(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 4 394 816 A1

(12) EUROPEAN PATENT APPLICATION
published in accordance with Art. 153(4) EPC

(43) Date of publication:
03.07.2024 Bulletin 2024/27

(21) Application number: **22885257.0**

(22) Date of filing: **01.08.2022**

(51) International Patent Classification (IPC):
H01F 27/02 *(2006.01)* ***H01F 27/25*** *(2006.01)*
H01F 27/26 *(2006.01)* ***H01F 38/30*** *(2006.01)*
H01F 41/00 *(2006.01)*

(86) International application number:
PCT/CN2022/109366

(87) International publication number:
WO 2023/071357 (04.05.2023 Gazette 2023/18)

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME
Designated Validation States:
KH MA MD TN

(30) Priority: **25.10.2021 CN 202111240282**

(71) Applicant: **Hengdian Group DMEGC Magnetics Co., Ltd.**
Jinhua, Zhejiang 322118 (CN)

(72) Inventors:
- **WANG, Xiaoyun**
  Jinhua, Zhejiang 322118 (CN)
- **JIN, Tianming**
  Jinhua, Zhejiang 322118 (CN)

(74) Representative: **De Bonis, Paolo**
Buzzi, Notaro & Antonielli d'Oulx S.p.A.
Corso Vittorio Emanuele II, 6
10123 Torino (IT)

(54) ANTI-DIRECT-CURRENT NANOCRYSTALLINE DOUBLE-MAGNETIC-CORE CURRENT TRANSFORMER MAGNETIC CORE AND MANUFACTURING METHOD THEREFOR

(57) Disclosed in the present disclosure are an anti-direct-current nanocrystalline double-magnetic-core current transformer magnetic core and a manufacturing method therefor. The anti-direct-current nanocrystalline double-magnetic-core current transformer magnetic core comprises a first nanocrystalline magnetic core, a second nanocrystalline magnetic core, and an annular packaging shell; and the first nanocrystalline magnetic core is sleeved at the outer side of the second nanocrystalline magnetic core, and the first nanocrystalline magnetic core and the second nanocrystalline magnetic core are coaxially arranged. The manufacturing method for the anti-direct-current nanocrystalline double-magnetic-core current transformer magnetic core comprises the following step: sequentially mounting the first nanocrystalline magnetic core and the second nanocrystalline magnetic core into the packaging shell to obtain the anti-direct-current nanocrystalline double-magnetic-core current transformer magnetic core. According to the anti-direct-current nanocrystalline double-magnetic-core current transformer magnetic core provided by the present application, two nanocrystalline magnetic cores are comprised in the anti-direct-current nanocrystalline double-magnetic-core current transformer magnetic core, and the magnetic cores are excellent in stability, good in linearity, high in sensitivity, and large in the adjustment range of magnetic conductivity. In addition, the manufacturing method provided by the present application is simple and low in processing cost.

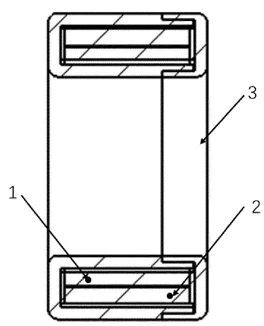

FIG. 1

EP 4 394 816 A1

Description

TECHNICAL FIELD

[0001] Embodiments of the present application relates to the technical field of precision transformer magnetic cores, for example, an anti-direct-current nanocrystalline double-magnetic-core current transformer magnetic core and a preparation method thereof.

BACKGROUND

[0002] With the development of technology, a large number of frequency conversions, switching power supplies, and rectifying installations have been applied in related industrial and civil circuit systems. The widespread use of these installations leads to the presence of certain direct-current components in the circuit. The current transformers are easily saturated by magnetization when there is a large direct-current component, which bring great challenges to the accuracy of current detection. With the development of smart grids, the demand for magnetic cores with anti-direct-current components is rapidly increasing.

[0003] In order to achieve the purpose of anti-direct-current components, amorphous alloy magnetic materials are usually used to manufacture the magnetic cores of the transformers, but amorphous alloy magnetic core transformers have problems of low initial magnetic permeability, poor magnetic core stability, and average anti-direct-current characteristics.

[0004] Nanocrystalline materials have the following excellent comprehensive magnetic properties: high saturation magnetic flux density, high initial magnetic permeability, low H_c, low high-frequency loss under high magnetic flux density, and the resistivity is 80 $\mu\Omega\cdot$cm, which is higher than the Permalloy (50-60 $\mu\Omega\cdot$cm). After treated by a longitudinal or transverse magnetic field, nanocrystalline materials can obtain a high Br or low Br value, which are the best comprehensive performance materials in the market at present, and are widely used in power supplies, transformers, wireless charging and other fields.

[0005] Relevant researchers use nanocrystalline materials to prepare anti-direct-current component transformers, and CN 103928227A discloses a method for preparing a single-core anti-direct-current component transformer iron core, which sequentially comprises the following steps: a nanocrystalline soft magnetic alloy strip material with a thickness of 18-28 μm is subjected to tension pre-crystallization annealing treatment with a tension of 10-60 MPa, a tension-applied annealing temperature of 520-670°C, and an operating speed of the tension-applied strip material of 0.01-0.2 m/s; the nanocrystalline soft magnetic alloy strip material treated by tension pre-crystallization annealing treatment is winded to the transformer iron core, and the wound iron core is subjected to annealing treatment again with a annealing temperature of 400-550°C and a annealing time of 30-120 min. The method uses a simple substance low magnetic permeability iron-based nanocrystalline magnetic core to prepare an anti-direct-current component transformer. The magnetic permeability of the magnetic core made by this method is low, and the angle difference of the transformer made by this magnetic core is large, the sensitivity is average, and the cost is high.

