Sept. 8, 1942. G. B. JONAS 2,295,082

PERMANENT MAGNET AND METHOD OF MAKING THE SAME

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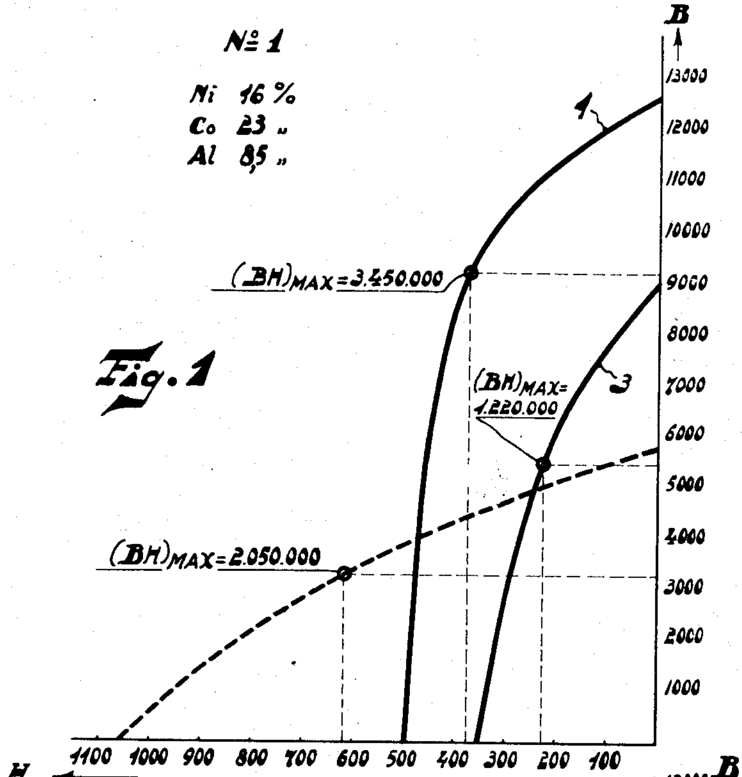

Fig. 1

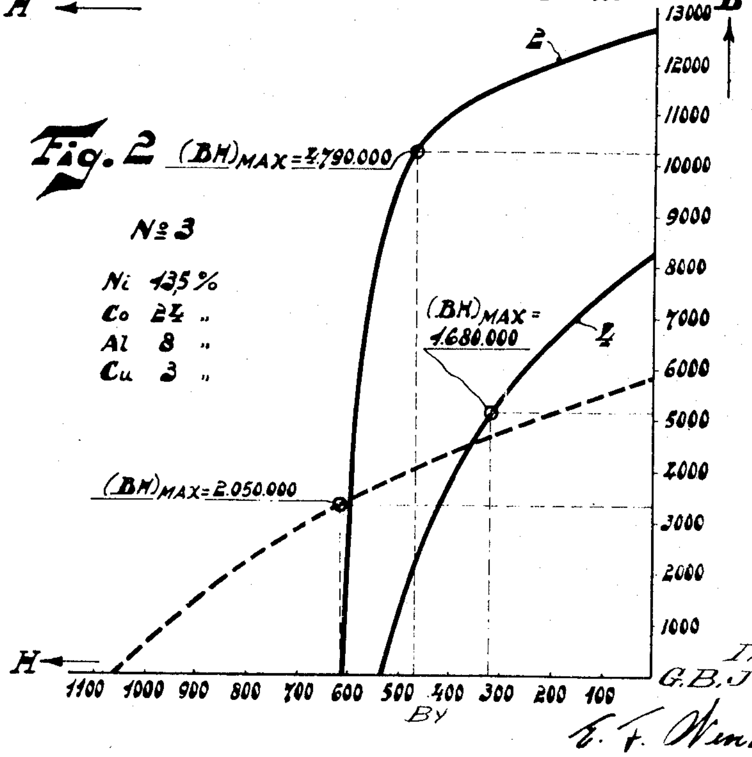

Fig. 2

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PERMANENT MAGNET AND METHOD OF MAKING THE SAME

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21 Claims. (Cl. 175—21)

This invention relates to permanent magnets and to a method of manufacturing them.

