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(54) Rare earth-based permanent magnet.

(57) Disclosed is a novel rare earth-based permanent magnet prepared by the so-called two-alloy method in which powders of two kinds of rare earth-containing magnetic alloys each having a different composition from the other are blended together in a specified proportion and the powder blend is shaped in a magnetic field into a green body which is sintered. In the invention, the first magnetic alloy has a composition of the formula $R_2T_{14}B$, in which R is a rare earth element selected from the group consisting of neodymium, praseodymium, dysprosium and terbium and T is iron or a combination of iron and cobalt, while the second alloy has a composition of the formula $R_aFe_bCo_cB_dM_e$, in which R has the same meaning as defined above, M is an element selected from the group consisting of gallium, aluminum, copper, zinc, indium, silicon, phosphorus, sulfur, titanium, vanadium, chromium, manganese, germanium, zirconium, niobium, molybdenum, palladium, silver, cadmium, tin, antimony, hafnium, tantalum and tungsten, the subscript a is a positive number in the range from 15 to 40, b is zero or a positive number not exceeding 80, c is a positive number in the range from 5 to 85, d is zero or a positive number not exceeding 20 and e is zero or a positive number not exceeding 20 with the proviso that $a+b+c+d+e$ is 100, and the powders are blended in a weight ra-tio of 99:1 to 70:30.

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BACKGROUND OF THE INVENTION

The present invention relates to a novel rare earth-based permanent magnet or, more particularly, to a rare earth-based permanent magnet having remarkably improved magnetic properties such as the residual magnetic flux density, coercive force, maximum energy produuct and the like.

Several types of rare earth-based permanent magnets are known in the prior art and widely used in practical applications by virtue of their very excellent magnetic properties as compared with other non-rare earth permanent magnets. Among the various types of the rare earth-based permanent magnets, those prepared from a ternary alloy of neodymium, iron and boron are highlighted and their application fields are expanding in recent years because they can be manufactured at a relatively low cost owing to the abundance of neodymium among the rare earth elements and omission of expensive cobalt, which is a principal constituent in the samarium-cobalt magnets developed in the early stage of the history of rare earth-based permanent magnets, while they still have excellent magnetic properties comparable with or even better than the magnetic properties of other types of rare earth-based permanent magnets. Extensive investigations have been undertaken and many proposals and attempts have been made for the improvement of the magnetic properties and stability of these neodymium-iron-boron based permanent magnets. For example, an excellent neodymium-iron-boron permanent magnet can be produced by the so-called two-alloy method in which, instead of the conventional powder-metallurgical method using a powder of the single alloy having the same composition as the magnet, two alloys having different compositions are prepared and the fine powders obtained by pulverizing the two alloys are mixed together in a specified proportion to give a powder mixture which is molded into a shape of the desired magnet in a magnetic field followed by sintering. The permanent magnet prepared by this two-alloy method sometimes has much better magnetic properties than the magnets prepared by the single-alloy method even when the overall chemical compositions of the magnets are the same.

The above mentioned two-alloy method can be classified into three types depending on the procedure by which the alloy powders before blending are prepared. In the method of the first type disclosed, for example, in Japanese Patent Kokai 63-93841, 63-252403, 63-278308, 1-108707, 1-146310, 1-146309 and 1-155603, either one or both of the two alloys are prepared by the so-called liquid-quenching method so that the alloy thus produced can be an amorphous or microcrystalline alloy. It is recently reported by E. Otuki, et al. in Eleventh International Workshop on Rare Earth Magnets, Pittsubugh, Penn., October 1990, page 328 that the rare earth-based permanent magnet prepared by using this liquid-quenching method may have an extremely high maximum energy product of 50 MGOe or even larger.

In the second-type method disclosed in Japanese Patent Kokai 61-81603, 61-81504, 61-71605, 61-81606, 61-81607, 61-119007, 61-207546, 63-245903 and 1-177335, two different alloys of a rare earth element R each having a chemical composition of the formula $R_2Fe_{14}B$ as an intermetallic compound are prepared by modifying the kind and content of the rare earth element or elements, one being rich and the other being lean in the content of neodymium.

In the third-type method disclosed in Japanese Patent Kokai 60-230959, 61-263201, 62-181402, 62-182248, 62-206802, 62-70746, 63-6808, 63-104406, 63-114939, 63-272006, 1-111843 and 1-146308, one of the alloy powders having a chemical composition of the formula $R_2Fe_{14}B$, in which R is mainly neodymium, is mixed with a second powder prepared from a certain element or alloy of a low melting point or carbide, boride, hydride and the like of a rare earth element followed by the powder metallurgical process for the preparation of a magnet.

The above described two-alloy methods of the prior art have their respective advantages and disadvantages so that none of these prior art methods are quite satisfactory from the practical standpoint of view. For example, the first-type method disclosed by Otuki has a problem that the coercive force of the permanent magnet obtained thereby cannot be high enough to rarely exceed 9 kOe, which is subject to a decrease as the temperature is increased, although a considerably large value of the maximum energy product can be obtained by the method.

Even when the problem relative to the low coercive force can somehow be solved at least at room temperature, a serious problem inherent in the liquid-quenching method is the poor susceptibility of the alloy particles to magnetic orientation because, as is mentioned above, the particles as prepared by the liquid-quenching method have an amorphous or microcrystalline structure exhibiting no magnetic anisotropy so that the otherwise effective molding method of the powder in a magnetic field is hardly effective to effect magnetic orientation of such non-anisotropic particles.

In the second-type method, an alloy phase rich in the content of neodymium and a phase having a formula of $Nd_{1+x}Fe_4B_4$ co-exist with the $R_2Fe_{14}B$ compound in the magnetic alloy while these two phases are both non-magnetic at room temperature. Accordingly, the magnetic orientation of magnetic particles is greatly disturbed by the presence of such non-magnetic particles so that the magnetic properties of the thus prepared permanent magnet cannot be fully improved. This situation of disturbed magnetic orientation is similar also in the third-type method because the additive powder is also non-magnetic to cause an increase in the demagnetizing field with a consequent decrease in the effective strength of the magnetic field so as not to give full orientation of the magnetic particles along the direction of the magnetic field.