[0006] CN 1107240491A discloses a nanocrystalline alloy double-core current transformer, wherein the nanocrystalline alloy double-core current transformer comprises a ring-shaped structure nanocrystalline magnetic core and an amorphous alloy magnetic core. The nanocrystalline magnetic core is sheathed and installed on the outer side of the amorphous alloy magnetic core, and the nanocrystalline magnetic core and the amorphous alloy magnetic core are coaxially arranged. The amorphous alloy magnetic core is made by winding an amorphous alloy magnetic strip material, and the amorphous alloy magnetic strip material contains the following mass percentages of elements: 8%-12% of silicon, 5%-8% of boron, 1.0%-1.8% of manganese, 0.5%-1.3% of cobalt, 1.2%-2.2% of vanadium, 2.5%-4.0% of carbon, and a remainder is iron. The nanocrystalline alloy double-core current transformer described in this patent contains two magnetic cores, but only one is a nanocrystalline alloy magnetic core, and the core of its low conduction part is an amorphous alloy magnetic core. The magnetic cores prepared by this process have poor core stability, average anti-direct-current characteristics and average linearity of magnetic permeability.

[0007] Based on the poor stability of the low magnetic permeability magnetic cores in the related composite magnetic cores and the problem of a large angular difference of the produced transformer and the high cost of the magnetic cores caused by the low magnetic permeability of a single-core low magnetic permeability iron-based nanocrystalline magnetic core, it is necessary to provide a composite magnetic core that can retain the high magnetic permeability characteristics of the high magnetic permeability magnetic core and ensure the good stability of the low magnetic permeability magnetic core, and has a relatively low cost of the magnetic core production.

SUMMARY

[0008] The following is a summary of the topics described in detail herein. This summary is not intended to limit the scope of protection of the claims.

[0009] An embodiment of the present application provides an anti-direct-current nanocrystalline double-magnetic-core current transformer magnetic core and a preparation method thereof. The anti-direct-current nanocrystalline double-magnetic-core current transformer magnetic core includes a high magnetic permeability nanocrystalline magnetic core and a low magnetic permeability nanocrystalline magnetic core, which not only retains the high conductivity of the high magnetic permeability magnetic core, but also ensures the good stability of the low magnetic permeability magnetic core; and because of combined use with a high magnetic permeability magnetic core, the magnetic permeability of the low magnetic permeability magnetic core can be adjusted in a wide range to meet broader application requirements.

[0010] In a first aspect, an embodiment of the present application provides an anti-direct-current nanocrystalline double-magnetic-core current transformer magnetic core, which comprises a first nanocrystalline magnetic core, a second nanocrystalline magnetic core, and a ring-shaped packaging shell.

[0011] Preferably, the first nanocrystalline magnetic core is sheathed and installed on the outer side of the second nanocrystalline magnetic core, and the first nanocrystalline magnetic core and the second nanocrystalline magnetic core are coaxially arranged.

[0012] Preferably, a magnetic permeability of the first nanocrystalline magnetic core is 80000-200000 H/m, such as 80000 H/m, 90000 H/m, 100000 H/m, 120000 H/m, 140000 H/m, 160000 H/m, 170000 H/m, 180000 H/m, 190000 H/m or 200000 H/m; however, the magnetic permeability is not limited to the listed values, and other unlisted values in the numerical range are also applicable.

[0013] Preferably, a magnetic permeability of the second nanocrystalline magnetic core is 500-4000 H/m, such as 500 H/m, 1000 H/m, 1500 H/m, 2000 H/m, 2500 H/m, 3000 H/m, 3500 H/m or 4000 H/m, however, the magnetic permeability is not limited to the listed values, and other unlisted values in the numerical range are also applicable

[0014] The anti-direct-current nanocrystalline double-magnetic-core current transformer magnetic core disclosed by the present application includes a first nanocrystalline magnetic core with higher magnetic permeability and a second nanocrystalline magnetic core with lower magnetic permeability, so that the anti-direct-current nanocrystalline double-magnetic-core current transformer magnetic core can not only keep the high conductivity of the high magnetic permeability magnetic core, but also ensure the good stability of the low magnetic permeability magnetic core, and the manufacturing cost of the magnetic core is relatively low. In addition, because of combined use with the high permeability magnetic core, the magnetic permeability of the low magnetic permeability magnetic core can be adjusted in a wide range to meet broader application requirements.

[0015] In a second aspect, the embodiment of the application provides a method for preparing an anti-direct-current nanocrystalline double-magnetic-core current transformer magnetic core according to the first aspect, which includes the following steps:

sequentially installing the first nanocrystalline magnetic core and the second nanocrystalline magnetic core into an interior of the packaging shell to obtain the anti-direct-current nanocrystalline double-magnetic-core current transformer magnetic core.

[0016] Preferably, the interior of the packaging shell is filled with a filler.

[0017] Preferably, the filler includes sponge and/or silica gel.

[0018] The filler in the present application is used to fix the magnetic core inside the packaging shell, so that the magnetic core inside the package shell is not easy to shake, thereby improving the stability of the transformer.

[0019] Preferably, a preparation method of the first nanocrystalline magnetic core includes the following steps:

(1) winding an iron-based nanocrystalline alloy strip material into a first magnetic ring; and

(2) performing an annealing treatment on the first magnetic ring obtained in step (1) to obtain the first nanocrystalline magnetic core.

[0020] Preferably, a thickness of the iron-based nanocrystalline alloy strip material in step (1) is 20-30 μm, such as 20 μm, 21μm, 22 μm, 23 μm, 24 μm, 25 μm, 26 μm, 27 μm, 28 μm, 29 μm or 30 μm; however, the thickness is not limited to the listed values, and other unlisted values in the numerical range are also applicable.

[0021] Preferably, an environment of the annealing treatment in step (2) is a vacuum environment and/or a reducing atmosphere environment.

[0022] Preferably, the reducing atmosphere includes an argon atmosphere and/or a nitrogen atmosphere.