The permanent magnet according to the invention exhibits the feature that it consists of a Ni-Al-Fe alloy having a cobalt content of 16 to 30%, a nickel content of 12 to 20% and an aluminium content of 6 to 11% and that in one (principal) direction (anisotrope) it has a $(BH)_{max}$ value which is at least 2,000,000, for instance 4,000,000 to 5,000,000, and which is at least 50%, for instance 100 to 200%, higher than that of a permanent magnet which is made from the same alloy, but whose magnetic properties are at least substantially equal in all directions (isotrope). Since, as is well known, the size and weight of magnets are dependent upon the $(BH)_{max}$ value of the magnet steel used, the advantageous results obtained by the present invention will be readily appreciated.

The magnets according to the invention preferably have a cobalt content of about 20% to 25%, a nickel content of about 13% to 17% and an aluminum content of about 7% to 10%, and with such compositions it is possible to obtain $(BH)_{max}$ values greater than 3,000,000. I have found that such high $(BH)_{max}$ values are due to the pronounced arched shape of the demagnetization curves and, as is well known, the fullness factor

$$\frac{(BH)_{max}}{B_r \times Hc}$$

is decisive for this shape. Magnets according to the invention having a $(BH)_{max}$ value of at least 3,000,000 have a fullness factor of at least 0.45, generally 0.50 or more.

The magnets according to the invention can be made by subjecting the alloys to the action of a magnetic field during the cooling required for magnetic hardening.

Figs. 1 and 2 are demagnetization curves of permanent magnets according to the invention.

It is already known that the magnetic properties of certain ferro-magnetic materials having a high permeability are greatly influenced when, during the thermal treatment, the cooling from high temperatures is effected in a magnetic field.

This effect has also been examined with alloys for permanent magnets (see periodical "Nature" dated July 30, 1938, page 209). This periodical refers to an iron alloy for permanent magnets of the Ni-Al type which consists of 18% Ni, 10% Al, 12% Co, 6% Cu and 54% Fe and is cooled from a temperature of 1200° C. in a magnetic field. In this case an improvement in the remanence and in the $(BH)_{max}$ value is obtained. The remanence, for instance, was raised from about 7350 to about 7900 Gauss and the $(BH)_{max}$ from 1,500,000 to 1,800,000.

As a possible explanation of the influence of the magnetic field it is pointed out that when ferro-magnetic materials are not subjected to a magnetic field during the cooling operation, they show the same magnetic properties in all directions. When using a magnetic field during the cooling operation the material exhibits anisotropy in such manner that, after subsequent magnetisation in a direction corresponding to the direction of the magnetic field during cooling, the magnetic properties in this direction are improved whereas the magnetic properties in other directions are reduced.

It appears from the considerations stated in this respect in the above-mentioned periodical that the said process of cooling in a magnetic field yields an improvement of about 7% in remanence and of 20% in $(BH)_{max}$ for magnet steel, but that surprising improvements are not to be expected in this field. This tallies with the prevailing theoretical conceptions and with the fact that most of the alloys used in practice do not show at all or only slightly show this effect.

I have found that treatment in a magnetic field yields quite unexpected results and more particularly permits one to obtain $(BH)_{max}$ values up to about 5,000,000, when used for the alloys stated in the preamble. It is remarked in this respect that up until now it has been possible only in special cases to produce a permanent magnet having a $(BH)_{max}$ value exceeding 2,000,000. None of the commercial magnets have such values, but have values ranging between about 1.8×10^6 and 1.9×10^6.

The progress according to the invention is more surprising, because a group of Ni-Al-Fe alloys is used which is very uneconomical and hence unusual in practice viz. alloys having a high cobalt content (more than 16%), while at the same time I obtain permanent magnets affording maximum economy. The permanent magnets according to the invention must be magnetized subsequent to the cooling in the direction of the lines of magnet force used to magnetize the magnet during the cooling, i. e. the lines of force during the subsequent magnetization should substantially coincide with the magnetic lines of force used during the cooling. If the magnetic lines of force during the subsequent magnetization were perpendicular to the direction of the lines of force used during the cooling, the high $(BH)_{max}$ value of the present invention would not be obtained. When I refer to the improvement in $(BH)_{max}$ value of a permanent magnet according to the invention, I mean the improvement over a permanent magnet of the same composition, but which is subjected to a magnetization only after the heat treatment. The magnetic field preferably has an intensity of more than 3,000 Gauss.