The third-type method using a low melting-point powder is based on an idea that the particles of the low melting-point phase in the powder mixture may have an effect of removing the nucleation sites, such as the lattice defects and the oxide phase, found on the grain boundary of the $R_2Fe_{14}B$ compound during sintering to have an effect of cleaning of the grain boundaries leading to an increase in the coercive force. Presence of such a low melting-point phase in the powder mixture, however, is an adverse condition for the improvement of the magnetic properties of the permanent magnets to cancel the advantage. When the low melting-point phase has a melting point of, for example, around 660 °C, the melt of this phase would have a considerably decreased viscosity at the temperature of sintering which is usually at about 1100 °C so that the magnetic particles which have been oriented in the molding process in a magnetic field may float in the low-viscosity melt to cause random rotation resulting in shuffling of once magnetically oriented particles in the course of sintering which proceeds by the liquid-phase sintering to effect shrinkage of the molded body. In other words, it is important in the liquid-phase sintering of the neodymium-based magnet that the melt of the low melting-point phase in the sintering process has a viscosity high enough not to allow free rotation of the magnetic particles but low enough to give a fully densified structure of the sintered body with a full cleaning effect of the grain boundaries.

In short, the two-alloy methods of the prior art, so to say, have been established without detailed consideration of the balance between the magnetic orientation of the magnetic particles to which the liquid-phase constituent of the mixture pertains and the improvement in the coercive force of the magnet leading to adjustment of the magnetic properties and the melting point of the low melting-point phase to optimize the balance above mentioned.

SUMMARY OF THE INVENTION

The present invention accordingly has an object to provide a rare earth-based permanent magnet having well-balanced magnetic properties prepared by the two-alloy method which, however, has been established after a fundamental reconsideration of the above discussed problems in the prior art two-alloy methods relative to the composition of each of the alloy powders.

Thus, the rare earth-based permanent magnet provided by the invention is a product prepared by a process comprising the steps of:

(a) mixing a powder of a first magnetic alloy or intermetallic compound having a ternary composition substantially represented by the formula

$R_2T_{14}B$, (I)

in which R is a rare earth element which preferably is selected from the group consisting of neodymium, praseodymium, dysprosium and terbium and T is iron or a combination of iron and cobalt in such a proportion that the amount of cobalt does not exceed 40% by weight of the total amount of iron and cobalt, and a powder of a second magnetic alloy or intermetallic compound having a composition substantially represented by the formula

$R_aFe_bCo_cB_dM_e$, (II)

in which R has the same meaning as defined above, M is an element selected from the group consisting of gallium, aluminum, copper, zinc, indium, silicon, phosphorus, sulfur, titanium, vanadium, chromium, manganese, germanium, zirconium, niobium, molybdenum, palladium, silver, cadmium, tin, antimony, hafnium, tantalum and tungsten, the subscript a is a positive number in the range from 15 to 40, b is zero or a positive number not exceeding 80, c is a positive number in the range from 5 to 85, d is zero or a positive number not exceeding 20 and e is zero or a positive number not exceeding 20 with the proviso that $a + b + c + d + e$ is 100, in a weight proportion of the first magnetic alloy powder to the second magnetic alloy powder in the range from 99:1 to 70:30 to give a powder mixture;

(b) shaping the powder mixture into a form of magnet by compression molding in a magnetic field; and

(c) sintering the shaped form of the powder mixture by heating in vacuum or in an atmosphere of an inert gas.

The second alloy powder is characterized by the unique metallographic structure including, besides the $R_2T_{14}B$ phase, at least one of the phases having a chemical composition of the formulas RT_4L, RT_3, RT_2, R_2T_7 and RT_5, in which R and T each have the same meaning as defined above and L is boron or a combination of boron and the element M, e.g., gallium.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

As is described above, the rare earth-based permanent magnet of the invention is prepared by the so-called two-alloy method in which powders of two kinds of magnetic alloys having specified but different compositions are mixed together in a specified weight proportion and the powder mixture is subjected to shaping by molding in a magnetic field to give a green body which is sintered by heating in vacuum or in an atmosphere of an inert gas such as argon followed, usually, by an aging treatment at a temperature substantially lower than the sintering temperature.

The first of the two magnetic alloys, referred to as the Alloy I hereinafter, is basically a ternary alloy mainly consisting of the metallographic phase expressed by the formula $R_2T_{14}B$. In this formula, R is a rare earth element including yttrium but preferably selected from the group consist-ing of neodymium, praseodymium, dysprosium and terbium although a limited portion thereof can be replaced with other rare earth elements including yttrium and the elements having an atomic number in the range from 57 to 71 inclusive. T in the formula is iron or a combination of at least 60% by weight of iron and 40% by weight or less of cobalt. Although cobalt is an optional ingredient, the amount thereof in the combination of iron and cobalt, when added, should be at least 0.1% by weight or, preferably, at least 1% by weight in order that the advantage obtained by the combined use of cobalt can be fully exhibited. Namely, addition of cobalt to the Alloy I is effective in increasing the Curie point of the alloy and also increasing the corrosion resistance of the magnet.

The Alloy I is prepared by melting together each a specified and weighed amount of the respective ingredients R, i.e. one or more of the rare earth elements, T, i.e. iron or iron and cobalt, and boron each in a metallic or elementary form in vacuum or in an atmosphere of an inert gas which is preferably argon. It is optional to use a ferroboron as the source material of boron and a part of the iron source in combination with an appropriate amount of elementary iron or boron to adjust the iron to boron ratio depending on the composition of the ferroboron. Although the above mentioned source materials of the respective ingredients shoud have a purity as high as possible, small amounts of impurities usually unavoidable in industrial production of the materials may have no particular adverse influences. The melt of the alloy is cast in a metal mold and cooled to give an alloy ingot mainly consisting of the phase of $R_2T_{14}B$. Since this phase is formed by the peritective reaction between the incipient phase of α-iron and a liquid phase rich in the content of the rare earth element, it would be a possible case that the ingot of the Alloy I contains small amounts of the remaining α-iron phase, a phase rich in the content of boron and/or a phase rich in the content of the rare earth element. When the fraction of these extraneous phases are too large, the alloy ingot is subjected to a solution treatment by heating at 700 to 1200 °C for at least 1 hour in vacuum or in an atmosphere of an inert gas so as to convert these phases into the phase of $R_2T_{14}B$, the fraction of which should desirably be as large as possible.

The ingot of the Alloy I obtained in the above described manner is finely pulverized either by a wet process or dry process using a suitable pulverizing machine. Namely, the ingot is first crushed into coarse particles which are then finely pulverized. It is essential in each method of pulverization that surface oxidation of the alloy particles, which is highly reactive with atmospheric oxygen, should be avoided as far as possible. For example, the wet-process pulverization is performed in a non-reactive organic solvent such as fluorinated hydrocarbon solvents and the dry-process pulverization is performed in an atmosphere of an inert gas such as nitrogen. When fine pulverization of the coarse particles is conducted by using a jet mill, nitrogen is used as the jet gas. The powder of the Alloy I shoud have an average particle diameter in the range from 0.5 to 20 μm or, preferably, in the range from 1 to 10 μm. When the average particle diameter of the particles is too large, the powder mixture of the two magnetic alloys cannot be sintered to effect full densification while the average particle diameter should not be too small because a too fine powder is highly susceptible to the surface oxidation of the particles by the atmospheric oxygen to cause serious degradation of the magnetic properties of the magnets.

