

**CYLINDRICAL VCM MAGNETIC GRAVITY COMPENSATOR, VCM AND
ASSEMBLY THEREOF**

5 [0001] The invention relates to the related technical field of a VCM, in particular to a cylindrical VCM magnetic gravity compensator, the VCM and assembly thereof.

10 [0002] A cylindrical VCM is a linear motion actuator that converts electrical energy into mechanical energy. Different from a traditional system in which a servo motor is matched with a ball screw, the VCM can directly drive a load. Therefore, the cylindrical VCM has the advantages such as simple structure, no maintenance, high response, high precision, etc., and is widely applied in the fields such as semiconductor, industrial automation, etc.

15 [0003] However, the cylindrical VCM in the prior art generally has a problem, that is, when the motor is stationary, it needs to be energized at all times to overcome the gravity of the motor itself and the load, which will cause energy loss. This part of the lost electrical energy will be converted into heat, which is emitted to the surrounding environment. This additional heat generation will lead to a thermal expansion effect in equipment. This thermal expansion effect will cause a technical defect difficult to
20 overcome for high-precision equipment. For example, the technical defect is not allowed in high-precision applications such as a lithography machine, etc.

25 [0004] In order to solve the above-mentioned problem, a technical scheme of using a magnetic gravity compensator to offset gravity was proposed in the industry. The magnetic field force generated by a permanent magnet material is used to offset the gravity of the load, and no additional power supply is required. In addition, compared with mechanical coupling, magnetic coupling has lower rigidity, which can thus be used as a vibration isolator.

30 [0005] HEIDENHAIN proposed a magnetic gravity compensator structure with negative stiffness in patent WO2011/131462. The main part of the structure includes two sets of axially magnetized annular permanent magnets and a set of axially magnetized conical permanent magnet. ORACLE proposed a classic cylindrical VCM structure in patent US6194796, but the VCM structure does not have gravity

compensation function. ETEL proposed a cylindrical VCM with a magnetic gravity compensator function in patent US9172291, where the coil is wound on a tapered iron core. ASML proposed a VCM with an integrated magnetic gravity compensation function in patent US6791443, which has two forms such as plane and cylinder.

5 There are several sets of radially magnetized permanent magnets in the cylindrical structure. SMEE proposed two cylindrical VCMs with a magnetic gravity compensator compensation function in patent CN105281530 and patent CN103034065.

10 [0006] This technical problem has received extensive attention from the prior art, but the magnetic gravity compensator of the prior art is still difficult to combine with the VCM, requires a radially magnetized permanent magnet ring, and has disadvantages such as complex structure, high cost, etc.

15 [0007] The magnetic gravity compensator of the prior art is difficult to combine with the VCM, requires a radially magnetized permanent magnet ring, and has disadvantages such as complex structure, high cost, etc., so the invention provides a cylindrical VCM magnetic gravity compensator, a VCM and assembly thereof.

20 [0008] In order to achieve the above objective, the technical scheme of the invention is as follows:

[0009] The cylindrical VCM magnetic gravity compensator comprises a rotor and a stator; the rotor comprises a rotor support and a rotor permanent magnet, the
25 longitudinal section of the rotor support is U-shaped, and the rotor permanent magnet is mounted at the U-shaped opening; the stator comprises a stator core, a stator magnet assembly and a stator shaft; the longitudinal section of the stator is E-shaped, the stator core is mounted on two parallel sides outside the E-shape, the stator shaft is mounted on the shaft at the center of the E-shape, the stator magnet
30 assembly includes a stator permanent magnet and a stator magnetic block overlapped to each other, the stator magnet assembly is sleeved on the periphery of the stator shaft, and the stator permanent magnet is located between the stator magnetic block and the E-shaped bottom; the two parallel sides of the U-shape fit into the two gaps formed by the three parallel sides of the E-shape.

[0010] Further, the rotor permanent magnet has several groups.

5 [0011] A VCM, wherein on the basis of any cylindrical VCM magnetic gravity compensator mentioned above, the rotor comprises a cable and a coil winding, the coil winding is mounted on an outer wall between the rotor permanent magnet and the U-shaped bottom, and the coil winding is connected to the outside through the cable.