The cooling operation may be effected in a usual manner which is best suited for obtaining favorable magnetic and mechanical properties, and one skilled in the art can select that cooling method which is best suited for use with a certain type of alloy when the cooling is effected without the application of a magnetic field. I employ the same cooling methods when applying the magnetic field during the cooling.

Furthermore it has been found advisable that the action of the magnetic field should take place at least in a temperature-interval which extends from the Curie-temperature to about 150° C. below this temperature and which is a part of the temperature-interval traversed during the cooling of the alloy necessary for hardening. I have found, that the time during which the temperature of the alloy remains in this interval between the Curie-point and the temperature 150° C. below this point has an influence on the magnitude of the effect. From this it follows that the process is particularly suitable for alloys with which, during the cooling stage of the treatment hitherto used, the time during which the temperature of the alloy remains within this interval has a certain minimum duration, e. g. 30 seconds, for optimum magnetic properties. I have found that in these cases the average cooling speed in the usual cooling operation, say between 1,250° C. and 600° C., should be low, i. e. about 10° C. per sec. at the utmost, and preferably about 1° C. to 5° C. per sec. In connection with the internal change of the alloy necessary for the occurrence of the effect, during the action of the magnetic field, it is advantageous to use alloys having a high Curie-point, for instance higher than about 780° C. The above-described alloys containing more than 16% Co can satisfy this condition.

As regards the aluminium content it is to be remarked that this should be adapted by a judicious choice to the contents of the other elements, and primarily to the nickel content.

In order to obtain excellent results as regards the value of $(BH)_{max}$ it is advisable that the nickel content should not exceed 17%.

The use of copper, which is desirable in many modern magnet-steel alloys, is not essential and a high content, i. e. above 7%, is even inadvisable. However, I have found that in obtaining extremely high $(BH)_{max}$ values it is advisable to admit small quantities of copper, for instance 1 to 3%. Generally it is advisable to reduce the nickel content in the case of high copper contents.

Titanium, which has also proved to be such a valuable element for various magnetic steel alloys and was present in the best magnetic steels hitherto known, is not an essential element of my alloy, although a total percentage of Al and Ti of less than about 12%, the Al percentage being from 6% to 11%, may be used in my alloy. However, a high titanium content, for instance more than about 5%, has proved to be detrimental.

In the following Table I are given several examples from which appears that the whole above-mentioned field of alloys can be split up into sections each of which shows particular magnetic properties.

Table I

No.	L.	Percent	Remanence Br	Coercitive force	$(BH)_{max}$
a	Ni Co Al	14-20 21-25 8-10	9,750-13,500	300-560	2-3.5×10^6
b	Ni Co Al Ti	14-18 22-25 6-8 0.4-4	9,200-12,000	470-765	2.5-4.2×10^6
c	Ni Co Al Ti Cu	13-16.5 18.5-25 6.5-8.5 1-3 1-7	9,300-11,250	510-720	3-4×10^6
d	Ni Co Al Cu	12-15 20-27.5 8-8.5 1.5-6.5	9,250-12,500	520-630	3.5-4.8×10^6

From this table, which is based on the results obtained from about 50 test-series, it clearly appears that the region of alloys designated by *a* is preferably to be used when value is attached to extremely high values of the remanence. The kind of alloys designated by *b*, which contains Ni, Al and Co and in addition Ti should be used if it is attempted to raise the coercive force to the highest possible extent. It is to be remarked that both in the case *a* and in the case *b* the $(BH)_{max}$ obtained with the largest values of the remanence and of the coercive force respectively has at the same time the remarkable value of about 3.5×10^6 and 4.2×10^6 respectively.

The kind of alloy denoted by *c*, which in addition contains copper with respect to the last-mentioned alloy, may also be used for this purpose, and the alloy *d* (without titanium) permits more particularly maximum values and this jointly with remarkable values both for the remanence and for the coercive force.

