



(11)

EP 4 506 639 A1

(12)

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

(43) Date of publication:
12.02.2025 Bulletin 2025/07

(51) International Patent Classification (IPC):
F25B 9/14 (2006.01)

(21) Application number: **23841691.1**

(52) Cooperative Patent Classification (CPC):
F25B 9/14

(22) Date of filing: **03.01.2023**

(86) International application number:
PCT/CN2023/070022

(87) International publication number:
WO 2024/016613 (25.01.2024 Gazette 2024/04)

(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 ME MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA
Designated Validation States:
KH MA MD TN

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(30) Priority: **21.07.2022 CN 202210874398**
21.07.2022 CN 202221913164 U

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(54) INTEGRATED STIRLING REFRIGERATOR

(57) The present application provides an integrated Stirling refrigerator, comprising: an eccentric axle box, a sealed cavity filled with a gas working medium therein; an eccentric shaft, rotatably arranged in the sealed cavity in an axial direction and having an eccentric section and a non-eccentric section; a stator assembly, arranged in the axial direction and fixed in the sealed cavity; a rotor assembly, arranged on the non-eccentric section in the axial direction and forming an air gap with the stator assembly in the axial direction; a compression connecting rod assembly, arranged in the sealed cavity and connected to the eccentric section; and an expansion connecting rod assembly, arranged in the sealed cavity and connected to the eccentric section, wherein the stator assembly and the rotor assembly form an axial flux motor arranged in the axial direction, to drive the eccentric shaft via the rotor assembly to rotate in the axial direction. In the integrated Stirling refrigerator in the present application, the axial flux motor is formed in the axial direction of the eccentric shaft by the stator assembly and the rotor assembly, so that the size in the axial direction can be reduced, and an overall structure is more compact.

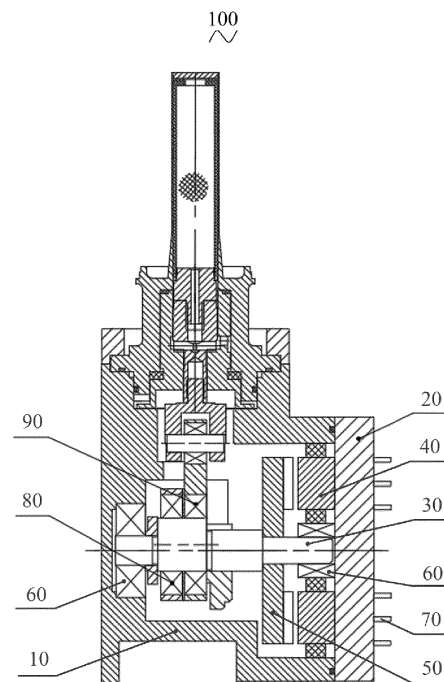


FIG. 1

Description

TECHNICAL FIELD

[0001] The present disclosure relates to the technical field of refrigeration, and in particular, to an integrated Stirling refrigerator.

BACKGROUND

[0002] Cooled infrared detectors are able to detect a tiny temperature difference between a target and a background, which are not only suitable for detecting spatial, remote, dark and small targets, especially have advantages in the real-time high-resolution identification of ultrahigh-speed, high-radar stealth targets, but also suitable for all-weather and independent use in complex electromagnetic environments, and have become the main technology for global multi-dimensional information acquisition and battlefield situational awareness. The cooled infrared detector components have been widely used in the new generation of infrared reconnaissance systems, precision-guided weapons, air defense and anti-missile warning equipment, and the application field has been expanding rapidly. The cooled infrared detectors have irreplaceable advantages in working range, target detection and tracking, especially in dynamic imaging of fast-moving targets. However, the cooled infrared detectors have a high cost and large size, which limits their battlefield applications.

[0003] With the progress of science and technology, technology research of the high operation temperature infrared detector device (HOT device) has made great breakthroughs, and the detector's operation temperature has been greatly improved. Some foreign mid-wave infrared detectors have their operation temperature increased to a 130 - 150K temperature range, and there is a trend to further increase it to 150 - 200K. The development success of the HOT devices has made it possible to develop a smaller, lighter, higher efficient ultra-compact Stirling refrigerator, which has also become a hot-spot for the refrigerator development around the world.