The second of the two magnetic alloys, referred to as the Alloy II hereinafter, is basically a five-component alloy having a composition represented by the formula $R_aFe_bCo_cB_dM_e$, in which R has the same meaning as defined above for the Alloy I and M is an element selected from the group consisting of gallium, aluminum, copper, zinc, indium, silicon, phosphorus, sulfur, titanium, vanadium, chromium, manganese, germanium, zirconium, niobium, molybdenum, palladium, silver, cadmium, tin, antimony, hafnium, tantalum and tungsten or, preferably, gallium.

The subscript a in the formula is a positive number in the range from 15 to 40 or, preferably, from 25 to 35, b is zero or a positive number not exceeding 80 or, preferably, a positive number in the range from 5 to 45, c is a positive number in the range from 5 to 85 or, preferably, in the range from 15 to 65, d is zero or a positive number not exceeding 20 or, preferably, a positive number in the range from 1 to 15 and e is zero or a positive number not exceeding 20 or, preferbly, not exceeding 10 with the proviso that the sum of the subscripts $a+b+c+d+e$ is 100. When the value of the subscript a, i.e. the atomic fraction of the rare earth element, is too small, the deficiency in the content of the rare earth element provides no sufficient amount of the liquid phase in the sintering process so that the sintered body cannot be fully densified. When the value of the subscript a is too large, on the other hand, the melting point of the Alloy II would be too low to exhibit the desired effect for the improvement of the magnetic properties of the resulting permanent magnet. When the value of the subscript c, i.e. the atomic fraction of cobalt, is too small, none of the unique metallographic phases of the formulas RT_4L, RT_3, RT_2, R_2T_7 and RT_5 described before, which can be detected and identified by the combination of the techniques using a scanning electron microscope and electron microprobe analyzer equipped with a wavelength dispersion X-ray spectrometer, could be formed in the Alloy II so that no full improvement can be obtained in the magnetic properties of the permanent magnet. When the value of e, i.e. the atomic fraction of the element denoted by M or, in particular, gallium, is too large, the saturation magnetic flux den-sity of the alloy would be decreased not to impart high magnetic properties to the permanent magnet.

The method for the preparation of an ingot of the Alloy II or a fine powder thereof is not different in principle from that for the preparation of an ingot of the Alloy I or a fine powder thereof described above. The requirement for the average particle diameter of the Alloy II powder is also about the same as for the Alloy I powder. It is of course that the liquid-quenching method is applicable also in this case. Namely, the thin belt of the alloy formed by quenching, which is crystallographically amorphous or microcrystalline, formed by the liquid-quenching method is subjected to a heat treatment at a temperature higher than the temperature of crystallization for a certain length of time so as to cause crystallization or growth by recrystallization resulting in the appearance of the characteristic phase or phases.

The metallographic phases contained in the Alloy II include, besides the phase of the formula $R_2T_{14}B$, in which R and T each have the meaning as defined before, and a phase rich in the content of the rare earth element or elements containing at least 35 atomic % of the rare earth element or elements, which were also the constituents of the alloys used in the prior art two-alloy method or the rare earth-boron based magnetic alloys known in the prior art, at least one of the above mentioned five kinds of the unique metallographic phases which appear as an equilibrium phase in the Alloy II as a consequence of the high cobalt content of at least 5 atomic %.

Following are the presumable reasons for the advantages obtained as a consequence of the presence of these unique metallographic phases in the Alloy II. In the first place, it is pointed out that some of these characteristic phases have a Curie point higher than room temperature as a consequence of the content of cobalt. Further, some of these phases each have magnetic crystalline anisotropy in the direction of a particular crystallographic axis. When the powders of the Alloys I and II are mixed together and the powder mixture is brought in a magnetic field for molding, accordingly, a major portion of the particles has magnetic anisotropy and to give good magnetic orientation in alignment of the easy-magnetization axis to give excellent magnetic properties of the resulting sintered permanent magnet.

In the second place, it is advantageous that these phases each have a melting point in the range from 700 to 1155 °C, which is suitable for the liquid-phase sintering of the neodymium-containing rare earth-based permanent magnet prepared by the method of sintering. Namely, the above mentioned melting point is higher than the melting point of the phase rich in the content of neodymium, i.e. 500 to 650 °C, but lower than the melting point of the $R_2Fe_{14}B$ phase which is 1155 °C. Accordingly, presence of these characteristic phases efficiently avoids the disadvantage that the once aligned particles in the magnetic field is disturbed as a consequence of the too low viscosity of the melt in the absence of these characteristic phases while the melting point thereof is low enough to give a good cleaning effect for the grain boundaries so as to contribute to an increase in the density of the sintered body.

In addition, the relatively high resistance of the Alloy II against oxidation is a consequence of the content of cobalt therein. While otherwise the Alloy II is more susceptible to oxidation than the Alloy I due to the higher content of the rare earth element or elements than the Alloy I, addition of cobalt to the Alloy II has an effect of compensating for the increase in the oxidation susceptibility so as to contribute to the stabilization of the magnetic properties of the magnet obtained therefrom by preventing degradation due to oxidation. When gallium is contained as the element M in the Alloy II, gallium is concentrated at the grain boundaries even after sintering to exhibit an effect of increasing the coercive force of the sintered magnet.

The powders of the Alloys I and II prepared in the above described manner are mixed together in a specified weight proportion as uniformly as possible. This mixing process is also conducted in an atmosphere of an inert gas such as nitrogen in order to minimize oxidation of the particle surface. Instead of mixing the finely pulverized powders of the alloys each having an average particle diameter of 0.5 to 20 µm, it is optional that each of the alloys is first crushed into coarse particles and the coarse particles of the respective alloys are mixed together in a specified weight proportion followed by fine pulverization. The mixing proportion of the powder of the Alloy I to the powder of the Alloy II is in the range from 99:1 to 70:30 by weight or, preferably, in the range from 95:5 to 85:15 by weight. When the content of the Alloy II is too small, the density of the sintered magnet cannot be fully increased so as not to give a high coercive force while, when the content thereof is too large, the non-magnetic phases would have some predominance in the sintered body so that the saturation magnetic flux density of the magnet would be decreased.

