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(54) COMPOSITE SOFT MAGNETIC POWDERY MATERIAL AND MAGNETICALLY BIASING PERMANENT MAGNETIC CORE CONTAINING SAME

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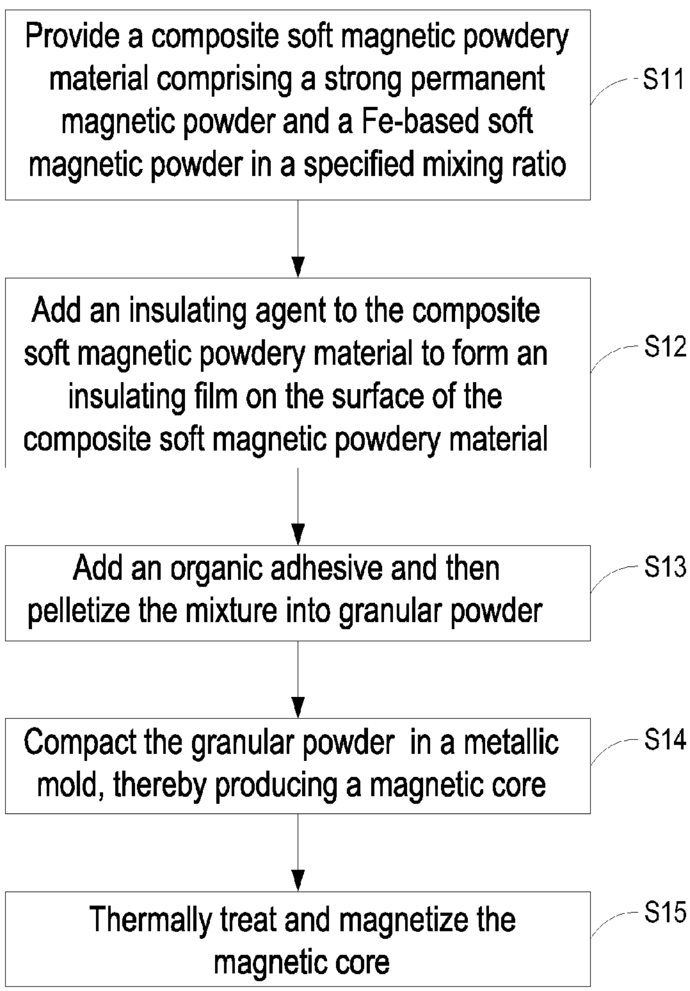
(57) **ABSTRACT**

The present invention relates to a composite soft magnetic powdery material. The composite soft magnetic powdery material includes a strong permanent magnetic powder and a Fe-based soft magnetic powder. The mixing ratio of the Fe-based soft magnetic powder to the strong permanent magnetic powder is from 5:5 to 9:1. The composite soft magnetic powdery material has a magnetic permeability of from 5 to 50.



