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(54) **CYLINDRICAL PERMANENT MAGNETIC COUPLING DEVICE**

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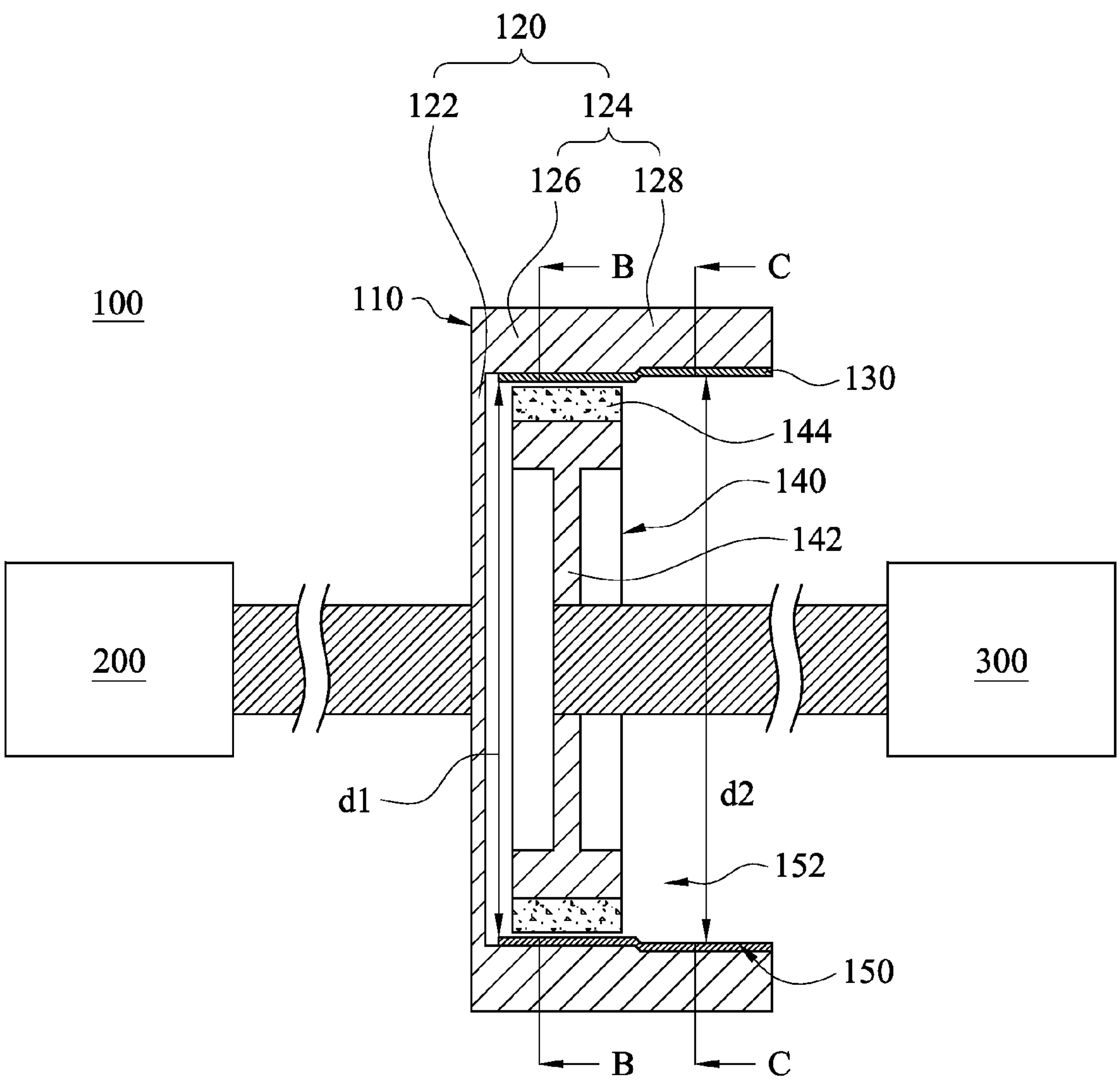
(57) **ABSTRACT**

A cylindrical permanent magnetic coupling device includes a conductor rotor and a permanent magnet rotor. The conductor rotor includes a bottom and a sidewall surrounding the bottom for defining a cavity, in which the cavity includes at least two different inner diameters. The permanent magnet rotor is arranged in the cavity for providing at least two different air gaps between the conductor rotor and the permanent magnet rotor.



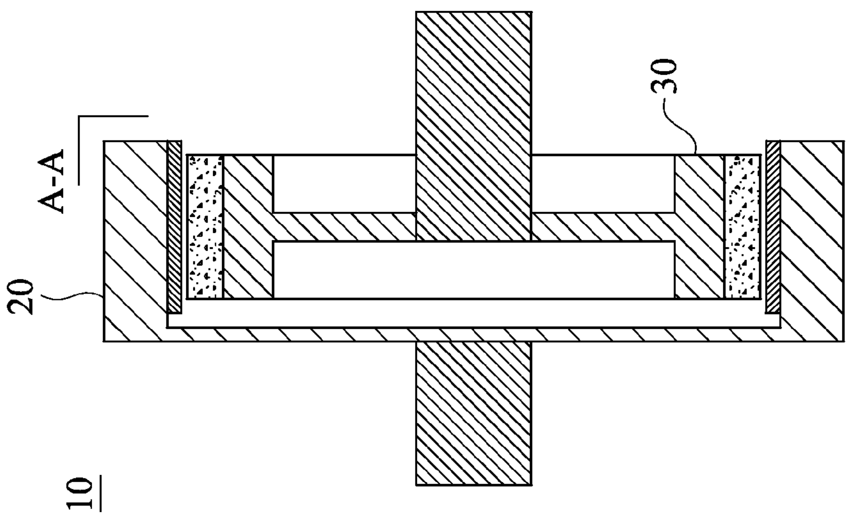


Fig. 1A
(prior art)

