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(54) LINEAR ACTUATOR, AND PUMP DEVICE AND COMPRESSOR DEVICE USING THE SAME

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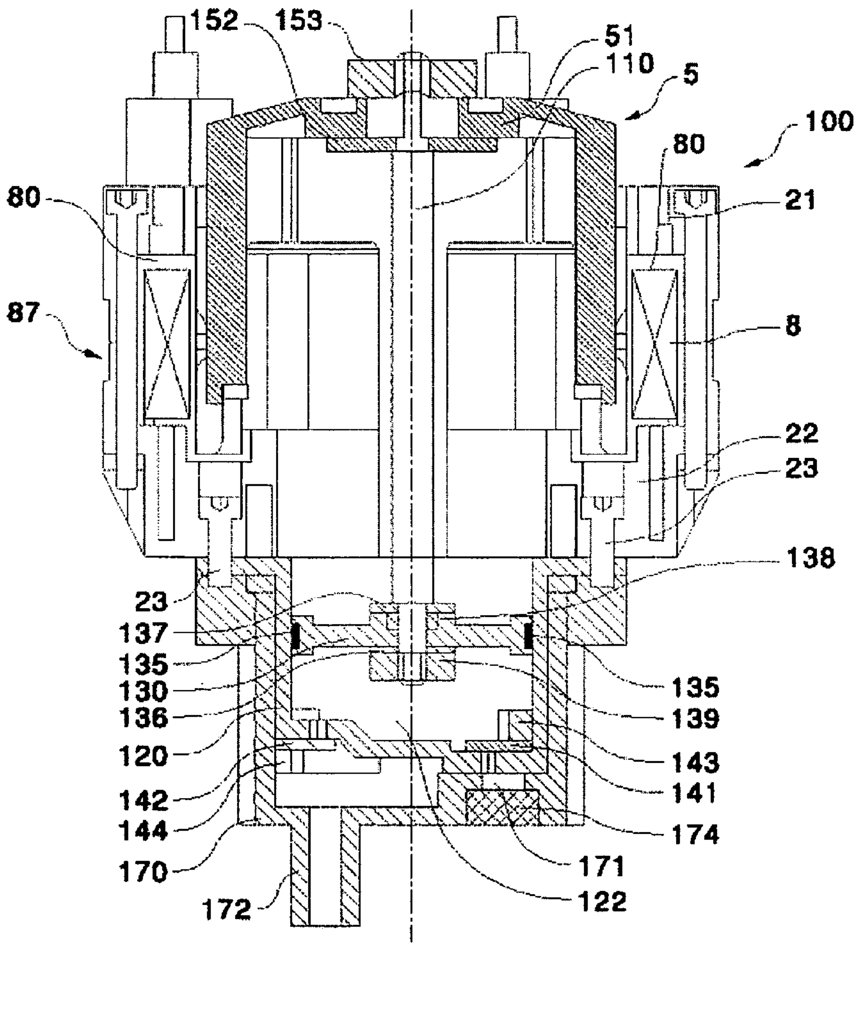
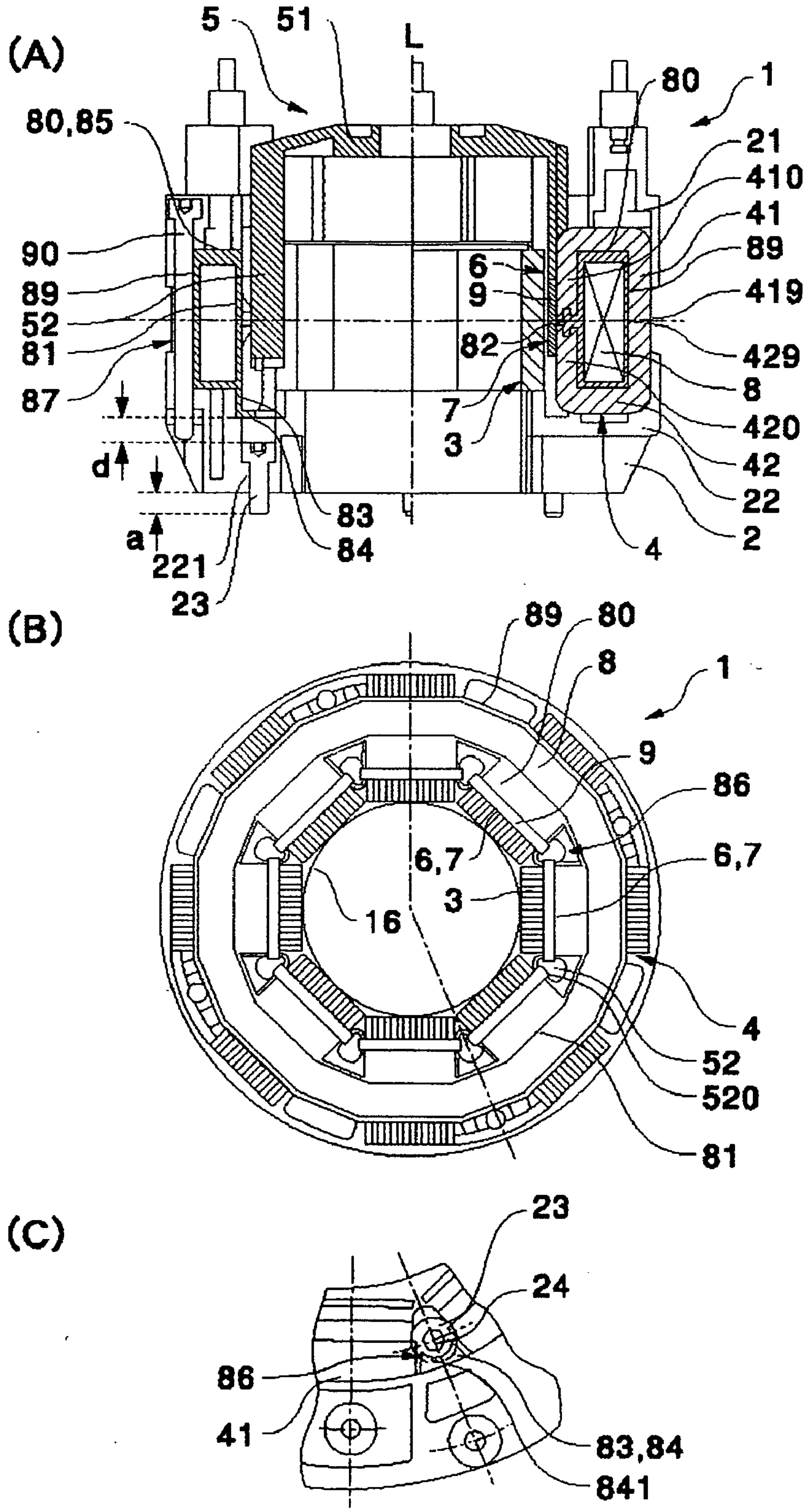
(57) **ABSTRACT**

A linear actuator includes a driving part provided with an inner yoke and an outer yoke, a magnet disposed between the inner yoke and the outer yoke, and a movable body which is to be driven to reciprocate in the axial direction. The driving part includes a coil for generating an alternating magnetic field in a first gap space and a second gap space which are formed between the inner yoke and the outer yoke. The movable body is interlocked and driven with the alternating magnetic field. The driving part further includes a coupling means disposed along the axial direction in a gap space which is formed by the outer yokes adjacent to each other in a circumferential direction or by the inner yokes adjacent to each other in the circumferential direction. The coupling means connects the driving part to a main body part side which is provided with a moved body that is driven by the movable body.