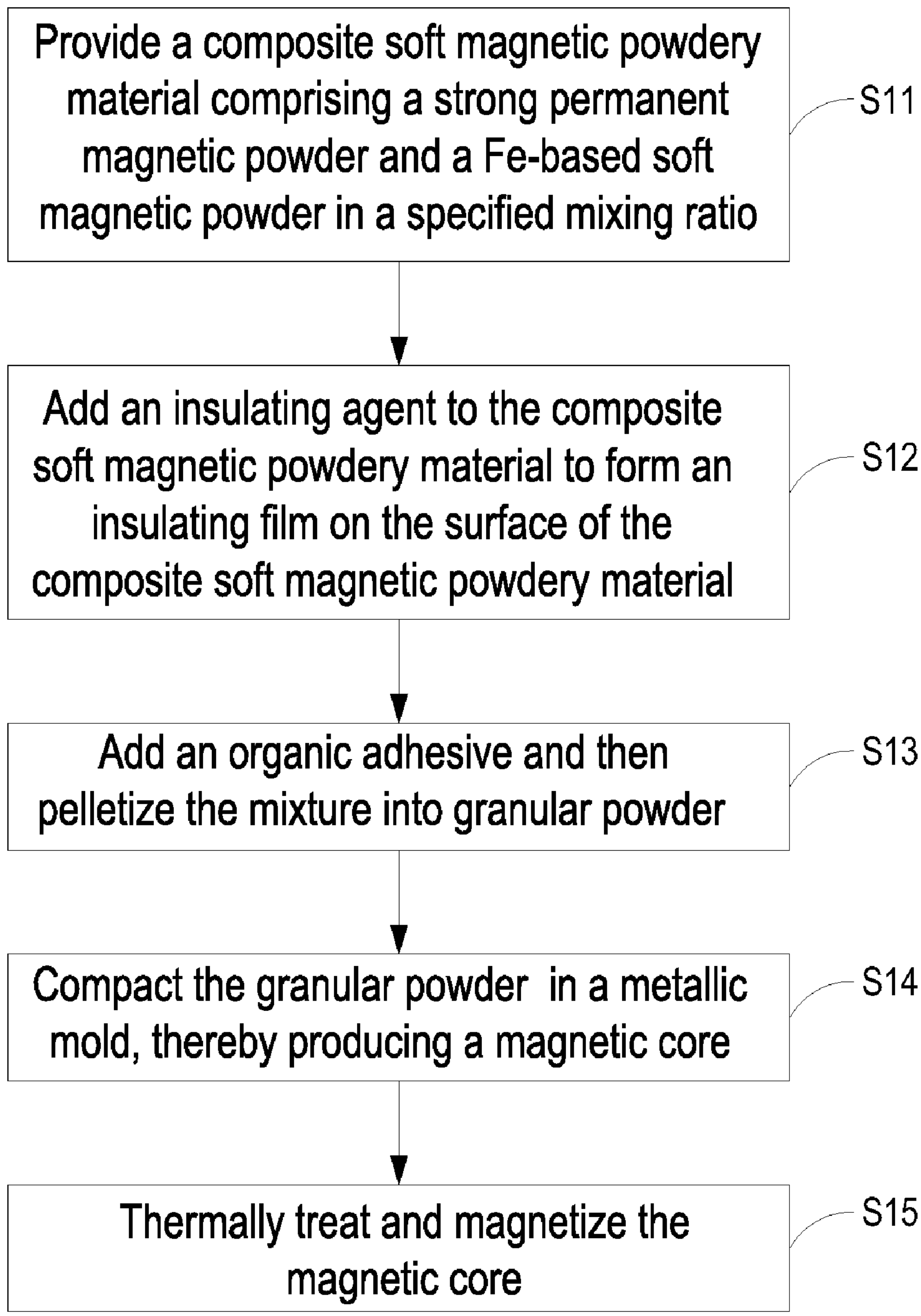

Provide a composite soft magnetic powdery material comprising a strong permanent magnetic powder and a Fe-based soft magnetic powder in a specified mixing ratio
S11
Add an insulating agent to the composite soft magnetic powdery material to form an insulating film on the surface of the composite soft magnetic powdery material
S12
Add an organic adhesive and then pelletize the mixture into granular powder
S13
Compact the granular powder in a metallic mold, thereby producing a magnetic core
S14
Thermally treat and magnetize the magnetic core
S15