10 [0012] Further, the coil winding has several groups.

[0013] Further, the number of the stator magnet assemblies is equal to the sum of the number of the rotor permanent magnets and the coil windings.

15 [0014] Further, the material of the rotor permanent magnet and/or the stator permanent magnet is a rare earth permanent magnet with a high magnetic energy level.

20 [0015] Preferably, the rare earth permanent magnet with a high magnetic energy level is a neodymium iron boron permanent magnet, a samarium cobalt permanent magnet, an AlNiCo permanent magnet or a ferrite permanent magnet.

[0016] Preferably, the material of the stator core and/or the stator magnetic block is a high permeability material.

25 [0017] Preferably, the material of the rotor support and/or the stator shaft is a polymer material or a surface-insulated aluminum or a non-magnetic stainless steel.

30 [0018] A magnetic gravity compensation type cylindrical VCM assembly, wherein the assembly comprises a base, a linear guide, a spring, and any VCM mentioned above, the stator is fixedly connected to the base, the rotor is connected to the linear guide through a sliding block, and one end of the spring is fixedly connected to the rotor and the other end is fixedly connected to the linear guide.

[0019] The outstanding advantages and beneficial effects of the invention are as follows:

1. Simple manufacturing: Compared with the existing technical scheme, the permanent magnet magnetization direction in the technical scheme of the invention is axial magnetization, so that a whole piece of permanent magnet can be used very easily, and the structure and assembly are simpler, thus reducing the production cost;

2. Easy combination with the VCM: The gravity compensator structure disclosed in the invention can be seamlessly connected with the cylindrical VCM structure so as to form the VCM with a gravity compensation module;

3. Good stiffness: Compared with a spring of the same volume, the gravity compensator has a very low stiffness coefficient and is suitable for use as a vibration isolator; in addition, the stiffness characteristic of the compensator is negative, and the compensator can be used in combination with the spring with the same absolute stiffness coefficient so as to realize gravity compensation with approximately zero stiffness.

4. Low temperature rise: Because the gravity compensation structure offsets the gravity, the ampere force only needs to provide the force required for dynamic adjustment, so the current and heat are greatly reduced, and the accuracy error caused by thermal expansion is avoided. The compensator is very suitable for high precision applications such as semiconductor etc.

[0020] In order to explain the embodiments of the invention or the technical scheme in the prior art more clearly, the drawings to be used in the description of the embodiments or the prior art will be briefly introduced below. Obviously, the drawings in the following description are only some embodiments of the invention. For a person of ordinary skill in the art, other drawings can be obtained from these drawings without creative work.

Figure 1 is the schematic diagram of the overall three-dimensional structure of the VCM of the invention;

Figure 2 is the schematic diagram of the longitudinal section structure of the cylindrical VCM magnetic gravity compensator in embodiment 1;

Figure 3 is the schematic diagram of the longitudinal section structure of the cylindrical VCM magnetic gravity compensator in embodiment 2;

Figure 4 is the schematic diagram of the longitudinal section structure of the VCM in embodiment 3;

Figure 5 is the schematic diagram of the longitudinal section structure of the VCM in embodiments 4 and 5;

5 Figure 6 is the schematic diagram of the three-dimensional structure of the rotor of the VCM in embodiment 4;

Figure 7 is the exploded view of the stator of the VCM in embodiment 5;

Figure 8 is the magnetic field distribution diagram of the rotor of the VCM at different positions in embodiment 4;

10 Figure 9 is the relationship between the levitation force of the magnetic gravity compensator and the position of the rotor in embodiment 4;

Figure 10 is the relationship between the ampere force of the VCM part and the position of the rotor in embodiment 4;

15 Figure 11 is the schematic diagram of the structure of the magnetic gravity compensation type cylindrical VCM assembly in embodiment 7.

[0021] The specific embodiments of the invention are further described below according to the drawings. It should be noted here that the description of these embodiments is used to help understand the invention, but does not constitute a
20 limitation to the invention. In addition, the technical features involved in the various embodiments of the invention described below can be combined with each other as long as they do not conflict with each other.

