Apparatus for producing linear motion

The present invention relates to electromagnetic apparatus for producing linear motion.

One means of producing linear motion directly by electromagnetic means is the linear electric motor devised by Professor Laithwaite of Imperial College, London. This device can be considered as a conventional rotary electric motor in which the stator and armature have been split axially and unrolled. Although the device is very effective, it does have the disadvantage that considerable unbalanced attractive forces exist between the stator and moving armature, so that some means such as a track or wheeled carriage has to be used to maintain a separation between the stator and the armature.

A second form of linear motor has a cylindrical topology like a conventional electric motor but with the magnetic field-producing elements disposed transversely around the longitudinal axis so that the magnetic fields alternate in polarity along the axis of the motor.

Examples of such linear motors are shown in OLS 2,229,711; EP 0221 228; US 4,714,300; EPO 280 743; EP 0 314 493 and WO 93/01646.

OLS 2,229711 discloses a dc motor in the form of a piston with a single coil which moves in a cylinder under the action of magnetic fields which are generated by the successive energising of ring-shaped coils spaced axially along the inner surface of the cylinder surrounding the piston.

EPO 221 228 discloses an arrangement in which both linear and rotary motion of a shaft are produced, the linear motion of the shaft being produced by circumferential coils and the rotary motion by axial peripheral coils in the usual way.

US 4,414,300 discloses a pressure modulator for use in anti-skid brake systems in which a plunger is caused to oscillate longitudinally in a chamber under the influence of a longitudinally-varying magnetic field pattern generated between a winding on the inside of an outer portion of the chamber and a number of magnets disposed around the periphery of the plunger, or vice versa.

EPO 280 743 discloses a screw for an injection moulding machine which is moved linearly by the interaction between magnets on a shaft forming part of the injection screw and a number of coils surrounding the shaft and to which a three-phase alternating current is applied.

EP0 314 493 discloses another arrangement in which a shuttle is caused to oscillate in a chamber by the interaction between two magnetic fields, one generated by a winding on the shuttle and the other by a winding forming part of the chamber wall.

WO 93/01646 discloses another arrangement in which a piston is driven longitudinally in a cylinder by means of the interaction between two radial magnetic fields, one generated by a series of circumferential coils forming part of the cylinder wall and the other by a plurality of magnets forming part of the piston, or vice versa. For many purposes, the arrangements disclosed in WO 93/01646 are quite satisfactory. However, if the invention of WO 93/01646 is to be used as a combined fluid/electromagnetic actuator, the need to provide fluid-tight seals both on the piston and where the piston rod emerges through an end wall of the cylinder is a disadvantage, particularly as heavy and off-axis loads will tend to bend the piston rod out of true. Also, the solid construction of the piston and piston rod means that larger sizes of the device will become very heavy.

It is an object of the present invention to provide an improved electromagnetic apparatus for producing linear motion which is lighter in construction and which has increased transverse stiffness.

According to the present invention there is provided an electromagnetic apparatus for producing a linearly-directed force, comprising at least two tubular members adapted to slide telescopically, one within the other, means for producing a first magnetic field the polarity of which alternates along at least a portion of the axial length of the inner tubular member, means for producing a second magnetic field the polarity of which alternates along at least a portion of the axial length of the outer tubular member, and means for varying at least one of the magnetic fields so as to cause the magnetic fields to interact to provide an axial force tending to cause relative motion between the tubular members.

Preferably there is provided at least one seal between the inner surface of the outer tubular member and the outer surface of the inner tubular member so as to prevent the access of harmful environmental components to those parts of the device where relative motion occurs.

The outer ends of the tubular members may include flanges by means of which they can be attached to components of another structure.

The device may be so constructed that the inner tubular member carries an array of permanent magnets and the outer tubular member an assembly of coils which are selectively energised to provide the said variation of one of the magnetic fields, or vice versa. Other arrangements are possible, for example, both tubular members may carry electrical coils, or the permanent magnets may be replaced by low-reluctance magnetic elements or by a conducting sleeve in which a pattern of eddy currents is induced.