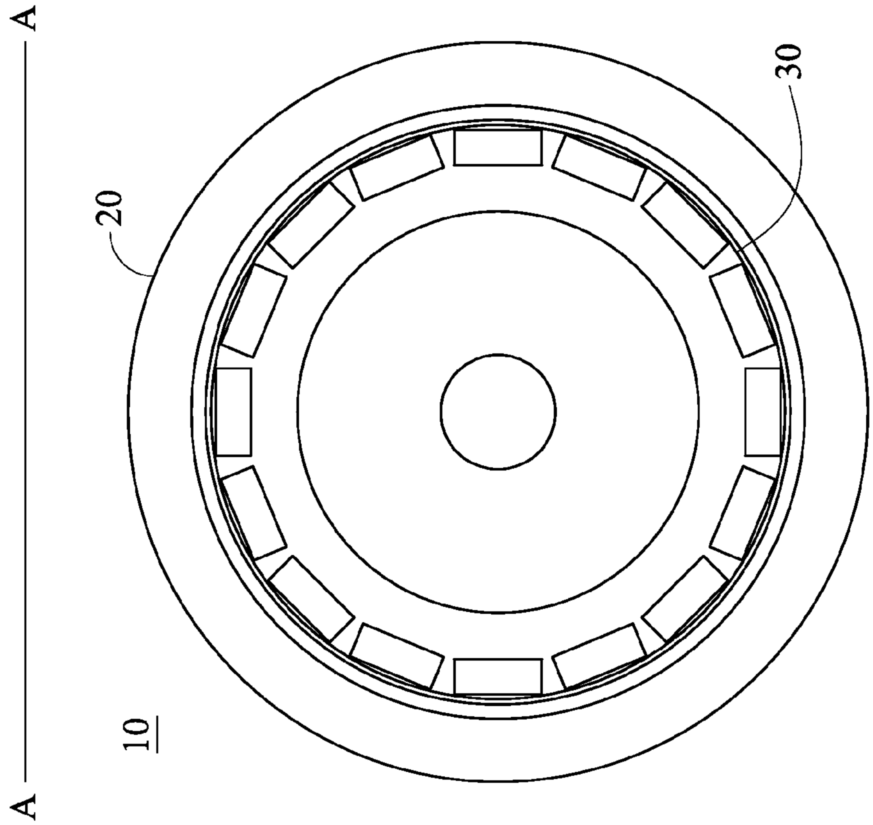


Fig. 1B
(prior art)