The powder mixture of the Alloys I and II is then shaped into a green body of a desired form of the magnet by compression molding in a magnetic field. The direction of the magnetic field is usually perpendicular to the direction of compression but can be parallel. Quite satisfactory results of magnetization molding can be obtained in a magnetic field of 15 kOe and under a compression force of 1000 kgf/cm^2 though not particularly limitative thereto.

The green body of the powder mixture as compression-molded is subjected to sintering by heating in vacuum or in an atmosphere of an inert gas such as argon at a temperature in the range from 900 to 1200 °C for a length of time of at least 30 minutes. The sintered body is usually subjected to an aging treatment by heating at a temperature substantially lower than the sintering temperature or, usually, in the range from 400 to 800 °C for 30 minutes or longer. Advantageously, the sintering process of the green body of the mixed powders is so efficient that the thus sintered body usually has a high density of at least 95% of the true density, i.e. the density of an alloy ingot having the same chemical composition as the average composition of the mixed powders, so as to exhibit a high residual magnetic flux density.

In the following, the rare earth-based permanent magnet of the invention is described in more detail by way of inventive examples and comparative examples making comparison between the two-alloy method and the single-alloy method. Namely, two Alloys I and II were prepared in each of the inventive examples and these alloys were processed in a weight ratio of 85:15 to 95:5 into a sintered permanent magnet in the above described manner while the permanent magnet in the comparative example having the same number as the inventive example was prepared from a single alloy ingot having the same chemical composition as the weighted average of the Alloys I and II in the corresponding inventive example.

Inventive Example 1 and Comparative Example 1.

An ingot of an alloy, referred to as the Alloy I-1 hereinbelow, having a composition of the formula 12.5Nd-6.0B-81.5Fe in the atomic proportion, was prepared in Inventive Example 1 by melting together neodymium metal and iron metal each having a purity of at least 99.9% by weight and a ferroboron containing about 20% by weight of boron, the balance being iron, each in a calculated and weighed amount to give a composition of the above given formula under an atmosphere of argon in a high-frequency induction furnace followed by casting of the melt. The ingot was subjected to a solution treatment by heating at 1070 °C for 20 hours under an atmosphere of argon.

Separately, an ingot of another alloy, referred to as the Alloy II-1 hereinbelow, was prepared in substantially the same manner as above from metals of neodymium, dysprosium, iron, gallium and cobalt each having a purity of at least 99.9% by weight and a ferroboron each in a calculated and weighed amount corresponding to the composition of the formula 20.0Nd-10.0Dy-20.0Fe-6.0B-4.0Ga-40.0Co.

The Alloys I-1 and II-1 were separately pulverized in an atmosphere of nitrogen each into a coarse powder having a particle size to pass a 30 mesh screen and these coarse powders of the Alloy I-1 and Alloy II-1 were taken and blended in a weight ratio of 90:10 taking 30 minutes in a V-mixer filled with nitrogen gas to replace air. The powder blend was then finely pulverized in a jet mill using high-pressure nitrogen as the jet gas into a fine powder mixture having an average particle diameter of about 5µm.

A metal mold was filled with the fine powder mixture obtained above, which was brought in a magnetic field of 15 kOe to effect magnetic orientation of the particles and compression-molded under a compressive pressure of about 1000 kgf/cms into a shaped green body. This green body was subjected to sintering by heating at 1070 °C for 1 hour under an atmosphere of argon in a sintering furnace followed by an aging treatment by keeping for 1 hour at a temperature of 530°C into a sintered permanent magnet, which is referred to as the Magnet 1a hereinbelow.

In Comparative Example 1, an ingot of a further alloy, referred to as the Alloy III-1, was prepared in substantially the same manner as above from the same lots of the metals of neodymium, dysprosium, iron, gallium and cobalt and ferroboron each taken in an amount corresponding to the composition of the formula 13.1Nd-0.8Dy-3.2Co-6.0B-0.3Ga-76.6Fe in the atomic percentage, which was equivalent to the weighted average of the two formulas 12.5Nd-6.0B-81.5Fe for the Alloy I-1 and 20.0Nd-10.0Dy-20.0Fe-6.0B-4.0Ga-40.0Co for the Alloy II-1 combined in a weight ratio of 90:10. The ingot of the Alloy III-1 was pulverized into a fine powder in the same manner as in the pulverization of the Alloy I-1 and II-1 and the fine powder of the Alloy III-1 was processed singly into a permanent magnet, referred to as the Magnet 1b hereinbelow, in the same manner as above.

The Magnets 1a and 1b prepared above were subjected to the measurements of the density ρ in g/cm3 and the magnetic properties including residual magnetic flux density Br in kG, coercive force iHc in kOe and maximum energy product $(BH)_{max}$ in MGOe to give the results shown in Tables 4 and 5, respectively, given below.

Inventive Examples 2 to 70 and Comparative Examples 2 to 70.

The experimental procedure in each of Inventive Examples 2 to 70, in which Magnets 2a to 70a, respectively, were prepared, was substantially the same as in Inventive Example 1 described above except that the compositions of the two types of the alloys and/or mixing proportion of the alloys were different. Namely, the first magnetic alloy was selected from the Alloys I-1 to I-18 indicated in Table 1 below and the second magnetic alloy was selected from the Alloys II-1 to II-58 indicated in Table 2 below.

The experimental procedure in each of Comparative Examples 2 to 70, in which Magnets 2b to 70b, respectively, were prepared was substantially the same as in Comparative Example 1 described above except that each of the Magnets 2b to 70b was prepared from Alloys III-2 to III-70, respectively, while the composition of each of these alloys was the weighted average of the first-type alloy and the second-type alloy used in the Inventive Example having the same number. For example, the Alloy III-2 prepared and used in Comparative Example 2 for the Magnet 2b had a composition equivalent to the weighted average of the Alloy I-1 and Alloy II-2 prepared and used in Inventive Example 2 in a weight ratio of 90:10 for the Magnet 2a. The composition of these Alloys III-2 to III-70 is shown in Table 3 below.

The Magnets 2a to 70a and 2b to 70b were each subjected to the measurements of the density and magnetic properties to give the results respectively shown in Table 4 below, which also shows the mixing ratio of the two types of the alloys by weight in Inventive Examples 2 to 70, and in Table 5 below.