According to the present invention in a particular aspect there is provided an electromagnetic apparatus for producing a linearly-directed force comprising two cup-shaped members, one fitted within the other and adapted to allow relative motion therebetween, means for producing a first magnetic field the polarity of which alternates along at least a part of the axial length of one of the cup-shaped

members, means for producing a second magnetic field the polarity of which alternates along at least a part of the axial length of the other cup-shaped member, and means for varying at least one of the magnetic fields so as to cause the magnetic fields to interact to provide an axial force tending to cause relative motion between the cup-shaped members.

Preferably, there are seals interposed between the cup-shaped members so that they form an enclosed space and one of the cup-shaped members has an opening therein so as to enable fluid to pass into and out of the enclosed space.

The device may be constructed as a moving-coil or moving-magnet device as desired, but in a preferred arrangement the outer cup-shaped member has an electromagnetic element consisting of a plurality of annular coils separated by ferromagnetic spacers which are arranged to present a constant reluctance to a radially-directed magnetic field originating from a magnetic field-generating element associated with the inner cup-shaped element. Preferably the magnetic-field generating element associated with the inner cup-shaped element is a plurality of permanent magnets.

The invention will now be described, by way of example, with reference to the accompanying drawings in which:-

Figure 1 is a schematic longitudinal section of an electromagnetic apparatus embodying the invention for producing linear motion.

Figure 2 is a schematic longitudinal section of a second embodiment of the invention

Figure 3 is a schematic longitudinal section of a third embodiment of the invention and

Figure 4 is a schematic longitudinal section of a means for producing a variable magnetic field for use in carrying out the present invention.

Referring to Figure 1 of the drawings, an apparatus 100 for producing linear motion electromagnetically consists of an outer tubular member 101 which has a mounting flange 102 at one end. Inside the outer tubular member 101 is an axial array of coils 103 which are mounted on a polished steel liner 104. An inner tubular member 105 is arranged to be a good sliding fit in the liner 104 of the outer tubular member 101. The inner tubular member 105 also has a mounting flange 106 at its outer end. A portion 107 of the inner tubular member 105 is provided with a series of annular magnets 108 arranged to produce a magnetic field pattern which alternates in the axial direction and interacts with the magnetic field pattern produced by the coils 103. The outside diameter of the annular magnets 108 is approximately the same as that of the remainder of the inner tubular member 105. A seal 109 is provided where the inner tubular member 105 projects from the outer tubular element 101. A bearing and wiper ring 110 is fitted to the end of the inner tubular member 105 which works inside the outer tubular member 101. The bearing and wiper ring 110 acts to constrain any radial deflection of the inner tubular member 105 and to clean the inner surface of the liner 104 of the outer tubular member 101.

Also included, but not shown in the drawing, is a sensor for determining the position in the outer tubular member 101 of the inner tubular member 105. Signals from this sensor are used to control the action of a power supply 111, which is capable of generating electric currents of variable frequency, phase and amplitude, connected to the array of coils 103, so that the electric currents flowing in the coils 103 produce a magnetic field pattern which interacts with that of the array of magnets 108 on the inner tubular member 105 to produce an axial electromagnetic force of a desired magnitude and direction.

The construction of the device is such that it can withstand considerable transverse loads. Also, the presence of the seal 109 permits the device to be used in hazardous or difficult environments, providing that the open ends of the tubular members 101 and 105 are closed off.

If so desired, the portion of the inner tubular member 105 which projects beyond the outer tubular member 101 when the inner tubular member 105 is at the inner limit of its travel may be of larger or smaller diameter than the remainder. Also, the flanges 102 and 105 may incorporate O-ring seals so that when they are assembled to other structures the volume bounded by the outer faces of the flanges 102 and 106 is sealed. The device may then be adapted to act as a pneumatic spring or actuator as well as providing an electromagnetically-generated linear force.