[0004] With the increase of the operation temperature of infrared detectors, Stirling refrigerators have been developing towards smaller size, lighter weight, higher performance, lower power consumption and lower cost (referred to as SWaP3). Compared to linear motor-driven split Stirling refrigerators, rotary motor-driven integrated Stirling refrigerators have the advantages of compact structure, small size, light weight and low power consumption and the like, and can be widely used in infrared detectors of 80K temperature range.

[0005] Integrated Stirling refrigerators using a radial flux structure for rotary drive are known in the art. However, such integrated Stirling refrigerators have a large size along a length direction of an eccentric shaft, and there is still some room for reducing the size of the Stirling refrigerators.

TECHNICAL PROBLEM

[0006] To this end, in order to solve the above technical problem, the present disclosure provides an integrated Stirling refrigerator with small size and compact structure.

TECHNICAL SOLUTION

10 [0007] In order to achieve the above object, the technical solution of the embodiments according to the present disclosure is realized below.

[0008] An integrated Stirling refrigerator, comprising:

15 an eccentric shaft box defining therein a sealed cavity filled with a gas medium;
an eccentric shaft provided rotatably around a rotation axis within the sealed cavity and comprising an eccentric segment with its center line offset from the rotation axis and a non-eccentric segment with its center line coinciding with the rotation axis;
20 a stator assembly provided around the rotation axis and fixed within the sealed cavity;
a rotor assembly provided on the non-eccentric segment around the rotation axis, with an air gap formed between the rotor assembly and the stator assembly along an axial direction;
25 a compression link assembly provided within the sealed cavity and coupled to the eccentric segment;
30 and
an expansion link assembly provided within the sealed cavity and coupled to the eccentric segment;
wherein the stator assembly and the rotor assembly form an axial flux motor arranged in the axial direction and configured to drive the eccentric shaft to rotate about the rotation axis through the rotor assembly.

40 [0009] In one embodiment, the eccentric shaft box comprises a housing and an end plate, the housing having an opening and the end plate being sealingly connected to the opening.

[0010] In one embodiment, the opening in the housing is circular in shape, and the end plate is in a shape of a circular plate matching the shape of the opening.

45 [0011] In one embodiment, the housing and the end plate are made of aluminum alloy, and the end plate and the housing are connected by a sealing ring or are sealingly welded.

50 [0012] In one embodiment, two ends of the eccentric shaft are connected to a bearing fixed to the housing and a bearing fixed to the end plate, respectively.

[0013] In one embodiment, one end of the eccentric shaft is connected to an inner ring of a deep groove ball bearing fixed inside the housing, and another end thereof is connected to an inner ring of a thrust ball bearing fixed to an inner side of the end plate.

55 [0014] In one embodiment, the stator assembly is fixed

to the inner side of the end plate and is coaxially provided with respect to the thrust ball bearing.

[0015] In one embodiment, motor lead pins protrude from an outer side of the end plate, the motor lead pins extend through the end plate in the axial direction and are electrically isolated from the end plate through insulation sintering.

[0016] In one embodiment, the stator assembly comprises a stator core and a winding; the stator core is provided with a bottom portion perpendicular to the axial direction, a plurality of teeth protruding from the bottom portion in the axial direction towards the rotor assembly; the winding comprises a plurality of coils, each of which is arranged around and electrically isolated from a corresponding one of the teeth; the rotor assembly comprises a rotor disk and a plurality of permanent magnets; the rotor disk is mounted around the non-eccentric segment, the permanent magnets are fixed on a side of the rotor disk facing towards the stator assembly, and the permanent magnets are magnetized in the axial direction, with each two circumferentially adjacent permanent magnets having opposite polarities therebetween.

[0017] In one embodiment, the air gap between the rotor assembly and the stator assembly is 0.2 mm.