FIG. 1

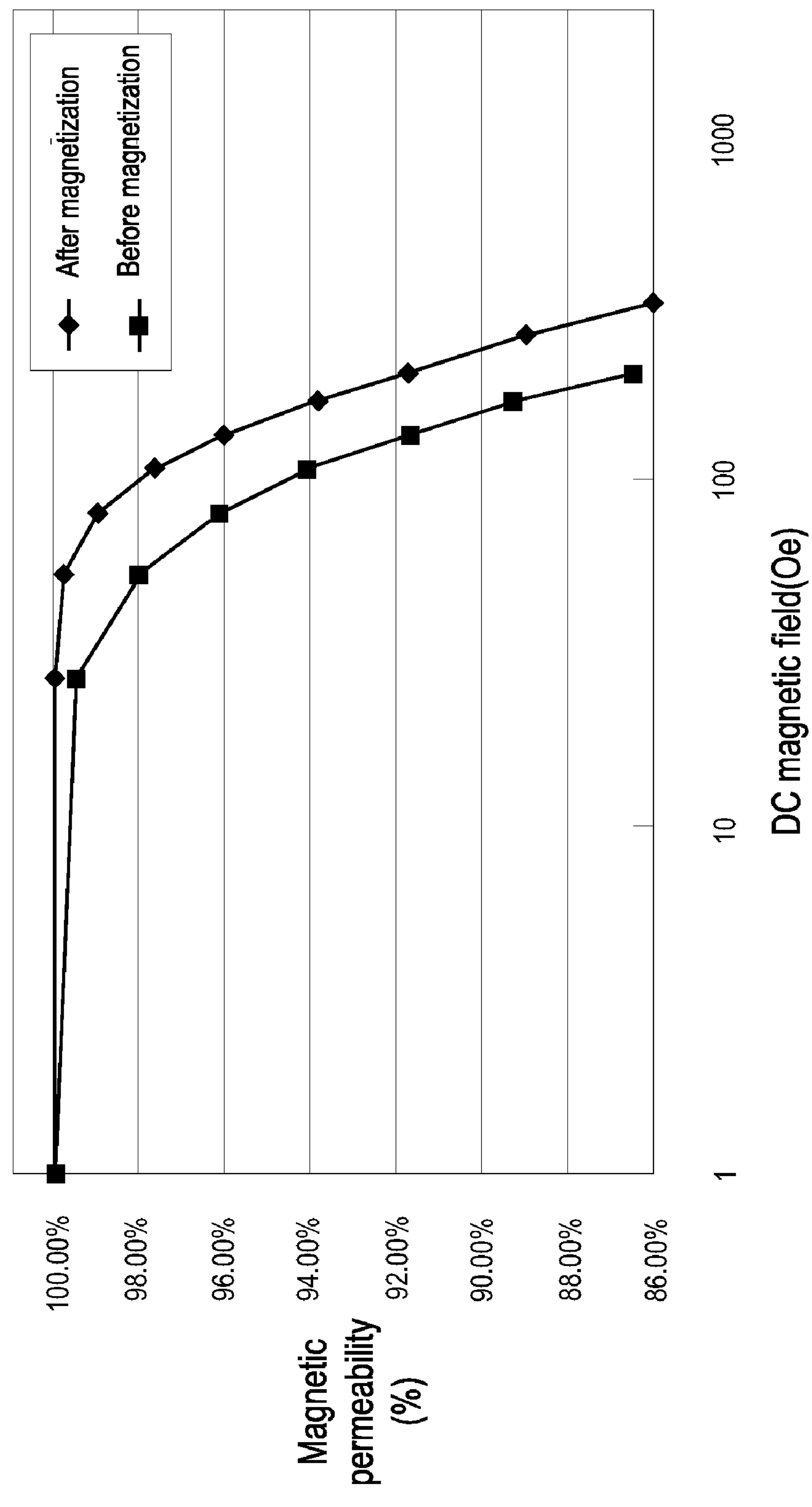

After magnetization
Before magnetization
Magnetic permeability (%)
100.00%
98.00%
96.00%
94.00%
92.00%
90.00%
88.00%
86.00%
1
10
100
1000
DC magnetic field(Oe)

FIG. 2

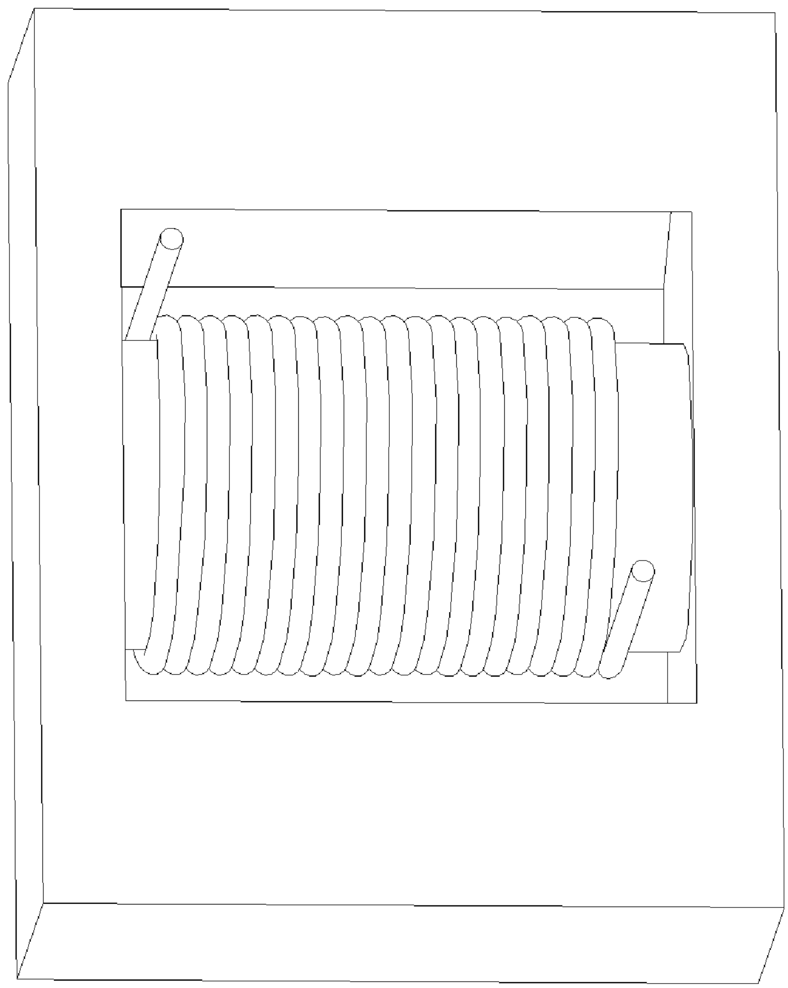


FIG. 3


Inductance
(uH)
140
120
100
80
60
40
20
0
-10
-8
-6
-4
-2
0
2
4
6
8
10
Current(A)