[0023] Preferably, the annealing treatment in step (2) includes a first heating, a first heat preservation, a second heating, a second heat preservation and cooling in sequence.

[0024] A terminal temperature of the first heating is 470-490°C,such as 470°C, 475°C, 480°C, 485°C or 490°C; however, the terminal temperature is not limited to the listed values, and other unlisted values in the numerical range are also applicable.

[0025] Preferably, a heating rate of the first heating is 1-5°C/min, such as 1°C/min, 2°C/min, 3°C/min, 4°C/min or

5°C/min; however, the heating rate is not limited to the listed values, and other unlisted values in the numerical range are also applicable.

[0026] A time of the first heat preservation is 60-90 min, such as 60 min, 65 min, 70 min, 75 min, 80 min, 85 min or 90 min; however, the time is not limited to the listed values, and other unlisted values in the numerical range are also applicable.

[0027] Preferably, a terminal temperature of the second heating is 540-570°C, which can be 540°C, 545°C, 550°C, 555°C, 560°C, 565°C or 570°C; however, the terminal temperature is not limited to the listed values, and other unlisted values in the numerical range are also applicable.

[0028] Preferably, a heating rate of the second heating is 0.5-3.5°C/min, such as 0.5°C/min, 1°C/min, 1.5°C/min, 2°C/min, 2.5°C/min, 3°C/min or 3.5°C/min; however, the heating rate is not limited to the listed values, and other unlisted values in the numerical range are also applicable.

[0029] Preferably, a time of the second heat preservation is 60-120 min, such as 60 min, 70 min, 80 min, 90 min, 100 min, 110 min or 120 min; however, the time is not limited to the listed values, and other unlisted values in the numerical range are also applicable.

[0030] Preferably, a terminal temperature of the cooling is less than or equal to 200°C, such as 200°C, 190°C, 180°C, 170°C, 160°C or 150°C; however, the terminal temperature is not limited to the listed values, and other unlisted values in the numerical range are also applicable.

[0031] Preferably, a preparation method of the second nanocrystalline magnetic core includes the following steps:

(a) after subjecting an iron-based nanocrystalline alloy strip material to tension pre-crystallization annealing treatment, winding to obtain a second magnetic ring; and

(b) sequentially impregnating and curing the second magnetic ring obtained in step (a) to obtain the second nanocrystalline magnetic core.

[0032] Preferably, a thickness of the iron-based nanocrystalline alloy strip material in step (a) is 16-22 μm, such as 16 μm, 16.5 μm, 17 μm, 17.5 μm, 18 μm, 18.5 μm, 19 μm, 19.5 μm, 20 μm, 21 μm or 22 μm; however, the thickness is not limited to the listed values, and other unlisted values in the numerical range are also applicable.

[0033] Preferably, an annealing temperature of the tension crystallization annealing treatment in step (a) is 500-570°C, such as 500°C, 510°C, 520°C, 530°C, 540°C, 550°C, 560°C or 570°C; however, the annealing temperature is not limited to the listed values, and other unlisted values in the numerical range are also applicable.

[0034] Preferably, an applied tension of the tension crystallization annealing treatment in step (a) is 20-100 MPa, such as 20 MPa, 30 MPa, 40 MPa, 50 MPa, 60 MPa, 70 MPa, 80 MPa, 90 MPa, or 100 MPa; however, the applied tension is not limited to the listed values, and other unlisted values in the numerical range are also applicable.

[0035] Preferably, an operating speed of the tension-applied strip material of the tension crystallization annealing treatment in step (a) is 1-10 m/min, such as 1 m/min, 2 m/min, 3 m/min, 4 m/min, 5 m/min, 6 m/min, 7 m/min, 9 m/min or 10 m/min; however, the operating speed is not limited to the listed values, and other unlisted values in the numerical range are also applicable.

[0036] Preferably, an impregnating liquid for the impregnating in step (b) is a mixed liquid of epoxy resin adhesive and diluent.

[0037] Preferably, a total mass fraction of epoxy resin adhesive and diluent in the impregnating solution is 100wt%, and a mass fraction of the epoxy resin adhesive is 25-30wt%,such as 25wt%, 26wt%, 27wt%, 28wt%, 29wt% or 30wt%; however, the mass fraction is not limited to the listed values, and other unlisted values in the numerical range are also applicable. A remainder is diluent.

[0038] Preferably, a time of the impregnating in step (b) is 5-10 min, such as 5 min, 6 min, 7 min, 8 min, 9 min or 10 min; however, the impregnating time is not limited to the listed values, and other unlisted values in the numerical range are also applicable.

[0039] Preferably, a temperature of the curing in step (b) is 110-150°C, such as 110°C, 115°C, 120°C, 125°C, 130°C, 135°C, 140°C, 145°C or 150°C; however, the curing temperature is not limited to the listed values, and other unlisted values in the numerical range are also applicable.

[0040] Preferably, a time of the curing in step (b) is 120-180 min, such as 120 min, 125 min, 130 min, 135 min, 140 min, 145 min, 150 min, 155 min, 160 min, 165 min, 170 min, 175 min or 180min; however, the curing time is not limited to the listed values, and other unlisted values in the numerical range are also applicable.