【Fig.1】


(A)
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51
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419
429
8
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42
22
2
4
d
a
221
23
83
84
(B)
89
80
8
1
9
86
6,7
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3
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520
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(C)
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86
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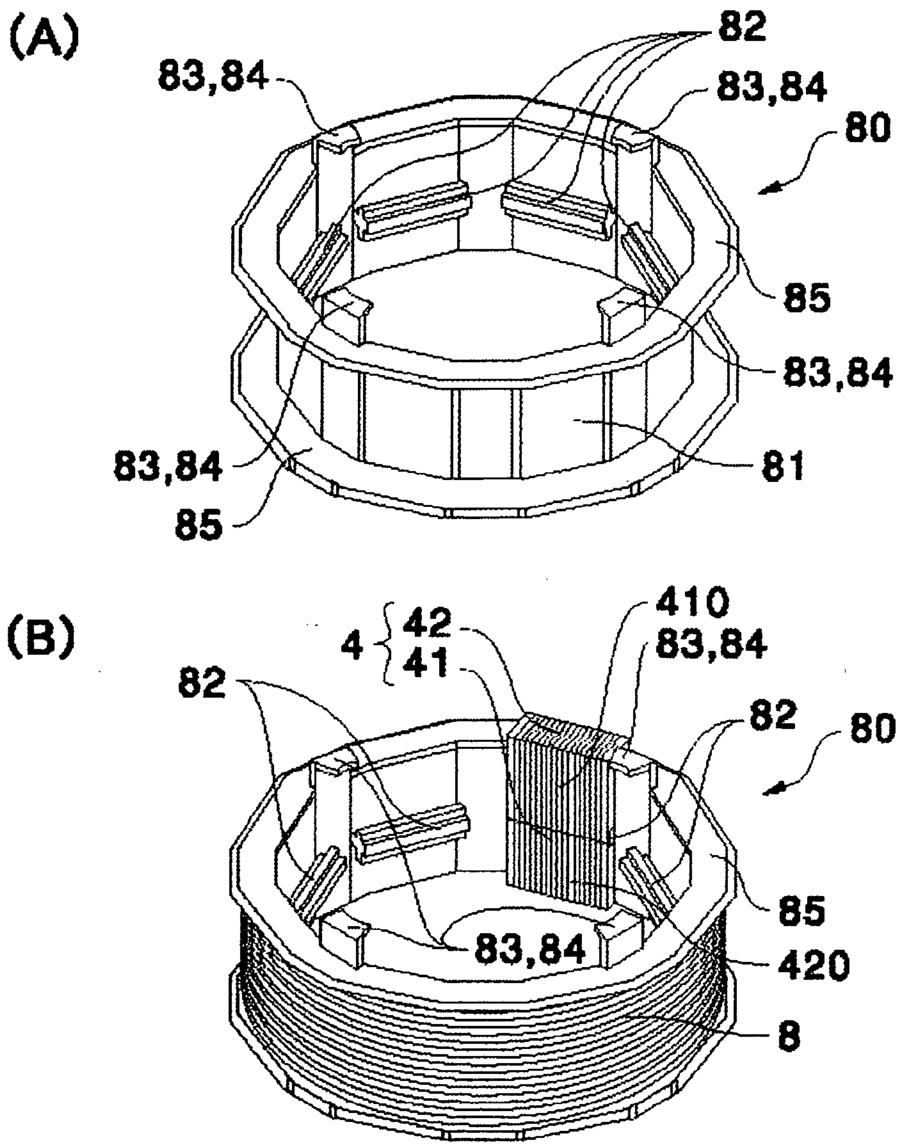
83,84
841

【Fig.2】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(B)
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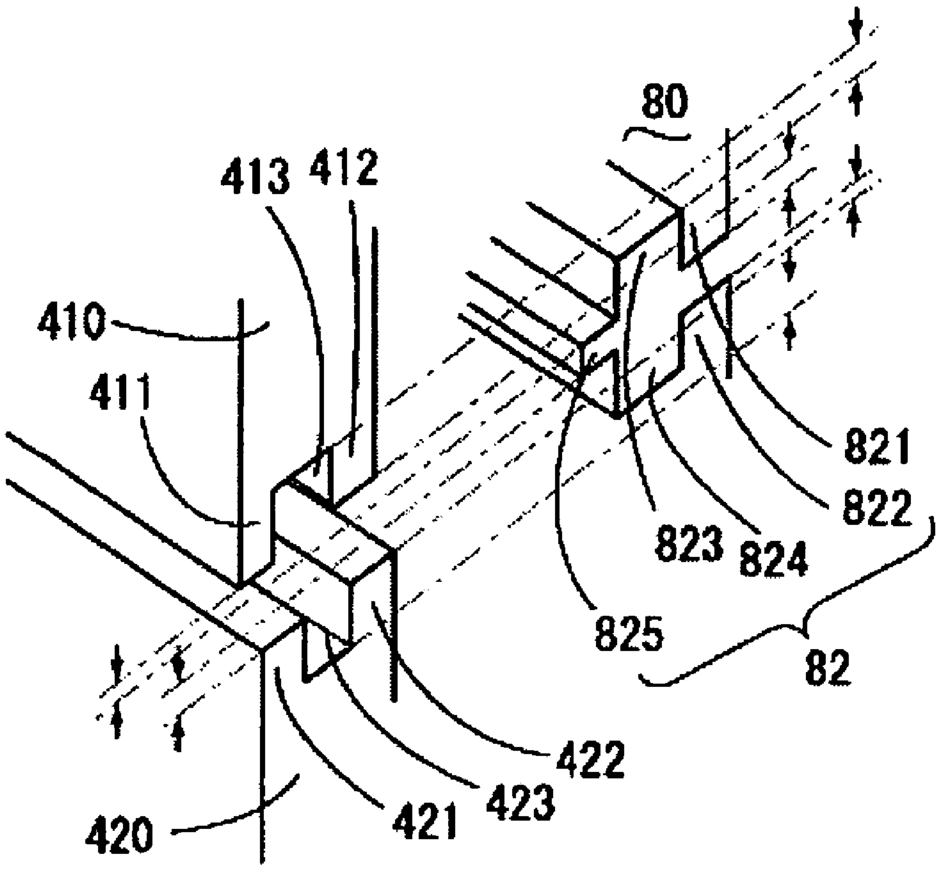
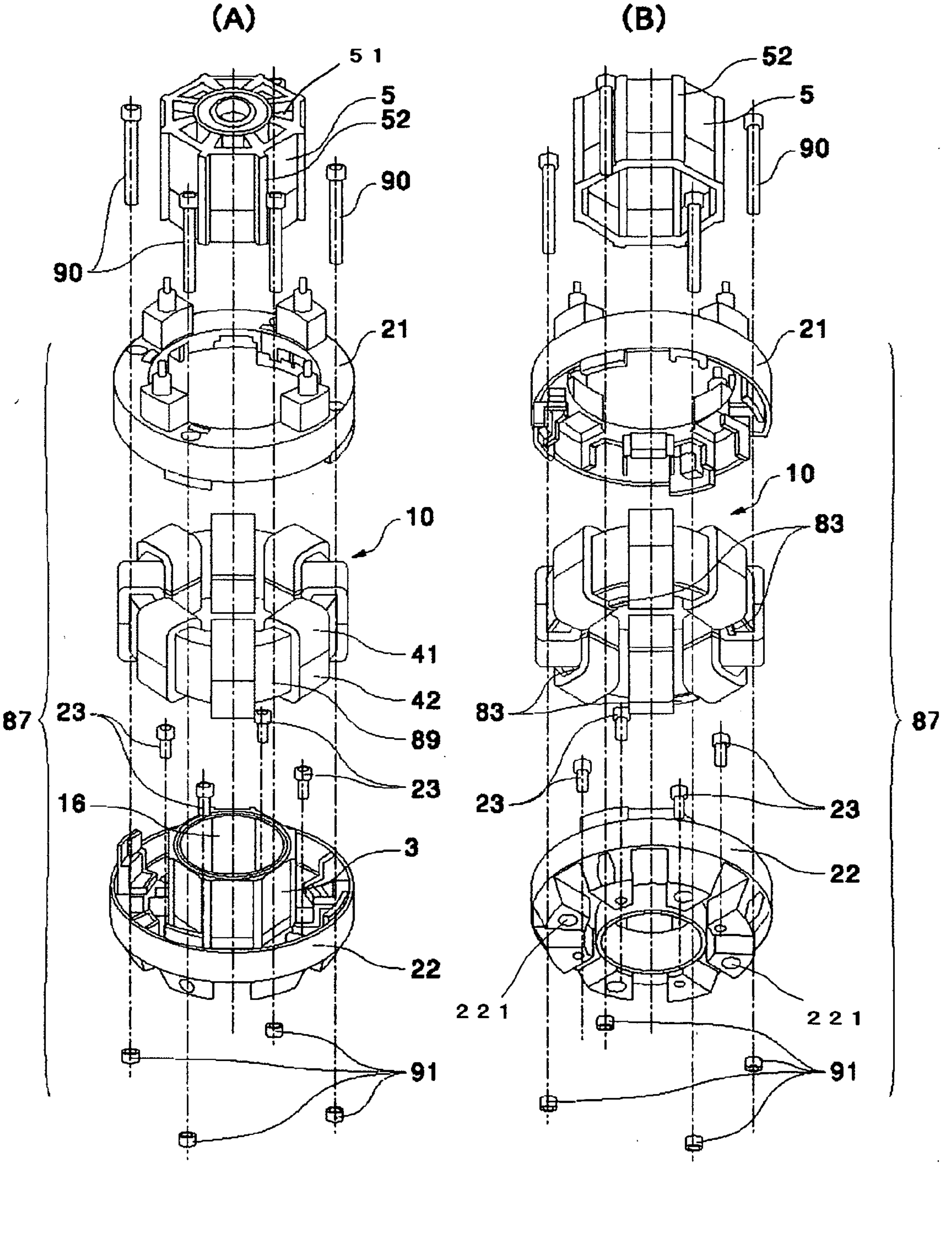
【Fig.3】