FIG. 4

COMPOSITE SOFT MAGNETIC POWDERY MATERIAL AND MAGNETICALLY BIASING PERMANENT MAGNETIC CORE CONTAINING SAME

FIELD OF THE INVENTION

[0001] The present invention relates to a magnetic powder and a magnetic core containing such magnetic powder, and more particularly to a composite soft magnetic powdery material and a magnetically biasing permanent magnetic core containing such composite soft magnetic powdery material.

BACKGROUND OF THE INVENTION

[0002] In a magnetic element such as a power choke and a transformer used in for example a switching power supply, an AC component of a voltage is usually superposed with a DC component. Therefore, a magnetic core used in this magnetic element needs to have a magnetic characteristic of a good magnetic permeability such that magnetic core is not magnetically saturated by the superposition of the DC component.

[0003] Recently, since the electronic products are developed toward minimization, the electronic components contained in the electronic products become small in size and light in weight. Therefore, the magnetic elements such as transformers or inductors are also small-sized. In a case that the volume of the magnetic core of the magnetic element is reduced, the magnetic core is readily magnetically saturated and thus the magnetic element can only withstand less current.

[0004] For addressing the above problems, a magnetic gap in a magnetic path of a magnetic core is increased and a permanent magnet is disposed in the gap. That is, the magnetic core is magnetically biased to eliminate a DC magnetic flux caused by the superposition of DC current. U.S. Pat. No. 6,856,231 disclosed a magnetically biasing bond magnet comprising magnetic powder and plastic resin in order to reduce core loss and increase the magnetic bias. Since the magnetic gap in the magnetic path of the magnetic core is necessary, the process of fabricating the magnetic core is complicated. Moreover, if the permanent magnet is not tightly fitted into the magnetic gap, more core loss is generated in the magnetic gap due to a leakage flux produced from the magnetic gap.

[0005] U.S. Pat. No. 6,545,582 disclosed a magnetic core having an effective magnetic bias. Since the magnetic path of the magnetic core is not completely closed, a permanent magnet can be attached onto an outer surface of the magnetic core and thus such magnetic core is easily assembled. The permanent magnet attached onto the outer surface of the magnetic core, however, increases the overall volume of the magnetic core and is detrimental to minimization of the magnetic core.

[0006] As previously described, the process of disposing the permanent magnet in the magnetic gap of the magnetic core is complicated. If the permanent magnet is not tightly fitted into the magnetic gap, more core loss is generated in the magnetic gap due to a leakage flux produced from the magnetic gap. Moreover, the process of attaching the permanent magnet onto the outer surface of the magnetic core increases the overall volume of the magnetic core.

[0007] Therefore, there is a need of providing a composite soft magnetic powdery material and a magnetically biasing permanent magnetic core containing such composite soft magnetic powdery material so as to obviate the drawbacks encountered from the prior art.

SUMMARY OF THE INVENTION

[0008] It is an object of the present invention to provide a composite soft magnetic powdery material and a magnetically biasing permanent magnetic core containing such composite soft magnetic powdery material. The magnetic core of the present invention has excellent DC superposition characteristic, good anti-saturation ability, low core loss and is effectively magnetized.

[0009] Another object of the present invention provides a magnetically biasing permanent magnetic core having reduced volume, low core loss, increased magnetic permeability and enhanced safety.

[0010] A further object of the present invention provides a magnetically biasing permanent magnetic core capable of withstanding medium- to high-level current and easily fabricated.

[0011] In accordance with an aspect of the present invention, there is provided a composite soft magnetic powdery material. The composite soft magnetic powdery material includes a strong permanent magnetic powder and a Fe-based soft magnetic powder. The mixing ratio of the Fe-based soft magnetic powder to the strong permanent magnetic powder is from 5:5 to 9:1. The composite soft magnetic powdery material has a magnetic permeability of from 5 to 50.

