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United States Patent
Schroeder , et al.

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Axial anti-backlash stepper/servo motor

Abstract

A motor is provided. The motor includes a motor body and a rotor assembly. The rotor assembly includes a magnetic core mounted to a rotor shaft. The rotor assembly may include standoffs for accurately axially locating the magnetic core relative to rotor bearings. A drive nut adjustment arrangement may be provided. A mechanical interconnection between the drive nut and rotor shaft may be provided. A trailing end lead screw support may be provided. An axial preload arrangement may be provided to axially locate the rotor assembly within the motor body.

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Parent Case Text

This patent application is a continuation of U.S. PCT Patent Application No. PCT/US2020/027505, filed Apr. 9, 2020, which claims the benefit of U.S. Provisional Patent Application No. 62/833,375, filed Apr. 12, 2019, the entire teachings and disclosure of which are incorporated herein by reference thereto.

Claims

What is claimed is:

1. A rotor assembly for a motor, the rotor assembly comprising: a rotor shaft defining a rotor shaft axis, the rotor shaft providing a first axial abutment; first and second bearings radially supporting the rotor shaft, an outboard side of the first bearing axially abutting the first axial abutment; a magnetic core having a first end and a second end mounted between the first and second bearings; a first standoff axially abutting an inboard side of the first bearing and axially abutting the first end of the magnetic core; a second standoff axially abutting an inboard side of the second bearing and the second of the magnetic core; and a shaft retainer attached to the rotor shaft and axially abutting the outboard side of the second bearing.
2. The rotor assembly of claim 1, wherein the shaft retainer is threadedly attached to threading provided on an outer surface of the rotor shaft.

3. The rotor assembly of claim 1, wherein: the first and second bearings have radially inner and outer races; the first standoff axially abuts the inner race of the first bearing; the second standoff axially abuts the inner race of the second bearing; the inner race of the first bearing axially abuts the first axial abutment; and the shaft retainer axially abuts the inner race of the second bearing.
4. A motor comprising: a rotor assembly of claim 1; a motor body with the rotor assembly mounted within the motor body, the first and second bearings radially supporting the rotor assembly within the motor body, the motor body providing a first motor body axial abutment, the outboard side of the first bearing axially abutting the first motor body axial abutment; and a rotor assembly retainer axially abutting the outboard side of the second bearing and engaging the motor body.
5. The motor of claim 4, wherein: the first and second bearings have inner and outer races; the first standoff axially abuts the inner race of the first bearing; the second standoff axially abuts the inner race of the second bearing; the inner race of the first bearing axially abuts the first axial abutment; the shaft retainer axially abuts the inner race of the second bearing; the outer race of the first bearing axially abuts the first motor body axial abutment; and the rotor assembly retainer axially abuts the outer race of the second bearing.
6. The motor of claim 5, wherein the rotor assembly retainer is threadedly secured to the motor body for axially threading the rotor assembly retainer along the rotor shaft axis.
7. The motor of claim 5, wherein the rotor assembly retainer is provided by a threaded retainer and a preload member, the preload member positioned axially between and in axial abutment with the outer race of the second bearing and the threaded retainer, the threaded retainer threadedly secured to the motor body.
8. The motor of claim 4, wherein the shaft retainer is threadedly attached to threading provided on an outer surface of the rotor shaft.
9. The motor of claim 7, wherein the preload member is a polymer disc.
10. A method of assembling the motor of claim 4 comprising: axially stacking the first bearing, first standoff, magnetic core, second standoff and second bearing on the rotor shaft along the rotor shaft axis against the first axial abutment provided by the rotor shaft; securing the first bearing, first standoff, magnetic core, second standoff and second bearing on the rotor shaft with the shaft retainer; and inserting the first bearing, first standoff, magnetic core, second standoff, second bearing, rotor shaft and shaft retainer into the motor body with the magnetic core positioned within a magnetic stator and the first bearing axially in axial abutment with the first motor body axial abutment.
11. The method of claim 10, further comprising attaching the rotor assembly retainer to the motor body and axially abutting the rotor assembly retainer against the outboard side of the second bearing.
12. The method of claim 11, wherein attaching the rotor assembly retainer to the motor body includes threading the rotor assembly retainer to corresponding threading of the motor body.
13. The method of claim 10, wherein securing the first bearing, first standoff, magnetic core, second standoff and second bearing on the rotor shaft with the shaft retainer includes threadedly securing the shaft retainer to the rotor shaft along the rotor shaft axis.
14. The method of claim 10, wherein the step of stacking includes press fitting the magnetic core to the rotor shaft such that the magnetic core and rotor shaft are angularly fixed to one another about the rotor shaft axis.
15. The method of claim 10, further comprising adhesively securing the magnetic core to the rotor shaft.
16. The method of claim 10, wherein: the first and second bearings have inner and outer races; the first standoff axially abuts the inner race of the first bearing; the second standoff axially abuts the inner race of the second bearing; the inner race of the first bearing axially abuts the first axial abutment; the shaft retainer axially abuts the inner race of the second bearing; the outer race of the first bearing axially abuts the first motor body axial abutment; and the rotor assembly retainer axially abuts the outer race of the second bearing.