A large number of elements other than those mentioned up till now may be added in considerable quantities as additional alloy constituents such that in each instance the stated improvement of at least 50% in $(BH)_{max}$ is obtained. However, a distinction must be made between those metals which do not influence the anistropy effect, but do affect the magnetic properties of the alloys and those other metals of the periodic system which are usually present in permanent magnets and which affect both the anistropy effect and the magnetic properties of the alloys. As examples of the former metal I might mention, silicon, vanadium, antimony, tin and sulphur, and as examples of the latter metals I may mention chromium and manganese. More particularly, assume that a magnet of an Al-Fe-Ni-Co alloy when treated in the usual prior art manner has a $(BH)_{max}$ value of 1,500,000 and when treated in the manner of the present invention has a $(BH)_{max}$ value which, due to the anistropy effect, is double, i. e. 3,000,000. If an element such as silicon, vanadium, antimony, tin and sulphur is added to this alloy and the alloy is treated in accordance with prior art methods, the $(BH)_{max}$ value will decrease to a value between about 1,000,000 and 1,500,000. However, the anistropy effect is not affected by the addition of these elements and if the alloy is treated in the manner of the present invention, a $(BH)_{max}$ value of about 2,000,000,

i. e. approximately double the value obtained when using the prior art treatment, will be obtained.

If, instead of the above mentioned elements, an element such as chromium and manganese, is added to the alloy and the alloy is treated in a prior art manner, the $(BH)_{max}$ value will be decreased to about 1,000,000 to 1,500,000 but when the alloy is treated by the method of the present invention the $(BH)_{max}$ value will be decreased to about 1,400,000, i. e. to a value less than double the value obtained by the prior art treatment. Additions of other elements such as, for instance, calcium and to a lower degree tungsten may give rise to a slight but clearly perceptible increase in a characteristic magnetic value, for instance in remanence, but as a rule they tend to influence the other characteristic magnetic values. It will be understood that neither the anisotropy-effect nor the magnetic properties are materially influenced by the presence of slight quantities of other elements, for instance, in the form of impurities (i. e. in quantities of the order of some tenths of a per cent).

When making use of the invention one might expect that the highest attainable $(BH)_{max}$ value would occur with alloys whose $(BH)_{max}$ value is about 2,000,000 (which is practically the highest attainable value up till now) without cooling in a magnetic field. To my astonishment I have found, however, that with these alloys the anisotropy-effect which can be obtained when making use of the invention manifests itself to a small extent only or is not available at all, whereas in contradistinction thereto it has been found that it is with magnet steel alloys having comparatively much lower optimum $(BH)_{max}$ values that this effect occurs to a remarkable extent so that these magnet steels, which are unusual as regards composition, permit final values of the $(BH)_{max}$ far exceeding the values hitherto attainable by means of the best kinds of steel.

Without cooling in a magnetic field higher values of $(BH)_{max}$ generally involved hitherto a lower remanence; for instance, $(BH)_{max}$ values of about 2,000,000 could only be attained at comparatively low values of the remanence, for instance not more than 9,000 Gauss. This is due inter alia to the fact that the improvement in $(BH)_{max}$ could only be obtained by raising the coercive force, which increase was obtained to a greater or less extent at the cost of the remanence.

I have found that with steel alloys which have a high cobalt-content and which, when heat treated in a manner suitable for obtaining an optimum $(BH)_{max}$ value, have a remanence of more than 10,000 Gauss, the improvement in the $(BH)_{max}$ value due to the remarkably strong anistropy-effect of the steel is considerable and that in general the remanence has a considerable influence in obtaining high $(BH)_{max}$ values. In this manner I have found it possible to obtain the unprecedented $(BH)_{max}$ value of more than 2.5×10^6 and even more than 4.5×10^6, while at the same time securing a very high remanence, for instance, more than 12,000 Gauss. Thus, the present invention makes it possible to comply in a practical manner with the frequent desire to have a high $(BH)_{max}$ together with a high remanence.

In contradistinction to what has been said in the above article in "Nature" with respect to the change in coercive force I have found that more particularly with alloys according to the invention showing the higher $(BH)_{max}$ values, not only the remanance but also the coercive force, measured in a preferred direction is increased. The enormous increase in the $(BH)_{max}$ value is partly to be ascribed thereto.

In the following Table II are stated, by way of example, various alloys, which have been cooled according to a usual heat treatment (third column) and in a magnetic field (fourth column).