【Fig.4】


(A)
(B)
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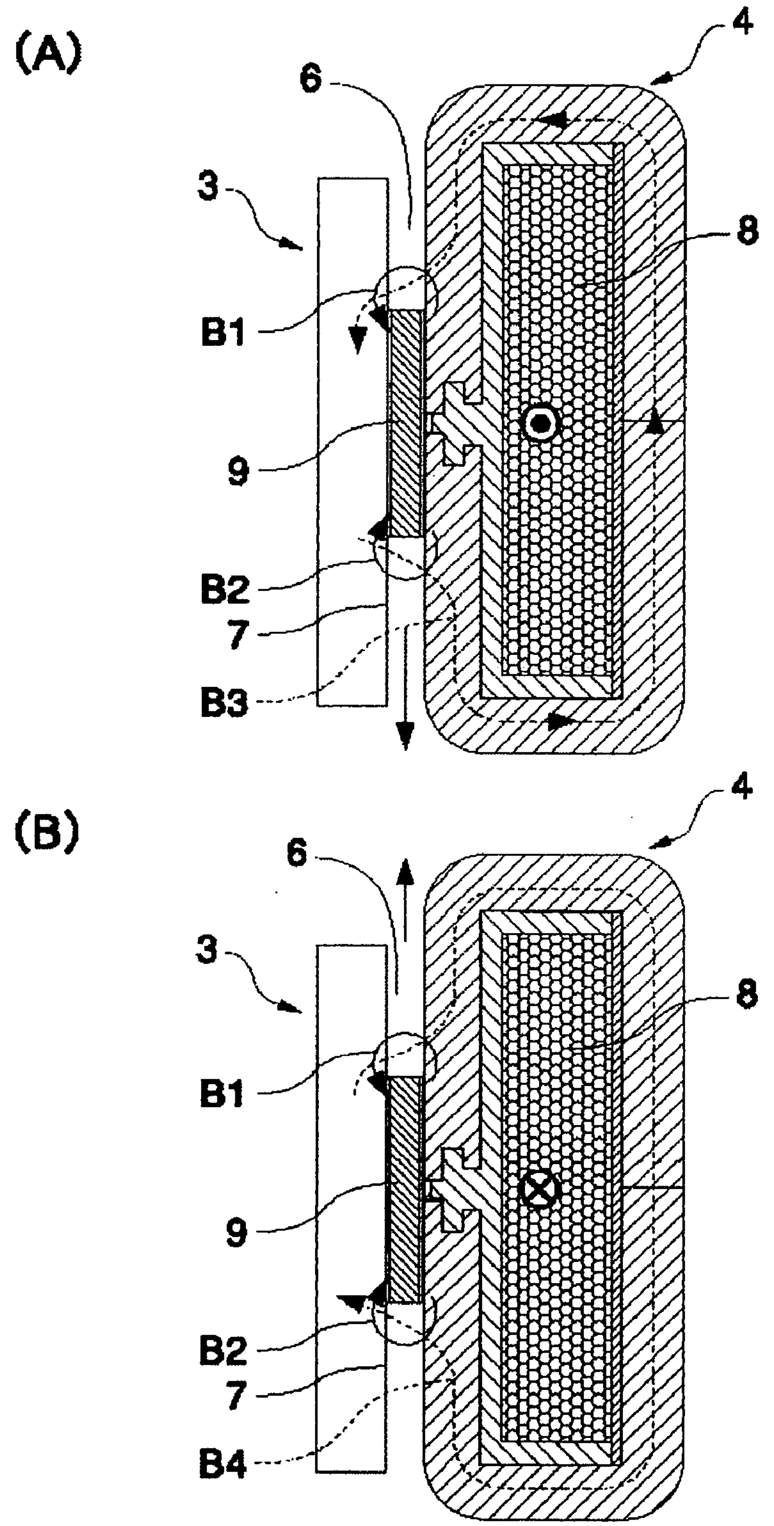
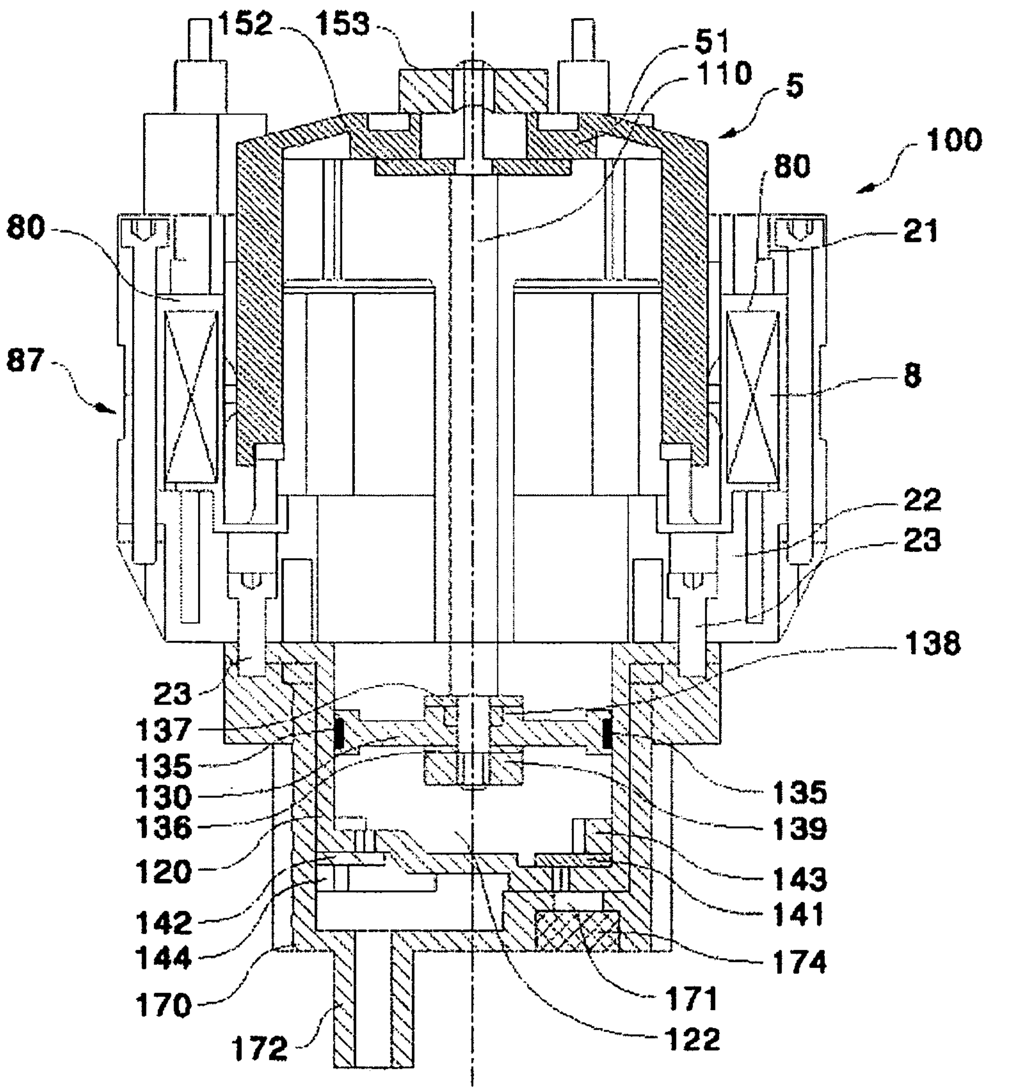
【Fig.5】



【Fig.6】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LINEAR ACTUATOR, AND PUMP DEVICE AND COMPRESSOR DEVICE USING THE SAME

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to Japanese Application No. 2004-40708 filed Feb. 18, 2004, which is incorporated herein by reference.