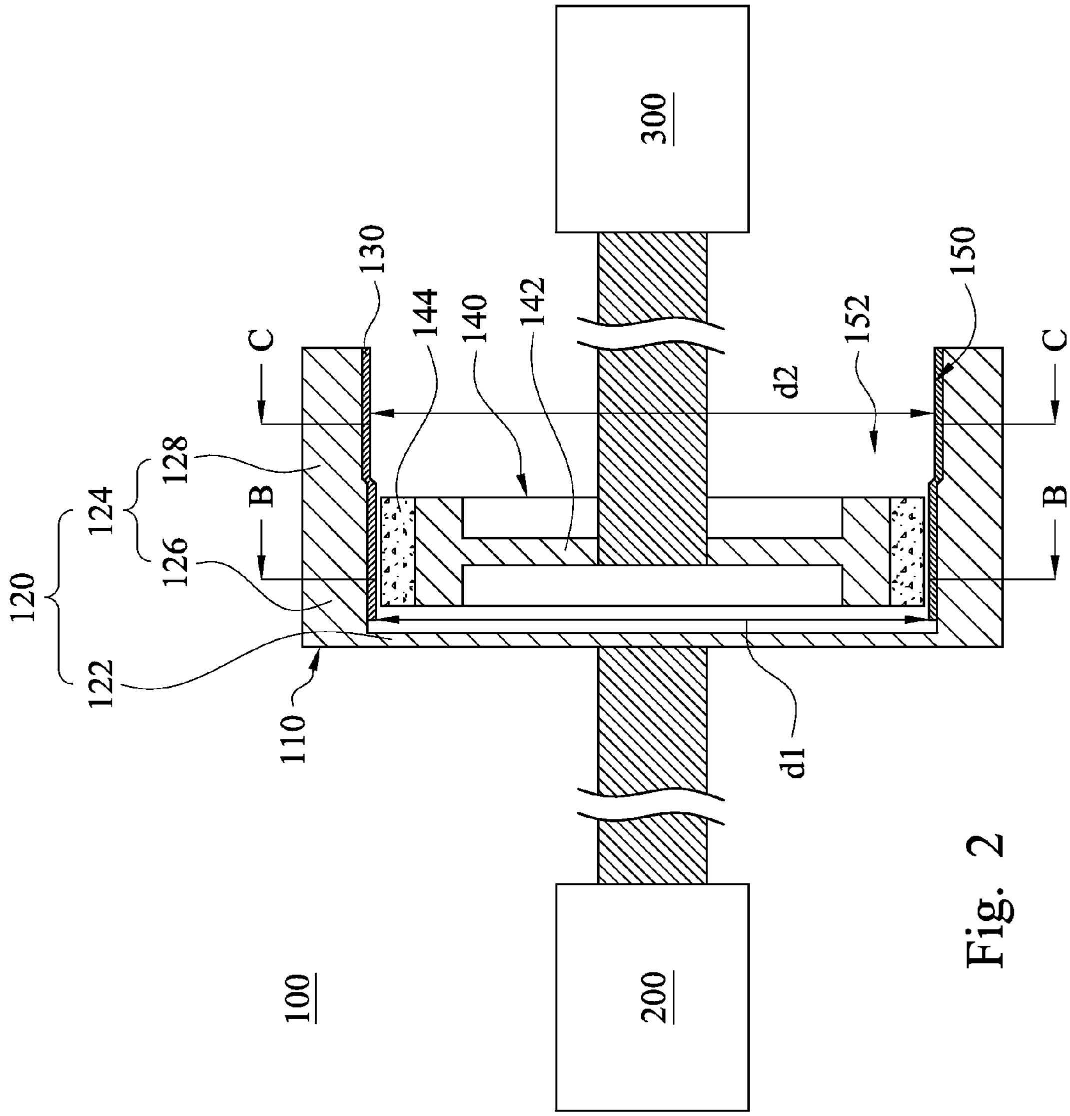

100
200
300
110
120
122
124
126
128
130
140
142
144
150
152
d1
d2
B
B
C
C

Fig. 2

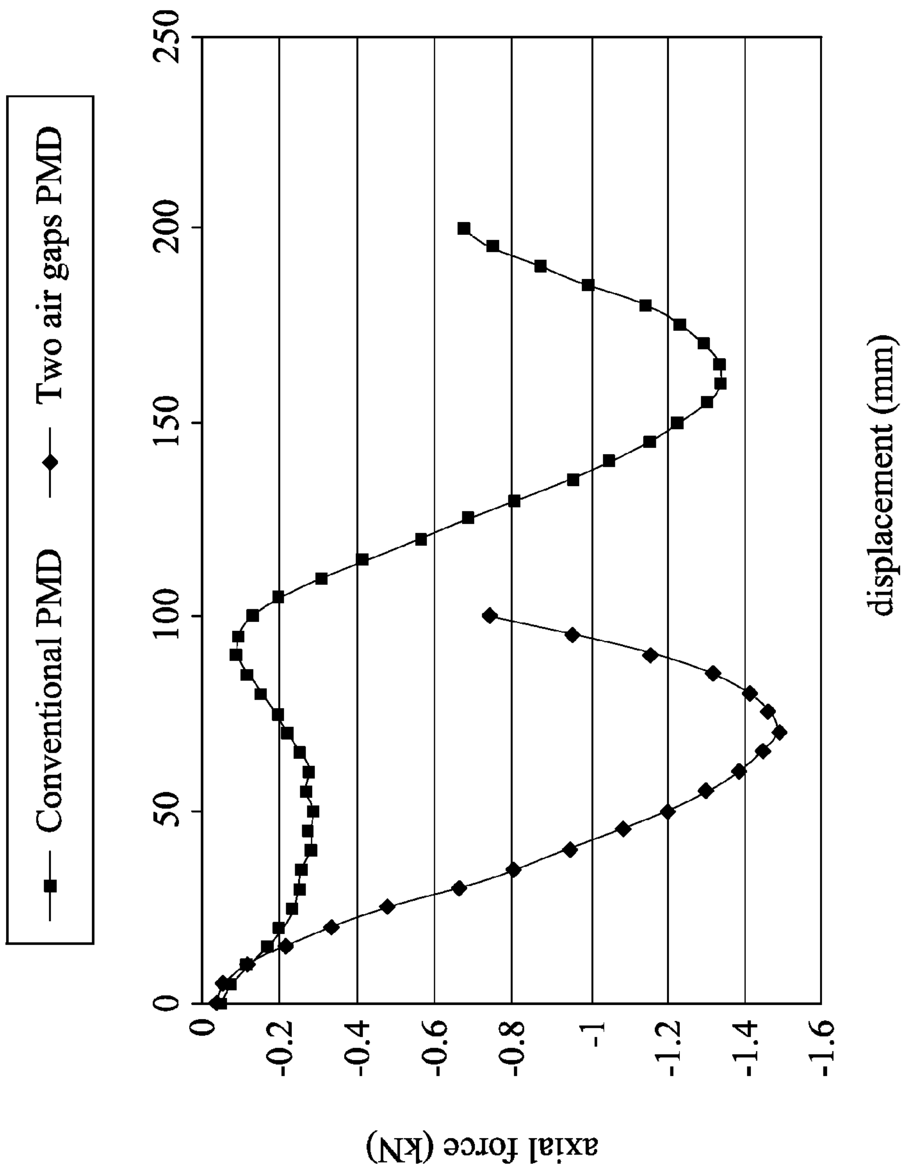

Conventional PMD
Two air gaps PMD
0
50
100
150
200
250
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
-1.6
axial force (kN)
displacement (mm)

