

TITLE OF INVENTION

Improved Dual Coil Actuator With Combined Configuration of Axial and Radial Magnets

FIELD OF THE INVENTION

The present invention relates to a moving coil actuator that utilizes a dual coil design and the interaction of an axially magnetized permanent magnet and one or more radially magnetized permanent magnets arranged in an annular ring to produce very high magnetic forces.

DESCRIPTION OF RELATED ART

Moving coil actuators are electromagnetic devices that provide linear mechanical motion on the coil in response to the interaction of electrical and magnetic circuits. As shown in Fig 1, one type of a conventional linear moving coil actuator consists of a cylindrical inner core and an outer shell which surrounds the inner core to define an annular space between the two. An annular magnet is mounted on the inner wall of the outer shell while another annular magnet is mounted on the outer wall of the inner core. This combination provides a single closed magnetic circuit. A circular coil winding is positioned between the air gaps. When current is passed in the coil winding, a linear force is produced by the interaction of the current and the magnetic flux density across the air gap.

Fig 2 shows another conventional design of a moving coil actuator. In this design, an axial magnet is attached to the closed end of a cylindrical shell. A ferro-magnetic pole piece is attached to the other end of the axial magnet. Flux is thereby produced in the air gap between this ferro-magnetic pole piece and the open end of the shell. When current is passed in the coil winding of a circular coil assembly, a linear force is produced.

U.S. Patent No. 4,692,999 issued to Frandsen discloses a moving coil actuator that uses 2 annular magnets attached on the inner wall of the outer shell to provide a flux path towards a center cylindrical core. In this configuration, the moving coil assembly is formed by dual coil sections instead of a single coil. This dual coil design allows the coil winding to interact or “cut” the air gap at 2 positions. This results in a larger linear force, and an improvement in the efficiency of the moving coil actuator.

U.S. Patent No. 4,808,955 issued to Mikhail Godkin and Jack Kimble discloses another moving coil actuator which also uses a multiple coil design. In the dual coil design disclosed, similar to

the design described by U.S. Patent No. 4,692,999 issued to Frandsen, 2 annular magnets are attached on the inner wall of the outer shell. However, in this design, additional 2 annular magnets are also attached to the outer wall of the inner core. In the single ended embodiment, a first and a second magnetic circuits are provided which allows the 2 coil sections to cut the flux more efficiently.

U.S. Patent No. 5,345,206 issued to Morcos discloses a moving coil actuator which uses sets of axially-magnetized cylindrical permanent magnets mounted in the center of actuator core. In the single embodiment with 2 axially-magnetized permanent magnet sections (see Fig 3), 2 magnetic circuits are formed, allowing the 2 coil sections to cut the flux more efficiently. This dual coil design enables the moving coil to have a linear force that is larger than a conventional moving coil design as described in Fig 2, with both having the same diameter but with the dual coil design having a longer axial length.

The configuration of the moving coil actuator of the prior art can be further improved to offer improved performance and other economic benefits.

SUMMARY OF INVENTION

The present invention uses a different configuration of an axially magnetized permanent magnet with one or more radially magnetized permanent magnets to provide 2 magnetic circuits, thereby allowing the 2 coil sections of a dual coil actuator to cut the flux more efficiently at the air gaps.

The first object of the invention is to provide a different configuration wherein the moving coil actuator has :-

a cylindrical shell having a closed end, an inner surface extending from the closed end along a longitudinal portion of the cylindrical shell to an open end,

an inner core fixed onto the inner surface of the closed end, within a centre of the cylindrical shell to define an annular air gap therebetween,

a coil assembly movably disposed within the annular air gap and connectable to an electrical power supply, the coil assembly including a coil carrier disposed within the annular air gap, a first coil winding formed on the coil carrier, and wound to have a first polarity, and a second coil winding formed on the coil carrier, wound to have a second polarity opposite to the first polarity, the first coil winding and second coil spaced apart, the first coil winding and second coil winding in proximity to the axially-magnetized cylindrical

permanent magnet means and such that the first and second coil windings are wound in series but in opposite directions;

the configuration consisting of an inner core of a longitudinal arrangement including an axially-magnetized permanent magnet, said axially magnetized permanent magnet having a first direction of magnetization; and

an annular arrangement of radially magnetized permanent arc magnets, said radially magnetized permanent arc magnets being attached to the inner surface of the closed end, the radially magnetized cylindrical permanent arc magnet having a second direction of magnetization.