[0022] It should be noted that in the description of the invention, the orientation or
25 positional relationship indicated by the terms "upper", "lower", etc. are based on the description of the structure of the invention shown in the drawings, and are only for the convenience of describing the invention instead of indicating or implying that the pointed device or component must have a specific orientation and be constructed and operated in a specific orientation; therefore, the terms cannot be understood as
30 a limitation to the invention. The upper and lower positional relationships of the structures in the drawings can be reversed in a specific embodiment.

[0023] In addition, unless otherwise clearly specified and limited, the terms "installation" and "connection" shall be understood in a broad sense. For example,

the connection can be a fixed connection, a detachable connection, or an integral connection; the connection can be a mechanical connection or an electrical connection; the connection can be a direct connection, or an indirect connection through an intermediate medium, or a connection inside two structures. A person of ordinary skill in the art can understand the specific meaning of the above terms in the invention according to the general idea of the invention and the context of the scheme.

[0024] Embodiment 1

As shown in Figures 1 and 2, the cylindrical VCM magnetic gravity compensator comprises the rotor 1 and the stator 2; the rotor 1 includes the rotor support 4 and the rotor permanent magnet 6, the longitudinal section of the rotor support 4 is U-shaped, and the rotor permanent magnet 6 is arranged at the U-shaped opening; that is, the three-dimensional structure of the rotor bracket 4 is a cylindrical structure with a bottom, and the rotor permanent magnet 6 is mounted on the edge of the open end of the cylindrical structure, or the side wall of the entire cylindrical structure is composed of the rotor permanent magnet 6, or the periphery of the side wall of the cylinder is wrapped with the rotor permanent magnet 6. the stator 2 includes the stator core 7, the stator magnet assembly and the stator shaft 10; the longitudinal section of the stator 2 is E-shaped, that is, the three-dimensional structure of the stator 2 is a cylindrical structure with a bottom and a column in the middle; the stator core 7 is mounted on the two parallel sides outside the E-shape, and the stator shaft 10 is mounted on the shaft at the center of the E-shape, that is, the position of the stator core 7 is on the side wall of the cylindrical structure with the column, and the stator shaft 10 is mounted at the position of the middle column. The stator shaft 10 can be a solid cylindrical shaft or a hollow cylindrical structure; the stator magnet assembly includes the stator permanent magnet 8 and the stator magnetic block 9 overlapped to each other, and the stator magnet assembly is sleeved on the periphery of the stator shaft 10. In specific implementation, it is also allowed that only the stator magnet assembly is mounted without the stator shaft 10 in the middle, and the stator permanent magnet 8 is located between the stator magnetic block 9 and the E-shaped bottom; the two parallel sides of the U-shape fit into the two gaps formed by the three parallel sides of the E-shape, which is expressed by a three-dimensional structure; that is, the rotor 1 is generally a cylindrical structure with a

bottom, and the stator 2 is also a cylindrical structure with a bottom as a whole, except that the center of the cylindrical structure of the stator 2 is provided with a columnar structure; the rotor 1 and the stator 2 are cooperated together, the inner diameter of the cylindrical structure of the rotor 1 is equivalent to the diameter of the columnar structure of the stator 2, the outer diameter of the wall of the cylindrical structure of the rotor 1 is equivalent to the inner diameter of the cylindrical structure of the stator 2, and the two cylindrical structures have the same depth, so that the rotor 1 and the stator 2 can achieve clearance fit.

[0025] The rotor 1 and the stator 2 are assembled concentrically, and the rotor 1 can move relative to the stator 2 in a vertical direction; needless to say, the magnetic pole direction of the rotor permanent magnet 6 and the stator magnet assembly is the same, and the magnetic poles of the two magnets achieve magnetic gravity compensation by means of like polarities repelling each other to avoid heat generation when energized, which can be used in high-precision instruments.

[0026] The above is the basic type of the embodiment of the invention. In order to improve the technical effect, the following improvements can be made to the basic type of the embodiment. The following improvements can be combined with each other where there is no contradiction. This structure can be used as a gravity compensator alone or in conjunction with an external VCM.