Table 1

Alloy No.	Atomic %					
	Nd	Pr	Dy	B	Co	Fe
I-1	12.5	-	-	6.0	-	81.5
I-2	10.0	2.5	-	6.0	-	81.5
I-3	12.5	-	-	6.0	1.5	80.0
I-4	10.0	2.5	-	6.0	1.5	80.0
I-5	10.0	2.5	-	6.0	5.0	76.5
I-6	11.2	0.5	0.5	6.0	10.0	71.8
I-7	12.0	0.5	-	6.0	20.0	61.5
I-8	12.5	-	-	6.5	35.5	45.5
I-9	12.0	0.5	-	6.0	5.0	76.5
I-10	12.5	-	-	6.0	2.0	79.5
I-11	12.5	-	-	6.0	3.0	78.5
I-12	12.5	-	-	6.0	10.0	71.5
I-13	10.0	2.0	0.5	6.0	5.0	76.5
I-14	-	12.5	-	6.0	-	81.5
I-15	-	12.5	-	6.0	3.0	78.5
I-16	-	12.5	-	6.0	10.0	71.5
I-17	2.5	10.0	-	6.0	15.0	66.5
I-18	11.5	-	1.0	6.0	20.0	61.5

Table 2-1

Alloy No.	Atomic %							
	Nd	Pr	Dy	B	Co	Fe	M•element	Tb
II-1	20.0	-	10.0	6.0	40.0	20.0	4.0Ga	-
II-2	15.0	-	15.0	6.0	48.0	10.0	6.0Ga	-
II-3	15.0	-	15.0	6.0	38.0	20.0	6.0Ga	-
II-4	15.0	-	15.0	6.0	28.0	30.0	6.0Ga	-
II-5	15.0	-	15.0	6.0	18.0	40.0	6.0Ga	-
II-6	15.0	-	10.0	12.0	45.0	10.0	8.0Ga	-
II-7	12.0	-	12.0	2.0	60.0	10.0	4.0Ga	-
II-8	12.0	2.0	10.0	2.0	60.0	10.0	4.0Ga	-
II-9	10.0	-	10.0	6.0	43.0	20.0	6.0Ga	5.0
II-10	20.0	-	10.0	6.0	44.0	20.0	-	-
II-11	15.0	-	15.0	6.0	54.0	10.0	-	-
II-12	15.0	-	15.0	6.0	44.0	20.0	-	-
II-13	15.0	-	15.0	6.0	34.0	30.0	-	-
II-14	15.0	-	15.0	6.0	24.0	40.0	-	-
II-15	15.0	-	10.0	12.0	43.0	20.0	-	-
II-16	12.0	-	12.0	2.0	64.0	10.0	-	-
II-17	12.0	2.0	10.0	2.0	64.0	10.0	-	-
II-18	10.0	-	10.0	6.0	49.0	20.0	-	5.0
II-19	15.0	-	15.0	6.0	50.0	10.0	4.0Ga	-

Table 2-2

Alloy No.	Atomic %						
	Nd	Pr	Dy	B	Co	Fe	M•element
II-20	-	20.0	10.0	6.0	40.0	20.0	4.0Ga
II-21	20.0	-	10.0	6.0	48.0	10.0	6.0Ga
II-22	10.0	10.0	10.0	6.0	48.0	10.0	6.0Ga
II-23	8.0	10.0	10.0	6.0	42.0	20.0	4.0Ga
II-24	10.0	8.0	10.0	6.0	40.0	20.0	6.0Ga
II-25	9.0	7.0	9.0	6.0	55.0	9.0	5.0Ga
II-26	10.0	5.0	10.0	12.0	44.0	15.0	4.0Ga
II-27	5.0	10.0	10.0	2.0	45.0	20.0	8.0Ga
II-28	20.0	-	10.0	6.0	44.0	20.0	-
II-29	20.0	-	10.0	6.0	54.0	10.0	-
II-30	10.0	10.0	10.0	6.0	54.0	10.0	-
II-31	10.0	8.0	10.0	6.0	46.0	20.0	-
II-32	9.0	7.0	9.0	6.0	60.0	9.0.	-
II-33	10.0	5.0	10.0	12.0	48.0	15.0	-
II-34	5.0	10.0	10.0	2.0	53.0	20.0	-
II-35	20.0	-	10.0	6.0	40.0	20.0	4.0Al
II-36	20.0	-	10.0	6.0	40.0	20.0	4.0Cu
II-37	20.0	-	10.0	6.0	40.0	20.0	4.0Zn
II-38	20.0	-	10.0	6.0	40.0	20.0	4.0In

Table 2-3

Alloy No.	Atomic %						
	Nd	Pr	Dy	B	Co	Fe	M•element
II-39	20.0	-	10.0	6.0	40.0	20.0	4.0Si
II-40	20.0	-	10.0	6.0	42.0	20.0	2.0P
II-41	20.0	-	10.0	6.0	42.0	20.0	2.0S
II-42	20.0	-	10.0	6.0	40.0	20.0	4.0Ti
II-43	20.0	-	10.0	6.0	40.0	20.0	4.0V
II-44	20.0	-	10.0	6.0	40.0	20.0	4.0Cr
II-45	20.0	-	10.0	6.0	40.0	20.0	4.0Mn
II-46	10.0	10.0	10.0	6.0	40.0	20.0	4.0Ge
II-47	10.0	10.0	10.0	6.0	40.0	20.0	4.0Zr
II-48	10.0	10.0	10.0	6.0	40.0	20.0	4.0Nb
II-49	10.0	10.0	10.0	6.0	40.0	20.0	4.0Mo
II-50	10.0	10.0	10.0	6.0	40.0	20.0	4.0Pd
II-51	10.0	10.0	10.0	6.0	40.0	20.0	4.0Ag
II-52	10.0	10.0	10.0	6.0	40.0	20.0	4.0Cd
II-53	10.0	10.0	10.0	6.0	40.0	20.0	4.0Sn
II-54	10.0	10.0	10.0	6.0	40.0	20.0	4.0Sb
II-55	10.0	10.0	10.0	6.0	40.0	20.0	4.0Hf
II-56	10.0	10.0	10.0	6.0	40.0	20.0	4.0Ta
II-57	10.0	10.0	10.0	6.0	40.0	20.0	4.0W
II-58	10.0	10.0	10.0	6.0	38.0	20.0	4.OCr + 2.OSi