BENEFICIAL EFFECT

[0018] The integrated Stirling refrigerator according to the present disclosure has at least the following beneficial effects: In the integrated Stirling refrigerator of the present disclosure, an axial flux motor is formed by the stator assembly and the rotor assembly and arranged in the axial direction of the eccentric shaft, which can reduce the size along the axial direction and make the overall structure more compact while maintaining the performance of the Stirling refrigerator. In addition, under the same outer diameter size, the axial flux motor has a higher torque density relative to the conventional radial flux motor, which can make the Stirling refrigerator have a smaller volume and weight, and lower power consumption.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019]

FIG. 1 shows a schematic diagram of a cross-sectional structure of an integrated Stirling refrigerator according to an embodiment of the present disclosure;

FIG. 2 shows a partially enlarged view of the integrated Stirling refrigerator in FIG. 1;

FIG. 3 shows an exploded view of a stator assembly and a rotor assembly in FIG. 2.

[0020] The components in the figures are labeled as follows:

10, housing; 20, end plate; 30, eccentric shaft; 40, stator assembly (wherein, 41, stator core; 42, tooth; 43, winding); 50, rotor assembly (wherein, 51, rotor disk; 52, permanent magnet); 60, bearing; 70, motor lead pin; 80, compression link assembly; 90, expansion link assembly; 100, Stirling refrigerator.

EMBODIMENTS OF THE INVENTION

[0021] The technical solutions of the present disclosure are hereinafter described in further detail in connection with the drawings and specific embodiments.

[0022] Unless otherwise defined, all technical and scientific terms used herein have the same meaning as commonly understood by those skilled in the art to which the present disclosure pertains. Terms used in the present disclosure are intended for describing specific embodiments only and are not intended to limit the manner in which the present disclosure can be realized. The term "and/or" as used herein is meant to cover any and all combinations of one or more of the relevant listed items.

[0023] In the description of the present disclosure, it is to be understood that the terms "center", "up", "down", "front", "back", "left", "right", "vertical", "horizontal", "top", "bottom", "inside", "outside", and other indications of the orientations or positional relationships are based on those shown in the figures and are intended only to facilitate the description of the present disclosure and to simplify the description, and are not intended to indicate or imply that the device or element referred to must have a particular orientation, be constructed and operated in a particular orientation, and therefore are not to be construed as limitations of the present disclosure. In the description of the present disclosure, unless otherwise indicated, "plurality" means two or more.

[0024] In the description of the present disclosure, it is to be noted that, unless otherwise expressly specified and limited, the terms "mounted", "connected", "coupled" are to be understood in a broad sense. For example, it may be a fixed connection or a detachable connection, or a connection in one piece; it may be a direct connection, an indirect connection through an intermediate medium, or a connection between internal spaces of two elements. For those of ordinary skill in the art, the specific meaning of the above terms in the present disclosure may be understood in accordance with the specific circumstances.

[0025] In a radial flux motor, the direction of the magnetic flux is set to be along the radial direction perpendicular to the rotation axis, and the magnetic flux path is much longer compared to an axial flux motor, because the magnetic flux travels from one rotor pole to a first tooth of the stator, and then to a second tooth through a stator guard before it reaches another rotor pole. Unlike the radial flux motor, the axial flux motor has a magnetic flux direction parallel to the rotation axis and has a shorter and

more direct flux path, with the flux path extending directly from one pole to another through an air gap. The shorter flux path of the magnetic field helps to increase the efficiency and power density of the motor. In addition, the axial flux motor has some advantages over the radial motor in terms of winding. Comparatively, the axial flux motor has more active winding copper and less overhang such that the ability to increase the number of turns is greater and less heat is caused by end effects. In sum, it can be seen that the axial flux motor can provide higher output power with less material and more compact construction, comparing with the radial flux motor.

[0026] To this end, on the basis of the above theoretical study, the present disclosure provides an integrated Stirling refrigerator, which, by adopting an axial flux motor to provide a rotary drive, not only achieves a reduction in size but it also can achieve a reduction in weight and power consumption. Referring to FIG. 1, an integrated Stirling refrigerator 100 in accordance with an embodiment of the present disclosure includes a housing 10, an end plate 20, an eccentric shaft 30, a stator assembly 40, a rotor assembly 50, a compression link assembly 80, and an expansion link assembly 90. The eccentric shaft 30, the stator assembly 40, the rotor assembly 50, the compression link assembly 80 and the expansion link assembly 90 are all mounted in a space formed by the housing 10 and the end plate 20. The rotor assembly 50, the compression link assembly 80 and the expansion link assembly 90 are all mounted on the eccentric shaft 30. The stator assembly 40 and the rotor assembly 50 form an axial flux motor to provide power to drive the eccentric shaft 30 to rotate, and the rotation of the eccentric shaft 30 drives the compression link assembly 80 and the expansion link assembly 90 to perform compression and expansion operations, respectively, so as to realize refrigeration.