Figure 2 shows another embodiment of the invention which is identical to that of Figure 1 except that the liner 104 is replaced by a copper or aluminium tube 201, which may be plated with a hard metal such as chromium so that the tube 201 also acts as the liner 104. Alternatively, a separate liner can be used. Coils 202 in the inner tubular member 105 replace the magnets 108 and generate eddy currents in the copper or aluminium tube 201, which interact with the magnetic field produced by the coils 202. Those components which are common to both embodiments have the same reference numerals.

Figure 3 shows a third embodiment of the invention in which the two tubular members are closed off.

Referring to Figure 3, an apparatus for producing electromagnetically a linearly-acting force consists of two hollow cup-shaped members 301, 302 one of which (301) is adapted to move linearly within the other (302). Each of the cup-shaped members 301 and 302 has a tubular section 303, 304, respectively, and end closure members 305 and 306 ,respectively, positioned at the outer ends of the tubular sections 303 and 304 to form an enclosure 307. As before, an axial array of coils 308 is contained between the tubular section 304 of the cup-shaped member 302 and a polished steel liner 309. At the inner end of the cup-shaped member 301 there is an axially-extending annular array of magnets 310 which produces a magnetic field which alternates axially and interacts with the magnetic field produced by the coils 308 when they are energised by a suitable power

supply 311. As before, there is included a sensor for determining the position of the cup-shaped member 301 within the cup-shaped member 302 and producing signals which are used to control the action of the power supply 311, which again is capable of producing electric currents of variable phase, frequency and amplitude, so that the coils 308 produce a magnetic field pattern which interacts with that of the array of magnets 310 on the cup-shaped member 301 to produce an axial electromagnetic force of a desired magnitude and direction.

The cup-shaped member 302 is sealed to the cup-shaped member 301 by a sliding bearing and seal 312 and the inner end of the cup-shaped member is supported by another sliding bearing 313. In this form of the invention there is no need to provide another seal at the inner end of the cup-shaped member 301 because of the end-closures 305 and 306. As before, considerable lateral stiffness is imparted by the design of the device.

The sealing of the enclosure 307 enables the device to act as a pneumatic spring because movement of one cup-shaped member relative to the other causes a change in the volume of the enclosure 307, and hence the pressure of a compressible medium in the enclosure 307. If one or other of the cup-shaped members has a suitable port in it, the device can be connected to an external reservoir and so be enabled to function as a pneumatic or hydraulic ram as well as an electromagnetic linear force producer. If the device is used as an actuator, then such an arrangement would enable a static or slowly-varying load to be accommodated without drawing an electric current from the power supply 311.

Figure 4 shows an arrangement of coils for use with any of the forms of the invention described above. Referring to Figure 4, the array of magnetic field-producing coils associated with the outer members 102, 302 previously described, is made up from a stack of circular coils 401 which are interposed between rings 402 made of a ferromagnetic material and external ferromagnetic spacer rings 403. The dimensions of the coils 401, rings 402 and spacers 403, are such that the assembly forms a single cylindrical coil assembly 404. In order that the

assembly 404 presents a constant reluctance to a radially-directed magnetic field produced by the member moving within the coil assembly 404, each module of the coil assembly 404 is skewed by one coil axial length 401. In other arrangement which is not illustrated, the rings 402 are skewed back and forth over one complete rotation so as to balance any off-axis forces generated by the coil assembly 404.

In the form of invention described with reference to Figures 1 and 2, more than one telescopic stage can be used and the terms "inner " and "outer" tubular members are to be interpreted accordingly, as referring to any particular stage of the apparatus.



