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(54) **Electromagnetic actuator**

(57) A solenoid actuator (200) for use in a fuel injection system is disclosed. The actuator comprises a generally cylindrical core member (202) having a longitudinal axis (A) and defining, at an end thereof, an inner pole face (210) of the actuator, a wire coil (212) disposed around the core member (202) and arranged to be connected to a power source in use so as to generate a magnetic field around the coil, an outer ring (218) arranged concentrically around the end of the core member (202) and defining an outer pole face (220) of the actuator, the outer and inner pole faces (210, 220) being substantially co-planar, and a support ring (216) of non-magnetic material having a relatively low magnetic permeability, the support ring (216) being disposed between the end of the core member (202) and the outer ring (218). In one embodiment, the actuator (200) is receivable in a recess (308) in a housing (302), and is arranged such that substantially all of the flux in a part of a of a magnetic circuit defined by the magnetic field is guided to pass between the outer ring (218) and the housing (302) in use of the actuator.

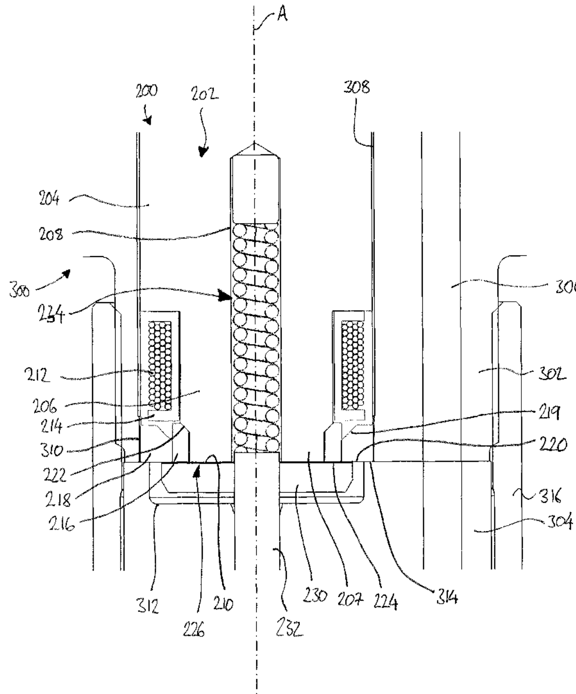

FIGURE 4

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Description

Field of the invention

[0001] The present invention relates to an electromagnetic actuator for use in a fuel injection system. In particular, but not exclusively, the invention relates to a solenoid actuator for use in a fuel injector or a fuel pump.

Background to the invention

[0002] A known electromagnetic or solenoid actuator comprises a coil of wire disposed around a generally cylindrical fixed core. The coil and the core are housed in a tubular can or sleeve, at least one end of which is open. The core and the sleeve are made from a soft magnetic material with high magnetic permeability, which is capable of carrying a high flux density without becoming magnetically saturated. Typical materials include soft ferromagnetic materials, such as ferritic iron alloys.

[0003] On passing an electrical current through the coil, a toroidal magnetic field defining a magnetic circuit is generated around the coil. The resulting magnetic flux passes axially through the core and through the sleeve. At the open end of the sleeve, the magnetic flux emerges from the actuator via the end face of the core and reenters the actuator by passing into the sleeve. The end face of the core is known as the inner pole face of the actuator, and the corresponding open end of the sleeve is known as the outer pole face.

[0004] A moveable armature is located close to the inner and outer pole faces. The armature is also made from a soft magnetic material and is positioned such that, when the coil is energised, the armature is within the magnetic field that emerges from the actuator. Energisation of the coil therefore results in the armature moving towards the pole faces, so as to minimise the magnetic flux path between the outer and inner pole faces. The armature is biased away from the pole faces, for example by a spring, so that when the coil is de-energised, the armature moves away from the pole faces.

[0005] In this way, the energisation state of the coil controls the axial position of the armature with respect to the pole faces. Typically, the actuator is arranged so that the armature is moveable between first and second positions, for example by providing suitable stops for movement of the armature. By connecting the armature to a suitable element, linear movement of the element between the first and second positions can be effected.

[0006] Dual-pole actuators of this type have been used in many applications, particularly in the field of internal combustion engines. For example, pumps for fuel or other fluids employ actuators of this type in which the armature is connected to a pumping element such as a piston or plunger. The pumping element is reciprocable in a pumping chamber, so that movement of the pumping element between the first and second positions causes displacement of the fluid.