[0041] As a preferred technical solution of the present application, the preparation method of the anti-direct-current nanocrystalline double-magnetic-core current transformer magnetic core in the second aspect of the present application includes the following steps:

sequentially installing a first nanocrystalline magnetic core and a second nanocrystalline magnetic core into a packaging shell to obtain the anti-direct-current nanocrystalline double-magnetic-core current transformer magnetic core;

the first nanocrystalline magnetic core is obtained by the following preparation method, which comprises the following steps:

(1) winding an iron-based nanocrystalline alloy strip material with a thickness of 20-30 μm into a first magnetic ring; and

(2) performing an annealing treatment on the first magnetic ring obtained in step (1) in a vacuum environment and/or a reducing atmosphere environment to obtain the first nanocrystalline magnetic core; the annealing treatment is as follows: firstly, heating to 470-490°C at a heating rate of 1-5°C/min, keeping the temperature for 60-90 min, then heating to 540-570°C at a heating rate of 0.5-3.5°C /min, keeping the temperature for 60-120 min, and finally cooling to less than or equal to 200°C;

the second nanocrystalline magnetic core is obtained by the following preparation method, which includes the following steps:

(a) subjecting an iron-based nanocrystalline alloy strip material with a thickness of 16-22 μm to a tension pre-crystallization annealing treatment at 550°C-570°C and an operating speed of the tension-applied strip material of 1-10 m/min, and then winding the material to obtain a second magnetic ring; an applied tension of the tension crystallization annealing treatment is 20-100 MPa; and

(b) sequentially impregnating the second magnetic ring obtained in step (a) for 5-10min and curing at 110-150°C for 120-180 min to obtain the second nanocrystalline magnetic core; an impregnating solution for the impregnating is a mixture of epoxy resin adhesive and diluent; in the impregnating solution, the total mass fraction of epoxy resin adhesive and diluent is 100wt%, a mass fraction of the epoxy resin adhesive is 25-30wt%, and a remainder is diluent.

[0042] Compared with the related art, the embodiments of the present application have the following beneficial effects:

(1) the magnetic core of the anti-direct-current nanocrystalline double-magnetic-core current transformer magnetic core provided by the embodiment of the present application has excellent stability, good linearity, high sensitivity and a wide adjustment range of magnetic permeability; and

(2) the preparation method of the anti-direct-current nanocrystalline double-magnetic-core current transformer magnetic core provided by the embodiment of the present application is simple, the overall structure is relatively simplified, and the processing cost is low.

[0043] Other aspects will become apparent after reading and understanding the drawings and detailed description.

BRIEF DESCRIPTION OF DRAWINGS

[0044] The accompanying drawings are used to provide a further understanding of the technical solutions of the present application, constitute a part of the description, explain the technical solutions of the present application in conjunction with examples of the present application, and have no limitation on the technical solutions of the present application.

FIG. 1 is a structural schematic diagram of an anti-direct-current nanocrystalline double-magnetic-core current transformer magnetic core provided by Example 1 of the present application;

wherein, 1 is a second nanocrystalline magnetic core, 2 is a first nanocrystalline magnetic core, and 3 is a packaging shell.

DETAILED DESCRIPTION

[0045] The technical solutions of the present application will be further described below with reference to the accompanying drawings and through specific embodiments. It should be apparent to those skilled in the art that the embodiments are merely used for a better understanding of the present application, and should not be regarded as a specific limitation of the present application.

Example 1

[0046] This Example 1 provides an anti-direct-current nanocrystalline double-magnetic-core current transformer magnetic core as shown in FIG. 1. The anti-direct-current nanocrystalline double-magnetic-core current transformer magnetic core includes a first nanocrystalline magnetic core 2, a second nanocrystalline magnetic core 1, and a ring-shaped packaging shell 3. The first nanocrystalline magnetic core 2 is sheathed and installed on the outer side of the second nanocrystalline magnetic core 1, and the first nanocrystalline magnetic core 2 and the second nanocrystalline magnetic core 1 are coaxially arranged.
[0047] The first nanocrystalline magnetic core has a magnetic permeability of 150000 H/m; the second nanocrystalline magnetic core has a magnetic permeability of 2000 H/m.
[0048] The first nanocrystalline magnetic core is obtained by the following preparation method, which includes the following steps:
a first nanocrystalline magnetic core and a second nanocrystalline magnetic core were sequentially installed into the interior of the packaging shell to obtain the anti-direct-current nanocrystalline double-magnetic-core current transformer magnetic core.
[0049] The preparation method of the first nanocrystalline magnetic core includes the following steps:

(1) an iron-based nanocrystalline alloy strip material with a thickness of 25 μm was wound into a first magnetic ring; and

(2) the first magnetic ring obtained in step (1) was subjected to an annealing treatment to obtain a first nanocrystalline magnetic core in an argon atmosphere; the annealing treatment includes the following steps: firstly, a temperature was heated to 480°C at a heating rate of 4°C/min, the temperature was kept for 75 min, then the temperature was heated to 565°C at a heating rate of 2°C /min, the temperature was kept for 100 min, and finally the temperature was cooled to 200°C.

[0050] The second nanocrystalline magnetic core is obtained by the following preparation method, which includes the following steps:

(a) an iron-based nanocrystalline alloy strip material with a thickness of 20 μm was subjected to a tension crystallization annealing treatment at 570°C and an operating speed of the tension-applied strip material of 3 m/min, and then wound to obtain a second magnetic ring; an applied tension of the tension crystallization annealing treatment was 75 MPa; and

(b) the second magnetic ring obtained in step (a) was sequentially impregnated for 8 min and cured at 130°C for 150 min to obtain the second nanocrystalline magnetic core; a impregnating solution of the impregnating was a mixture of epoxy resin adhesive and diluent; in the impregnating solution, the total mass fraction of epoxy resin adhesive and diluent was 100wt%, a mass fraction of the epoxy resin adhesive was 28wt%, and a remainder was diluent.