Fig. 3

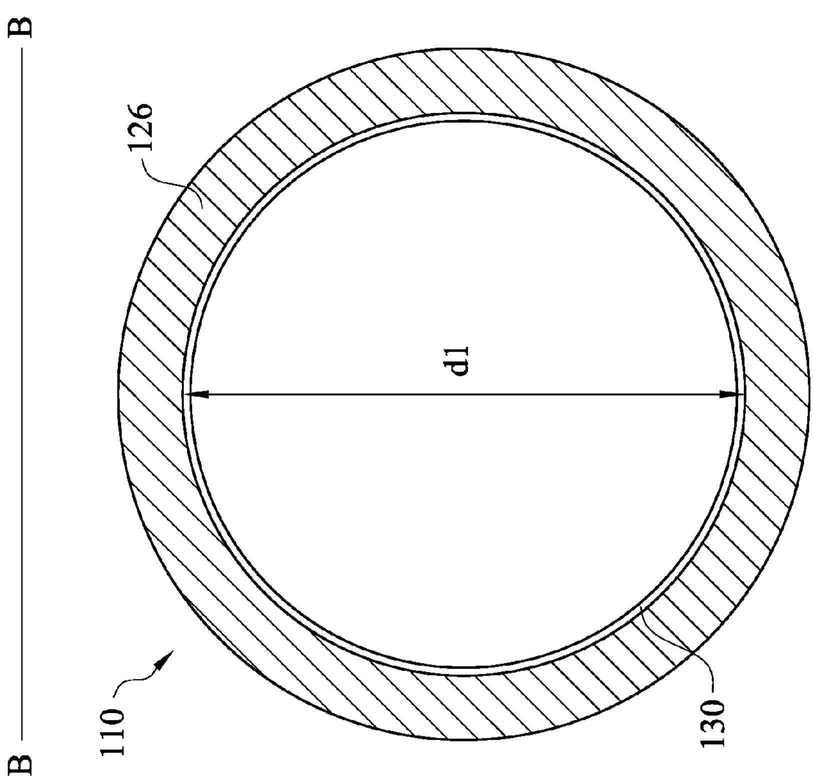


Fig. 4A

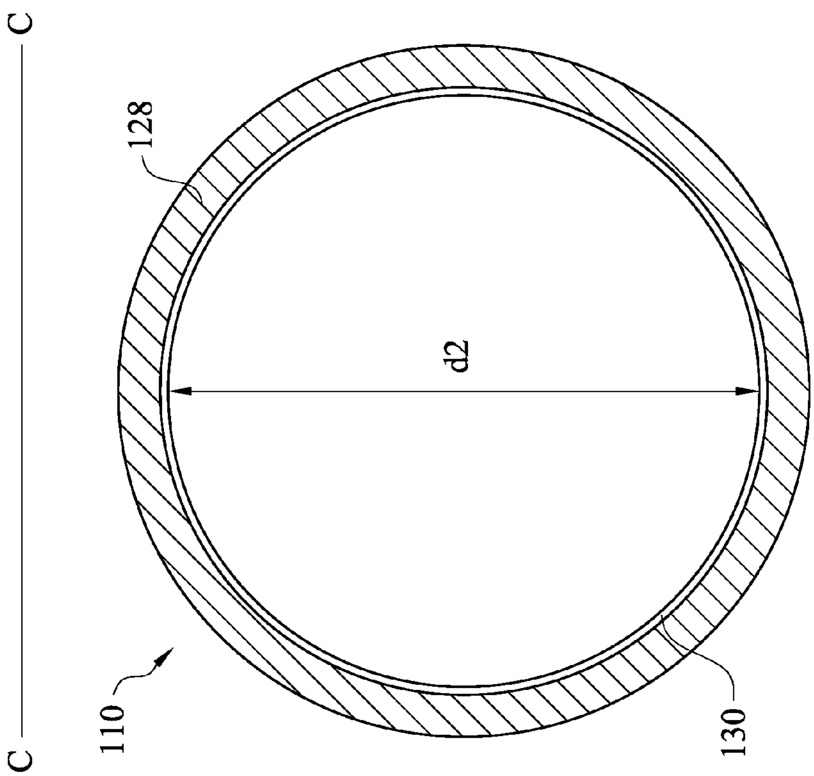


Fig. 4B

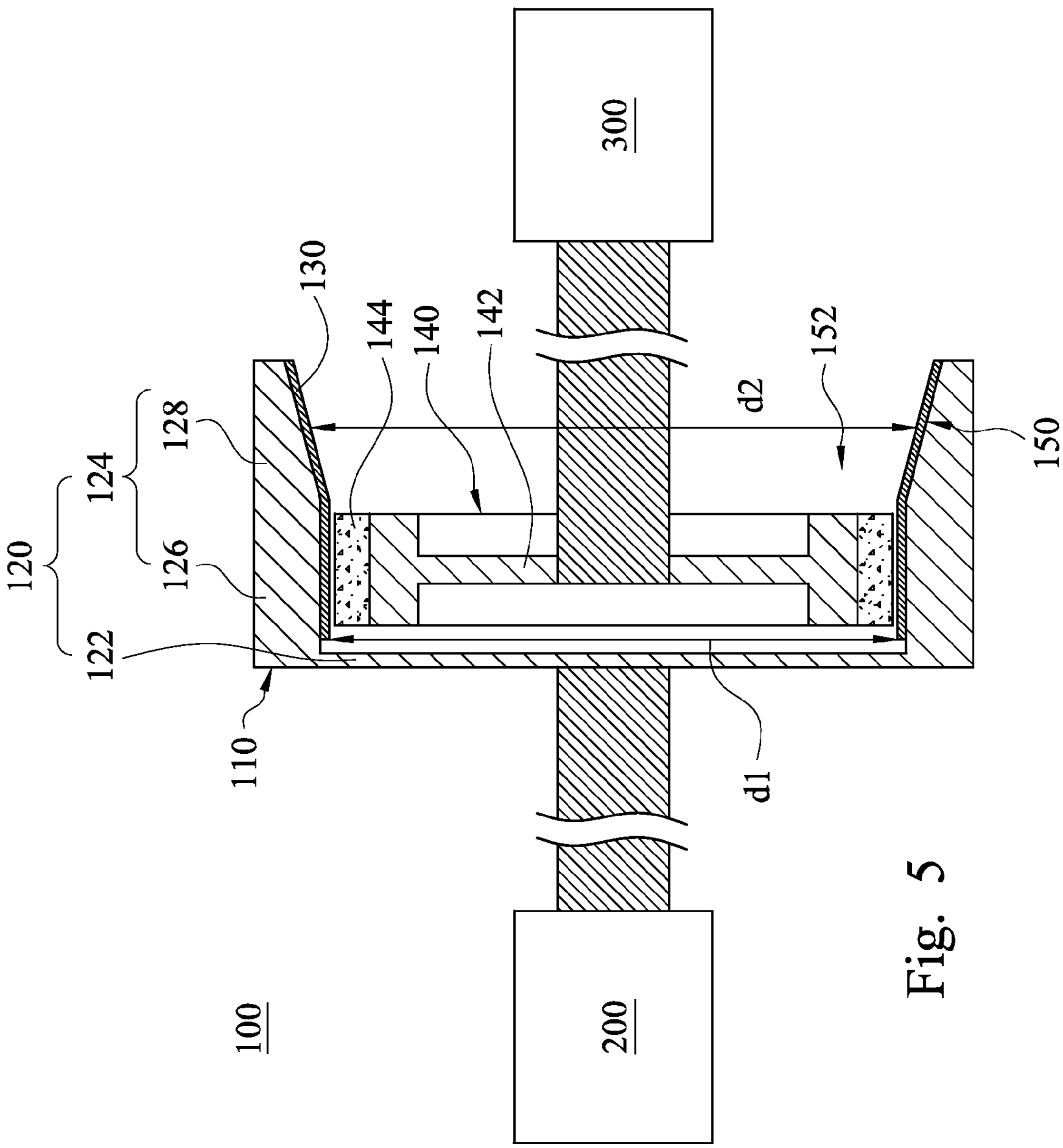


Fig. 5

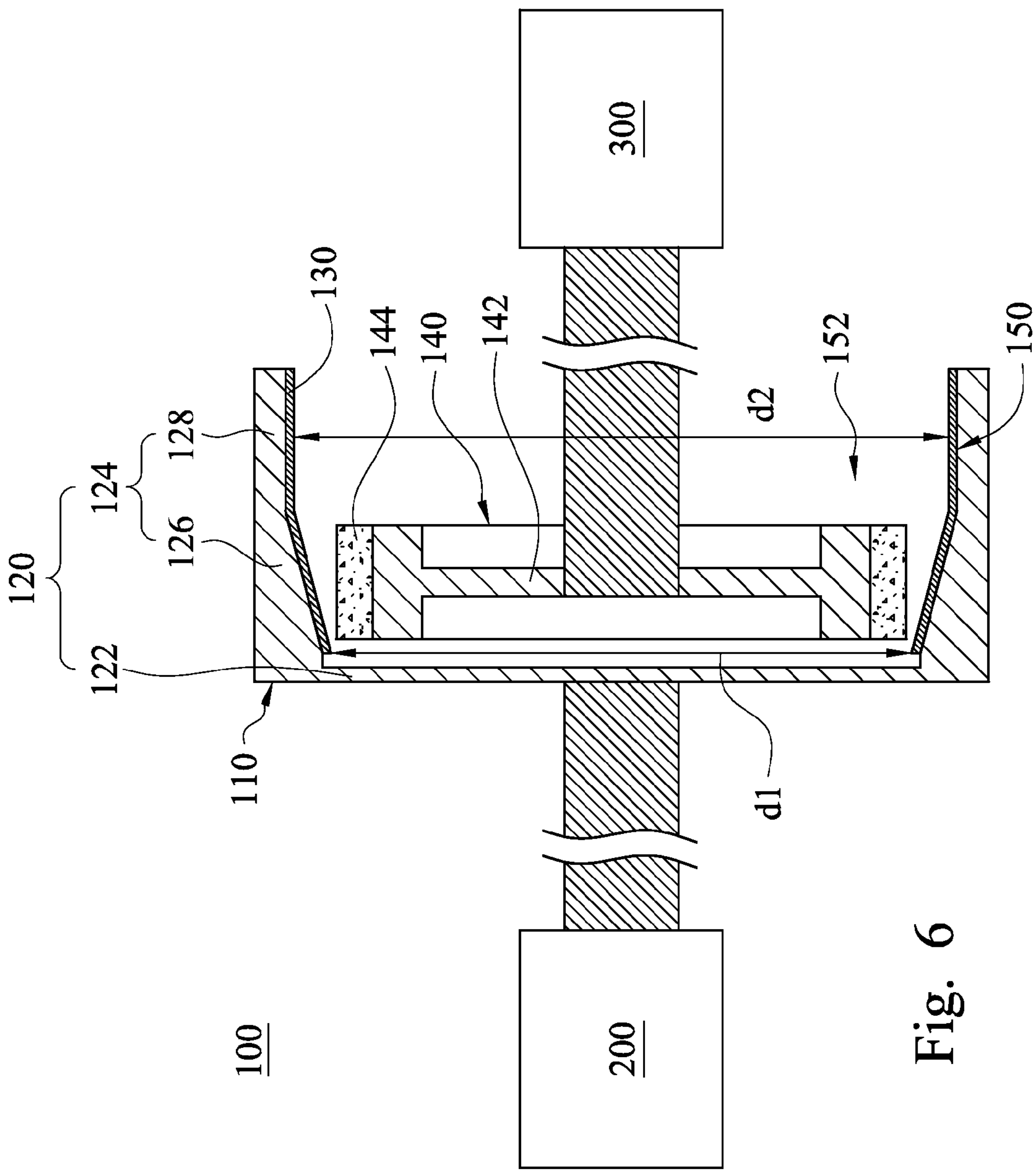


Fig. 6

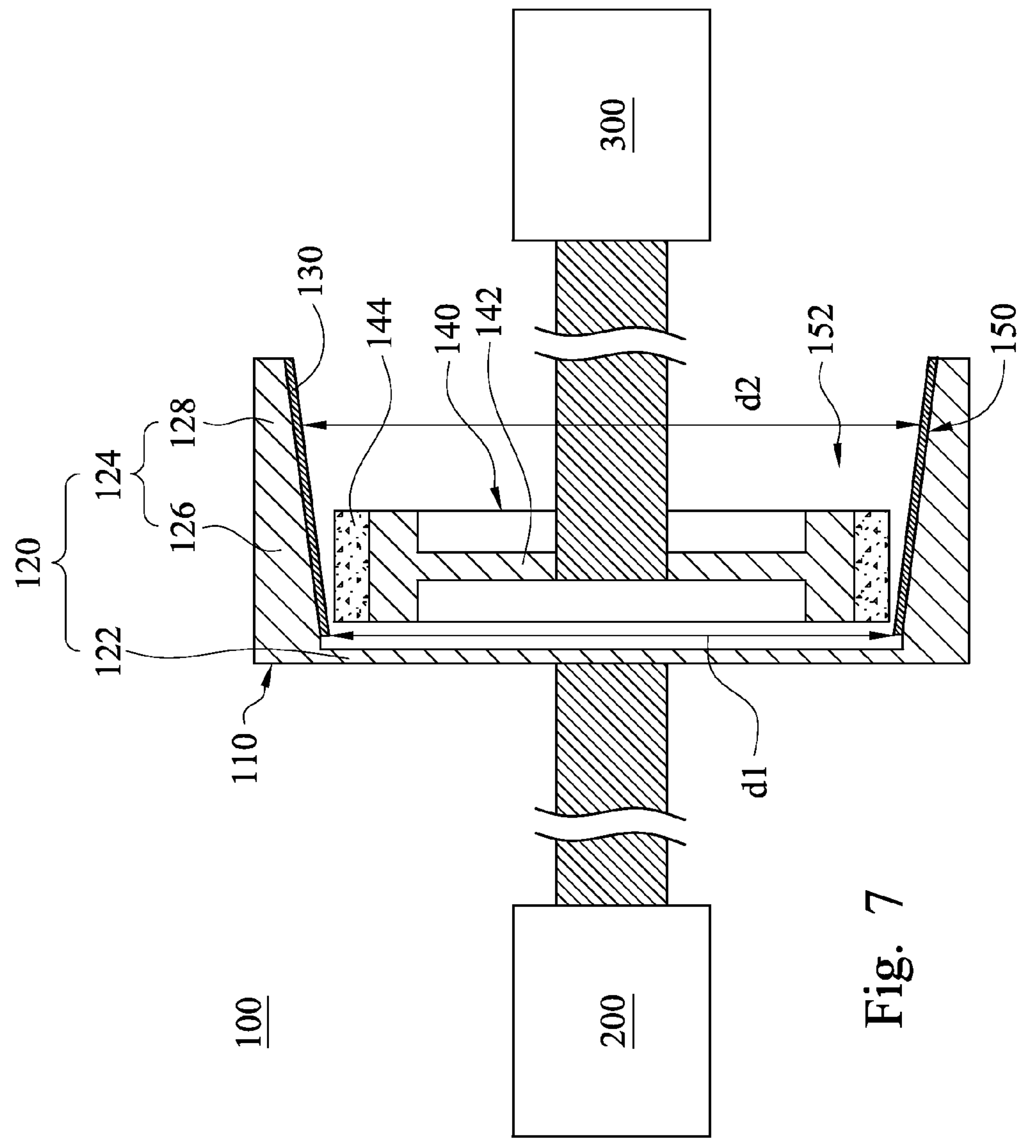


Fig. 7

CYLINDRICAL PERMANENT MAGNETIC COUPLING DEVICE

RELATED APPLICATIONS

[0001] This application claims priority to China Application Serial Number 201310404847.1, filed Sep. 6, 2013, which is herein incorporated by reference.

BACKGROUND

[0002] 1. Field of Invention

[0003] The present invention relates to a permanent magnetic coupling device. More particularly, the present invention relates to a cylindrical permanent magnetic coupling device.

[0004] 2. Description of Related Art

[0005] A permanent magnetic coupling device is a transmission device that transmits torque through an air gap. The permanent magnetic coupling device includes a conductor rotor and a permanent magnet rotor. The conductor rotor is fixed on an active shaft and connected to a motor. The permanent magnet rotor is fixed on a load shaft and connected to a load. The air gap is formed between the conductor rotor and the permanent magnet rotor so that the connection between the motor and the load is changed from a mechanical connection to a magnetic connection. By controlling the length or area of the air gap between the permanent magnet rotor and the conductor rotor, the output torque of the load shaft can be changed and thereby the rotational speed of the load can be adjusted.

[0006] The permanent magnetic coupling device has the following advantages on actual applications: the drive motor can be actuated without loading, so that the initial current of the motor is decreased, thus prolonging the motor operation life and reducing the effects on a power system; because of transmitting the torque through the air gap, the connection accuracy required between the motor and the load is lowered, and the mechanical vibration and noise are reduced; adopting the permanent magnetic coupling device can achieve the continuous adjustment of flow or pressure, and thus is more energy-saving smaller than adopting a valve or damper.