[0012] In accordance with another aspect of the present invention, there is provided a magnetically biasing magnetic core having a magnetic permeability of from 5 to 50. The magnetically biasing magnetic core includes a composite soft magnetic powdery material and at least one additive. The composite soft magnetic powdery material comprises a strong permanent magnetic powder and a Fe-based soft magnetic powder. The mixing ratio of the Fe-based soft magnetic powder to the strong permanent magnetic powder is from 5:5 to 9:1

[0013] The above contents of the present invention will become more readily apparent to those ordinarily skilled in the art after reviewing the following detailed description and accompanying drawings, in which:

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] FIG. **1** is a process of fabricating a magnetically biasing permanent magnet using the composite soft magnetic powdery material of the present invention;

[0015] FIG. **2** is a graph showing the DC characteristic of the magnetic core before magnetization and after magnetization;

[0016] FIG. **3** schematically illustrates a winding coil is wound around a stick-shaped magnetic core of the present invention; and

[0017] FIG. **4** is a plot showing the relationship between the inductance of the magnetic device of FIG. **3** and the DC magnetically biasing current.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0018] The present invention will now be described more specifically with reference to the following embodiments. It is to be noted that the following descriptions of preferred embodiments of this invention are presented herein for purpose of illustration and description only. It is not intended to be exhaustive or to be limited to the precise form disclosed.

[0019] The present invention relates to a composite soft magnetic powdery material comprising a strong permanent magnetic powder and a Fe-based soft magnetic powder. The mixing ratio of the Fe-based soft magnetic powder to the strong permanent magnetic powder is from 5:5 to 9:1. A too small proportion of the strong permanent magnetic powder results in a too low magnetically biasing magnetic field and thus the magnetic core having an inferior anti-saturation performance. Whereas, a too large proportion of the strong permanent magnetic powder results in a too low magnetic permeability of the magnetic core and thus such magnetic core is not feasible. For achieving both good magnetic anti-saturation property and high magnetic permeability, the mixing ratio of the Fe-based soft magnetic powder to the strong permanent magnetic powder is preferable from 5:5 to 9:1.

[0020] The Fe-based soft magnetic powder used in the preparation of the soft magnetic core of the present invention includes carbonyl iron powder, atomizing iron powder, electrolytic iron powder, Fe—Si alloy powder, Fe—Ni alloy powder, Fe—Si—Al alloy powder, Fe—Si—Cr alloy powder, or Fe-based amorphous power. Preferably, the strong permanent magnetic powder has an intrinsic coercive force of 5 kOe or more and a Curie temperature (Tc) of 300° C. or more. More preferably, the strong permanent magnetic powder has an intrinsic coercive force of 10 kOe or more and a Curie temperature (Tc) of 500° C. or more. Generally, the relatively higher intrinsic coercive force can provide a magnetic core which has an excellent DC superposition property. The relatively higher Curie temperature can prevent the composite soft magnetic powdery material from being demagnetized due to the high core operation temperature. An exemplary strong permanent magnetic powder includes rare-earth permanent magnetic powder such as NdFeB series, SmCo series, SmFeN series and the like.

[0021] Hereinafter, a process of fabricating a magnetically biasing permanent magnet using the composite soft magnetic powdery material of the present invention will be illustrated with reference to the flowchart of FIG. **1**.

[0022] First of all, as shown in Step S**11**, a composite soft magnetic powdery material comprising a Fe-based soft magnetic powder and a strong permanent magnetic powder in a mixing ratio of from 5:5 to 9:1 is provided.

[0023] Next, as shown in Step S**12**, an insulating agent is added to the composite soft magnetic powdery material to form an insulating film on the surface of the composite soft magnetic powdery material in order to increase the resistivity and reduce eddy current losses. The insulating agent used in the present invention includes but is not limited to phosphoric acid solution, silicate solution, titanate ester solution, and so on.

[0024] Next, as shown in Step S**13**, an organic adhesive is added to the mixture and then pelletized. The organic adhesive includes for example organic resin, e.g. polypropylene resin, 6-nylon resin, 12-nylon resin, polyethylene resin, polyimide resin, phenolic resin and epoxy resin. Alternatively, the composite soft magnetic powdery material, the insulating agent and the organic adhesive can be intensely stirred and uniformly mixed to form slurry. The slurry is then pelletized into larger-sized granular powder by a doctor blade method or using a pelletizer, so that the powder has a desired flowing property.