Example 2

[0051] This example provides an anti-direct-current nanocrystalline double-magnetic-core current transformer magnetic core. The anti-direct-current nanocrystalline double-magnetic-core current transformer magnetic core includes a first nanocrystalline magnetic core 2, a second nanocrystalline magnetic core 1, and a ring-shaped packaging shell 3. The first nanocrystalline magnetic core 2 is sheathed and installed on the outer side of the second nanocrystalline magnetic core 1, and the first nanocrystalline magnetic core 2 and the second nanocrystalline magnetic core 1 are coaxially arranged.
[0052] The first nanocrystalline magnetic core has a magnetic permeability of 150000 H/m; the second nanocrystalline magnetic core has a magnetic permeability of 2000 H/m.
[0053] The anti-direct-current nanocrystalline double-magnetic-core current transformer magnetic core is obtained by the following preparation method, which includes the following steps:
a first nanocrystalline magnetic core and a second nanocrystalline magnetic core were sequentially installed into the interior of the packaging shell to obtain the anti-direct-current nanocrystalline double-magnetic-core current transformer magnetic core.
[0054] The preparation method of the first nanocrystalline magnetic core is the same as Example 1.
[0055] The second nanocrystalline magnetic core is obtained by the following preparation method, which includes the following steps:

(a) an iron-based nanocrystalline alloy strip material with a thickness of 18 μm was subjected to a tension crystallization annealing treatment at 550°C and an operating speed of the tension-applied strip material of 2 m/min, and then wound to obtain a second magnetic ring; an applied tension of the tension crystallization annealing treatment was 100 MPa; and

(b) the second magnetic ring obtained in step (a) was sequentially impregnated for 8 min and cured at 130°C for 150 min to obtain the second nanocrystalline magnetic core; an impregnating solution of the impregnating was a mixture of epoxy resin adhesive and diluent; in the impregnating solution, the total mass fraction of epoxy resin adhesive and diluent was 100wt%, a mass fraction of the epoxy resin adhesive was 28wt%, and a remainder was diluent.

Example 3

[0056] This example provides an anti-direct-current nanocrystalline double-magnetic-core current transformer magnetic core. The anti-direct-current nanocrystalline double-magnetic-core current transformer magnetic core includes a first nanocrystalline magnetic core 2, a second nanocrystalline magnetic core 1, and a ring-shaped packaging shell 3.The first nanocrystalline magnetic core 2 is sheathed and installed on the outer side of the second nanocrystalline magnetic core 1, and the first nanocrystalline magnetic core 2 and the second nanocrystalline magnetic core 1 are coaxially arranged.

[0057] The first nanocrystalline magnetic core has a magnetic permeability of 200000 H/m; the second nanocrystalline magnetic core has a magnetic permeability of 2000 H/m.

[0058] The anti-direct-current nanocrystalline double-magnetic-core current transformer magnetic core obtained by the following preparation method includes the following steps:
a first nanocrystalline magnetic core and a second nanocrystalline magnetic core were sequentially installed into the interior of the packaging shell to obtain the anti-direct-current nanocrystalline double-magnetic-core current transformer magnetic core.

[0059] The preparation method of the first nanocrystalline magnetic core includes the following steps:

(1) an iron-based nanocrystalline alloy strip material with a thickness of 30 μm was wound into a first magnetic ring; and

(2) the first magnetic ring obtained in step (1) was subjected to an annealing treatment to obtain a first nanocrystalline magnetic core in a vacuum environment; the annealing treatment includes the following steps: firstly, a temperature was heated to 490°C at a heating rate of 5°C/min, the temperature was kept for 60 min, then the temperature was heated to 570°C at a heating rate of 3.5°C /min, the temperature was kept for 60 min, and finally the temperature was cooled to 190°C.

[0060] The preparation method of the second nanocrystalline magnetic core is the same as Example 1.

Example 4

[0061] This example provides an anti-direct-current nanocrystalline double-magnetic-core current transformer magnetic core. The anti-direct-current nanocrystalline double-magnetic-core current transformer magnetic core includes a first nanocrystalline magnetic core 2, a second nanocrystalline magnetic core 1, and a ring-shaped packaging shell 3. The first nanocrystalline magnetic core 2 is sheathed and installed on the outer side of the second nanocrystalline magnetic core 1, and the first nanocrystalline magnetic core 2 and the second nanocrystalline magnetic core 1 are coaxially arranged.

[0062] The first nanocrystalline magnetic core has a magnetic permeability of 150000 H/m; the second nanocrystalline magnetic core has a magnetic permeability of 1000 H/m.

[0063] The anti-direct-current nanocrystalline double-magnetic-core current transformer magnetic core obtained by the following preparation method includes the following steps:
a first nanocrystalline magnetic core and a second nanocrystalline magnetic core were sequentially installed into the interior of the packaging shell to obtain the anti-direct-current nanocrystalline double-magnetic-core current transformer magnetic core.

[0064] The preparation method of the first nanocrystalline magnetic core is the same as Example 1.

[0065] The second nanocrystalline magnetic core is obtained by the following preparation method, which includes the following steps:

(a) an iron-based nanocrystalline alloy strip material with a thickness of 20 μm was subjected to a tension crystallization annealing treatment at 570°C and an operating speed of the tension-applied strip material of 2 m/min, and then wound to obtain a second magnetic ring; an applied tension of the tension crystallization annealing treatment was 80 MPa; and

(b) the second magnetic ring obtained in step (a) was sequentially impregnated for 6.5 min and cured at 120°C for 56 min to obtain the second nanocrystalline magnetic core; a impregnating solution for the impregnating was a mixture of epoxy resin adhesive and diluent; in the impregnating solution, a mass fraction of the epoxy resin adhesive was 26wt%, and a mass fraction of the diluent was 74wt%.

Example 5

[0066] This example provides an anti-direct-current nanocrystalline double-magnetic-core current transformer magnetic core. The anti-direct-current nanocrystalline double-magnetic-core current transformer magnetic core includes a first nanocrystalline magnetic core 2, a second nanocrystalline magnetic core 1, and a ring-shaped packaging shell 3. The first nanocrystalline magnetic core 2 is sheathed and installed on the outer side of the second nanocrystalline magnetic core 1, and the first nanocrystalline magnetic core 2 and the second nanocrystalline magnetic core 1 are coaxially arranged.
[0067] The first nanocrystalline magnetic core has a magnetic permeability of 150000 H/m; the second nanocrystalline magnetic core has a magnetic permeability of 2000 H/m.
[0068] The preparation method of an anti-direct-current nanocrystalline double-magnetic-core current transformer magnetic core is the same as that of Example 1 except that the curing temperature in step (b) was changed to 100°C and the curing time was changed to 200 min.