17. A motor comprising: a motor body; a rotor assembly including: a rotor shaft defining rotor shaft axis; a magnetic core; a first bearing; a rotor assembly retainer including: a retainer member; and a preload member axially positioned between an outboard side of the first bearing and the retainer member, the preload member being a disc having a Shore-A durometer value of between 10 and 80.

18. The motor of claim 17, wherein the preload member is a polymer disc.

19. The motor of claim 17, wherein the retainer member is threadedly engaged with the motor body for axial adjustment along the rotor shaft axis to adjust the axial force applied to the first bearing through the preload member.

20. The motor of claim 18, wherein the first bearing has radial inner and outer races, the preload member axially abutting outboard side of the outer race.

21. A motor comprising: a motor body; a rotor assembly rotatably carried in the motor body, the rotor assembly including: a rotor shaft; a magnetic core; a first bearing; a rotor assembly retainer including: a retainer member; and a polymer disc axially positioned between an outboard side of the first bearing and the retainer member.

22. The motor of claim 21, wherein the retainer member is threadedly engaged with the motor body for axial adjustment along the rotor shaft axis to adjust the axial force applied to the first bearing through the preload member.

23. The motor of claim 22, wherein the first bearing has radial inner and outer races, the preload member axially abutting outboard side of the outer race.

Description

FIELD OF THE INVENTION

This invention generally relates to motors and particularly stepper/servo motors.

BACKGROUND OF THE INVENTION

Linear actuators that utilize stepper/servo motors are often used in highly precision systems where highly precise linear motion is desired. However, by nature, stepper motors are not design for axial loads. Therefore, axial backlash and accuracy are not typically addressed.

Unfortunately, backlash in the system can reduce accuracy of the position of the object being driven by the motor.

One problem associated with these types of motors relates to the assembly method that relies on adhesive and a press fit to maintain the rotor position within the body. The press fit is used to locate the magnetic core on the rotor shaft. Unfortunately, imprecise gaps are created between the bearings that support the rotor shaft and the magnetic core on the rotor shaft. Thus, when the assembly of components is mounted within the motor body, backlash can occur between the rotor and the magnetic stator as a result of an imprecise assembly process. More particularly, the components of the rotor are not consistently and accurately aligned with one another resulting in imprecise and improper alignment of the magnetic core of the rotor assembly and the magnetic stator.

Another problem with current designs is that a variable-force wave spring is used to axially secure the rotor assembly within the motor body and to allow for compensating for expansion of the components, e.g. due to thermal expansion. Unfortunately, as determined by the instant inventors, this allows for a wide variation of movement in the system and contributes to backlash. Also, during assembly, due to the use of a variable force spring, the inventors have identified that assemblers will often over tighten the assembly such that the

wave spring becomes fully compressed and thus overloads the bearings in the axial direction resulting in premature wear of the bearings and increase resistance on the motor reducing the overall output force of the motor.