[0025] Next, as shown in Step S**14**, the granular powder is compacted in a metallic mold under a compacting pressure between 4 T/cm^2 to 20 T/cm^2, thereby producing a magnetic core. Generally, as the compacting pressure is increased, the magnetic permeability of the magnetic core is increased. Moreover, if the particles of the strong permanent magnetic powder are closer to each other, the magnetically biasing performance is enhanced. A too large compacting pressure is detrimental to the structure of the strong permanent magnetic powder and thus the intrinsic coercive force of the strong permanent magnetic powder is decreased. It is preferred that the compacting pressure between 6 T/cm^2 to 15 T/cm^2. For increasing the compacting density of the magnetic core, the shape of the granular powder should be matched. In other words, the Fe-based soft magnetic powder and the strong permanent magnetic powder have substantially identical shapes. If the magnetic powder is deformed into a flake-like form, the magnetic coercive force is relatively higher but the magnetic permeability is relatively smaller when the magnetic path is perpendicular to the magnetic powder plane; and the magnetic permeability is increased but the anti-saturation property is considerably reduced when the magnetic path is parallel with the magnetic powder plane. In addition, the use of the flat magnetic power may increase the eddy current loss because the average particle size of the powder is relatively larger. As a consequence, it is preferred that the Fe-based soft magnetic powder and the strong permanent magnetic powder have spherical or nearly spherical shapes. For minimizing sharp increase of eddy current loss at high-frequency, the Fe-based soft magnetic powder and the strong permanent magnetic powder have maximum particle size equal to or less than 100 μm, and average particle size between 5 μm and 50 μm.

[0026] Next, as shown in Step S**15**, the magnetic core is thermally treated and then magnetized by a magnetic field of for example 3T or more. The strong permanent magnetic powder included in the magnetic core is magnetized to provide a magnetic bias on the Fe-based soft magnetic powder. As a consequence, the anti-saturation property of the overall magnetic core after magnetization is increased and thus the magnetic core is feasible for use.

[0027] The magnetically biasing magnetic core of the present invention has a magnetic permeability of from 5 to 50. A magnetic core with too low magnetic permeability is not feasible. Whereas, a magnetic core with too high magnetic permeability has inferior DC superposition characteristic. For avoiding eddy current loss, the magnetically biasing magnetic core of the present invention has a specific resistance of 0.1 Ω·cm or more. Furthermore, magnetically biasing magnetic core of the present invention has a density of 5.5 g/cm^3 or more. A too small density results in reduced effective biasing magnetic field and thus the DC superposition characteristic is decreased.

[0028] Hereinafter, the present invention will be described in more detail through the following examples.

Example 1

[0029] In this example, Fe-3% Si Fe-based soft magnetic powder and NdFeB strong permanent magnetic powder in a weight ratio of 7:3 are mixed together in a powder mixer. The NdFeB strong permanent magnetic powder is one kind of atomizing powder, and has a spherical shape, an average diameter of 30 μm and an intrinsic coercive force of 9.4 kOe. The Fe-based soft magnetic powder has an average diameter of about 12 μm. The composite soft magnetic powdery material comprising the mixture of the Fe-based soft magnetic powder and the strong permanent magnetic powder is treated with an insulating agent (e.g. silicon resin) and then mixed with 5 wt % of organic adhesive (e.g. epoxy resin). Next, the composite soft magnetic powdery material treated with the insulating agent and mixed with the organic adhesive is uniformly mixed, pelletized and dried into dry powder. The dry powder passing through a sieve of 60 meshes is compacted in a metallic mold under a compacting pressure of 8 T/cm^2, thereby producing a magnetic core. The magnetic core is removed from the metallic mold and then subject to a curing process in a thermostat oven for 30 minutes at a temperature of 160° C. Then, the organic adhesive coated on the magnetic core is solidified and magnetized by a magnetic field of 4 T. Thereafter, the specific resistance of the magnetic core is measured to be greater than 10^3 Ω·cm.

[0030] FIG. **2** is a graph showing the DC characteristic of the magnetic core before magnetization and after magnetization. The measured data indicates that the anti-saturation performance of the magnetic core after magnetization is enhanced.