Example 6

[0069] This example provides an anti-direct-current nanocrystalline double-magnetic-core current transformer magnetic core. The anti-direct-current nanocrystalline double-magnetic-core current transformer magnetic core includes a first nanocrystalline magnetic core 2, a second nanocrystalline magnetic core 1, and a ring-shaped packaging shell 3. The first nanocrystalline magnetic core 2 is sheathed and installed on the outer side of the second nanocrystalline magnetic core 1, and the first nanocrystalline magnetic core 2 and the second nanocrystalline magnetic core 1 are coaxially arranged.
[0070] The first nanocrystalline magnetic core has a magnetic permeability of 150000 H/m; the second nanocrystalline magnetic core has a magnetic permeability of 2000 H/m.
[0071] The preparation method of an anti-direct-current nanocrystalline double-magnetic-core current transformer magnetic core is the same as that of Example 1 except that the curing temperature in step (b) was changed to 200°C and the curing time was changed to 100 min.

Example 7

[0072] This example provides an anti-direct-current nanocrystalline double-magnetic-core current transformer magnetic core. The anti-direct-current nanocrystalline double-magnetic-core current transformer magnetic core includes a first nanocrystalline magnetic core 2, a second nanocrystalline magnetic core 1, and a ring-shaped packaging shell 3. The first nanocrystalline magnetic core 2 is sheathed and installed on the outer side of the second nanocrystalline magnetic core 1, and the first nanocrystalline magnetic core 2 and the second nanocrystalline magnetic core 1 are coaxially arranged.
[0073] The first nanocrystalline magnetic core has a magnetic permeability of 150000 H/m; the second nanocrystalline magnetic core has a magnetic permeability of 400 H/m.
[0074] The preparation method of the first nanocrystalline magnetic core is the same as Example 1.
[0075] The second nanocrystalline magnetic core is obtained by the following preparation method, which includes the following steps:

(a) an iron-based nanocrystalline alloy strip material with a thickness of 22 μm was subjected to a tension crystallization annealing treatment at 500°C and an operating speed of the tension-applied strip material of 1.5 m/min, and then wound to obtain a second magnetic ring; an applied tension of the tension crystallization annealing treatment was 20 MPa; and

(b) the second magnetic ring obtained in step (a) was sequentially impregnated for 5 min and cured at 110°C for 180 min to obtain the second nanocrystalline magnetic core; a impregnating solution for the impregnating was a mixture of epoxy resin adhesive and diluent; in the impregnating solution, a mass fraction of the epoxy resin adhesive was 25wt%, and a mass fraction of the diluent was 75wt%.

[0076] The anti-direct-current nanocrystalline double-magnetic-core current transformer magnetic core prepared by this example can be used in circuit environments with large direct-current components. The current transformer made by this material can still ensure the accuracy of the transformer when the direct-current component of the circuit under test is large.

Example 8

[0077] This example provides an anti-direct-current nanocrystalline double-magnetic-core current transformer magnetic core. The anti-direct-current nanocrystalline double-magnetic-core current transformer magnetic core includes a first nanocrystalline magnetic core 2, a second nanocrystalline magnetic core 1, and a ring-shaped packaging shell 3. The first nanocrystalline magnetic core 2 is sheathed and installed on the outer side of the second nanocrystalline magnetic core 1, and the first nanocrystalline magnetic core 2 and the second nanocrystalline magnetic core 1 are coaxially arranged.

[0078] The first nanocrystalline magnetic core has a magnetic permeability of 150000 H/m; the second nanocrystalline magnetic core has a magnetic permeability of 4000 H/m.

[0079] The preparation method of the first nanocrystalline magnetic core is the same as Example 1.

[0080] The second nanocrystalline magnetic core is obtained by the following preparation method, which includes the following steps:

(a) an iron-based nanocrystalline alloy strip material with a thickness of 16 μm was subjected to a tension crystallization annealing treatment at 530°C and an operating speed of the tension-applied strip material of 10 m/min, and then wound to obtain a second magnetic ring; an applied tension of the tension crystallization annealing treatment was 50 MPa; and

(b) the second magnetic ring obtained in step (a) was sequentially impregnated for 10 min and cured at 130°C for 150 min to obtain the second nanocrystalline magnetic core; a impregnating solution for the impregnating was a mixture of epoxy resin adhesive and diluent; in the impregnating solution, a mass fraction of the epoxy resin adhesive was 28wt%, and a mass fraction of the diluent was 72wt%.

[0081] The anti-direct-current nanocrystalline double-magnetic-core current transformer magnetic core prepared by this example can be applied to circuit environments with small direct-current components. The current transformer made of this material can maintain high accuracy while ensuring the transformer has certain anti-direct-current bias characteristics.

Comparative Example 1

[0082] This comparative example provides a single-core anti-direct-current component transformer as provided in Example 1 of CN 103928227A.

[0083] Compared with Example 1, it can be seen that the transformer provided by this comparative example only contains one magnetic core, which makes the angle difference of the prepared transformer larger and the cost is higher.

Comparative Example 2

[0084] This comparative example provides a nanocrystalline alloy double-magnetic-core current transformer as provided in Example 1 of CN 107240491A.

[0085] Compared with Example 1, it can be seen that the magnetic core stability of the transformer provided by this comparative example is poor and the anti-direct-current characteristic is average.

[0086] The anti-direct-current nanocrystalline magnetic-core current transformer magnetic cores provided by Examples 1-6 and Comparative Examples 1-2 were tested for errors in half-wave direct-current-state, and the test data are shown in Table 1.