[0027] The housing 10 is a hollow structure and has an opening on one side thereof, the end plate 20 is sealingly connected to the side of the housing 10 where the opening is located, and the housing 10 and the end plate 20 form an eccentric shaft box that is filled with a gas medium therein. More specifically, the opening in the housing 10 is circular, the end plate 20 is in the shape of a circular plate matching the shape of the circular opening, and the end plate 20 closes the opening from an outside to form a sealed cavity. The eccentric shaft 30, the stator assembly 40, the rotor assembly 50, the compression link assembly 80 and the expansion link assembly 90 are enclosed within the sealed cavity inside the eccentric shaft box formed by the housing 10 and the end plate 20, and the sealed cavity is filled with the high-pressure gas medium.

[0028] The housing 10 and the end plate 20 can be made of aluminum alloy. Sealing between the end plate 20 and the housing 10 can be achieved through a sealing ring or by means of welding, such that the sealed cavity formed by them can withstand the high-pressure gas (helium) medium.

[0029] The eccentric shaft 30 defines a rotation axis,

and the eccentric shaft 30 has an eccentric segment with its center line offset from the rotation axis and a non-eccentric segment with its center line coinciding with the rotation axis. Both ends of the eccentric shaft 30 are mounted within the sealed cavity formed by the housing 10 and the end plate 20 by means of bearings 60, and the eccentric segment moves eccentrically about the rotation axis as the eccentric shaft 30 rotates about the rotation axis. Specifically, one end of the eccentric shaft 30 is connected to an inner ring of the bearing 60 (deep groove ball bearing) mounted in the housing 10, and the other end is connected to an inner ring of the bearing 60 (thrust ball bearing) fixed on an inner side of the end plate 20, such that the eccentric shaft 30 can be mounted rotatably around the rotation axis in the housing 10. The rotation axis of the eccentric shaft 30 coincides with a center line of the opening of the housing 10 and a center line of the end plate 20, and the thrust ball bearing is embedded in a center hole of the end plate 20, enabling the stator assembly 40 and the rotor assembly 50 to withstand an axial force generated by the axial flux motor during the rotation of the motor.

[0030] The stator assembly 40 is fixedly mounted on the inner side of the end plate 20 and is coaxially provided with respect to the thrust ball bearing, and the rotor assembly 50 is coaxially and fixedly mounted on the non-eccentric segment of the eccentric shaft 30. An air gap is formed between the rotor assembly 50 and the stator assembly 40 in an axial direction, such that the stator assembly 40 and the rotor assembly 50 form the axial flux motor which, upon being energized, generates power to drive the eccentric shaft 30 to rotate around the rotation axis. In a particular embodiment, the air gap between the rotor assembly 50 and the stator assembly 40 is approximately 0.2 mm, facilitating the unobstructed rotation of the rotor assembly 50 without affecting the performance of the closed magnetic circuit.

[0031] Referring to FIGS. 2 and 3, the stator assembly 40 includes a stator core 41 and a winding 43. The stator core 41 includes a bottom portion perpendicular to the axial direction, and a plurality of teeth 42 protruding from the bottom portion in the axial direction towards the rotor assembly 50, with winding receiving slots (see FIG. 3) formed between adjacent teeth 42. The winding 43 is a three-phase electrical winding having a plurality of coils, each of which is arranged around a corresponding one of the teeth 42 of the stator core 41 and electrically isolated from the corresponding tooth 42 by means of an insulating tape.

[0032] The rotor assembly 50 has a rotor disk 51 mounted around the non-eccentric segment of the eccentric shaft 30, the rotor disk 51 having a center bore receiving the non-eccentric segment of the eccentric shaft 30 therein. A plurality of permanent magnets 52 is fixed to a side of the rotor disk 51 facing the stator assembly 40. Each of the permanent magnets 52 is inserted at least partially into a slot of the rotor disk 51, and is fixed to the slot of the rotor disk 51 by means of

gluing, so that the permanent magnets 52 can be uniformly distributed along a circumferential direction of the rotor disk 5. Each permanent magnet 52 is magnetized along the axial direction, with each two circumferentially adjacent permanent magnets 52 having opposite polarities therebetween.