FIELD OF THE INVENTION

[0002] The present invention relates to a linear actuator, and also relates to a pump device and a compressor device that are provided with the linear actuator.

BACKGROUND OF THE INVENTION

[0003] A conventional pump device or a conventional compressor device in which a piston moves linearly within a cylinder is provided with a main body part, in which the cylinder is formed, and a linear actuator that drives the piston. As a drive part of the linear actuator, a linear motor is used to reciprocally move the piston in an axial direction. (See, for example, Japanese Patent Laid-Open No. 2000-337725).

[0004] A Stirling cycle refrigerating machine having the conventional linear actuator is constructed such that its main body part and the linear actuator are constructed in an integral manner. However, recently there has been a demand that only the main body part is integrated into the device side in advance and the linear actuator be attached on the main body part afterwards.

SUMMARY OF THE INVENTION

[0005] In view of the demand described above, it is an object and advantage of the present invention to provide a linear actuator that is separately formed from a main body part and is capable of being fitted afterward to the main body part previously integrated into a device without making the linear actuator larger in the radial direction. Further, it is another object and advantage of the present invention to provide a pump device and a compressor device that uses the linear actuator.

[0006] In order to achieve the above object and advantage, according to an embodiment of the present invention, there is provided an linear actuator including a driving part having a plurality of inner yokes and a plurality of outer yokes, a magnet which is disposed between the inner yokes and the outer yokes, and a movable body which is driven by the driving part so as to reciprocate in an axial direction. The plurality of inner yokes is disposed in a circumferential direction and, each of which has a planar opposing face to the outer yoke. The plurality of outer yokes are disposed in a circumferential direction around the inner yokes such that a first gap space and a second gap space separating from each other in the axial direction are formed between an outer peripheral face of the inner yoke and the outer yoke, and each of the plurality of outer yokes has a planar opposing face to the inner yoke. The driving part also includes a coil for generating an alternating magnetic field in the first gap space and the second gap space. The magnetic path of the alternating magnetic field is formed of the outer yoke, the first gap space, the inner yoke, the second gap space and the outer yoke in this order or vice versa. The driving part further includes a coupling means that is disposed along the axial direction in a gap space which is formed by the outer yokes adjacent to each other in a circumferential direction or by the inner yokes adjacent to each other in the circumferential direction. The coupling means is used for coupling the driving part to a main body part side which is provided with a body to be moved that is driven by the movable body. The movable body is interlocked with the alternating magnetic field to be driven to reciprocate in the axial direction.

[0007] In accordance with an embodiment of the present invention, the driving part is provided with a drop-out preventing part for being capable of abutting with the coupling means to prevent the coupling means from dropping out in a direction which is opposite to a direction that the driving part is coupled to the main body part by the coupling means. According to the construction described above, in the case that the coupling means is operated by using a jig to couple the driving part to the main body part side, even when the jig disengages with the coupling means, the coupling means can be prevented by the drop-out preventing part from dropping out. Therefore, the coupling means does not drop out from the driving part. Accordingly, since the loss of the coupling means is prevented, the coupling operation can be performed with ease.

[0008] In accordance with an embodiment of the present invention, the drop-out preventing part is preferably constructed by being integrally molded to an electrically insulative coil bobbin on which the coil is wound around and by which isolation from the outer yoke is ensured. According to the construction described above, the coupling means can be mounted on the driving part before the coil bobbin is fitted to the driving part, and the coil bobbin fitted to the driving part prevents the dropping out of the coupling means.

[0009] In accordance with an embodiment of the present invention, the coupling means is disposed in the gap space which is formed by the outer yokes adjacent to each other in the circumferential direction and is disposed at a position which is nearer on the main body part side than the outer yoke. A part of the coupling means may overlap with the outer yoke in the axial direction. According to the construction described above, the drop-out preventing part can be constructed by using the portion of the outer yoke that overlaps with the coupling means in the axial direction. In addition, the thickness of the stacked yoke can be increased by the overlapped portion between the coupling means and the outer yoke in the axial direction, and thus the magnetic saturation is restricted and the thrust of the movable body can be ensured.

[0010] In accordance with an embodiment of the present invention, the outer yoke is formed so as to be extended from a portion located on an outer circumferential side of the coil to an inner circumferential side over end faces of the coil in the axial direction. The inner circumferential side portion of the outer yoke forms a first facing portion for constructing the first gap space and a second facing portion for constructing the second gap space and the respective first facing portion and the second facing portion are formed so as to be opposed to the inner yoke. The drop-out preventing part is formed to be protruded to a position which is nearer on the main body part side than the outer yoke. According to the construction described above, the coupling means is capable of abutting with the drop-out preventing part to securely prevent the dropping-out of the coupling means. Therefore, various troubles caused between the outer yoke and the coupling means can be eliminated. For example, the trouble that the coupling means is caught by the end portions of the outer yokes that are adjacent to each other in the circumferential direction can be prevented.

[0011] In accordance with an embodiment of the present invention, the coupling means includes a male screw, which can be retreated within the driving part to a position where the male screw abuts with the drop-out preventing part. According to the construction described above, when the linear actuator is handled separately, the male screw can be retreated into the driving part such that the male screw is protected from damage due to collision of the male screw with other portion or the like.

[0012] In accordance with an embodiment of the present invention, when the coupling means includes a male screw, the male screw is formed with an engaging recessed part with which the male screw is rotated. In this case, the male screw and the drop-out preventing part disposed in the gap space of the outer yokes, which are adjacent to each other in the circumferential direction, preferably overlap with each other in the axial direction excluding the engaging recessed part of the male screw. According to the construction described above, the engaging recessed part for rotating the male screw can be operated without being obstructed by the drop-out preventing part.

[0013] As described above, according to the embodiment of the present invention, the driving part includes the coupling means that is disposed along the axial direction in a gap space, which is formed by the outer yokes adjacent to each other in a circumferential direction or which is formed by the inner yokes adjacent to each other in the circumferential direction. Therefore, the coupling means is not required to be disposed on the outer side of the outer yoke in the radial direction, and thus the driving part can be coupled to the main body part side without making the driving part larger in the radial direction. Accordingly, the linear actuator is not required to be made larger in the radial direction. In addition, even after the linear actuator has been assembled, a jig for operating the coupling means can be inserted from the gap space to engage with the coupling means only by removing the movable body, and thus the coupling means can be operated by the jig to couple the driving part to the main body part.

[0014] Other features and advantages of the invention will be apparent from the following detailed description, taken in conjunction with the accompanying drawings that illustrate, by way of example, various features of embodiments of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] **FIG. 1**(A) is a longitudinal cross-sectional view showing an essential portion of a linear actuator in accordance with an embodiment of the present invention, **FIG. 1**(B) is a transverse cross-sectional view showing the linear actuator in **FIG. 1**(A), and **FIG. 1**(C) is a plan view showing a coupling portion of the linear actuator in which a movable member is removed.

[0016] **FIG. 2**(A) is a perspective view showing a coil bobbin which is used in the linear actuator in accordance with the embodiment of the present invention and **FIG. 2**(B) is an explanatory perspective view showing the coil bobbin and an outer yoke.

[0017] **FIG. 3** is an explanatory view showing engaging parts of the coil bobbin and the outer yoke that are used in the linear actuator in accordance with the embodiment of the present invention.