Table 3-1

Alloy No.	Atomic %							
	Nd	Pr	Dy	B	Co	Fe	M•element	Tb
III-1	13.1	-	0.8	6.0	3.2	76.6	0.3Ga	-
III-2	12.7	-	1.2	6.0	3.7	75.9	0.5Ga	-
III-3	12.7	-	1.2	6.0	3.0	76.6	0.5Ga	-
III-4	12.7	-	1.2	6.0	2.2	77.4	0.5Ga	-
III-5	12.7	-	1.2	6.0	1.4	78.2	0.5Ga	-
III-6	12.7	-	0.8	6.5	3.8	75.5	0.7Ga	-
III-7	12.6	-	0.6	6.4	2.7	77.2	0.5Ga	-
III-8	12.6	-	0.4	6.3	1.9	78.5	0.3Ga	-
III-9	10.2	2.3	1.0	5.7	4.9	75.6	0.3Ga	-
III-10	10.1	2.5	0.6	5.7	3.9	76.9	0.3Ga	-
III-11	10.0	2.2	1.2	6.0	5.3	74.0	0.7Ga	0.6
III-12	13.1	-	0.8	6.0	3.5	76.6	-	-
III-13	12.7	-	1.2	6.0	4.2	75.9	-	-
III-14	12.7	-	1.2	6.0	3.5	76.6	-	-
III-15	12.7	-	1.2	6.0	2.7	77.4	-	-
III-16	12.7	-	1.2	6.0	1.9	78.2	-	-
III-17	12.7	-	0.8	6.5	3.7	76.3	-	-
III-18	12.6	-	0.6	6.4	2.6	77.8	-	-
III-19	12.6	-	0.4	6.3	1.8	78.9	-	-
III-20	10.2	2.3	1.0	5.7	5.2	75.6	-	-
III-21	10.1	2.5	0.7	5.7	4.2	76.8	-	-
III-22	10.0	2.2	1.2	6.0	6.1	73.9	-	0.6
III-23	13.1	-	0.8	6.0	4.5	75.3	0.3Ga	-
III-24	12.7	-	1.2	6.0	5.3	74.5	0.3Ga	-

Table 3-2

Alloy No.	Atomic %							
	Nd	Pr	Dy	B	Co	Fe	M•element	Tb
III-25	10.8	2.3	0.8	6.0	4.5	75.3	0.3Ga	-
III-26	9.4	3.6	0.6	6.0	3.9	76.2	0.3Ga	-
III-27	10.8	2.3	0.8	6.0	8.4	71.2	0.5Ga	-
III-28	3.1	10.0	0.8	6.0	8.4	71.2	0.5Ga	-
III-29	11.1	1.1	1.3	6.0	12.6	67.6	0.3Ga	-
III-30	11.8	1.1	0.8	6.0	21.6	58.2	0.5Ga	-
III-31	12.2	0.6	0.8	6.5	37.1	42.4	0.4Ga	-
III-32	11.8	0.9	0.9	6.5	8.3	71.3	0.3Ga	-
III-33	11.9	0.8	0.6	6.4	7.3	72.8	0.2Ga	-
III-34	11.9	0.8	0.8	5.7	5.5	74.7	0.6Ga	-
III-35	13.1	-	0.8	6.0	4.5	75.6	-	-
III-36	12.7	-	1.2	6.0	5.3	74.8	-	-
III-37	10.8	2.3	0.8	6.0	4.5	75.6	-	-
III-38	9.4	3.6	0.6	6.0	3.9	76.5	-	-
III-39	10.8	2.3	0.8	6.0	8.4	71.7	-	-
III-40	3.1	10.0	0.8	6.0	8.4	71.7	-	-
III-41	11.1	1.1	1.3	6.0	12.6	67.9	-	-
III-42	11.8	1.1	0.8	6.0	21.6	58.7	-	-
III-43	12.2	0.6	0.8	6.5	37.1	42.6	-	-
III-44	11.8	0.9	0.9	6.5	8.3	71.6	-	-
III-45	11.9	0.8	0.6	6.4	7.3	73.0	-	-
III-46	11.9	0.8	0.8	5.7	5.5	75.3	-	-
III-47	13.1	-	0.8	6.0	3.2	76.6	0.3Al	-

Table 3-3

Alloy No.	Atomic %							
	Nd	Pr	Dy	B	Co	Fe	M•element	Tb
III-48	13.1	-	0.8	5.9	5.9	74.0	0.3Cu	-
III-49	13.1	-	0.8	6.0	12.4	67.4	0.3Zn	-
III-50	10.8	2.3	0.8	6.0	3.1	76.7	0.5In	-
III-51	10.8	2.3	0.8	6.0	7.8	72.0	0.3Si	-
III-52	10.8	1.8	1.3	6.0	8.0	71.9	0.2P	-
III-53	1.6	11.5	0.8	6.0	3.3	76.6	0.2S	-
III-54	1.6	11.5	0.8	6.0	5.9	73.9	0.3Ti	-
III-55	1.6	11.5	0.8	6.0	12.4	67.4	0.3V	-
III-56	3.9	9.2	0.8	6.0	7.8	72.0	0.3Cr	-
III-57	3.9	9.2	0.8	6.0	17.0	62.8	0.3Mn	-
III-58	12.3	0.8	0.8	6.0	3.2	76.6	0.3Ge	-
III-59	12.3	0.8	0.8	6.0	5.9	73.9	0.3Zr	-
III-60	12.3	0.8	0.8	6.0	12.4	67.4	0.3Nb	-
III-61	10.0	3.1	0.8	6.0	3.1	76.7	0.3Mo	-
III-62	10.0	3.1	0.8	6.0	7.7	72.1	0.3Pd	-
III-63	10.0	2.6	1.2	6.0	7.7	72.2	0.3Ag	-
III-64	0.8	12.3	0.8	6.0	3.1	76.7	0.3Cd	-
III-65	0.8	12.3	0.8	6.0	5.9	73.9	0.3Sn	-
III-66	0.8	12.3	0.8	6.0	12.3	67.5	0.3Sb	-
III-67	3.1	10.0	0.8	6.0	7.6	72.2	0.3Hf	-
III-68	3.1	10.0	0.8	6.0	16.9	62.9	0.3Ta	-
III-69	12.3	0.8	0.8	6.0	4.9	74.9	0.3W	-
III-70	11.4	0.8	1.7	6.0	21.3	58.3	0.2Si + 0.3Cr	-