[0033] The stator assembly 40 is fixed on the inner side of the end plate 20, and motor lead pins 70 protrude from an outer side of the end plate 20. The motor lead pins 70 extend through the end plate 20 (stator fixing plate) in the axial direction, for supplying a three-phase alternating current (AC) power to the winding 43 of the stator assembly 40. The motor lead pins 70 are electrically insulated from the end plate 20 (stator fixing plate) by insulation sintering.

[0034] The insulation sintering between the motor lead pins 70 and the end plate 20, on one hand, ensures that the motor lead pins 70 are electrically isolated from the end plate 20 and, on the other hand, ensures that the high-pressure gas (helium) inside the housing 10 does not leak from around the motor lead pins 70.

[0035] The compression link assembly 80 and the expansion link assembly 90 are connected to the eccentric segment of the eccentric shaft 30. Upon being driven by the rotation of the axial flux motor formed by the stator assembly 40 and the rotor assembly 50, the eccentric shaft 30 drives the compression link assembly 80 and the expansion link assembly 90 to perform eccentric movements. The compression link assembly 80 is connected to an end of a compression piston assembly located inside the housing 10, the expansion link assembly 90 is connected to an end of a pushing piston assembly located inside the housing 10, and an end of the pushing piston assembly located outside the housing 10 is configured to be connected to a regenerator.

[0036] The operation process of the above-described integrated Stirling refrigerator 100 is as follows: under the control of a motor drive controller, power is supplied to the stator assembly 40 through the motor lead pins 70; the winding 43 of the stator assembly 40 is energized to drive the rotor assembly 50 to rotate around the rotation axis, driving the eccentric shaft 30 to rotate around the rotation axis, which in turn drives the compression link assembly 80 and the expansion link assembly 90 connected to the eccentric segment of the eccentric shaft 30 to carry out reciprocating motions. During the reciprocating motions of the compression link assembly 80 and the expansion link assembly 90 driven by the eccentric shaft 30, the pushing piston assembly makes a reciprocating linear motion to compress the high-pressure gas in the sealed cavity of the housing 10, realizing a reverse Stirling cycle and obtaining cold energy, making the regenerator alternately exchange heat and produce cold energy.

[0037] The rotary axial flux motor has the advantages of small size, light weight, high power density, etc. Under the same outer diameter size, the axial flux motor can provide 30% more torque density compared to the traditional radial flux motor. With the increase of the operation

temperature of the infrared detectors, the Stirling refrigerators have been developing in the direction of SWaP3, which enables the axial flux motor to bring into good play its advantages in size, weight and performance compared to the radial flux motor. The integrated Stirling refrigerator according to the present disclosure reduces the volume and weight of the refrigerator while maintaining the performance of the Stirling refrigerator by applying the rotary axial flux motor to the Stirling refrigerator. The adoption of this structural form can make the integrated Stirling refrigerator more compact, smaller in size and weight, and lower in power consumption.

[0038] It is to be noted that, in this disclosure, the terms "comprise", "include" or any other variations thereof are intended to cover non-exclusive inclusion, such that a process, method, article or apparatus comprising a set of elements includes not only those elements but also other elements that are not expressly listed or that are inherent to such process, method, article or apparatus. Without further limitation, the fact that an element is defined by the phrase "include a ..." does not exclude the existence of another identical element in the process, method, article, or device including that element.

[0039] The foregoing are only specific embodiments of the present disclosure, but the scope of the present disclosure is not limited thereto. Any changes or substitutions that may be readily conceivable by those skilled in the art within the scope of the technology disclosed in the present disclosure shall fall into the scope of the present disclosure. Therefore, the scope of the present disclosure shall be determined based on the appended claims.