[0027] Embodiment 2

As shown in Figure 3, the rotor permanent magnet 6 has several groups in the cylindrical VCM magnetic gravity compensator; the several groups of rotor permanent magnets 6 are mounted in the same way, which can provide greater levitation force and are suitable for applications with heavier loads.

[0028] Embodiment 3

A VCM, wherein the rotor 1 also includes the cable 3 and the coil winding 5, and the coil winding 5 is mounted on the outer wall between the rotor permanent magnet 6 and the U-shaped bottom in the above embodiment of the cylindrical VCM magnetic gravity compensator; that is, the rotor permanent magnet 6 is mounted on the outer wall of the lower middle of the rotor support 4, the coil winding 5 is mounted on the

outer wall of the upper middle of the rotor support 4, and the coil winding 5 is connected to the outside through the cable 3; the coil winding 5 is usually made of copper core or aluminum core enameled wire, and the coil winding 5 is fixed on the rotor support 4 by means of gluing etc.

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[0029] As shown in Figure 4, the rotor 1 has a group of coil winding 5 and a group of rotor permanent magnet 6, and the feature is that the length of the rotor 1 is short, and the rotor 1 has light mass, but small ampere force.

10 [0030] Embodiment 4

As shown in Figures 5 and 6, the coil winding has several groups and can provide large ampere force in the VCM.

[0031] As shown in Figure 5, the rotor 1 has two groups of coil winding 5 and 1 group of rotor permanent magnet 6. In the actual application process, the two groups of coil winding 5 and the stator permanent magnet 8 constitute a VCM, which can realize dynamic adjustment of motion.

[0032] The magnetic field of the rotor permanent magnet 6 interacts with the magnetic field of the stator permanent magnet 8 so as to form a magnetic gravity compensator, which provides a levitation force opposite to the direction of gravity of the load 13. When the coil winding 5 is not energized, the relationship between the levitation force and the position of the rotor 1 is shown in Figure 9. It can be seen from the figure that within a travel range of 3mm, the gravity compensator provides an approximate "negative spring" characteristic. In this preferred embodiment, the relationship between the levitation force F and the position x of the rotor 1 can be expressed as: $F=k \cdot x+F_0$.

[0033] When the gravity compensator is matched with the spring 12 with a matching stiffness coefficient, zero stiffness gravity compensation can be realized, so the gravity compensator is very suitable for applications where vibration isolation is required.

[0034] Figure 10 shows the working characteristic of the VCM in the preferred embodiment. As shown in Figure 8, when the coil winding 5 is supplied with appropriate direct current, according to the order of a, b, and c in Figure 8, the shallower the depth of the stator 1 in the rotor 2, the magnetic field distribution of the rotor at different positions will generate ampere force in the magnetic field of the stator permanent magnet 8. When the current is constant, the output is related to the position; when the position is fixed, the motor output is directly proportional to the current; therefore, the dynamic adjustment of the movement state of a workpiece can be achieved by adjusting the magnitude of the current.

[0035] Figures 9 and 10 respectively show the working characteristics of the magnetic gravity compensator and the VCM after a decoupling analysis. Combining the two can realize the movement adjustment of the load 13 workpiece with gravity compensation.

[0036] Embodiment 5

As shown in Figures 5 and 7, the number of the stator magnet assemblies is equal to the sum of the number of the rotor permanent magnets 6 and the coil windings 5 in the VCM.

[0037] Embodiment 6

The material of the rotor permanent magnet 6 and/or the stator permanent magnet 8 is a rare earth permanent magnet with a high magnetic energy level in the VCM of the embodiment. The rare earth permanent magnet with a high magnetic energy level is a neodymium iron boron permanent magnet, a samarium cobalt permanent magnet, an AlNiCo permanent magnet or a ferrite permanent magnet in the specific implementation. It needs to be explained that what is connected with "and/or" in this technical scheme means that any one of the conjunctions is this attribute, any few are this attribute, and all of them are this attribute. Taking the conjunctions in this section as an example, there are several cases, e.g. the material of only the rotor permanent magnet 6 is a rare earth permanent magnet with high magnetic energy level, or the material of only the stator permanent magnet 8 is a rare earth permanent magnet with high magnetic energy level, or the material of both the rotor permanent magnet 6 and the stator permanent magnet 8 is a rare earth permanent magnet with

high magnetic energy level. Other cases using "and/or" are the same as this, and will not be repeated here.