Table 4-1

Magnet No.	Alloi I: Alloy II (weight ratio)	Residual magnetic flux density, kG	Coercive force, kOe	Maximum energy product, MGOe	Density, g/cm^3
1a	I-1:II-1(90:10)	13.7	14.2	45.5	7.42
2a	I-1:II-2(90:10)	13.6	14.0	44.5	7.43
3a	I-1:II-3(90:10)	13.5	14.2	44.2	7.42
4a	I-1:II-4(90:10)	13.4	14.3	43.5	7.45
5a	I-1:II-5(90:10)	13.5	14.6	44.1	7.46
6a	I-1:II-6(90:10)	13.6	13.5	44.2	7.42
7a	I-1:II-6(93:7)	13.7	13.3	45.5	7.47
8a	I-1:II-6(95:5)	13.8	13.4	45.8	7.45
9a	I-2:II-7(90:10)	13.7	14.7	45.1	7.40
10a	I-2:II-8(92:8)	13.7	14.4	45.4	7.46
11a	I-2:II-9(85:15)	13.4	16.8	42.3	7.41
12a	I-1:II-10(90:10)	13.8	13.2	45.4	7.43
13a	I-1:II-11(90:10)	13.7	12.5	44.7	7.42
14a	I-1:II-12(90:10)	13.6	12.2	44.3	7.43
15a	I-1:II-13(90:10)	13.4	12.9	43.7	7.44
16a	I-1:II-14(90:10)	13.6	12.6	44.8	7.47
17a	I-1:II-15(90:10)	13.7	12.5	44.5	7.45
18a	I-1:II-15(93:7)	13.7	12.3	45.7	7.46
19a	I-1:II-15(95:5)	13.8	12.4	45.9	7.46
20a	I-2:II-16(90:10)	13.8	12.7	45.4	7.41

Table 4-2

Magnet No.	Alloi I: Alloy II (weight ratio)	Residual magnetic flux density, kG	Coercive force, kOe	Maximum energy product, MGOe	Density, g/cm^3
21a	I-2:II-17(92:8)	13.8	13.4	45.7	7.45
22a	I-2:II-18(85:15)	13.5	14.8	42.5	7.42
23a	I-3:II-1(90:10)	13.8	14.5	45.6	7.39
24a	I-3:II-19(90:10)	13.6	15.0	44.4	7.40
25a	I-4:II-1(90:10)	13.7	14.0	44.8	7.41
26a	I-4:II-20(92:8)	13.8	15.5	45.7	7.38
27a	I-5:II-21(90:10)	13.7	13.9	44.5	7.40
28a	I-5:II-22(90:10)	13.7	16.2	45.0	7.41
29a	I-6:II-23(90:10)	13.6	17.1	44.5	7.42
30a	I-7:II-24(90:10)	13.6	14.3	44.6	7.40
31a	I-8:II-25(90:10)	13.8	14.4	46.2	7.53
32a	I-9:II-26(90:10)	13.9	13.5	46.4	7.47
33a	I-9:II-26(93:7)	14.0	12.5	46.5	7.49
34a	I-10:II-27(90:10)	13.7	13.9	45.0	7.44
35a	I-3:II-1(90:10)	13.8	12.5	44.6	7.42
36a	I-3:II-2(90:10)	13.6	13.0	44.2	7.42
37a	I-4:II-28(90:10)	13.8	12.0	44.3	7.45
38a	I-4:II-28(92:8)	13.8	13.5	45.1	7.42
39a	I-5:II-29(90:10)	13.8	11.9	44.4	7.47
40a	I-5:II-30(90:10)	13.7	13.2	44.5	7.46

Table 4-3

Magnet No.	Alloi I: Alloy II (weight ratio)	Residual magnetic flux density, kG	Coercive force, kOe	Maximum energy product, MGOe	Density, g/cm^3
41a	I-6:II-31(90:10)	13.6	14.1	44.2	7.48
42a	I-7:II-31(90:10)	13.7	12.3	44.5	7.49
43a	I-8:II-32(90:10)	13.8	12.4	45.8	7.52
44a	I-9:II-33(90:10)	13.9	11.8	46.2	7.47
45a	I-9:II-33(93:7)	14.0	11.5	46.4	7.48
46a	I-10:II-34(90:10)	13.7	11.9	44.9	7.45
47a	I-1:II-35(90:10)	13.5	14.5	45.6	7.44
48a	I-11:II-36(90:10)	13.5	13.5	43.4	7.41
49a	I-12:II-37(90:10)	13.4	13.4	44.1	7.49
50a	I-2:II-38(90:10)	13.7	14.5	44.7	7.45
51a	I-5:II-39(90:10)	13.5	13.8	44.5	7.48
52a	I-13:II-40(90:10)	13.3	15.6	42.8	7.47
53a	I-14:II-41(90:10)	13.6	14.1	44.5	7.50
54a	I-15:II-42(90:10)	13.6	14.3	45.6	7.46
55a	I-16:II-43(90:10)	13.7	13.4	45.2	7.50
56a	I-5:II-44(90:10)	13.6	13.3	45.4	7.46
57a	I-17:II-45(90:10)	13.7	12.4	45.5	7.53
58a	I-1:II-46(90:10)	13.6	13.8	44.0	7.43
59a	I-11:II-47(90:10)	13.6	13.7	45.0	7.44
60a	I-12:II-48(90:10)	13.6	13.8	44.0	7.49

Table 4-4

Magnet No.	Alloi I: Alloy II (weight ratio)	Residual magnetic flux density, kG	Coercive force, kOe	Maximum energy product, MGOe	Density, g/cm^3
61a	I-2:II-49(90:10)	13.6	12.9	45.0	7.46
62a	I-5:II-50(90:10)	13.5	13.4	44.7	7.47
63a	I-13:II-51(90:10)	13.1	16.4	40.2	7.43
64a	I-14:II-52(90:10)	13.4	13.3	44.4	7.39
65a	I-15:II-53(90:10)	13.3	12.5	43.5	7.39
66a	I-16:II-54(90:10)	13.6	13.5	44.0	7.54
67a	I-5:II-55(90:10)	13.6	13.1	44.0	7.42
68a	I-17:II-56(90:10)	13.7	11.9	45.0	7.54
69a	I-10:II-57(90:10)	13.6	13.9	45.2	7.45
70a	I-18:II-58(91:9)	13.0	12.7	41.6	7.53

Table 5-1

Magnet No.	Residual magnetic flux density, kG	Coercive force, kOe	Maximum energy product, MGOe	Density, g/cm^3
1b	12.8	9.2	36.0	7.44
2b	12.8	7.9	34.5	7.41
3b	12.7	8.5	37.3	7.42
4b	12.6	8.8	36.5	7.47
5b	12.7	7.5	33.3	7.42
6b	12.6	7.0	34.7	7.44
7b	12.7	7.7	36.8	7.41
8b	12.8	7.0	34.8	7.44
9b	12.8	8.9	37.2	7.39
10b	12.7	8.1	37.9	7.43
11b	12.5	9.5	36.5	7.47
12b	12.8	8.7	36.0	7.43
13b	12.9	7.3	34.6	7.43
14b	12.8	8.1	37.3	7.44
15b	12.6	8.5	36.7	7.46
16b	12.8	7.0	33.5	7.43
17b	12.7	7.0	34.8	7.44
18b	12.8	7.1	36.9	7.42
19b	12.9	7.9	34.9	7.45
20b	12.9	7.9	37.3	7.40