Claims

1. An integrated Stirling refrigerator, comprising:

an eccentric shaft box defining therein a sealed cavity filled with a gas medium;
 an eccentric shaft (30) provided rotatably around a rotation axis within the sealed cavity and comprising an eccentric segment with its center line offset from the rotation axis and a non-eccentric segment with its center line coinciding with the rotation axis;
 a stator assembly (40) provided around the rotation axis and fixed within the sealed cavity;
 a rotor assembly (50) provided on the non-eccentric segment around the rotation axis, with an air gap formed between the rotor assembly (50) and the stator assembly (40) along an axial direction;
 a compression link assembly (80) provided within the sealed cavity and coupled to the eccentric segment; and
 an expansion link assembly (90) provided within the sealed cavity and coupled to the eccentric segment;

- wherein the stator assembly (40) and the rotor assembly (50) form an axial flux motor arranged in the axial direction and configured to drive the eccentric shaft (30) to rotate about the rotation axis through the rotor assembly. 5
2. The integrated Stirling refrigerator according to claim 1, wherein the eccentric shaft box comprises a housing (10) and an end plate (20), the housing (10) having an opening and the end plate (20) being sealingly connected to the opening. 10
 3. The integrated Stirling refrigerator according to claim 2, wherein the opening in the housing (10) is circular in shape, and the end plate (20) is in a shape of a circular plate matching the shape of the opening. 15
 4. The integrated Stirling refrigerator according to claim 2, wherein the housing (10) and the end plate (20) are made of aluminum alloy, and the end plate (20) and the housing (10) are connected by a sealing ring or are sealingly welded. 20
 5. The integrated Stirling refrigerator according to claim 2, wherein two ends of the eccentric shaft (30) are connected to a bearing (60) fixed to the housing (10) and a bearing (60) fixed to the end plate (20), respectively. 25
 6. The integrated Stirling refrigerator according to claim 5, wherein one end of the eccentric shaft (30) is connected to an inner ring of a deep groove ball bearing fixed inside the housing (10), and another end thereof is connected to an inner ring of a thrust ball bearing fixed to an inner side of the end plate (20). 30 35
 7. The integrated Stirling refrigerator according to claim 6, wherein the stator assembly (40) is fixed to the inner side of the end plate (20) and is coaxially provided with respect to the thrust ball bearing. 40
 8. The integrated Stirling refrigerator according to claim 5, wherein motor lead pins (70) protrude from an outer side of the end plate (20), and the motor lead pins (70) extend through the end plate (20) in the axial direction and are electrically isolated from the end plate (20) through insulation sintering. 45
 9. The integrated Stirling refrigerator according to any of claims 1-8, wherein the stator assembly (40) comprises a stator core (41) and a winding (43); the stator core (41) is provided with a bottom portion perpendicular to the axial direction, a plurality of teeth (42) protruding from the bottom portion in the axial direction towards the rotor assembly (50); the winding (43) comprises a plurality of coils, each of which is arranged around and electrically isolated from a corresponding one of the teeth (42); the rotor assembly (50) comprises a rotor disk (51) and a plurality of permanent magnets (52); the rotor disk (51) is mounted around the non-eccentric segment, the permanent magnets (52) are fixed on a side of the rotor disk (51) facing towards the stator assembly (40), and the permanent magnets (52) are magnetized in the axial direction, with each two circumferentially adjacent permanent magnets (52) having opposite polarities therebetween. 50 55
 10. The integrated Stirling refrigerator according to claim 9, wherein the air gap between the rotor assembly (50) and the stator assembly (40) is 0.2 mm.