Table II

1	2					3			4			5	6	7
No.	Composition in per cent					Optimum $(BH)_{max}$ obtained by making use of a usual thermal treatment without magnetic field, after annealing			Results obtained by making use of a thermal treatment corresponding to that of the preceding column, but in accordance with the invention in a magnetic field, after annealing			Average cooling speed in the cooling region between about 1,200° to 600° C.	Improvement in $(BH)_{max}$ expressed in per cent	Fullness factor $\left(\frac{(BH)_{max}}{B_r \times H_c}\right)$
	Ni	Al	Co	Cu	Ti	$(BH)_{max}$	Hc	B_R	$(BH)_{max}$	H_c	B_r	*°C. p./sec.*		
1	16.0	8.5	23	-----	-----	1,220,000	348	9,050	3,450,000	492	12,650	1	183	0.55
2	13.5	8	24	1.5	-----	1,320,000	370	9,450	3,770,000	505	13,100	2.6	186	0.57
3	13.5	8	24	3	-----	1,680,000	535	8,300	4,790,000	615	12,700	1.8	185	0.60
4	16	7.8	25	-----	2.8	1,600,000	604	7,600	3,057,000	640	10,000	4	91	0.48
5	14	7.1	24	3	2.4	1,720,000	595	7,900	3,780,000	660	11,050	4	120	0.52
6	14	7.5	20	6.5	1.8	1,650,000	620	7,350	3,250,000	676	9,825	4.3	97	0.49
7	16.5	8.1	20	1.1	2.3	1,824,000	640	8,150	3,117,000	685	10,200	4	71	0.45

The average cooling speed stated in the fifth column was used in both of the said cases and is so chosen that in cooling without magnetic field about the highest attainable product of B and H is attained.

Column 6 gives the percentage improvement of the $(BH)_{max}$ value according to column 4 over the $(BH)_{max}$ value according to column 3. It appears therefrom that, for instance, a composition according to the examples numbered 1 to 3 permits a magnet steel to be obtained which is about three times better than the same steel which has not been cooled in a magnetic field. From the other examples it appears that this composition yields also an improvement of the $(BH)_{max}$ value of at least 50%. From example 2 according to the invention it appears that in contradistinction to the prior art a very high $(BH)_{max}$ may quite well be associated with a remanence already high in itself.

The accompanying Figures 1 and 2 show the de-magnetisation curves of the examples numbered 1 and 3 in the table. The curves 1 and 2 correspond to a magnet steel according to the invention, whereas curves 3 and 4 correspond to the same steel treated according to the third column of the table. For comparison both figures represent in dotted lines the de-magnetisation curve of a known modern magnet steel having a very high $(BH)_{max}$. It appears from the figures that the high $(BH)_{max}$ of the magnets according to the invention primarily results from a highly raised remanence and a more arched shape of the de-magnetisation curve, although the improvement of the coercive force with respect to the same steel cooled without magnetic field (compare curves 1 with 3 and 2 with 4) is also material.

For a proper understanding of the commercial importance of the present invention, it should be noted that the results given in the above tables are not limited to magnets of small dimensions or to testpieces.

I claim:

1. A permanent magnet consisting of a ferrous alloy containing about 16% to 30% cobalt, about 12% to 20% nickel, about 6% to 11% aluminum and the remainder principally iron, said magnet being magnetically-anisotropic and having a $(BH)_{max}$ value in the principal direction at least about 50% higher than the $(BH)_{max}$ value of a substantially magnetically-isotropic permanent magnet of the same alloy.

2. A permanent magnet consisting of a ferrous alloy containing about 20% to 25% cobalt, about 13% to 17% nickel, about 7% to 10% aluminum and the remainder principally iron, said magnet being magnetically-anisotropic and having a $(BH)_{max}$ value in the principal direction which is at least 2,500,000 and is at least about 50% higher than the $(BH)_{max}$ value of a substantially magnetically-isotropic permanent magnet of the same alloy.

3. A permanent magnet consisting of a ferrous alloy containing about 20 to 25% cobalt, about 13.5% to 16.5% nickel, about 7.1% to 8.5% aluminum and the remainder principally iron, said magnet being magnetically-anisotropic and having a $(BH)_{max}$ value in the principal direction which is equal to at least about 3,000,000 and which is at least 50% greater than that of a substantially magnetically-isotropic permanent magnet of the same composition.