Table 1

		0.6A	3A	12A	60A	72A
Example 1	Ratio(%)	-0.3	-0.29	-0.25	-0.11	-0.05
	Phase(')	10	4.2	3.5	1.7	1.8
Example 2	Ratio(%)	-0.32	-0.31	-0.28	-0.1	-0.05
	Phase(')	11	4.5	3.8	1.7	1.7
Example 3	Ratio(%)	-0.35	-0.33	-0.29	-0.09	-0.03
	Phase(')	8	3.8	3.5	1.6	1.6
Example 4	Ratio(%)	-0.45	-0.43	-0.41	-0.33	-0.28
	Phase(')	11	4.4	3.8	1.7	1.8
Example 5	Ratio(%)	-0.53	-0.53	-0.53	-0.52	-0.51
	Phase(')	12	4.5	3.7	1.7	1.7
Example 6	Ratio(%)	-0.21	-0.18	-0.1	0.05	0.18
	Phase(')	11	4.2	3.8	1.7	1.7
Comparative Example 1	Ratio(%)	-0.55	-0.55	-0.55	-0.54	-0.53
	Phase(')	250	250	250	251	252
Comparative Example 2	Ratio(%)	-0.35	-0.3	-0.26	-0.03	0.05
	Phase(')	10	4.2	3.6	1.7	1.7

[0087] In summary, the anti-direct-current nanocrystalline double-magnetic-core current transformer magnetic core provided in the present application has excellent stability of magnetic core, good linearity, high sensitivity, and a larger adjustment range of magnetic permeability. The preparation method is simple, the overall structure is more simplified, and the processing cost is low.

[0088] The applicant has stated that although the detailed methods of the present application are described by using the above embodiments in the present application, the present application is not limited to the above detailed methods, and it should be understood by those skilled in the art that any changes or replacements that can easily be imagined by those skilled in the art within the scope of the technology disclosed in the present application fall within the scope of protection and disclosure in the present application.

Claims

1. An anti-direct-current nanocrystalline double-magnetic-core current transformer magnetic core, wherein the anti-direct-current nanocrystalline double-magnetic-core current transformer magnetic core comprises a first nanocrystalline magnetic core, a second nanocrystalline magnetic core, and a ring-shaped packaging shell.

2. The anti-direct-current nanocrystalline double-magnetic-core current transformer magnetic core according to claim 1, wherein the first nanocrystalline magnetic core is sheathed and installed on the outer side of the second nanocrystalline magnetic core, and the first nanocrystalline magnetic core and the second nanocrystalline magnetic core are coaxially arranged.

3. The anti-direct-current nanocrystalline double-magnetic-core current transformer magnetic core according to claim 1 or 2, wherein a magnetic permeability of the first nanocrystalline magnetic core is 80000-200000 H/m.

4. The anti-direct-current nanocrystalline double-magnetic-core current transformer magnetic core according to any one of claims 1 to 3, wherein a magnetic permeability of the second nanocrystalline magnetic core is 500-4000 H/m.

5. A preparation method for the anti-direct-current nanocrystalline double-magnetic-core current transformer magnetic core according to any one of claims 1 to 4, comprising:
sequentially installing the first nanocrystalline magnetic core and the second nanocrystalline magnetic core into an

interior of the packaging shell to obtain the anti-direct-current nanocrystalline double-magnetic-core current transformer magnetic core.

6. The preparation method according to claim 5, wherein the interior of the packaging shell is filled with a filler.

7. The preparation method according to claim 5 or 6, wherein the filler comprises sponge and/or silica gel.

8. The preparation method according to any one of claims 5 to 7, wherein a preparation method of the first nanocrystalline magnetic core comprises:

(1) winding an iron-based nanocrystalline alloy strip material into a first magnetic ring; and
(2) performing an annealing treatment on the first magnetic ring obtained in step (1) to obtain the first nanocrystalline magnetic core.

9. The preparation method according to claim 8, wherein a thickness of the iron-based nanocrystalline alloy strip material in step (1) is 20-30 μm;

preferably, an environment of the annealing treatment in step (2) is a vacuum environment and/or a reducing atmosphere environment;
preferably, the reducing atmosphere comprises an argon atmosphere and/or a nitrogen atmosphere;
preferably, the annealing treatment in step (2) comprises sequentially performing a first heating, a first heat preservation, a second heating, a second heat preservation, and cooling;
preferably, a terminal temperature of the first heating is 470-490°C;
Preferably, a heating rate of the first heating is 1-5°C/min;
preferably, a time of the first heat preservation is 60-90 min;
preferably, a terminal temperature of the second heating is 540-570°C;
preferably, a heating rate of the second heating is 0.5-3.5°C/min;
preferably, a time of the second heat preservation is 60-120 min;
preferably, a terminal temperature of the cooling is less than or equal to 200°C.

10. The preparation method according to any one of claims 5 to 7, wherein a preparation method of the second nanocrystalline magnetic core comprises:

(a) after subjecting an iron-based nanocrystalline alloy strip material to tension crystallization annealing treatment, winding to obtain a second magnetic ring; and
(b) sequentially impregnating and curing the second magnetic ring obtained in step (a) to obtain the second nanocrystalline magnetic core.

11. The preparation method according to claim 10, wherein a thickness of the iron-based nanocrystalline alloy strip material in step (a) is 16-22 μm;

preferably, an annealing temperature of the tension crystallization annealing treatment in step (a) is between 500 and 570°C;
preferably, an applied tension of the tension crystallization annealing treatment in step (a) is 20-100 MPa;
preferably, an operating speed of the tension-applied strip material of the tension crystallization annealing treatment in step (a) is 1-10 m/min.