A third source of backlash occurs at the lead end of drive nut, where insufficient contact between the threads of the nut and the threads of the lead screw may occur. This is particularly true as the drive nut wears with use. Insufficient contact allows for backlash in the system as the drive nut will have a degree of rotation when changing direction where the drive nut is not engaging the threads of the lead screw.

A fourth source of backlash is lag stemming from the fit between rotor and drive nut. As the pocket of the rotor and cooperating interface of the drive nut (often referred to as a boss) diverge from a line fit, the angular displacement increases, which is undesirable.

Additionally, as the screw exits the leading end of a hollow-shaft motor, the drive nut helps to stabilize whipping of the screw due to gravity and other forces. However, on the trailing end, e.g. the end opposite the nut, the lead screw is not radially supported. The subsequent whipping action of the screw that is transverse to the rotational axis of the rotor is a factor of additional backlash.

A related issue is if the motor and/lead screw are not properly aligned in the end system, this can put transverse loads on the lead screw. These transverse loads can cause slight deflection of the components of the nut such that the lead screw is not perfectly aligned with the rotational axis of the rotor shaft through which the lead screw extends. This offset/angled orientation can result in the outer periphery of the non-rotating lead screw contacting the inner periphery of the rotating rotor shaft. This interaction can damage the threads of the lead screw.

These and other advantages of the invention, as well as additional inventive features, will be apparent from the description of the invention provided herein.

BRIEF SUMMARY OF THE INVENTION

Embodiments of the invention provide improvements over the current state of the art as it relates to motors and particularly stepper and servo motors. Even more particularly, some embodiments are directed at reducing backlash within the system such that improved control and positioning may be provided.

In a particular embodiment, a rotor assembly for a motor is provided. The rotor assembly includes a rotor shaft, first and second bearings, a magnetic core, first and second standoffs and a shaft retainer. The rotor shaft defines a rotor shaft axis. The rotor shaft provides a first axial abutment. The first and second bearings are radially support the rotor shaft. An outboard side of the first bearing axially abuts the first axial abutment. The magnetic core has a first end and a second end mounted between the first and second bearings. The first standoff axially abuts an inboard side of the first bearing and axially abuts the first end of the magnetic core. The second standoff axially abuts an inboard side of the second bearing and the second of the magnetic core. The shaft retainer attaches to the rotor shaft and axially abuts the outboard side of the second bearing.

In an embodiment, the shaft retainer is threadedly attached to threading provided on an outer surface of the rotor shaft. The shaft retainer is thus axially movable along the shaft parallel to the shaft axis via the threaded engagement.

In an embodiment, the first and second bearings have radially inner and outer races. The first standoff axially abuts the inner race of the first bearing. The second standoff axially abuts the inner race of the second bearing. The inner race of the first bearing axially abuts the first axial abutment. The shaft retainer axially abuts the inner race of the second bearing. In a preferred embodiment all of these components are formed from metal to provide metal-on-metal contact at the abutting interfaces therebetween.

In one implementation, a motor is provided. The motor includes a rotor assembly, such as provided above, a motor body, and a rotor assembly retainer. The rotor assembly is mounted within the motor body. The first and second bearings radially supporting the rotor assembly within the motor body. The motor body provides a first motor body axial abutment. The outboard side of the first bearing axially abuts the first motor body axial abutment. The rotor assembly retainer axially abuts the outboard side of the second bearing and

In one embodiment, the contact zone is provided by a second tapered surface that cooperates with the first tapered surface. These two surfaces need not have the identical angle relative to the rotor shaft axis.

In one embodiment, the carrier member is threadedly attached to the rotor shaft.

In one embodiment, the motor includes a sleeve located radially between an outer periphery of the drive nut and an inner periphery of the rotor shaft defining the internal cavity. The flexible fingers of the drive nut and the radial compression member are located within the sleeve.

In one embodiment, the radial compression member includes an axially extending annular flange extending axially away from the conically tapered interface, the adjustment member including a free end received axially within the annular flange.