[0007] However, the slip power of the permanent magnetic coupling device is consumed on the conductor rotor, in which the temperature rise is proportional to the power loss, namely, the greater the power loss is, the higher the temperature rise is. When the power loss exceeds a limit value, the conductor rotor will be damaged by overheating, and will be cracked or even melted when serious. In addition, the loss is not evenly distributed on the conductor rotor, and the power loss density at a point of the conductor rotor is correlated with the magnetic density of the point. At the region near the permanent magnet rotor, the power loss goes higher due to the greater magnetic density. Once the local loss of the conductor rotor exceeds a certain value, the hot spots are formed on conductor rotor locally. Even though the overall temperature rise of the conductor rotor does not exceed the limit value, the conductor rotor is still damaged by overheating due to the existence of the hot spots.

[0008] The permanent magnetic coupling device can be classified to three types: cylindrical, disk-like and complex types. FIG. **1**A and FIG. **1**B illustrate cross-sectional schematic diagrams of a conventional cylindrical permanent magnetic coupling device from different view angles. A cylindrical permanent magnetic coupling device **10** includes a conductor rotor **20** connected to a motor and a permanent magnet rotor **30** connected to a load. Once the rotational speed of the permanent magnet rotor **30** needs adjusting, it can be achieved by adjusting the area of an air gap between the conductor rotor **20** and the permanent magnet rotor **30**. However, the permanent magnet rotor **30** is substantially enclosed by the conductor rotor **20**. Therefore, in the rotational speed area with greater power loss, the thermal dissipation area of the conductor rotor **20** and the air gap are smaller, thus causing the phenomena of temperature rise and local heat damage of the conductor rotor **20** to be more apparent.

SUMMARY

[0009] The present invention provides a cylindrical permanent magnetic coupling which has at least two different air gaps for improving the heat dissipation capability of the cylindrical permanent magnetic coupling. The air gap is a radial distance between the conductor rotor and the permanent magnet rotor.

[0010] An aspect of the present invention is to provide a cylindrical permanent magnetic coupling device including a conductor rotor and a permanent magnet rotor. The conductor rotor includes a bottom and a sidewall surrounding the bottom which are defined as a cavity, in which the cavity includes at least a first inner diameter and a second inner diameter other than the first inner diameter. The permanent magnet rotor is arranged in the cavity for providing at least two different air gaps between the conductor rotor and the permanent magnet rotor, wherein the two air gaps are respectively corresponding to the first inner diameter and the second inner diameter.

[0011] From the above, the permanent magnetic coupling device of the invention includes more than two kinds of inner diameters, there are more than two air gaps between the conductor rotor and the permanent magnet rotor. When the output of permanent magnetic coupling device is adjusted by changing the relative position between the conductor rotor and the permanent magnet rotor, the air gap there is increased gradually. Therefore, the heat dissipation capacity of the conductor rotor is improved and the force pulling the conductor rotor can be reduced.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] FIG. **1**A and FIG. **1**B are cross-sectional schematic diagrams of a conventional cylindrical permanent magnetic coupling device from different view angles;

[0013] FIG. **2** is a cross-sectional schematic view of a cylindrical permanent magnetic coupling device according to a first embodiment of the invention;

[0014] FIG. **3** is a comparative diagram of axial force of different cylindrical permanent magnetic coupling devices during speed adjustment;

[0015] FIG. **4**A and FIG. **4**B are right-side views of a base and a extending portion of a conductor rotor of an embodiment of the invention, respectively;

[0016] FIG. **5** is a cross-sectional schematic view of a cylindrical permanent magnetic coupling device according to a second embodiment of the invention;

[0017] FIG. **6** is a cross-sectional schematic view of a cylindrical permanent magnetic coupling device according to a third embodiment of the invention; and

[0018] FIG. **7** is a cross-sectional schematic view of a cylindrical permanent magnetic coupling device according to a fourth embodiment of this invention.

DETAILED DESCRIPTION

[0019] Reference will now be made in detail to the present embodiments of the invention, examples of which are illustrated in the accompanying drawings. Wherever possible, the same reference numbers are used in the drawings and the description to refer to the same or like parts.

[0020] In order to improve the heat dissipation capacity of a cylindrical permanent magnetic coupling device, the present invention provides a cylindrical permanent magnetic coupling device with a changeable air gap between a conductor rotor and a permanent magnet rotor thereof. When the output of the cylindrical permanent magnetic coupling device is adjusted, the air gap between the conductor rotor and the permanent magnet rotor is changed accordingly to improve the heat dissipation capacity of the cylindrical permanent magnetic coupling device.

[0021] FIG. **2** is a cross-sectional schematic diagram of a cylindrical permanent magnetic coupling device according to a first embodiment of this invention. A cylindrical permanent magnetic coupling device **100** includes a conductor rotor **110** and a permanent magnet rotor **140**. The conductor rotor **110** includes a bottom **122** and a sidewall **124** surrounding the bottom **122**. A cavity **150** is defined by the bottom **122** and the sidewall **124**, and the permanent magnet rotor **140** is disposed in the cavity **150**. The cavity **150** includes at least a first inner diameter d1 and a second inner diameter d2 other than the first inner diameter d1 for providing at least two different air gaps between the conductor rotor **110** and the permanent magnet rotor **140**, in which the two air gaps are respectively corresponding to the first inner diameter and the second inner diameter. Each of the air gaps between the conductor rotor **110** and permanent magnet rotor **140** is greater than or equal to about 4 mm.

[0022] The cavity **150** has an opening **152** for allowing the permanent magnet rotor **140** to be placed in the cavity **150**. The opening **152** and the bottom **122** are located at two opposite ends of the sidewall **124**. The inner diameter of the cavity **150** near the bottom **122** is regarded as the first inner diameter d1, and the inner diameter of the cavity **150** near the opening **150** is regarded as the second inner diameter d2, in which the first inner diameter d1 is smaller than the second inner diameter d2.

[0023] The conductor rotor **110** is connected to a motor **200**, and the permanent magnet rotor **140** is connected to a load **300**. The torque between both rotors is transmitted by the air gap, and the rotational speed of the permanent magnet rotor **140** is adjusted through the air gap area.

[0024] The conductor rotor **110** includes a magnetic cylinder **120** and a conductor ring **130**. The magnetic cylinder **120** includes the aforementioned bottom **122** and the sidewall **124**. The magnetic cylinder **120** is made of low carbon steel or a silicon steel plate. The conductor ring **130** is made of copper, aluminum or a Fe—Cu alloy.