4. A permanent magnet consisting of a ferrous alloy containing about 21% to 25% cobalt, about 14% to 20% nickel, about 8% to 10% aluminum and the remainder principally iron, said magnet being magnetically-anisotropic and having a $(BH)_{max}$ value in the principal direction which is at least 2,000,000 and which is at least 50% greater than that of a magnetically-isotropic permanent magnet of the same alloy, and a remanence of at least 8,000 Gausses.

5. A permanent magnet consisting of a ferrous alloy containing about 23% to 24% cobalt, about 13.5% to 16% nickel, about 7% to 8.5% aluminum and the remainder substantially iron, said magnet being magnetically-anisotropic and having a $(BH)_{max}$ value in the principal direction of at least 3,000,000.

6. A permanent magnet consisting of a ferrous alloy containing about 16% to 30% cobalt, about 12% to 20% nickel, about 6% to 11% aluminum, the remainder being iron and at least one of the elements titanium in an amount less than about 5% and copper in an amount less than about 7%, said magnet being magnetically anisotropic and having a $(BH)_{max}$ value in the principal direction of at least about 50% higher than the $(BH)_{max}$ value of a substantially magnetically-isotropic permanent magnet of the same alloy.

7. A permanent magnet consisting of a ferrous alloy containing about 20% to 25% cobalt, about 13.5% to 16.5% nickel, about 7.1% to 8.1% aluminum, the optional inclusion of one or both of the elements copper in an amount less than about 6.5% and titanium in an amount less than about 2.8% and the remainder iron, said magnet being magnetically-anisotropic and having a $(BH)_{max}$ value in the principal direction which is at least 3,000,000 and which is at least 50% greater than that of a magnetically-isotropic permanent magnet of the same alloy, and a remanence of at least 8,000 Gausses.

8. A permanent magnet consisting of a ferrous alloy containing about 23% to 24% cobalt, about 13.5% to 16% nickel, about 7% to 8.5% aluminum, the remainder being iron and small quantities of at least one of the elements copper and titanium, said magnet being magnetically-anisotropic and having a $(BH)_{max}$ value in the principal direction of at least 3,000,000.

9. A permanent magnet consisting of a ferrous alloy containing about 16% to 30% cobalt, about 12% to 20% nickel, about 6% to 11% aluminum, not more than 5% titanium and the remainder principally iron, the total aluminum-titanium content being not more than about 12%, said magnet being magnetically-anisotropic and having a $(BH)_{max}$ value in the principal direction at least about 50% higher than the $(BH)_{max}$ value of a substantially magnetically-isotropic permanent magnet of the same alloy.

10. A magnetically-anisotropic permanent magnet consisting of a ferrous alloy containing about 14% to 18% nickel, about 22% to 25% cobalt, about 6% to 8% aluminum, about 0.4% to 4% titanium and the remainder principally iron, said magnet having a coercive force of more than 450 Oersteds and a $(BH)_{max}$ value which is greater than 2,500,000 and which is at least 50% greater than that of a substantially magnetically-isotropic permanent magnet of the same composition.

11. A magnetically-anisotropic permanent magnet consisting of a ferrous alloy containing about 14% to 18% nickel, about 22% to 25% cobalt, about 6% to 8% aluminum, about 0.4% to 4% titanium and the remainder principally iron, said magnet having a coercive force of more than 450 Oersteds and a $(BH)_{max}$ value which is greater than 3,000,000 and which is at least 50% greater than that of a substantially magnetically-isotropic permanent magnet of the same composition.

12. A permanent magnet consisting of a ferrous alloy containing about 20 to 27.5% cobalt, about 12% to 15% nickel, about 8% to 8.5% aluminum, about 1.5% to 6.5% copper and the remainder principally iron, said magnet being magnetically-anisotropic and having a $(BH)_{max}$ value in the principal direction which is equal to at least about 3,500,000 and which is at least 50% greater than that of a substantially magnetically-isotropic permanent magnet of the same composition.

13. A magnetically-anisotropic permanent magnet consisting of a ferrous alloy containing about 13% to 16.5% nickel, about 18.5% to 25% cobalt, about 6.5% to 8.5% aluminum, about 1% to 3% titanium, about 1% to 7% copper and the remainder principally iron, said magnet having a $(BH)_{max}$ value which is greater than

3,000,000 and which is at least 50% greater than that of a substantially magnetically-isotropic permanent magnet of the same composition.