In another embodiment, a motor including a rotor assembly and a drive nut is provided. The rotor assembly is carried rotatably in the motor body. The rotor assembly includes a rotor shaft that defines a rotor shaft axis. The drive nut is configured to engage a lead screw. The drive nut is mechanically angularly fixed to the rotor assembly such that angular rotation between the drive nut and rotor shaft is prevented such that rotation of the rotor assembly rotationally drives the drive nut. The drive nut includes a plurality of flexible fingers having threads on an interior thereof for engaging the lead screw.

In one embodiment, the drive nut includes a base from which the flexible fingers axially extend. The base has a non-round outer periphery. The rotor shaft has an internal cavity in which, at least, the base of the drive nut is axially inserted. An inner surface of the rotor shaft defining the internal cavity has a non-round inner periphery that matches and angularly engages the non-round outer periphery of the base to prevent relative angular displacement between the drive nut and the rotor shaft.

In one embodiment, a coupling pin is provided to mechanically angularly fix the two components. The drive nut includes an axially extending recess. The rotor shaft including an axially extending recess. The coupling pin extends axially into the axially extending recess of the drive nut and axially into the axially extending recess of the rotor shaft to prevent angular rotation between the drive nut and the rotor shaft. Typically, the recesses and pin extend axially parallel to the rotor shaft axis.

In one embodiment, a coupling pin is provided. The drive nut includes a recess. The rotor shaft defines an internal cavity defined by an annular sidewall of the rotor shaft. The drive nut is located within the internal cavity. The rotor shaft includes a radially extending aperture extending through the sidewall. The coupling pin extends radially into the recess of the drive nut and radially into the radially extending aperture in the sidewall of the rotor shaft to prevent angular rotation between the drive nut and the rotor shaft.

In one embodiment, the coupling pin includes a tapered head that increases in diameter when moving radially outward and away from the rotor shaft axis. The aperture in the sidewall has a mating tapered profile receiving the tapered head of the coupling pin such that the coupling pin is fully radially recessed relative to a radial outer periphery of the sidewall of the rotor shaft.

In one embodiment, the drive nut includes first threading having a first orientation. The rotor shaft has a second threading having the first orientation for threadedly engaging the first threading of the drive nut to axially secure the drive nut to the rotor shaft. The rotor shaft has a third threading having a second orientation angularly opposite the first orientation. A drive nut retainer has fourth threading having the second orientation for threadedly engaging the third threading of the rotor shaft. The drive nut retainer axially abutting the drive nut. As such, the first and second threading provides a first threaded interface and the third and fourth threading provides a second threaded interface. The first and second threaded interfaces are oriented opposite one another (e.g. one is left handed while the other is right handed).

In one embodiment, the drive nut includes first and second axially facing abutments. The first and second axially facing abutments face axially away from one another. The rotor shaft has a third axially facing abutment that axially abuts the first axially facing abutment. The drive nut retainer has a fourth axially facing abutment that axially abuts the second axially facing abutment.

FIGS. 25-36 provide the data for the chart of FIG. 24;

FIG. 25 provides the data for the pentagon fit;

FIG. 26 provides the data for the triangle fit;

FIG. 27 provides the data for the D-shape fit;

FIG. 28 provides the data for the keyway fit;

FIG. 29 provides the data for the spline fit;

FIG. 30 provides the data for the knurled fit;

FIG. 31 provides the data for the heptagon fit;

FIG. 32 provides the data for the hexagon fit;

FIG. 33 provides the data for the boule D fit;

FIG. 34 provides the data for the involute fit;

FIG. 35 provides the data for the double square fit;

FIG. 36 provides the data for the octagon fit;

FIGS. 37 and 38 further illustrate a mechanical connection between a rotor shaft and drive nut that utilizes oppositely oriented threaded interfaces.

While the invention will be described in connection with certain preferred embodiments, there is no intent to limit it to those embodiments. On the contrary, the intent is to cover all alternatives, modifications and equivalents as included within the spirit and scope of the invention as defined by the appended claims.