Example 2

[0031] The Fe-based soft magnetic powder used in this example is carbonyl iron powder having an average diameter of 7 μm. The strong permanent magnetic powder used in this example is spherical NdFeB strong permanent magnetic powder fabricated through a mechanical alloy ball mill process and has an average diameter of 10 μm and an intrinsic coercive force of 11 kOe. The Fe-based soft magnetic powder and the strong permanent magnetic powder are mixed in a weight ratio of 9:1, 8:2, 7:3 and 6:4. The composite soft magnetic powdery material comprising the mixture of the Fe-based soft magnetic powder and the strong permanent magnetic powder is treated with an insulating agent (e.g. titanate ester solution), and then mixed with 4.2 wt % of organic adhesive (e.g. phenolic resin). Next, the composite soft magnetic powdery material treated with the insulating agent and mixed with the organic adhesive is uniformly mixed, pelletized and dried into dry powder. The dry powder is compacted in a metallic mold under a compacting pressure of 10 T/cm^2, thereby producing a magnetic core. The magnetic core is removed from the metallic mold and then subject to a curing process in a thermostat oven. Then, the organic adhesive coated on the magnetic core is solidified and magnetized by a magnetic field of 4 T. Thereafter, the electrical properties of the magnetic core are measured and indicated in Table 1. As shown in Table 1, the magnetic core after magnetization can withstand an increased magnetically biasing magnetic field. Moreover, as the proportion of the strong permanent magnetic powder is increase, the anti-saturation performance of the magnetic core is enhanced but the magnetic permeability is sharply decreased.

TABLE 1

Ratio	Density (g/cm^3)	Permeability (μ)	Magnetically biasing magnetic field (Oe) at 90% permeability: Before magnetization	After magnetization
9:1	6.564	24	46	56
8:2	6.453	18	78	92

TABLE 1-continued

Ratio	Density (g/cm^3)	Permeability (μ)	Magnetically biasing magnetic field (Oe) at 90% permeability: Before magnetization	After magnetization
7:3	6.334	13	214	287
6:4	6.184	10	293	402

Example 3

[0032] In this example, Fe-1.5% Si Fe-based soft magnetic powder and Sm_2Co_{17} strong permanent magnetic powder are mixed together in a powder mixer. The Sm_2Co_{17} strong permanent magnetic powder has an average diameter of 5 μm, an intrinsic coercive force of 12 kOe and a Curie temperature of 850° C. The Fe-based soft magnetic powder and the strong permanent magnetic powder are mixed in a weight ratio of 8:2. The composite soft magnetic powdery material comprising the mixture of the Fe-based soft magnetic powder and the strong permanent magnetic powder is treated with an insulating agent (e.g. phosphoric acid solution), and then mixed with 4.2 wt % of organic adhesive (e.g. polyimide resin). The dry powder passing through a sieve of 60 meshes is compacted in a metallic mold under a compacting pressure of 12 T/cm^2, thereby producing a magnetic core. The magnetic core is removed from the metallic mold and then subject to a curing process in a thermostat oven. Then, the organic adhesive coated on the magnetic core is solidified and magnetized by a magnetic field of 5 T.

[0033] Next, as shown in FIG. **3**, a winding coil is wound around a stick-shaped magnetic core of the present invention. The stick-shaped magnetic core wound by the winding coil is placed as the middle post of a window-shaped ferrite core, thereby forming a magnetic device. The inductance of the magnetic device varied according to the DC magnetically biasing current is shown in the plot of FIG. **4**. As shown in FIG. **4**, the DC magnetic field generated from the magnetically biasing current and the magnetized direction of the magnetic core have identical directions. If the DC magnetic field is superposed with the magnetized direction, the inductance is readily saturated and then the inductance rapidly decreases. Whereas, if the direction of the DC magnetic field generated from the magnetically biasing current is opposed to the magnetized direction of the magnetic core, the both magnitudes are offset with each other. As a consequence, the speed of reach inductance saturation is slowed and the inductance maintains stable at larger current.

[0034] From the above description, the magnetic core fabricated from the composite soft magnetic powdery material comprising the Fe-based soft magnetic powder and the strong permanent magnetic powder has excellent DC superposition characteristic, good anti-saturation ability, low core loss and is effectively magnetized. In addition, the magnetically biasing permanent magnetic core of the present invention has reduced volume, low core loss, increased magnetic permeability and enhanced safety and is capable of withstanding medium- to high-level current and easily fabricated. In addition, since the strong permanent magnetic powder has a magnetic permeability of nearly 1 and the surrounding Fe-based soft magnetic powder has a magnetic permeability of above 2,000, a majority of magnetic flux passes through the Fe-based soft magnetic powder but a minority of magnetic flux passes through the strong permanent magnetic powder. Moreover, since the strong permanent magnetic powder has a higher intrinsic coercive force, the strong permanent magnetic powder is not easily demagnetized and thus the magnetically biasing permanent magnetic core has enhanced safety.