[0025] The sidewall **124** of the magnetic cylinder **120** includes a base **126** and an extending portion **128**, and the first inner diameter d1 of the magnetic cylinder **120** at the base **126** is smaller than the second inner diameter d2 of the magnetic cylinder **120** at the extending portion **128**. In the present embodiment, axial cross-sectional profiles of the base **126** and the extending portion **128** (parallel to the axial direction) are about rectangles, and the first inner diameter d1 of the magnetic cylinder **120** at the base **126** is smaller than the second inner diameter d2 of the magnetic cylinder **120** at the extending portion **128**. Axial lengths of the base **126** and the extending portion **128** are greater than an axial length of the permanent magnet rotor **140** respectively.

[0026] A magnetic ring **142** is made of low carbon steel or a silicon steel plate. A plurality of permanent magnets **144** is made of a permanent material, such as Nd—Fe—B. The permanent magnets **144** and the conductor ring **130** are located between the magnetic cylinder **120** and the magnetic ring **142**.

[0027] The conductor ring **130** at the base **126** is located closer to the permanent magnet rotor **140** than the conductor ring **130** at the extending portion **128**. A ratio of the second inner diameter d2 of the conductor ring **130** at the extending portion **128** to the first inner diameter d1 of the conductor ring **130** at the base **126** is between 1.0 to 1.5, i.e., d2/d1 is greater than 1 and smaller than or equal to 1.5. Once the rotational speed of the load needs reducing, the permanent magnet rotor **140** is shifted along the axial direction away from the conductor rotor **110**, and the conductor ring **130** is moved from the base **126** to the extending portion **128** so that the axial length of the air gap between the conductor rotor **110** and the permanent magnet rotor **140** is also increased. Meanwhile, the power loss of the conductor ring **130** is increased gradually. However, because two air gaps are used, as the power loss is increased, the axial distance between the conductor rotor **110** and the permanent magnet rotor **140** are also increased. With the increase of the axial distance, the quantity of air flow through the air gap can be increased to carry away more heat, and reduce the temperature increase. On the other hand, because the magnetic density of the conductor rotor **110** is reduced, the local power loss of the conductor rotor **110** is also decreased. Therefore, the temperature at the hottest point of the conductor rotor **110** is lowered, thereby protecting the conductor rotor **110** from overheating locally.

[0028] A cylindrical permanent magnetic coupling device (PMD) of which the rated rotational speed is 1500 rpm and the rated power is 300 kW is used as an example. As shown in the FIG. **1**, a conductor rotor **20** of the cylindrical permanent magnetic coupling device **10** has an inner diameter of 408 mm and a length of 100 mm. The cylindrical permanent magnetic coupling device **100** having the two air gaps with the same rated power is shown in FIG. **2**, in which the first inner diameter d1 of the conductor ring **130** at the base **126** is 408 mm, the second inner diameter d2 of the conductor ring **130** at the extending portion **128** is 416 mm, and a length of the conductor rotor **110** is 200 mm. A permanent magnet rotor **30** of the cylindrical permanent magnetic coupling device **10** is the same as the permanent magnet rotor **140** of the cylindrical permanent magnetic coupling device **100**, and the diameters of the rotors are 400 mm. Compared with the conventional cylindrical permanent magnetic coupling device **10**, when the conductor power loss is maximum, the length of the air gap in the cylindrical permanent magnetic coupling device **100** with two air gaps is increased once (from 4 mm to 8 mm), the quantity of air flow therein is increased once, the area of heat dissipation therein is increased by 30%, and the maximum local loss is decreased from 734 W/mm^2 to 514 W/mm^2, which is decrease by almost 30%.

[0029] Then, two types of cylindrical permanent magnetic coupling devices **10** and **100** are compared with respect to the required axial force during speed adjustment, and the result is shown in FIG. **3**. When the permanent magnet rotors **30** and **140** are fully coupled with the conductor rotors **20** and **110** respectively, the rotational speeds thereof reach the maximum, and displacements corresponding to a horizontal coordinate are about 0. When the permanent magnet rotors **30** and **140** are pulled out of the conductor rotors **20** and **110** respectively, the rotational speeds of respective loads are about 0. Meanwhile, the displacement of the conventional cylindrical permanent magnetic coupling **10** device is 100 mm, and the displacement of the cylindrical permanent magnetic coupling device **100** with two air gaps is 200 mm. Within the speed adjustment range, the maximum axial force of the conventional cylindrical permanent magnetic coupling device **10** is 1.48 kN, and the maximum axial force of the cylindrical permanent magnetic coupling device **100** with two air gaps is 1.33 kN. Therefore, compared with the axial force required for pulling the conductor rotor **20** out of the conventional cylindrical permanent magnetic coupling device **10**, the axial force required for pulling the conductor rotor **110** out of the cylindrical permanent magnetic coupling device **100** with two air gaps is decreased by 8.5%. Thus, during the speed adjustment of the cylindrical permanent magnetic coupling device **100** with two air gaps, because the axial force required by a load axis is smaller, the force outputted from the execution mechanism (not shown in the figure) can be reduced, thus shrinking the volume of the mechanism smaller and lowering the cost.

[0030] FIG. **4**A and FIG. **4**B are right-side views of the base **126** and the extending portion **128** of the conductor rotor **110**. The figures show the first inner diameter d1 of the conductor rotor **110** at the base **126** is smaller than the second inner diameter d2 of the conductor rotor **110** at the extending portion **128**. The conductor ring **130** is located on the inner surfaces of the base **126** and the extending portion **128**.

[0031] Reference is made back to FIG. **2**, the cylindrical permanent magnetic coupling device **100** of the present invention can provide more than two air gaps (i.e. the radial distance between the permanent magnets **144** and the conductor ring **130**). As the power loss of the rotor increases, the air gaps are also increased to provide the better heat dissipation capacity and reduce the temperature rise of the conductor rotor **110**.

[0032] The principle regarding how to decrease the temperature rise of the conductor rotor **110** by the cylindrical permanent magnetic coupling device is described in the aforementioned embodiments. In the following embodiments, the variations of the conductor rotor **110** are explained, and the same descriptions explained in the aforementioned embodiments are not stated again.

[0033] FIG. **5** is a cross-sectional schematic diagram of a cylindrical permanent magnetic coupling device according to a second embodiment of this invention. A cylindrical permanent magnetic coupling device **100** includes a conductor rotor **110** and a permanent magnet rotor **140**. The conductor rotor **110** has a cavity **150**, and the permanent magnet rotor **140** is located in the cavity **150**. The cavity **150** includes at least two different inner diameters for providing at least two different air gaps between the conductor rotor **110** and the permanent magnet rotor **140**.