[0018] **FIG. 4**(A) is an exploded perspective view obliquely viewed from above showing respective component members which construct the linear actuator in accordance with the embodiment of the present invention and **FIG. 4**(B) is an exploded perspective view obliquely viewed from below showing the respective component members shown in **FIG. 4**(A).

[0019] FIGS. **5**(A) and **5**(B) are explanatory views respectively showing different operating states of the linear actuator.

[0020] **FIG. 6** is a cross-sectional view showing an air pump device to which the present invention is applied.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0021] A linear actuator in accordance with an embodiment of the present invention will be described below with reference to the accompanying drawings.

[0022] **FIG. 1**(A) is a longitudinal cross-sectional view showing the essential portion of a linear actuator to which the present invention is applied, **FIG. 1**(B) is a transverse cross-sectional view showing the linear actuator shown in **FIG. 1**(A), and **FIG. 1**(C) is a plan view showing a coupling portion of the linear actuator in which a movable member is removed.

[0023] In FIGS. **1**(A) and **1**(B), a linear actuator **1** in accordance with an embodiment of the present invention is used in a pump device, a compressor device or the like for supplying various fluids. The linear actuator **1** includes a drive part **87** which is provided with a frame **2** for holding a stator from both sides in an axial direction and a movable member **5** which can be reciprocally moved with respect to the drive part **87** along the axial line "L".

[0024] As shown in FIGS. **1**(A) and **1**(B), in the drive part **87**, a cylindrical part **16** is formed on the holder **22** of the frame **2**, and inner yokes **3** which are held on a retainer not shown in the drawing are fixed on the outer peripheral side of the cylindrical part **16**. Eight pieces of the inner yoke **3** are disposed at equal angular intervals in a circumferential direction. The inner yoke **3** is formed in a flat plate shape, that is, both of an opposing face (outer side) to an outer yoke **4** and a rear face (inner side) are formed to be in a flat face.

[0025] The outer yoke **4** formed in a block shape is disposed between a pair of holders **21**, **22** which form the frame **2** such that a first and a second gap spaces **6**, **7** are constructed at separated positions in an axial direction with respect to the opposing face of the inner yoke **3**. Eight pieces of the outer yoke **4** are disposed at equal angular intervals in a circumferential direction via a gap space **86** respectively. The opposing face of the outer yoke **4** to the inner yoke **3** is formed to be in a flat face.

[0026] The outer yoke **4** is constructed of an upper and a lower outer yoke members **41**, **42**, which are respectively formed in a U-shape in a longitudinal cross section. The inner side bent portions in the axial direction of the respective outer yoke members **41, 42** are formed in a first and a second facing portions **410, 420** which respectively oppose to the inner yoke **3** through the first and the second gap spaces **6, 7**. The end parts **419, 429** of outer side bent portions in the axial direction of the respective outer yoke members **41, 42** abut with each other. Each of the outer yoke members **41, 42** is constructed as a block body in such a manner that a plurality of magnetic thin plates is laminated such that their end faces face the inner yoke **3**. Accordingly, the eddy current loss becomes relatively small in the outer yoke **4**.

[**0027**] A coil **8** formed in a planar ring shape is wound around a coil bobbin **80** and disposed in a space formed between the two outer yoke members **41, 42** of the outer yoke **4**. The coil bobbin **80** is integrally formed with a drop-out preventing part **83** which is described later. The outside of the coil **8** is covered with a cover **89** made of resin. The coil **8** is a common coil which is wound so as to surround the whole of the eight outer yokes **4**. The outer yoke members **41, 42** are respectively formed of a portion located on the outer circumferential side of the coil **8** to be bent on the inner circumferential side in the axial direction through the end faces of the coil **8** in the axial direction, and the inner end portions of the outer yoke members **41, 42** are formed to be the facing parts **410, 420**.

[**0028**] In the embodiment of the present invention, a cup-shaped movable body **5**, which is constructed as described above as shown in **FIG. 1**(A) and FIGS. **4**(A) and **4**(B), is arranged in the driving part **87**. The movable body **5** is made of a resin molded product and includes a bottom part **51** which is formed in a regular octagon shape and thin elongated magnet holding parts **52** which are respectively extended in the axial direction from the corner part of the bottom part **51**.

[**0029**] Grooves **520** for inserting and fixing both sides of the planar magnet **9** are formed on the side faces of the magnet holding part **52** so that both sides of the plate-shaped magnet **9** are inserted into the grooves **520**. The movable body **5** is formed with eight magnet holding parts **52** so that eight pieces of magnet **9** are held at equal angular intervals in the circumferential direction.

[**0030**] The magnet **9** is an Nd—Fe—B rare-earth magnet or a resin magnet, and its front/rear faces are respectively magnetized in reverse polarities.

[**0031**] The magnet holding part **52** is formed in a roughly triangular planar shape when viewed in the axial direction as shown in **FIG. 1**(B). The portion corresponding to the apex of the triangle is located between adjacent inner yokes **3** in a wedge-shaped manner and the portion corresponding to the base side of the triangle is located between adjacent outer yokes **4**.

[**0032**] The movable body **5** as constructed above is integrated into the driving part **87** as shown in **FIG. 1**(A). In this state, each of eight magnets **9** is located in the first and the second gap spaces **6** and **7** which are formed by the inner yoke **3** and the outer yoke **4**. The bottom part **51** of the movable body **5** is used as a fixing part for the base portion of an actuating shaft **110** which is formed in a round-bar shape or in a cylindrical shape as shown in **FIG. 6**. **FIG. 6** is a cross-sectional view showing an air pump device to which the present invention is applied. A piston **130**, which is a body to be moved of the air pump device **100**, is fixed at the tip end side of the actuating shaft **110**. The piston **130** is disposed within a case **170** on the main body part side which is coupled with the driving part **87** by using male screws **23** as a coupling means. The actuating shaft **110** is disposed on the inner side of the cylindrical part **16** as shown in FIGS. **1**(B) and **4**(A).

[**0033**] Each of four male screws **23** is rotatably and loosely engaged with a screw hole **221** formed in the holder **22** along the axial direction of the gap space **86** at equal intervals in the circumferential direction. Female screw parts which are screwed with the male screws **23** are formed in the case **170**. Therefore, a jig for coupling is inserted from the gap space **86** to screw the male screw **23** into the female screw part and thus the holder **22** can be coupled to the case **170**. As a result, the driving part **87** is integrated with the case **170** which is on the main body part side.

[**0034**] **FIG. 2**(A) is a perspective view showing a coil bobbin used in the linear actuator to which the present invention is applied and **FIG. 2**(B) is an explanatory perspective view showing the coil bobbin and an outer yoke.

[**0035**] In the linear actuator **1** according to the embodiment of the present invention, the coil bobbin **80** includes a cylindrical body part **81** and flange parts **85** formed so as to be extended outward in the radial direction from both ends of the body part **81**. The body part **81** ensures the isolation between the coil **8** and the first facing portion **410** and the second facing portion **420** of the outer yoke **4**. The flange part **85** ensures the isolation between the coil **8** and the outer yoke **4** located over the both end faces of the coil **8** in the axial direction.

[**0036**] As shown in FIGS. **1**(A), **2**(A) and **2**(B), a drop-out preventing part **83** is formed on the inner side of the flange part **85** in the radial direction so as to be extended in the axial direction of the body part **81**. The drop-out preventing part **83** is capable of abutting with the male screw **23** to prevent the male screw **23** from dropping out in the opposite direction with respect to the case **170** on the main body side when the case **170** is coupled to the holder **22**. The drop-out preventing part **83** is formed to protrude to a nearer position on the main body part side than the outer yoke member **42** which is located on the lower end face of the coil **8** on the side in which the main body part is connected. The tip end of the drop-out preventing part **83** is formed to be bent inward in the radial direction such that a drop-out preventing face **84** is formed. The drop-out preventing face **84** is extended to the position where the male screw **23** is disposed in the axial direction and a facing part **841** is formed in the drop-out preventing face **84**. The facing part **841** is formed so as to be opposed to a part of the peripheral part of the male screw **23** in the axial direction as shown in **FIG. 1**(C). Therefore, even when the male screw **23** moves in the dropping-out direction, the male screw **23** is capable of abutting with the facing part **841** of the drop-out preventing face **84** and thus the male screw **23** is prevented from dropping out in the reverse direction with respect to the side where the male screw **23** is connected with the main body part.