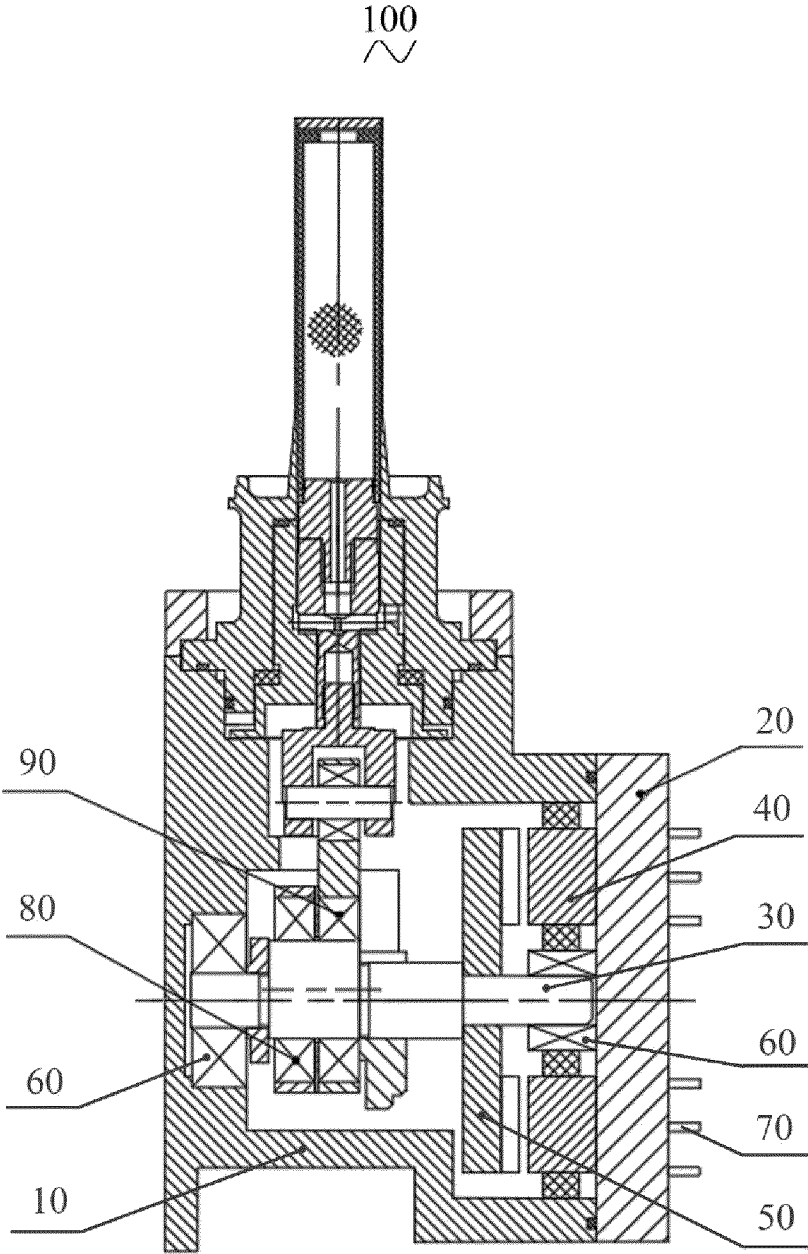


FIG. 1

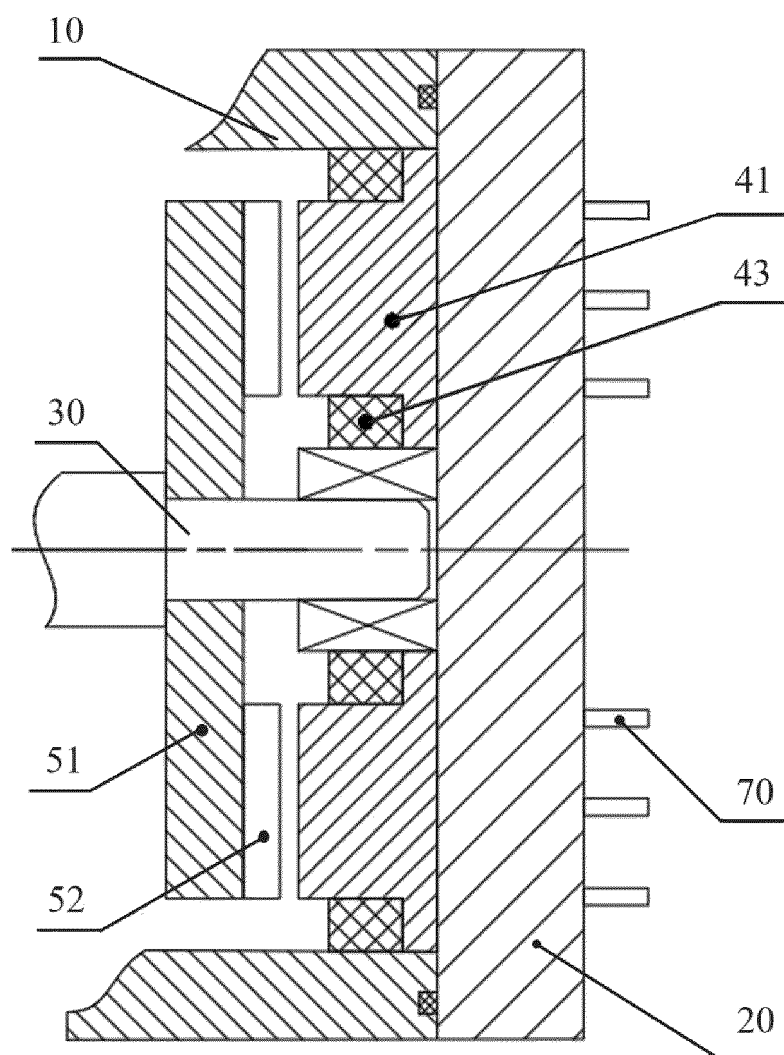


FIG. 2

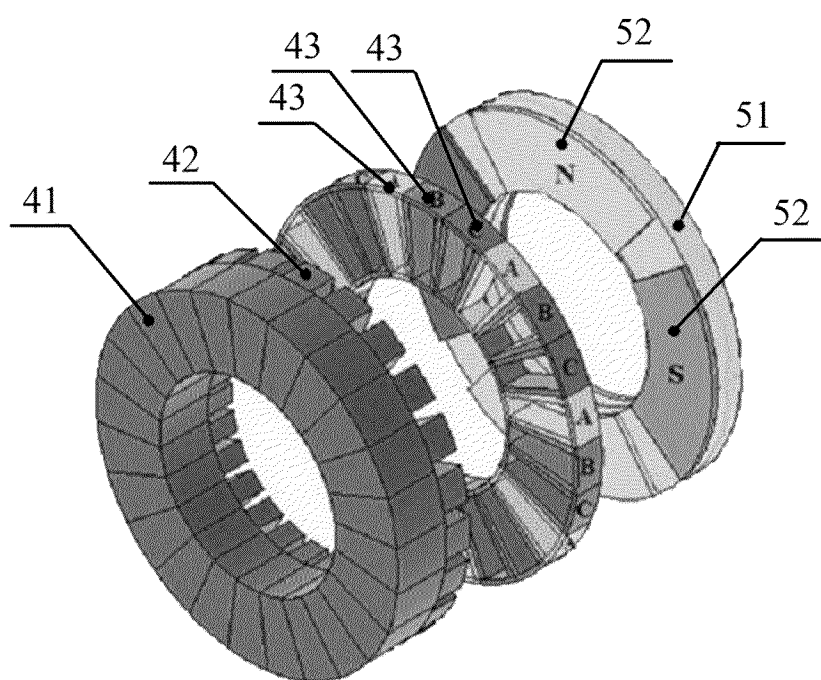


FIG. 3

INTERNATIONAL SEARCH REPORT

International application No.

PCT/CN2023/070022

A. CLASSIFICATION OF SUBJECT MATTER

F25B9/14(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)

IPC:F25B9, F02G1

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)

CNKI; CNTXT; WPABS; WPABSC; ENTXT; ENTXTC; DWPI; VEN: 制冷, 斯特林, 偏心轴, 轴, 定子, 转子, 压缩, 膨胀, 磁通, 尺寸, 大小, cool+, refrigerat+, eccentric shaft, axis, stator, rotor, compress+, expan+, flux, magnetic flow, size

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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A	CN 106196686 A (WUHAN GUIDE INFRARED CO., LTD.) 07 December 2016 (2016-12-07) description, paragraphs 23-28, and figures 1-3	1-10
A	CN 215597812 U (WUHAN GAOXIN TECHNOLOGY CO., LTD.) 21 January 2022 (2022-01-21) entire document	1-10
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A	JP 2010144518 A (MATSUMOTO KUNIO) 01 July 2010 (2010-07-01) entire document	1-10

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

* Special categories of cited documents:

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"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

07 April 2023

Date of mailing of the international search report

11 April 2023

Name and mailing address of the ISA/CN

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Beijing 100088

Facsimile No. (86-10)62019451

Authorized officer

Telephone No.

INTERNATIONAL SEARCH REPORT

International application No.

PCT/CN2023/070022

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2012161556 A1 (MIZUTANI RYOJI et al.,) 28 June 2012 (2012-06-28) entire document	1-10

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.

PCT/CN2023/070022

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