CLAIMS

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1) An electromagnetic apparatus for producing a linearly-directed force comprising at least two tubular members (101, 105) adapted to slide telescopically one within the other, means (103) for producing a first magnetic field the polarity of which alternates along at least a portion of one (101) of the tubular members (101, 105), means (108) for producing a second magnetic field the polarity of which alternates along at least a portion of the axial length of the other tubular member (105) and means (111) for varying at least one of the magnetic fields so as to cause the magnetic fields to interact to provide an axial force tending to cause relative motion between the tubular members (101, 105).

2) An apparatus according to claim 1 wherein the inner tubular member (105) has an array of permanent magnets (108) associated with it and the outer tubular element (101) has an assembly of coils (103) which are energised selectively by the means (111) to provide the said variation of one of the magnetic fields.

3) An apparatus according to claim1 or claim 2 wherein the means (202) for producing the first magnetic field is adapted to set up eddy currents in an associated member (201) thereby to generate the second magnetic field.

4) An apparatus according to claim 1, claim2 or claim 3 wherein there is included at least one bearing and seal (109,110) between the inner surface of the outer tubular member (101) and the outer surface of the inner tubular member (105) so as to prevent the access of harmful environmental components to those parts of the device where relative motion occurs.

5) An apparatus according to any preceding claim wherein each of the tubular members (101,105) has a flange (102,106) by means of which it can be attached to a structure.

6) An apparatus according to claim 5 wherein each of the flanges (102,106) is adapted to be sealed to the said structure.

7) An apparatus for producing electromagnetically a linearly-directed force comprising two cup-shaped members (301 ,302) one fitted within the other and

adapted to allow relative motion therebetween, means (308) for producing a first magnetic field the polarity of which alternates along at least a part of the length of one (302) of the cup-shaped members (301, 302), means (310) for producing a second magnetic field the polarity of which alternates along at least a part of the other (301) of the cup-shaped members (301, 302) and means (311) for varying at least one of the magnetic fields so as to cause the magnetic fields to interact to provide an axial force tending to cause relative motion between the cup-shaped members (301, 302).

8) An apparatus according to claim 7 wherein the means (311) for varying at least one of the magnetic field patterns comprises an electronic drive unit of known type adapted to vary the position, velocity and amplitude of the magnetic field pattern produced by a plurality of coils (308) associated with one (302) of the cup-shaped members (301,302).

9) An apparatus according to claim 7 wherein the means (311) for varying at least one of the magnetic field patterns is a multi-phase power supply, the frequency, phase and amplitude of the output from which can be varied to alter the magnetic field pattern produced by a plurality of coils (308) to which the power supply (311) is connected.

10) An apparatus according to any of claims 7, 8 or 9 wherein there is included means (312) for producing a fluid-tight seal at the position where the inner cup-shaped member (301) protrudes from the outer cup-shaped member (302).

11) An apparatus according to claim 10 wherein the space (307) enclosed between the cup-shaped members contains a fluid thereby to generate an axial force on the outer ends (305, 306) of the cup-shaped members (301, 302).

12) An apparatus according to claim 11 wherein the enclosed space (307) is connected to an external fluid reservoir.

13) An apparatus according to any preceding claim wherein the cross-sections of the tubular or cup-shaped members (101, 105, 301, 302) are non-circular.

14) An apparatus according to any preceding claim wherein the means (103, 308) for producing one of the magnetic field patterns comprises a plurality of annular coils, (401), a plurality of external spacers (403) made of a ferromagnetic material and having the same axial length as the coils (401), and a plurality of

rings (402) made of a ferromagnetic material interposed between the coils (401) and having the same internal diameter as the coils (402) and the same external diameter as the spacers (402), the rings and coils being so shaped axially as to present a constant reluctance to a radially-directed magnetic field pattern produced by the second magnetic field pattern generating means.

15) An apparatus according to claim 14 wherein each coil (401) ring (402) spacer (403) module is skewed or is displaced back and forth over one complete rotation a distance equal to the axial length of a coil (401).

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