Preferably, the axially magnetized cylindrical permanent magnet and the radially magnetized cylindrical permanent arc magnets are magnetized in opposite directions such that the 2 magnetic circuits produced by the first coil winding and the second coil winding are opposed in the axial direction, to produce an additive axial force when a current is applied to the coils.

Preferably the first direction of magnetization and the second direction of magnetization causes the flux at the closed end of the linear actuator to be guided radially inwards from the cylindrical shell towards the center of the cylindrical shell through the radially magnetized cylindrical permanent arc magnets.

Preferably, the annular arrangement consists of one or more radially magnetized permanent arc magnets.

Preferably the longitudinal arrangement consists of a ferro-magnetic inner core, the first end of which is attached to an inner surface of the closed end of the cylindrical shell, said second end of ferro-magnetic inner core attached to a first end of a second axially magnetized permanent magnet, second end of axially magnetized permanent magnet attached to a third ferro-magnetic pole piece.

Advantageously, the ferro magnetic inner core of the longitudinal arrangement has a through bore in the center allowing the attachment of a shaft from the coil assembly to the other end of the actuator, thereby allowing another part on the other side of the actuator to be moved.

Preferably, the first end of the ferro magnetic inner core of the longitudinal arrangement is attached to the inner surface of the closed end of the cylindrical shell by one or more screws.

- 5 Alternatively, the first end of the ferro magnetic inner core of the longitudinal arrangement is attached to the inner surface of the closed end of the cylindrical shell by one or more bolts.

- Advantageously, the one or more radially magnetized cylindrical permanent magnets are
10 diametrically magnetized arc magnets which are magnetized in a single direction radially.

Preferably, the radially diametrically magnetized cylindrical magnets are high energy Neodymium Iron Boron magnets arc magnets.

- 15 Preferably, the said moving coil actuator uses a different configuration of an axially magnetized permanent magnet with a radially magnetized permanent arc magnet to provide 2 magnetic circuits, thereby allowing the 2 coil sections of a dual coil actuator to cut the flux more efficiently at the air gaps.

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BRIEF DESCRIPTION OF THE DRAWINGS

For a better understanding of the invention, its advantages, and the objects attained by its use, reference should now be made to the accompanying drawings. The accompanying
25 drawings illustrate one or more embodiments of the invention and together with the description herein, serve to explain the workings and principles of the invention.

Fig. 1 is a cross-sectional schematic diagram illustrating a conventional linear moving coil actuator.

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Fig. 2 is a cross-sectional schematic diagram illustrating another type of conventional moving coil actuator wherein the axial magnet is attached to the closed end of a cylindrical shell.

- 35 Fig. 3 is a cross-sectional schematic diagram illustrating a third type of conventional moving coil actuator which uses sets of axially-magnetized cylindrical permanent magnets mounted in the centre of actuator core.

Fig 4 is a cross sectional schematic diagram of a moving coil actuator of this invention.

Fig 5 shows a schematic diagram of the polarity of the magnetic field threading the first coil and the second coil producing the additive axial force when a current is applied to the coils.

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Fig. 6 shows the cross section of the cylindrical shell with the arrangement of array of magnetized arc permanent magnets. .

Fig. 7 shows the cross section of the cylindrical shell with another arrangement of array of magnetized arc permanent magnets. .

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Fig. 8 shows diametrically magnetized arc magnets which are magnetized in a single direction.

Fig. 9 shows a further embodiment of the invention using a complete one piece annular magnet.

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Fig. 10 shows an embodiment of the invention wherein the axially magnetized permanent magnets has a through bore in the centre.

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DETAILED DESCRIPTION OF THE INVENTION

Fig 4 shows a cross sectional schematic diagram of a moving coil actuator of this invention. The moving coil linear actuator includes an open cylindrical shell 1 made of ferro-magnetic material. Such ferro-magnetic material can be cold rolled steel, vanadium permendur or 400-series stainless steel. A first end of this cylindrical shell is open while the second end 2, is closed. The closed end is made of a non ferro-magnetic material, such as Aluminum which has good mechanical properties and yet has low density. The closed end of the cylindrical shell acts as the base end cover of the linear actuator. An array of magnetized arc permanent magnets 3 are attached to the inner surface of closed end. The outer surface of the arc magnets are in direct contact with the inner wall of the outer shell while the inner surface of these arc magnets are joined to a ferro-magnetic inner core 4.