[**0037**] The drop-out preventing face **84** is formed so as not to overlap in the axial direction with the engaging recessed part **24** formed on the male screw **23** in order that the jig for coupling can engage with the engaging recessed part **24**. The outer yoke **4** may partly overlap with the male screw **23** in the axial direction but does not overlap with the engaging recessed part **24** in the axial direction. Therefore, the jig for coupling can be inserted in the axial direction to engage with the engaging recessed part **24** without being obstructed by the drop-out preventing face **84** and the outer yoke **4**.

[**0038**] **FIG. 1**(A) shows a state in which the male screw **23** protrudes from the holder **22** to the main body part side at the maximum. The protruding length (a) of the male screw **23** from the holder **22** in this state is set to be smaller than the opposing distance (d) between the male screw **23** and the drop-out preventing face **84**. Therefore, the male screw **23** can be completely retreated into the holder **22** to the position where the male screw **23** abuts with the drop-out preventing face **84**.

[**0039**] **FIG. 3** is an explanatory view showing the engaging parts of the coil bobbin and the outer yoke which are used in the linear actuator to which the present invention is applied.

[**0040**] As shown in FIGS. **1**(A), **2**(A), **2**(B) and **3**, an engaging protrusion part **82** is formed on the inner peripheral surface of the body part **81**. The engaging protrusion part **82** protrudes toward the inner yoke **3** so as to engage with both of the first facing portion **410** and the second facing portion **420**. The engaging protrusion part **82** serves as an engaging portion for preventing the first and the second facing portions **410**, **420** from being displaced by being attracted to the magnet **9**.

[**0041**] The engaging protrusion part **82** includes protrusion parts **823** and **824**, which respectively protrude in the axial direction so as to form recessed parts **821** and **822** opening in the axial direction together with the inner peripheral surface of the body part **81**. The engaging protrusion part **82** also includes a small projecting part **825**, which projects toward the inner yoke **3** from the center portion in the axial direction of the protrusion parts **823**, **824**.

[**0042**] Inner peripheral side protrusion parts **411**, **421** and outer peripheral side protrusion parts **412**, **422** are respectively formed on the tip end portions of the first facing portion **410** and the second facing portion **420**. Recessed parts **413**, **423** opening in the axial direction are respectively formed between the protrusion parts **411** and **412**, and between the protrusion parts **421** and **422**.

[**0043**] Accordingly, when the first and the second outer yoke members **41**, **42** are superposed on the coil bobbin **80** from both sides in the axial direction and the end parts **419**, **429** of the first and the second outer yoke members **41**, **42** are abutted with each other on the outer peripheral side of the coil **8**, the outer peripheral side protrusion parts **412**, **422** of the first and the second outer yoke members **41**, **42** respectively fit into the recessed parts **821**, **822** of the engaging protrusion part **82** on the inner peripheral side of the coil **8**, and the protrusion parts **823**, **824** of the engaging protrusion part **82** respectively fit into the recessed parts **413**, **423** of the first and the second outer yoke members **41**, **42**. In addition, the tip ends of the inner peripheral side protrusion parts **411**, **421** of the first and the second outer yoke members **41**, **42** may abut with the small projecting part **825** of the engaging protrusion part **82**.

[**0044**] The engaging protrusion part **82** is formed at eight positions on the coil bobbin **80** in the circumferential direction. In other words, eight engaging protrusion parts **82** are respectively disposed along the entire periphery so as to surround the inner yoke **3**. Accordingly, the first facing portion **410** and the second facing portion **420** are held by the coil bobbin **80** even when the attractive force of the magnet **9** is applied, and thus the first facing portion **410** and the second facing portion **420** do not displace in the radial direction.

[**0045**] **FIG. 4**(A) is an exploded perspective view obliquely viewed from above showing respective component members which construct the linear actuator in accordance with the embodiment of the present invention and **FIG. 4**(B) is an exploded perspective view obliquely viewed from below showing the respective component members shown in **FIG. 4**(A). In the embodiment of the present invention, the coil **8** and the outer yoke members **41**, **42** are previously assembled to be constructed as an assembly component **10**. The assembly component **10** is constructed such that, after the coil **8** is wound around the coil bobbin **80**, the first and the second outer yoke members **41**, **42** are superposed on the coil bobbin **80** from both the upper and lower sides in the axial direction.

[**0046**] Assembling of the linear actuator **1** in the embodiment of the present invention is performed according to the following steps. In other words, at first, the male screw **23** is dropped into the screw hole **221** formed in the holder **22**. Next, the assembly component **10** is set at the specified position of the holder **22** from the upper side of the male screw **23** such that the facing part **841** of the drop-out preventing face **84** is opposed to the male screw **23** in the axial direction. As a result, the dropping-out of the male screw **23** in the direction opposite to the main body part side is prevented.

[**0047**] Then, the holder **21** is put on the assembly component **10** from upper side, and the holders **21**, **22** are fixed by using fixing bolts **90** and fixing nuts **91**, which are disposed at four positions in the circumferential direction. Accordingly, the assembly component **10** is fixed to the holders **21**, **22** under the state that the assembly component **10** is held by the holders **21**, **22**. Finally, the movable body **5** is disposed in the gap space between the inner yoke **3** and the outer yoke **4**, and the linear actuator **1** is completed.

[**0048**] When the main body part is coupled to the driving part **87**, the coupling is performed after the movable body **5** is removed. In other words, when the movable body **5** is removed, the male screw **23** and the drop-out preventing part **83** are exposed, which are disposed in the gap space between the outer yokes **4** adjacent to each other in the circumferential direction, as shown in **FIG. 1**(C). As described above, the engaging recessed part **24** formed on the male screw **23** and the drop-out preventing face **84** are not overlapped with each other in the axial direction. Therefore, the jig for coupling can be inserted from the gap space **86** to engage with the engaging recessed part **24** of the male screw **23**, and thus the driving part can be connected to the main body part by means that the male screw **23** is turned by the jig to screw into the female screw formed in the main body part.

[**0049**] FIGS. **5**(A) and **5**(B) are explanatory views respectively showing different operating states of the linear actuator.

[0050] In the linear actuator **1** in the embodiment of the present invention, when the inner face of the magnet **9** is magnetized in an S-pole and its outer face is magnetized in an N-pole, the magnetic field is generated as shown by the arrows B**1**, B**2** expressed with the solid line in FIGS. **5**(A) and **5**(B). In this state, when an AC current flows in the coil **8** such that an electric current flows from the far side to the near side in the drawing as shown in **FIG. 5**(A), the magnetic field shown by the dotted line of the arrow B**3** is generated. At this time, in the first gap space **6**, the direction of the magnetic field generated from the magnet **9** is the same as that of the magnetic lines of force generated from the coil **8** and, in the second gap space **7**, the direction of the magnetic field generated from the magnet **9** is the opposite to that of the magnetic lines of force generated from the coil **8**. As a result, a downward force (toward the second gap space **7** side) in the axial direction is applied to the magnet **9** as shown in **FIG. 5**(A).

[0051] On the other hand, when the electric current flows from the near side to the far side in the drawing as shown in **FIG. 5**(B), the magnetic field shown by the dotted line of the arrow B**4** is generated. At this time, in the first gap space **6**, the direction of the magnetic field generated from the magnet **9** is opposite to that of the magnetic lines of force generated from the coil **8** and, in the second gap space **7**, the direction of the magnetic field generated from the magnet **9** is the same as that of the magnetic lines of force generated from the coil **8**. As a result, an upward force (toward the first gap space **6** side) in the axial direction is applied to the magnet **9** as shown in **FIG. 5**(B).

[0052] In this manner, the direction of force applied to the magnet **9** in the axial direction is interchanged according to the directions of the alternating magnetic field due to the coil **8**. Therefore, the movable body **5** which is integral with the magnet **9** oscillates in the axial direction and a reciprocal linear motion is obtained by the piston **130** which is connected to the movable body **5**.