Table 5-2

Magnet No.	Residual magnetic flux density, kG	Coercive force, kOe	Maximum energy product, MGOe	Density, g/cm^3
21b	12.8	8.1	38.0	7.43
22b	12.6	9.3	36.7	7.46
23b	12.6	8.5	37.0	7.38
24b	12.7	9.8	38.3	7.42
25b	12.8	9.8	38.3	7.40
26b	12.8	8.7	35.5	7.39
27b	12.5	9.2	36.5	7.42
28b	12.4	7.2	36.5	7.37
29b	12.7	9.3	33.8	7.37
30b	12.6	7.4	34.9	7.41
31b	12.7	8.8	36.8	7.50
32b	12.6	9.0	37.2	7.49
33b	12.9	7.0	38.8	7.47
34b	12.8	8.5	37.8	7.42
35b	12.6	8.1	36.5	7.44
36b	12.8	9.1	38.0	7.41
37b	12.8	8.8	37.3	7.41
38b	12.8	7.7	34.5	7.43
39b	12.6	8.2	35.6	7.44
40b	12.5	7.2	36.6	7.47

Table 5-3

Magnet No.	Residual magnetic flux density, kG	Coercive force, kOe	Maximum energy product, MGOe	Density, g/cm^3
41b	12.7	8.8	33.9	7.49
42b	12.7	7.4	35.9	7.48
43b	12.7	8.7	36.7	7.50
44b	12.7	8.4	37.12	7.49
45b	12.9	7.5	38.9	7.46
46b	12.8	8.1	37.8	7.42
47b	12.6	8.4	36.9	7.42
48b	12.7	9.6	38.6	7.43
49b	12.7	9.2	37.3	7.47
50b	12.6	8.3	35.5	7.39
51b	12.5	9.6	36.25	7.39
52b	12.4	7.0	35.5	7.42
53b	12.2	3.9	13.8	7.27
54b	12.4	4.7	31.9	7.35
55b	12.6	7.8	34.8	7.45
56b	12.5	8.0	35.2	7.48
57b	12.6	7.0	28.8	7.51
58b	12.4	7.5	24.8	7.41
59b	12.4	8.5	35.8	7.42
60b	12.7	8.5	36.8	7.47

Table 5-4

Magnet No.	Residual magnetic flux density, kG	Coercive force, kOe	Maximum energy product, MGOe	Density, g/cm^3
61b	12.6	8.1	35.8	7.42
62b	12.7	8.3	36.8	7.46
63b	12.6	8.7	35.8	7.40
64b	12.3	9.0	33.2	7.34
65b	12.1	7.9	32.8	7.37
66b	12.5	8.5	33.8	7.52
67b	12.2	8.3	34.5	7.43
68b	12.8	8.5	32.3	7.52
69b	12.4	9.5	36.1	7.42
70b	12.1	8.5	30.7	7.52

Claims

1. A rare earth-based permanent magnet which is a product prepared by a process comprising the steps of:

(a) mixing a powder of a first magnetic alloy having a ternary composition substantially represented by the formula

$R_2T_{14}B$,

in which R is a rare earth element and T is iron or a combination of iron and cobalt in such a proportion that the amount of cobalt does not exceed 40% by weight of the total amount of iron and cobalt, and a powder of a second magnetic alloy having a composition substantially represented by the formula

$R_aFe_bCo_cB_dM_e$,

in which R has the same meaning as defined above, M is an element selected from the group consisting of gallium, aluminum, copper, zinc, indium, silicon, phosphorus, sulfur, titanium, vanadium, chromium, manganese, germanium, zirconium, niobium, molybdenum, palladium, silver, cadmium, tin, antimony, hafnium, tantalum and tungsten, the subscript a is a positive number in the range from 15 to 40, b is zero or a positive number not exceeding 80, c is a positive number in the range from 5 to 85, d is zero or a positive number not exceeding 20 and e is zero or a positive number not exceeding 20 with the proviso that $a+b+c+d+e$ is 100, in a weight proportion of the first magnetic alloy powder to the second magnetic alloy powder in the range from 99:1 to 70:30 to give a powder mixture;

(b) shaping the powder mixture into a form of magnet by compression molding in a magnetic field; and

(c) sintering the shaped form of the powder mixture by heating in vacuum or in an atmosphere of an inert gas.

2. The rare earth-based permanent magnet as claimed in claim 1 in which the element denoted by M is gallium.

3. The rare earth-based permanent magnet as claimed in claim 1 in which the element denoted by R is a rare earth element selected from the group consisting of neodymium, praseodymium, dysprosium and terbium.

4. The rare earth-based permanent magnet as claimed in claim 3 in which the element denoted by R is neodymium.

5. The rare earth-based permanent magnet as claimed in claim 1 in which the subscript a is a positive number in the range from 25 to 35, b is a positive number in the range from 5 to 45, c is a positive number in the range from 15 to 65, d is a positive number in the range from 1 to 15 and e is zero or a positive number not exceeding 10 with the proviso that $a+b+c+d+e$ is 100.

6. The rare earth-based permanent magnet as claimed in claim 1 in which the second magnetic alloy has a metallographic structure comprising the phases of R2T14B and at least one of the formulas RT_4L, RT_3, RT_2, R_2T_7 and RT_5, in which R and T each have the same meaning as defined above and L is boron or a combination of boron and the element M.

European Patent
Office

EUROPEAN SEARCH REPORT

Application Number

EP 92 10 9366

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
Y A	WO-A-9 106 107 (KAWASAKI STEEL CORP.) * page 1; figure 2; table 3 * & EP-A-0 447 567 ---	1,3,4 6	H01F1/053
Y	PATENT ABSTRACTS OF JAPAN vol. 12, no. 379 (E-667)(3226) 11 October 1988 & JP-63 127 505 (TAIO YUDEN CO LTD) 31 May 1988 * abstract * ---	1,3,4	
A	EP-A-0 421 488 (HTACHI METALS LTD) * page 4, line 35 - line 50; claims 1,3 * ---	1-4	
A	IEEE TRANSACTIONS ON MAGNETICS. vol. 26, no. 5, September 1990, NEW YORK US pages 2640 - 2642; J.F.LIU ET AL: 'MAGNETIC PROPERTIES OF Ga DOPED NdFeCoB SINTERED MAGNETS' * table 1 * -----	1,2	

TECHNICAL FIELDS SEARCHED (Int. Cl.5)

H01F

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	27 AUGUST 1992	DECANNIERE L.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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