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A longitudinal arrangement is disposed within the centre of the cylindrical shell. The longitudinal arrangement consists of a ferro-magnetic inner core 4, an axially-magnetized permanent magnet 6 and a third ferro-magnetic pole piece 7. The first end of the ferro-magnetic inner core 4 is connected to the inner surface of the closed end 2. At the second end of this ferro-magnetic inner core 4, an axially magnetized permanent magnet 6

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is attached. The ferro-magnetic inner core 4 is therefore a solid piece. The first end of the ferro-magnetic inner core 4 is connected to the inner surface by a number of screws, the screws 5 being attached from the other outer surface of the closed end. This ensures the rigidity of the ferro-magnetic inner core within the linear actuator.

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The second end of the ferro-magnetic inner core is attached to a first end of an axially magnetized permanent magnet 6. A second ferro-magnetic pole piece 7 is disposed between the axially magnetized permanent magnet 6 and the open end of the cylindrical shell.

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A moving coil assembly 8 made from non ferro-magnetic material with 2 coil sections, 9 and 10 is disposed within the space formed inside the cylindrical shell as a result of the arrangements of the radially magnetized permanent magnet 3, ferro-magnetic inner core 4 and the other ferro-magnetic pole piece 7. The axial magnet and the radial magnet are magnetized in directions so that the 2 magnetic circuits are opposed in the axial direction, as shown in Fig 5.

As shown in Fig 5, the polarity of the magnetic field threading the first coil 9 is opposite to that threading the second coil 10. Hence, the two coils 9 and 10 must be wound in series but in opposite directions so as to produce an additive axial force when a current is applied to the coils. The coil windings are typically copper enamel wires although aluminum enamel wires may also be used.

Fig. 6 shows an arrangement with 5 arc magnets is used. The number of arc magnets used may not be 5 pieces. It can also be an odd or even number such as 6, 7, 8 or more pieces. However, it should be appreciated that using too many pieces will consequently increase the cost of production as more assembly time and more materials would be required. It should also be noted that all the magnets have the same magnetic polarity. These magnets are typically using high energy product Neodymium Iron Boron permanent magnets which are very commonly made in these shapes and widely used in large quantities for brushless rotary servo motors. However, for brushless servo motors, the magnets are typically used in pairs of alternate opposing polarity, as shown in Fig 7. In this example shown in Fig. 7, an arrangement using 8 poles is shown. This is one of the most common brushless motor design.

By using the configuration of an axial magnet and an array of radially arranged arc magnets, the flux at the closed end of the actuator is guided very efficiently, from the outer cylindrical shell radially inwards and towards the center through the array of arc magnets. This results in improved performance compared to designs described in prior art. The radially

arranged arc magnets attached to the closed end of the actuator can also be made relatively smaller than the axial magnet attached described in the prior art shown in Fig 3. Furthermore, the configuration use an overall smaller magnet volume compared to the other designs described in the prior art. This invention therefore results in reduction in costs of manufacturing. Moreover, the reduction of the volume of the magnet used and the usage of a light weight material such as Aluminum end cover to hold the magnets also result in a reduction in the overall mass of the actuator.

As shown in Fig 6, these arc magnets need not fill up the entire annular space. Gaps may be allowed between the magnets. By using these arc magnets even with gaps, it has been found that there is no significance difference in performance of the actuator. The array arrangement also allows for easy assembly as there is no need for very tight tolerance control. The costs of production of the linear actuator of this invention is also reduced since the volume of magnets required is less. The mass of the actuator is also reduced, contributing to reduced freight and storage costs.

For magnets used for such high performance actuators being typically high energy Neodymium Iron Boron magnets, use of the array arrangement of arc magnets with gaps, would lower the costs of production.

Alternatively, a singular complete arc magnets can be made with this invention, in place of the configuration of an array of arc magnets. Such a magnet will be more expensive although the magnetic polarity is radial, as shown in Fig 9.

Diametrically magnetized arc magnets can also be used, as shown in Fig 8. These diametrically magnetized arc magnets are permanent magnets that are magnetized in a single direction as opposed to magnets that are magnetized radially. These arc magnets are very common and produced in large quantities for brushless servo motors. They do not require sophisticated magnetizing equipment or process and are easily produced at lower costs.

Fig 10 shows a configuration of an axial magnet and a circular array of arc magnets (or a singular annular radial magnet), with the actuator having a through bore in the center. This is made possible because of the high efficiency in the flow of flux at the closed end of the actuator through the radially magnetized permanent magnets or a series of arc magnets. Such a bore allows the attachment of a shaft from the coil assembly to the other end of the actuator, thereby allowing another part on the other side of the actuator (the closed end) to be moved. Another example is for users to route a vacuum tube through this bore for holding parts with a vacuum suction cup or other holding devices.