[0053] As described above, in the driving part **87** in the embodiment of the present invention, the male screw **23** for coupling the holder **22** to the main body part is disposed along the axial direction in the gap space **86** formed between the outer yokes **4** which are adjacent to each other in the circumferential direction. Accordingly, the male screw **23** is not required to dispose on the outer side of the outer yoke **4** in the radial direction, and thus the driving part **87** can be coupled to the main body part without making the driving part **87** larger in the radial direction. In addition, even after the driving part **87** has been assembled, a jig for rotating the male screw **23** can be inserted from the gap space **86** to engage with the engaging recessed part **24** of the male screw **23**, and thus the male screw **23** can be rotated by the jig to couple the driving part **87** with the main body part.

[0054] Moreover, the driving part **87** is provided with the facing part **841** which may abut with the male screw **23** to prevent the male screw **23** from dropping out. Therefore, the male screw **23** is prevented by the facing part **841** from dropping out to the direction that is opposite to the direction in which the driving part **87** is coupled to the main body part. Accordingly, in the case that the male screw **23** is rotated with the jig to screw into the female screw that is disposed on the main body part side, even when the jig disengages with the male screw **23**, the male screw **23** does not drop out from the driving part **87**. Further, since the loss of the male screw **23** is prevented, the coupling operation can be performed at ease.

[0055] The drop-out preventing part **83** is integrally molded together with the coil bobbin **80** made of electrically insulative material and around which the coil **8** is wound. The coil bobbin **80** ensures the isolation of the outer yoke **4**. Therefore, the male screw **23** can be fitted to the holder **22** before the coil bobbin **80** is mounted to the holder **22** and, when the coil bobbin **8** is mounted to the holder **22**, the dropping-out of the male screw **23** can be prevented.

[0056] The male screw **23** is disposed at the position which is nearer on the main body part side than the outer yoke **4** and a part of the male screw **23** overlaps with the outer yoke **4** in the axial direction. Therefore, the stacked thickness of the outer yoke **4** can be increased by the amount of which the outer yoke **4** overlaps with the male screw **23** in the axial direction, and thus the magnetic saturation is restricted and the thrust of the movable body **5** can be ensured.

[0057] The outer yoke **4** is formed to extend from the portion located on the outer peripheral side of the coil **8** to the position opposing to the inner yoke **3** through both the upper and lower end faces of the coil **8** in the axial direction. The end portion of the outer yoke **4** opposing to the inner yoke **3** is formed to be the first facing portion **410** constructing the first gap space **6** and the second facing portion **420** constructing the second gap space **7**. The drop-out preventing face **84** of the drop-out preventing part **83** is formed so as to protrude to a position on the main body part side of the outer yoke **42** that is extended over the lower end face of the coil **8** as shown in **FIG. 1**(A). According to the construction described above, the male screw **23** can abut with the drop-out preventing face **84** to prevent from dropping-out securely. Therefore, various troubles caused between the outer yoke **4** and the male screw **23** can be eliminated, for example, the male screw **23** is caught by the end parts of the outer yokes **4** which are adjacent to each other in the circumferential direction.

[0058] The male screw **23** can be completely retreated into the holder **22** to the position where the male screw **23** abuts with the drop-out preventing face **84**. Therefore, when the linear actuator **1** is handled separately, the male screw **23** can be retreated into the driving part **87** such that the male screw **23** is protected from damage due to collision of the male screw **23** with other components or the like.

[0059] In the embodiment of the present invention, the male screw **23** is used as a coupling means for connecting the driving part **87** to the main body part. However, the coupling means in the present invention is not limited to the male screw **32**. In other words, various coupling means capable of connecting the holder **22** to the main body part may be used. Alternatively, a male screw may be disposed in the main body part and a female screw may be disposed in the holder **22**.

[0060] In the embodiment of the present invention, the coupling means is disposed along the axial direction in the gap space that is formed by the outer yokes adjacent to each other in the circumferential direction. However, the coupling means may be disposed along the axial direction in the gap space that is formed by the inner yokes adjacent to each other in the circumferential direction.

[0061] In the embodiment of the present invention, the drop-out preventing part **83** is integrally molded to the coil bobbin **80**. However, the drop-out preventing part **83** is not necessary to be integrally formed with the coil bobbin **80** and may be discretely formed in advance and fixed to the coil bobbin **80**. Also, the drop-out preventing part **83** may be integrally molded with the cover **89** or the holder **22** without using the coil bobbin **80**. In addition, instead of providing the drop-out preventing part **83** as described above, the male screw **23** is located so as to overlap with the outer yoke **4** in the axial direction and the outer yoke **4** is used as the drop-out preventing part.

[0062] The linear actuator **1** according to the present invention may be applied to a pump device or a compressor device as described with reference to **FIG. 6**.

[0063] **FIG. 6** is a cross-sectional view showing an air pump device to which the present invention is applied.

[0064] In an air pump device **100** in the embodiment of the present invention in **FIG. 6**, the upper end of an actuating shaft **110** is connected to the movable body **5** of the linear actuator **1** by using a washer **152** and a nut **153**. The actuating shaft **110** penetrates through the cylindrical part **16** of the frame **2**, which holds the inner yoke **3** as shown in FIGS. **4**(A) and **4**(B).

[0065] A main body case **170**, which is provided with an air inlet port **171** and an air outlet port **172**, is fixed with the male screws **23** on the bottom part of the holder **22** of the driving part **87**. A filter **174** is attached to the air inlet port **171**. A cylinder case **120** is disposed within the main body case **170**. A valve **141** is fixed on the bottom part of the cylinder case **120** by a valve presser **143** at a portion corresponding to the air inlet port **171**, and a valve **142** is fixed by a valve presser **144** at a portion corresponding to the air outlet port **172**.

[0066] A piston **130** which constructs a cylinder chamber **122** together with the bottom part of the cylinder case **120** is disposed within the inside of the cylinder case **120**. A pressure ring **135** is mounted on the side face of the piston **130** for ensuring air tightness with the inner peripheral side face of the cylinder case **120**.

[0067] The piston **130** is fixed to the lower tip end portion of the actuating shaft **110** with a nut **139** through washers **136**, **137** and an O-ring **138** and thus the piston **130** is driven in the axial direction by the oscillation of the actuating shaft **110**. Therefore, when the actuating shaft **110** moves toward the upper base end side in the axial direction (upward in the drawing) by the linear actuator **1**, the air is taken into the cylinder chamber **122** from the air inlet port **171**. When the actuating shaft **110** moves toward the lower tip end side in the axial direction (downward in the drawing) by the linear actuator **1**, the air in the cylinder chamber **122** is discharged from the air outlet port **172**. In the embodiment of the present invention, the resonance of a coil spring or an external leaf spring not shown in the drawing may be utilized in the oscillation of the actuating shaft **110** and therefore, the air pump device **100** provided with the small-sized linear actuator **1** can obtain excellent pumping characteristics.

[0068] While the description above refers to particular embodiments of the present invention, it will be understood that many modifications may be made without departing from the spirit thereof. The accompanying claims are intended to cover such modifications as would fall within the true scope and spirit of the present invention.

[0069] The presently disclosed embodiments are therefore to be considered in all respects as illustrative and not restrictive, the scope of the invention being indicated by the appended claims, rather than the foregoing description, and all changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced therein.

What is claimed is:

1. A linear actuator comprising:

a driving part including:

a plurality of inner yokes which are disposed in a circumferential direction and, each of which has a planar opposing face;

a plurality of outer yokes which are disposed in a circumferential direction around the inner yokes such that a first gap space and a second gap space separated from each other in an axial direction are formed between an outer peripheral face of the inner yoke and the outer yoke, and each of the plurality of outer yokes has a planar opposing face to the inner yoke;

a coil for generating an alternating magnetic field in the first gap space and the second gap space, whose magnetic path is formed by the outer yoke, the first gap space, the inner yoke, the second gap space and the outer yoke; and

a coupling means which is disposed along the axial direction in a gap space which is formed by the outer yokes adjacent to each other in a circumferential direction or by the inner yokes adjacent to each other in the circumferential direction;

a magnet which is disposed between the inner yoke and the outer yoke; and

a movable body which is interlocked with the alternating magnetic field to be driven to reciprocate in the axial direction;

wherein the coupling means connects the driving part to a main body part side which is provided with a moved body that is driven by the movable body.