12. The preparation method according to claim 10 or 11, wherein an impregnating solution for the impregnating in step (b) is a mixture of epoxy resin adhesive and diluent;

preferably, the diluent comprises acetone;
preferably, in the impregnating solution, the total mass fraction of epoxy resin adhesive and diluent is 100wt%, a mass fraction of the epoxy resin adhesive is 25-30wt%, and a remainder is diluent;
preferably, a time of the impregnating in step (b) is 5-10 min;
Preferably, a temperature of the curing in step (b) is 110-150°C;
preferably, a time of the curing in step (b) is 120-180 min.

13. The preparation method according to any one of claims 5 to12, comprising:

sequentially installing the first nanocrystalline magnetic core and the second nanocrystalline magnetic core into the interior of the packaging shell to obtain the anti-direct-current nanocrystalline double-magnetic-core current transformer magnetic core;
the first nanocrystalline magnetic core is obtained by using the following preparation method, comprising:

(1) winding an iron-based nanocrystalline alloy strip material with a thickness of 20-30 μm into a first magnetic ring; and
(2) performing an annealing treatment on the first magnetic ring obtained in step (1) under a vacuum environment and/or a reducing atmosphere environment to obtain the first nanocrystalline magnetic core; the annealing treatment is as follows: firstly, heating to 470-490°C at a heating rate of 1-5°C/min, keeping the temperature for 60-90 min, then heating to 540-570°C at a heating rate of 0.5-3.5°C/min, keeping the temperature for 60-120 min, and finally cooling to less than or equal to 200°C, and then taking out of a furnace;

the second nanocrystalline magnetic core is obtained by using the following preparation method, comprising:

(a) subjecting an iron-based nanocrystalline alloy strip material with a thickness of 16-22 μm to a tension pre-crystallization annealing treatment at 550°C-570°C and an operating speed of the tension-applied strip material of 1-10 m/min, and then winding the material to obtain a second magnetic ring; an applied tension of the tension pre-crystallization annealing treatment is 20-100 MPa; and
(b) sequentially impregnating the second magnetic ring obtained in step (a) for 5-10 min and curing at 110-150°C for 120-180 min to obtain the second nanocrystalline magnetic core; an impregnating solution for the impregnating is a mixture of epoxy resin adhesive and diluent; in the impregnating solution, the total mass fraction of epoxy resin adhesive and diluent is 100wt%, a mass fraction of the epoxy resin adhesive is 25-30wt%, and a remainder is diluent.

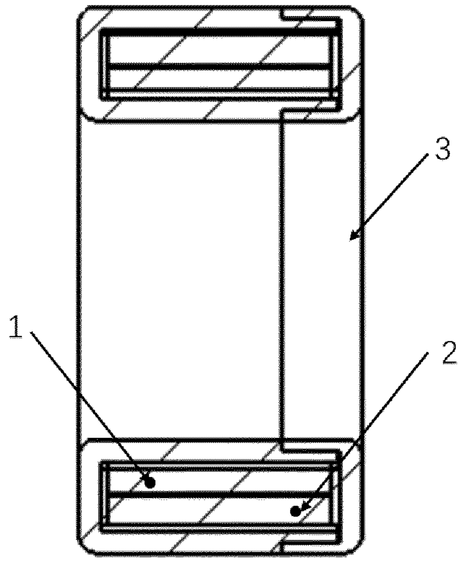

FIG. 1

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2022/109366

A. CLASSIFICATION OF SUBJECT MATTER

H01F 27/02(2006.01)i; H01F 27/25(2006.01)i; H01F 27/26(2006.01)i; H01F 38/30(2006.01)i; H01F 41/00(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H01F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

CNTXT; ENTXTC; DWPI; CNKI: 纳米晶, 双, 磁芯, 磁心, 铁芯, 铁心, 互感器, 环; nano crystalline, double, core, transformer, loop

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
PX	CN 113990604 A (HENGDIAN GROUP DMEGC MAGNETICS CO., LTD.) 28 January 2022 (2022-01-28) claims 1-10	1-13
X	CN 203250621 U (ANQING TIAN RUI NEW MATERIAL CO., LTD.) 23 October 2013 (2013-10-23) description, paragraphs 24-34	1, 2, 5-7
Y	CN 203250621 U (ANQING TIAN RUI NEW MATERIAL CO., LTD.) 23 October 2013 (2013-10-23) description, paragraphs 24-34	3-4, 8-13
Y	JP 2016181620 A (MITSUBISHI ELECTRIC CORP. et al.) 13 October 2016 (2016-10-13) description, paragraphs 17-81	3-4, 8-9, 13
Y	CN 104376950 A (ADVANCED TECHNOLOGY & MATERIALS CO., LTD.) 25 February 2015 (2015-02-25) description, paragraphs 18-93	10-13
A	CN 1688003 A (ADVANCED TECHNOLOGY & MATERIALS CO., LTD. et al.) 26 October 2005 (2005-10-26) entire document	1-13

☐ Further documents are listed in the continuation of Box C. ☑ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
07 October 2022	**19 October 2022**

Name and mailing address of the ISA/CN	Authorized officer
China National Intellectual Property Administration (ISA/CN) **No. 6, Xitucheng Road, Jimenqiao, Haidian District, Beijing 100088, China**	
Facsimile No. **(86-10)62019451**	Telephone No.

Form PCT/ISA/210 (second sheet) (January 2015)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CN2022/109366

Patent document cited in search report			Publication date (day/month/year)	Patent family member(s)			Publication date (day/month/year)
CN	113990604	A	28 January 2022	None			
CN	203250621	U	23 October 2013	None			
JP	2016181620	A	13 October 2016	None			
CN	104376950	A	25 February 2015	CN	104376950	B	23 February 2018
CN	1688003	A	26 October 2005	CN	1316521	C	16 May 2007

Form PCT/ISA/210 (patent family annex) (January 2015)

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- CN 103928227 A **[0005] [0082]**
- CN 1107240491 A **[0006]**
- CN 107240491 A **[0084]**