DETAILED DESCRIPTION OF THE INVENTION

FIG. 1 is a cross-sectional illustration of a motor 100. The motor 100 includes a motor body 102 and a rotor assembly 104 located within the motor body 102. The motor body includes a stator 106 and a cover member 108 which may also be referred to herein as an end bell 108. The rotor assembly 104 is operably coupled to an externally threaded screw 110 (e.g. a lead screw) to drive the screw 110.

The rotor assembly 104 includes a rotor shaft 112, first and second bearings 114, 116, a magnetic core 118, and first and second axial standoffs 120, 122.

When mounted within the motor body 102, bearings 114, 116 radially support the rotor shaft 112 for rotation about a rotor shaft axis 124. The magnetic core 118 is operably angularly secured to the rotor shaft 112 such that rotational forces generated between the magnetic core 118 and the stator 106 cause the rotor shaft 112 to rotate. This angular securement may occur by way of a press fit or an adhesive between the rotor shaft 112 and the magnetic core 118.

To properly axially position the magnetic core 118, the first and second bearings 114, 116, first and second axial standoffs 120, 122 and magnetic core 118 are axially stacked. More particularly, the first standoff 120 is in axial abutment with an inboard side 126 of the first bearing 114, and particularly an inboard side of a radially inner race 128 of the first bearing 114. Additionally, the first standoff 120 is in axial abutment with a first end 130 of the magnetic core 118. In this configuration, the magnetic core 118 is positioned axially between the first and second bearings 114, 116.

Similarly, the second standoff 122 is in axial abutment with an inboard side 132 of the second bearing 116,

and particularly an inboard side of a radially inner race 134 of the second bearing 116. Additionally, the second standoff 122 is in axial abutment with a second end 136 of the magnetic core 118 that is opposite of and faces axially away from the first end 130.

As such, the axial length L1 from an outboard side 138 of the first bearing 114 and an outboard side 140 of the second bearing 116 remains highly accurate during assembly of the rotor assembly 104. As such, when the motor is mass produced, the dimension remains constant from one motor to the next. To further promote accuracy and consistency, in an embodiment, the standoffs 120, 122 are formed from metal as are the inner races 128, 134 of the bearings 114, 116.

In particular, the axial spacing between the bearings and the magnetic core 118 is highly consistent such that when the rotor assembly 104 is mounted within the motor body 102, and particularly the stator 106, the magnetic core 118 is properly axially aligned with the stator 106. Proper axial alignment of the magnetic core 118 with the stator 106 reduces potential backlash between the magnetic core 118 and the stator 106 during assembly.

In the illustrated embodiment, the rotor shaft 110 includes a first axial abutment 142. During assembly, the outboard side 138 of the first bearing 114 is axially abutted against an inboard side of the first axial abutment 142 to locate the stack of the first and second bearings 114, 116, the first and second standoffs 120, 122 and the magnetic core 118. This precisely locates these components along rotor shaft axis 124.

In this embodiment, the outboard side of the inner race 128 of the first bearing 114 axially abuts first axial abutment 142.

To secure the stack of components at the desired axial location along the rotor shaft axis 124, a shaft retainer 144 is attached to the rotor shaft 112 and axially abuts an outboard side 140 of the second bearing 116. In this embodiment, the shaft retainer 144 axially abuts an outboard side of the inner race 134 of second bearing 116.

In a preferred embodiment, the shaft retainer 144 is attached threadedly to the rotor shaft 112. More particularly, the outer peripheral surface of the rotor shaft 112 includes threading that cooperates with inner threading of the shaft retainer 144.

During assembly, once the first and second bearings 114, 116, magnetic core 118 and first and second standoffs 120, 122 have been mounted to the rotor shaft 112, the shaft retainer 144 is attached to the rotor shaft 112. Thus, these components are axially captured between inboard sides of the first axial abutment 142 and the shaft retainer 144.

It is noted that the axial alignment and stacking of the components operates through the inner races 128, 134.

During some assembly processes, the shaft retainer 144 will be attached to the rotor shaft 112 prior to insertion of the rotor assembly 104 into the motor body 102.