[0038] In addition, the material of the stator core 7 and/or the stator magnetic block 9 is a high permeability material.

[0039] Moreover, the material of the rotor support 4 and/or the stator shaft 10 is a non-magnetic material, for example, a polymer material or a surface-insulated aluminum or a surface-insulated non-magnetic stainless steel.

[0040] Embodiment 7

As shown in Figure 11, a magnetic gravity compensation type cylindrical VCM assembly includes a base 14, a linear guide 11, a spring 12, and the VCM in any one of the above embodiments. The stator 2 is fixedly connected to the base 14, the rotor 1 is connected to the linear guide 11 through a sliding block, one end of the spring 12 is fixedly connected to the rotor 1 and the other end is fixedly connected to the linear guide 11. Concentric installation is ensured by the linear guide 11. The spring 12 is used to provide a stiffness characteristic opposite to the magnetic gravity compensator, so as to obtain approximately zero stiffness gravity compensation, and jointly compensate the gravity of the load 13. In practical applications, multiple modules as shown in Figure 11 can also be used in parallel to control the heavier load 13 synchronously.

[0041] The above and the drawings describe the embodiments of the invention in detail, but the invention is not limited to the described embodiments. As far as technicians in this field are concerned, various changes, modifications, replacements and deformations performed to these embodiments without departing from the principle and spirit of the invention and doing creative work are still within the protection scope of the invention.

Claims

1. A cylindrical VCM magnetic gravity compensator, wherein the magnetic gravity compensator comprises a rotor and a stator; the rotor comprises a rotor support and a rotor permanent magnet, the longitudinal section of the rotor support is U-shaped, and the rotor permanent magnet is mounted at the U-shaped opening; the stator comprises a stator core, a stator magnet assembly and a stator shaft; the longitudinal section of the stator is E-shaped, the stator core is mounted on two parallel sides outside the E-shape, the stator shaft is mounted on the shaft at the center of the E-shape, the stator magnet assembly includes a stator permanent magnet and a stator magnetic block overlapped to each other, the stator magnet assembly is sleeved on the periphery of the stator shaft, and the stator permanent magnet is located between the stator magnetic block and the E-shaped bottom; the two parallel sides of the U-shape fit into the two gaps formed by the three parallel sides of the E-shape.
2. The cylindrical VCM magnetic gravity compensator according to claim 1, wherein the rotor permanent magnet has several groups.
3. A VCM, wherein the VCM comprises the cylindrical VCM magnetic gravity compensator according to claim 1 or 2, the rotor comprises a cable and a coil winding, the coil winding is mounted on an outer wall between the rotor permanent magnet and the U-shaped bottom, and the coil winding is connected to the outside through the cable.
4. The VCM according to claim 3, wherein the coil winding has several groups.
5. The VCM according to claim 3 or 4, wherein the number of the stator magnet assemblies is equal to the sum of the number of the rotor permanent magnets and the coil windings.
6. The VCM according to claim 5, wherein the material of the rotor permanent magnet and/or the stator permanent magnet is a rare earth permanent magnet with a high magnetic energy level.

- 5 7. The VCM according to claim 6, wherein the rare earth permanent magnet with a high magnetic energy level is a neodymium iron boron permanent magnet, a samarium cobalt permanent magnet, an AlNiCo permanent magnet or a ferrite permanent magnet.
8. The VCM according to claim 5, wherein the material of the stator core and/or the stator magnetic block is a high permeability material.
- 10 9. The VCM according to claim 5, wherein the material of the rotor support and/or the stator shaft is a polymer material or a surface-insulated aluminum or a non-magnetic stainless steel.
- 15 10. A magnetic gravity compensation type cylindrical VCM assembly, wherein the assembly comprises a base, a linear guide, a spring, and the VCM according to any one of claims 3-9, the stator is fixedly connected to the base, the rotor is connected to the linear guide through a sliding block, and one end of the spring is fixedly connected to the rotor and the other end is fixedly connected to the linear guide.

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