2. The linear actuator according to claim 1, further comprising a drop-out preventing part which is provided in the driving part for being capable of abutting with the coupling means to prevent the coupling means from dropping out in a direction which is opposite to a direction that the driving part is coupled to the main body part by the coupling means.

3. The linear actuator according to claim 2, wherein the coupling means is disposed along the axial direction in the gap space which is formed by the outer yokes adjacent to each other in the circumferential direction, and the drop-out preventing part is constructed by being integrally molded to an electrically insulative coil bobbin on which the coil is wound around and by which isolation from the outer yoke is ensured.

4. The linear actuator according to claim 3, wherein the outer yoke is formed to extend from a portion located on an outer circumferential side of the coil to an inner circumferential side over end faces of the coil in the axial direction to form a first facing portion for constructing the first gap space and a second facing portion for constructing the second gap space such that the respective first facing portion and the second facing portion are opposed to the inner yoke, and the drop-out preventing part is formed to protrude to a position which is nearer on the main body part side than the outer yoke.

5. The linear actuator according to claim 2, wherein the coupling means is disposed along the axial direction in the gap space which is formed by the outer yokes adjacent to each other in the circumferential direction and is disposed at a position which is nearer on the main body part side than the outer yoke, and a part of the coupling means overlaps with the outer yoke in the axial direction.

6. The linear actuator according to claim 2, wherein the coupling means includes a male screw, which is capable of retreating within the driving part to a position where the male screw abuts with the drop-out preventing part.

7. The linear actuator according to claim 2, wherein the coupling means includes a male screw which is disposed along the axial direction in the gap space that is formed by the outer yokes adjacent to each other in the circumferential direction, the male screw is formed with an engaging recessed part with which the male screw is rotated, and the male screw and the drop-out preventing part disposed in the gap space between the outer yokes, which are adjacent to each other in the circumferential direction, overlap with each other in the axial direction excluding the engaging recessed part of the male screw.

8. A pump device comprising:

a linear actuator recited in one of claims **1** through **7**.

9. A compressor device comprising:

a linear actuator recited in one of claims **1** through **7**.

10. A linear actuator comprising:

a driving part including:

a plurality of inner yokes which are disposed in a circumferential direction and, each of the plurality of inner yokes has a planar opposing face to a corresponding outer yoke;

the plurality of outer yokes which are disposed in a circumferential direction around the inner yokes and each of the plurality of outer yokes has a planar opposing face to the corresponding inner yoke, wherein the plurality of outer yokes are disposed such that a first gap space and a second gap space separated from each other in an axial direction are formed between the planar opposing face of the inner yoke and the planar opposing face of the outer yoke;

a coil for generating an alternating magnetic field in the first gap space and the second gap space, whose magnetic path is formed by the outer yoke, the first gap space, the inner yoke, the second gap space and the outer yoke; and

a coupling means which is disposed along the axial direction in a gap space;

a magnet that is disposed between the inner yoke and the outer yoke; and

a movable body that is driven by the driving part so as to reciprocate in the axial direction;

wherein the coupling means connects the driving part to a main body part side which is provided with a moved body that is driven by the movable body.

11. The linear actuator according to claim 10, wherein the coupling means is formed by the outer yokes adjacent to each other in a circumferential direction.

12. The linear actuator according to claim 10, wherein the coupling means is formed by the inner yokes adjacent to each other in the circumferential direction;

13. The linear actuator according to claim 10, further comprising a drop-out preventing part which is provided in the driving part for being capable of abutting with the coupling means to prevent the coupling means from dropping out in a direction which is opposite to a direction that the driving part is coupled to the main body part by the coupling means.

14. The linear actuator according to claim 13, wherein the coupling means is disposed along the axial direction in the gap space which is formed by the outer yokes adjacent to each other in the circumferential direction, and the drop-out preventing part is constructed by being integrally molded to an electrically insulative coil bobbin on which the coil is wound around and by which isolation from the outer yoke is ensured.

15. The linear actuator according to claim 14, wherein the outer yoke is formed to extend from a portion located on an outer circumferential side of the coil to an inner circumferential side over end faces of the coil in the axial direction to form a first facing portion for constructing the first gap space and a second facing portion for constructing the second gap space such that the respective first facing portion and the second facing portion are opposed to the inner yoke, and the drop-out preventing part is formed to protrude to a position which is nearer on the main body part side than the outer yoke.

16. The linear actuator according to claim 11, wherein the coupling means is disposed at a position which is nearer on the main body part side than the outer yoke, and a part of the coupling means overlaps with the outer yoke in the axial direction.

17. The linear actuator according to claim 13, wherein the coupling means includes a male screw, which is capable of retreating within the driving part to a position where the male screw abuts with the drop-out preventing part.

18. The linear actuator according to claim 13, wherein the coupling means includes a male screw which is disposed along the axial direction in the gap space that is formed by the outer yokes adjacent to each other in the circumferential direction, the male screw is formed with an engaging recessed part with which the male screw is rotated, and the male screw and the drop-out preventing part disposed in the gap space between the outer yokes, which are adjacent to each other in the circumferential direction, overlap with each other in the axial direction excluding the engaging recessed part of the male screw.

19. A pump device comprising:

a linear actuator, the linear actuator comprising:

a driving part including:

a plurality of inner yokes which are disposed in a circumferential direction and, each of the plurality of inner yokes has a planar opposing face to a corresponding outer yoke;

the plurality of outer yokes which are disposed in a circumferential direction around the inner yokes and each of the plurality of outer yokes has a planar opposing face to the corresponding inner yoke, wherein the plurality of outer yokes are disposed such that a first gap space and a second gap space separated from each other in an axial direction are formed between the planar opposing face of the inner yoke and the planar opposing face of the outer yoke;

a coil for generating an alternating magnetic field in the first gap space and the second gap space, whose magnetic path is formed by the outer yoke, the first gap space, the inner yoke, the second gap space and the outer yoke; and

a coupling means which is disposed along the axial direction in a gap space;

a magnet that is disposed between the inner yoke and the outer yoke; and

a movable body that is driven by the driving part so as to reciprocate in the axial direction;

wherein the coupling means connects the driving part to a main body part side which is provided with a moved body that is driven by the movable body.

20. The pump device of claim 19, wherein the coupling means of the linear actuator is formed by the outer yokes adjacent to each other in a circumferential direction.

21. The pump device of claim 19, wherein the coupling means of the linear actuator is formed by the inner yokes adjacent to each other in the circumferential direction.

22. The pump device of claim 19, wherein the linear actuator further comprises a drop-out preventing part which is provided in the driving part for being capable of abutting with the coupling means to prevent the coupling means from dropping out in a direction which is opposite to a direction that the driving part is coupled to the main body part by the coupling means.

23. A compressor device comprising:

a linear actuator, the linear actuator comprising:

a driving part including:

a plurality of inner yokes which are disposed in a circumferential direction and, each of the plurality of inner yokes has a planar opposing face to a corresponding outer yoke;

the plurality of outer yokes which are disposed in a circumferential direction around the inner yokes and each of the plurality of outer yokes has a planar opposing face to the corresponding inner yoke, wherein the plurality of outer yokes are disposed such that a first gap space and a second gap space separated from each other in an axial direction are formed between the planar opposing face of the inner yoke and the planar opposing face of the outer yoke;

a coil for generating an alternating magnetic field in the first gap space and the second gap space, whose magnetic path is formed by the outer yoke, the first gap space, the inner yoke, the second gap space and the outer yoke; and

a coupling means which is disposed along the axial direction in a gap space;

a magnet that is disposed between the inner yoke and the outer yoke; and

a movable body that is driven by the driving part so as to reciprocate in the axial direction;

wherein the coupling means connects the driving part to a main body part side which is provided with a moved body that is driven by the movable body.

24. The compressor device of claim 23, wherein the coupling means of the linear actuator is formed by the outer yokes adjacent to each other in a circumferential direction.

25. The compressor device of claim 23, wherein the coupling means of the linear actuator is formed by the inner yokes adjacent to each other in the circumferential direction.

26. The compressor device of claim 23, wherein the linear actuator further comprises a drop-out preventing part which is provided in the driving part for being capable of abutting with the coupling means to prevent the coupling means from dropping out in a direction which is opposite to a direction that the driving part is coupled to the main body part by the coupling means.

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