[0034] The conductor rotor **110** is connected to a motor **200**, and the conductor rotor **110** includes a magnetic cylinder **120** and a conductor ring **130** arranged on an inner surface of the magnetic cylinder **120**. The permanent magnet rotor **140** is connected to the load **300**, and the permanent magnet rotor **140** includes a magnetic ring **142** and a plurality of permanent magnets **144** arranged on the side of the magnetic ring **142**.

[0035] A sidewall **124** includes a base **126** and an extending portion **128**, in which the base **126** is near the bottom **122**, and the extending portion **128** is connected to the base **126**. In the present embodiment, an axial cross-sectional profile of the base **126** is a rectangle, and an axial cross-sectional profile of the extending portion **128** is a trapezoid with the width which is gradually decreased in the direction from an end near the base **126** to an opposite end, such that a second inner diameter d2 of the cavity **150** near the opening **152** is greater than a first inner diameter d1 of the cavity **150** near the bottom **122**. The second inner diameter d2 of the extending portion **128** is increased gradually in the direction from the base **126** to the extending portion **128**.

[0036] Axial lengths of the base **126** and the extending portion **128** are greater than the axial length of the permanent magnet rotor **140** respectively.

[0037] The principles of improving the heat dissipation capacity and reducing the axial force required for pulling out the conductor rotor **110** by providing the different widths of the air gaps in accordance with different loads are the same as those described in the first embodiment.

[0038] FIG. **6** is a cross-sectional schematic diagram of a cylindrical permanent magnetic coupling device according to a third embodiment of this invention. A sidewall **124** of the magnetic cylinder **120** includes a base **126** and a extending portion **128**, and a first inner diameter d1 of a base **126** of the magnetic cylinder **120** is smaller than a second inner diameter d2 of an extending portion **128** of the magnetic cylinder **120**. In the present embodiment, in particular, an axial cross-sectional profile of the base **126** is a trapezoid with a width which is decreased gradually in the direction from an end near the bottom **122** to an opposite end, and an axial cross-sectional profile of the extending portion **128** is a rectangle, such that an inner diameter of the cavity **150** near the opening **152** is greater than an inner diameter of the cavity **150** near the bottom **122**. The first inner diameter d1 of the base **126** is increased gradually in the direction from the base **122** to the opening **152**.

[0039] FIG. **7** is a cross-sectional schematic diagram of a cylindrical permanent magnetic coupling device according to a fourth embodiment of this invention.

[0040] The present embodiment is different from the aforementioned embodiment in that an axial cross-sectional profile of a sidewall **124** of a magnetic cylinder **120** is a trapezoid, such that an axial cross-sectional profile of a cavity **150** is also a trapezoid, in which, in particular, an inner side is narrower and an outer side is wider. A first inner diameter d1 of the magnetic cylinder **120** near a bottom **122** is smaller than a second inner diameter d2 of the magnetic cylinder **120** near an opening **152**. In other words, the present embodiment can be seen as a variation of a base **126** and an extending portion **128** which are trapezoids.

[0041] According to the foregoing embodiments, the drive conductor rotor of the cylindrical permanent magnetic coupling device has two or more inner diameters, such that there are two or more air gaps between the conductor rotor and the permanent magnet rotor. When the output is adjusted by changing the relative position between the conductor rotor and the permanent magnet rotor, the air gap between them is increased gradually to improve the heat dissipation capacity of the conductor rotor, and the force pulling the conductor rotor can be reduced.

[0042] Although the present invention has been described in considerable detail with reference to certain embodiments thereof, other embodiments are possible. Therefore, the spirit and scope of the appended claims should not be limited to the description of the embodiments contained herein.

[0043] It will be apparent to those skilled in the art that various modifications and variations can be made to the structure of the present invention without departing from the scope or spirit of the invention. In view of the foregoing, it is intended that the present invention cover modifications and variations of this invention provided they fall within the scope of the following claims.

What is claimed is:

1. A cylindrical permanent magnetic coupling device, comprising:

a conductor rotor comprising a bottom and a sidewall surrounding the bottom which are defined as a cavity, wherein the cavity has at least a first inner diameter and a second inner diameter other than the first inner diameter; and

a permanent magnet rotor arranged in the cavity for providing at least two different air gaps between the conductor rotor and the permanent magnet rotor, wherein the two air gaps are respectively corresponding to the first inner diameter and the second inner diameter.

2. The cylindrical permanent magnetic coupling device of claim **1**, wherein the cavity has an opening, and the first inner diameter near the bottom is smaller than the second inner diameter near the opening.

3. The cylindrical permanent magnetic coupling device of claim **1**, wherein the conductor rotor is connected to a motor, and the permanent magnet rotor is connected to a load.

4. The cylindrical permanent magnetic coupling device of claim **1**, wherein the conductor rotor comprises:

a magnetic cylinder comprising the bottom and the sidewall; and

a conductor ring located on an inner surface of the sidewall.

5. The cylindrical permanent magnetic coupling device of claim **4**, wherein the magnetic cylinder is made of low carbon steel or a silicon steel plate.

6. The cylindrical permanent magnetic coupling device of claim **4**, wherein the conductor ring is made of copper, aluminum or a Fe—Cu alloy.

7. The cylindrical permanent magnetic coupling device of claim **4**, wherein the sidewall comprises a base near the bottom, and an extending portion connected to the base, wherein an inner diameter of the base is smaller than an inner diameter of the extending portion.

8. The cylindrical permanent magnetic coupling device of claim **7**, wherein axial cross-sectional profiles of the base and the extending portion are rectangles.

9. The cylindrical permanent magnetic coupling device of claim **7**, wherein an axial cross-sectional profile of the base is a rectangle, an axial cross-sectional profile of the extending portion is a trapezoid, and an inner diameter of the extending portion increases gradually in the direction from the base to the extending portion.

10. The cylindrical permanent magnetic coupling device of claim **7**, wherein axial cross-sectional profiles of the base and the extending portion are trapezoids.

11. The cylindrical permanent magnetic coupling device of claim **7**, wherein an axial cross-sectional profile of the extending portion is a rectangle, an axial cross-sectional profile of the base is a trapezoid, and an inner diameter of the base increases gradually in the direction from the bottom to an opening.

12. The cylindrical permanent magnetic coupling device of claim **7**, wherein an axial length of the base is greater than an axial length of the permanent magnet rotor, and an axial length of the extending portion is greater than the axial length of the permanent magnet rotor.

13. The cylindrical permanent magnetic coupling device of claim **1**, wherein the permanent magnet rotor comprises a magnetic ring, and a plurality of permanent magnets disposed on a side of the magnetic ring.

14. The cylindrical permanent magnetic coupling device of claim **1**, wherein each of the air gaps is greater than or equal to 4 mm.

* * * * *