-oersted, the product of the coercivity and the $(BH)_{max}$ of the magnet being between 3.0×10^9 and 3.8×10^9 .

7. A magnetically anisotropic permanent magnet, consisting of an alloy of the Fe-Ni-Al-Co-Cu type containing about 12.5 to 14.5% nickel, 7.5% to 8.5% aluminum, 23.5% to 25.5% cobalt, 2.9% to 3.3% copper, less than 0.05% carbon, and columbium within the range 0.5% to 3.25% (all within the usual manufacturing tolerances), with the balance mainly iron, said magnet having in preferred direction a coercivity in the range 650 to about 850 oersted, and a $(BH)_{max}$ in the range 3.8×10^6 to about 5.5×10^6 gauss-oersted, the product of the coercivity and the $(BH)_{max}$ of the magnet being between about 3.0×10^9 and 3.8×10^9 .

8. A magnetically anisotropic permanent magnet consisting of an alloy of the Fe-Ni-Al-Co-Cu type containing about 13.5% nickel, 8% aluminum, 24.5% cobalt, 3% copper, less than .05% carbon, and 0.5 to 3.25% columbium, with the balance substantially all iron.

9. A magnetically anisotropic permanent magnet consisting of an alloy of the Fe-Ni-Al-Co-Cu type containing about 13.5% nickel, 8% aluminum, 24.5% cobalt, 3% copper, and 0.5 to 3.25% columbium, with the balance substantially all iron.

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Number	Country	Date
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522,731	Great Britain	June 26, 1940