ADVANTAGEOUS EFFECTS OF THE INVENTION

5 The flux produced at the closed end of the actuator is guided from the outer shell radially inwards and towards the center through the configuration of an axial magnet and an annular radial very efficiently. This results in improved performance compared to designs described in prior art.

10 Moreover, the configuration use an overall smaller magnet volume compared to the other designs described in the prior art. This results is reduction in costs of manufacturing.

The reduction of the volume of the magnet used and the usage of a light weight material such as Aluminum end cover to hold the magnets also result in a reduction in the overall mass of the actuator, thereby reducing freight costs.

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CLAIMS

1. A improved dual moving coil linear actuator comprising:-

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a cylindrical shell having a closed end, an inner surface extending from the closed end along a longitudinal portion of the cylindrical shell to an open end,

10 an inner core within a centre of the cylindrical shell to define an annular air gap therebetween,

a coil assembly movably disposed within the annular air gap and connectable to an electrical power supply, the coil assembly including a coil carrier disposed within the annular air gap, a first coil winding formed on the coil carrier, and wound to have a first polarity, and
15 a second coil winding formed on the coil carrier, wound to have a second polarity opposite to the first polarity, the first coil winding and second coil spaced apart, the first coil winding and second coil winding in proximity to the axially-magnetized cylindrical permanent magnet means and such that the first and second coil windings are wound in series but in opposite directions;

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characterized in that said inner core consists of a longitudinal arrangement having an axially-magnetized permanent magnet, one end of the said longitudinal arrangement screwed onto the inner surface, said axially-magnetized permanent magnet having a first direction of magnetization; and

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an annular arrangement of radially magnetized permanent arc magnets, said radially magnetized permanent arc magnets being attached to the inner surface of the closed end, the radially magnetized cylindrical permanent arc magnet having a second direction of magnetization.

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2. A dual moving coil linear actuator as claimed in Claim 1 wherein the axially magnetized cylindrical permanent arc magnet and the radially magnetized cylindrical permanent magnets are magnetized in opposite directions such that the 2 magnetic circuits produced by the first coil winding and the second coil winding are opposed in the axial
35 direction, to produce an additive axial force when a current is applied to the coils.

3. A dual moving coil linear actuator as claimed in any of the preceding Claims wherein the first direction of magnetization and the second direction of magnetization

causes the flux at the closed end of the linear actuator to be guided radially inwards from the cylindrical shell towards the center of the cylindrical shell through the radially magnetized cylindrical permanent arc magnets.

5 4. The annular arrangement of radially magnetized permanent magnets for a dual moving coil linear actuator as claimed in Claim 1 wherein the annular arrangement consists of one or more radially magnetized permanent arc magnets.

10 5. The longitudinal arrangement as claimed in Claim 1 consisting of a ferro-magnetic inner core, the first end of which is attached to an inner surface of the closed end of the cylindrical shell, said second end of ferro-magnetic inner core attached to a first end of a second axially magnetized permanent magnet, second end of axially magnetized permanent magnet attached to a third ferro-magnetic pole piece.

15 6. The ferro-magnetic inner core of the longitudinal arrangement as claimed in Claim 5 wherein the ferro-magnetic inner core has a through bore in the center allowing the attachment of a shaft from the coil assembly to the other end of the actuator, thereby allowing another part on the other side of the actuator to be moved.

20 7. The ferro-magnetic inner core of the longitudinal arrangement as claimed in Claim 5 or Claim 6 wherein first end of the ferro magnetic inner core is screwed onto the inner surface of the closed end of the cylindrical shell by one or more screws.

25 8. The ferro-magnetic inner core of the longitudinal arrangement as claimed in Claim 5 or Claim 6 wherein first end of the ferro magnetic inner core is attached to the inner surface of the closed end of the cylindrical shell by one or more bolts.

30 9. A dual moving coil linear actuator as claimed in Claim 1 wherein the one or more radially magnetized cylindrical permanent magnets are diametrically magnetized arc magnets which are magnetized in a single direction radially.

35 10. The radially diametrically magnetized cylindrical magnets as claimed in Claim 7 wherein the radially diametrically magnetized cylindrical magnets are high energy Neodymium Iron Boron magnets arc magnets.

11. A dual moving coil actuator as claimed in Claim 1 wherein the said moving coil actuator uses a different configuration of an axially magnetized permanent magnet with a

radially magnetized permanent arc magnet to provide 2 magnetic circuits, thereby allowing the 2 coil sections of a dual coil actuator to cut the flux more efficiently at the air gaps.

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