14. In the manufacture of a permanent magnet the steps of forming a body of a ferrous alloy containing about 16% to 30% cobalt, about 12% to 20% nickel, about 6% to 11% aluminum and the remainder principally iron, and subjecting the body to a magnetic field during the cooling operation required for magnetic hardening.

15. In the manufacture of a permanent magnet, the steps of forming a body of a ferrous alloy containing about 16% to 30% cobalt, about 12% to 20% nickel, about 6% to 11% aluminum, and the remainder principally iron, subjecting the body to a magnetic field during the cooling operation required for magnetic hardening to thereby make the alloy magnetically-anisotropic, and subsequently magnetizing the body in a direction corresponding to the direction of magnetization during cooling to thereby obtain a $(BH)_{max}$ value at least 50% higher than that obtained with the same alloy without magnetization during the cooling.

16. In the manufacture of a permanent magnet, the steps of forming a body of a ferrous alloy having a Curie-temperature above about 780° C. and containing about 16% to 30% cobalt, about 12% to 20% nickel, about 6% to 11% aluminum and the remainder principally iron, subjecting the body to a magnetic field during the cooling operation required for magnetic hardening and while the alloy is at a temperature between its Curie-temperature and a temperature lying about 150° below the Curie-temperature to thereby make the alloy magnetically-anisotropic, and subsequently magnetizing the body in a direction corresponding to the direction of magnetization during cooling to thereby obtain a $(BH)_{max}$ value at least 50% higher than that obtained with the same alloy without magnetization during the cooling.

17. In the manufacture of a permanent magnet, the steps of forming a body of a ferrous alloy containing about 20% to 25% cobalt, about 13% to 17% nickel, about 7% to 10% aluminum and the remainder principally iron, subjecting the body to a magnetic field during the cooling operation required for magnetic hardening to thereby make the alloy magnetically-anisotropic, and subsequently magnetizing the body in a direction corresponding to the direction of magnetization during cooling to thereby obtain a $(BH)_{max}$ value at least 50% higher than that obtained with the same alloy without magnetization during the cooling.

18. In the manufacture of a permanent magnet, the steps of forming a body of a ferrous alloy containing about 20% to 25% cobalt, 13.5% to 16.5% nickel, 7.1% to 8.5% aluminum and the remainder principally iron, subjecting the body to magnetization during the cooling operation required for magnetic hardening, and subsequently magnetizing the body in a direction corresponding to the direction of magnetization during the cooling to thereby obtain a $(BH)_{max}$ value which is greater than 3,000,000 and which is at least 50% greater than that of a substantially-isotropic permanent magnet of the same composition.

19. In the manufacture of a permanent magnet, the steps of forming a body of a ferrous alloy containing about 23% to 24% cobalt, about 13.5% to 16% nickel, about 7% to 8.5% aluminum and the remainder principally iron, subjecting the body to magnetization during the cooling operation required for magnetic hardening and subsequently magnetizing the body in a direction corresponding to the direction of magnetization during the cooling to thereby obtain a $(BH)_{max}$ value greater than 3,000,000.

20. In the manufacture of a permanent magnet, the steps of forming a body of a ferrous alloy containing about 20% to 25% cobalt, about 13.5% to 16.5% nickel, about 7.1% to 8.5% aluminum, the optional inclusion of one or both of the elements copper in an amount less than about 6.5% and titanium in an amount less than about 2.8% and the remainder iron, cooling the body in a magnetic field from a temperature of about 1200° C. to a temperature of about 600° C. at a rate of between about 1 and 4.3 degrees centigrade per second to thereby make the alloy magnetically-anisotropic, and subsequently magnetizing the body in a direction corresponding to the direction of magnetization during cooling to thereby obtain a $(BH)_{max}$ value at least 50% higher than that obtained with the same alloy without magnetization during the cooling.

21. In the manufacture of a permanent magnet, the steps of forming a body of a ferrous alloy containing about 23% to 24% cobalt, about 13.5% to 16% nickel, about 7% to 8.5% aluminum, the remainder being iron and small quantities of at least one of the elements copper and titanium, subjecting the body to magnetization during the cooling operation required for magnetic hardening and subsequently magnetizing the body in a direction corresponding to the direction of magnetization during the cooling to thereby obtain a $(BH)_{max}$ value greater than 3,000,000.

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