To axially locate the rotor assembly 104 properly, and particularly the magnetic core 118, within the stator 106, the motor body 102 provides a first motor body axial abutment 146. The outboard side 140 of the first bearing 114, and particularly, an outboard side of the outer race 148 of the first bearing 114 is axially abutted against an inboard side of the first motor body axial abutment 146. In this embodiment, the first motor body axial abutment 146 is provided by end bell 108.

A rotor assembly retainer 150 axially abuts the outboard side 140 of the second bearing 116 and engages the motor body 102 to axially secure the rotor assembly 104 within the motor body 102. In a preferred embodiment and as illustrated, the rotor assembly retainer 150 axially abuts an outboard side of the outer race 152 of the second bearing 116.

The inner and outer races of the bearings support roller elements such as balls or rollers therebetween. The bearings may take the form of tapered roller bearings, single-row angular contact bearings, deep-groove bearings, and/or double-row angular contact bearings.

degrees relative to one another.

FIG. 16 illustrates an embodiment that utilizes a splined periphery. The splined periphery utilizes a plurality of radial projections angularly spaced around the drive nut 160. Here, more than 10 projections are provided but more or less than 10 are contemplated.

FIG. 17 illustrates a knurled peripheral shape.

FIG. 18 illustrates a heptagonal peripheral shape.

FIG. 19 illustrates a double hex peripheral shape.

FIG. 20 illustrates a double D peripheral shape. The double D has flats on opposite sides of the base region of the drive nut 160 that face radially away from one another.

FIG. 21 illustrates an octagonal peripheral shape.

The various designs provide different peripheral shapes provide varying levels of theoretical torque for a substantially same sized interface. FIG. 22 provides a chart that illustrates potential different maximum torque values for the different mating peripheries.

FIG. 23 is a cross-section illustrating a theoretical gap formed between flats of the various designs discussed above. Here, the gap G is defined as being the spacing between the flats 230 of the rotor shaft 112 and the corresponding flats 232 of the drive nut 160. The amount of angular displacement α that may occur between the drive nut 160 and rotor shaft 112 is dependent on this gap G as well as the shape of the peripheries.

The angular displacement α relates to the theoretical amount of angular displacement that the tip 236 between adjacent flats of an outer periphery may move angularly between adjacent flats 230 of the inner periphery about axis.

The tables in FIGS. 25-36 provide theoretical angular displacement α values for different amounts of gap G for various ones of the peripheral shapes discussed above. FIG. 24 is a graph showing these values.

With reference to FIGS. 1 and 37-38, a further mechanical connection between the drive nut 160 and the rotor shaft 112 is illustrated. In this embodiment, a pair of oppositely threaded interfaces 260, 262 are provided to angularly and axially secure the drive nut 160 to the rotor shaft.

The first threaded interface 260 is provided between the drive nut 160 and the rotor shaft 112. This threaded interface 260 has a first orientation (e.g. is either right handed or left handed).

The second threaded interface 262 is provided between a retainer 264 and the rotor shaft 112. This threaded interface 262 has a second orientation that is opposite of the first threaded interface 260 (e.g. is left hand or right handed). More particularly, if the first threaded interface 260 is right handed, then the second threaded interface would be left handed. If the first threaded interface 260 is left handed, then the second threaded interface would be right handed.

The retainer 264 has a radially inward extending flange 267 that acts axially against an axial abutment 268 of the drive nut 160 which acts axially against an axial abutment of the rotor shaft 112. In this embodiment, the axial abutment of the rotor shaft 112 is simply the free end 270 of the rotor shaft. As such, regardless of the direction of rotation of the motor, the drive nut 160 is axially fixed relative to the rotor shaft 112 because it is prevented from rotating relative to the rotor shaft 112.

A further problem identified with motors such as those of the illustrated embodiments where the screw 110 extend through a hollow shaft is that the free end of the screw that is located within the internal cavity of the rotor shaft 112 may bend or not be perfectly oriented along axis 124. This can occur as a result of, among other things, potential flexing of the drive nut 160 as a result of incorrect mounting of the motor 100 or due to radial loading of the screw 110. This can also occur due to whipping of the screw 110.