[0035] While the invention has been described in terms of what is presently considered to be the most practical and preferred embodiments, it is to be understood that the invention needs not be limited to the disclosed embodiment. On the contrary, it is intended to cover various modifications and similar arrangements included within the spirit and scope of the appended claims which are to be accorded with the broadest interpretation so as to encompass all such modifications and similar structures.

1. A composite soft magnetic powdery material comprising:
- a strong permanent magnetic powder; and
- a Fe-based soft magnetic powder, wherein the mixing ratio of said Fe-based soft magnetic powder to said strong permanent magnetic powder is from 5:5 to 9:1,
- wherein said composite soft magnetic powdery material has a magnetic permeability of from 5 to 50.

2. The composite soft magnetic powdery material according to claim **1** wherein said strong permanent magnetic powder has an intrinsic coercive force of 5 kOe or more and a Curie temperature (Tc) of 300° C. or more.

3. The composite soft magnetic powdery material according to claim **1** wherein said strong permanent magnetic powder includes rare-earth permanent magnetic powder.

4. The composite soft magnetic powdery material according to claim **3** wherein said rare-earth permanent magnetic powder is selected from a group consisting of NdFeB series, SmCo series and SmFeN series.

5. The composite soft magnetic powdery material according to claim **1** wherein said Fe-based soft magnetic powder is selected from a group consisting of carbonyl iron powder, atomizing iron powder, electrolytic iron powder, Fe—Si alloy powder, Fe—Ni alloy powder, Fe—Si—Al alloy powder, Fe—Si—Cr alloy powder, and Fe-based amorphous power.

6. The composite soft magnetic powdery material according to claim **1** wherein said composite soft magnetic powdery material has a specific resistance of 0.1 Ω•cm or more.

7. The composite soft magnetic powdery material according to claim **1** wherein said Fe-based soft magnetic powder and said strong permanent magnetic powder have substantially identical shapes.

8. The composite soft magnetic powdery material according to claim **7** wherein said Fe-based soft magnetic powder and said strong permanent magnetic powder have spherical or nearly spherical shapes.

9. The composite soft magnetic powdery material according to claim **7** wherein said Fe-based soft magnetic powder and said strong permanent magnetic powder have maximum particle size equal to or less than 100 μm, and average particle size between 5 μm and 50 μm.

10. A magnetically biasing magnetic core having a magnetic permeability of from 5 to 50, said magnetically biasing magnetic core comprising:
- a composite soft magnetic powdery material comprising a strong permanent magnetic powder and a Fe-based soft magnetic powder, wherein the mixing ratio of said Fe-based soft magnetic powder to said strong permanent magnetic powder is from 5:5 to 9:1; and
- at least one additive.

11. The magnetically biasing magnetic core according to claim **10** wherein said strong permanent magnetic powder has an intrinsic coercive force of 5 kOe or more and a Curie temperature (Tc) of 300° C. or more.

12. The magnetically biasing permanent magnetic core according to claim **10** wherein said strong permanent magnetic powder includes rare-earth permanent magnetic powder.

13. The magnetically biasing magnetic core according to claim **12** wherein said rare-earth permanent magnetic powder is selected from a group consisting of NdFeB series, SmCo series and SmFeN series.

14. The magnetically biasing magnetic core according to claim **10** wherein said Fe-based soft magnetic powder is selected from a group consisting of carbonyl iron powder, atomizing iron powder, electrolytic iron powder, Fe—Si alloy powder, Fe—Ni alloy powder, Fe—Si—Al alloy powder, Fe—Si—Cr alloy powder, and Fe-based amorphous power.

15. The magnetically biasing magnetic core according to claim **10** wherein said magnetically biasing magnetic core has a specific resistance of 0.1 Ω•cm or more and a density of 5.5 g/cm^3 or more.

16. The magnetically biasing magnetic core according to claim **10** wherein said Fe-based soft magnetic powder and said strong permanent magnetic powder have spherical or nearly spherical shapes.

17. The magnetically biasing magnetic core according to claim **16** wherein said Fe-based soft magnetic powder and said strong permanent magnetic powder have maximum particle size equal to or less than 100 μm, and average particle size between 5 μm and 50 μm.

18. The magnetically biasing magnetic core according to claim **10** wherein said at least one additive includes an insulating agent and/or an organic adhesive.

19. The magnetically biasing magnetic core according to claim **18** wherein said organic adhesive is selected from polypropylene resin, 6-nylon resin, 12-nylon resin, polyethylene resin, polyimide resin, phenolic resin or epoxy resin.

20. The magnetically biasing magnetic core according to claim **10** wherein said magnetically biasing magnetic core has been subject to magnetization.

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