[0007] In another example, an actuator of this type is employed to control fuel delivery from a fuel injector. One example of such a fuel injector is shown in Figures 1 and 2 of the accompanying drawings, and is described in the present applicant's granted European Patent No. EP-B-0767304, the contents of which are incorporated herein by reference.

[0008] The fuel injector 100 is intended for use with a common rail type fuel system and comprises a nozzle body 10 provided with a blind bore 16. An elongate valve needle 12 is slidable within the bore 16, the valve needle 12 including a tip region 14 which is arranged to engage a valve seat defined by the inner surface of the nozzle body 10 adjacent the blind end of the bore 16. The nozzle body 10 is provided with one or more apertures communicating with the bore 16, the apertures being positioned such that engagement of the tip 14 with the valve seat prevents fluid escaping from the nozzle body 10 through the apertures.

[0009] The solenoid actuator 44 is arranged to control fuel pressure in a control chamber 22 that receives an end of the valve needle 12. The control chamber 22 is connected to a high-pressure fuel supply line 18. The injector 100 is arranged so that, when the fuel pressure in the control chamber 22 is relatively high, the tip 14 of the valve needle 12 is engaged with the valve seat, and when the fuel pressure in the control chamber 22 is relatively low, the valve needle 12 is lifted away from the valve seat so as to allow delivery of fluid through the apertures.

[0010] The solenoid actuator 44 is located in a recess within a housing comprising a nozzle holder body 42. As shown most clearly in Figure 2, the actuator 44 comprises a generally cylindrical core member 44a, a coil 44b comprising a plurality of windings wound upon the core member 44a and being connected to a suitable controller, and a cylindrical yoke or sleeve 44c extending around the core member 44a and coil 44b. To prevent electrical short-circuiting, the coil 44b is encapsulated in an overmoulding of plastics material (not shown).

[0011] The core member 44a is provided with an annular flange 44i having a diameter just less than the diameter of the recess in the nozzle holder body 42. The flange 44i, and hence the core member 44a, are supported on the sleeve 44c, which in turn is supported on a shoulder 20a defined between the recess in the nozzle holder body 42 and a valve block 20 of the fuel injector 100. The sleeve 44c therefore holds the core member 44a in place within the injector 100. Conveniently, the actuator 44 is manufactured separately from the injector 100 and is inserted into the recess in the nozzle holder body 42 during manufacture of the injector 100, and therefore the sleeve 44c ensures that the actuator 44 is positioned correctly with respect to the other components of the fuel injector 100.

[0012] The faces of the core member 44a and sleeve 44c facing the valve member 36 define an inner pole face 44d and an outer pole face 44e, respectively. The lowermost end of the sleeve 44c, adjacent the outer pole face 44e, is formed into an internal flange 44f to reduce the gap between the inner and outer pole faces 44d, 44e. A lift stop 44h in the form of a tubular member is provided in an axial bore of the core member 44a. The lift stop 44h is made from a relatively wear-resistant material that is not chosen for its magnetic properties, such as hard steel. The lift stop 44h protrudes slightly beyond the pole faces 44d, 44e so as to limit movement of the armature 36a towards the pole faces 44d, 44e.

[0013] The actuator 44 controls the linear position of a valve member 36. The valve member 36 carries an armature 36a such that, upon energisation of the solenoid actuator 44, the armature 36a and valve member 36 are lifted such that a fluid flow path between the control chamber 22 and a low-pressure fuel drain is created. On de-energizing the solenoid actuator 44, the valve member 36 returns to its original position under the action of a spring 46 received within a blind bore of the core member 44a. In this way, the energisation state of the actuator 44 determines the position of the valve needle 12, and hence the delivery of fuel from the injector 100.

[0014] The magnetic field distribution in and around part of an actuator 44 of the type shown in Figures 1 and 2 is shown in schematic form and in reduced detail in Figure 3. The magnetic field distribution is represented by magnetic field lines, labelled F in Figure 3. As noted above, the magnetic field generated by the energised coil 44b is generally toroidal. However, the magnetic field is concentrated in the components that are made from soft magnetic materials. Thus the magnetic field is substantially confined to the core member 44a, the sleeve 44c and the armature 36a so as to form a magnetic circuit around the coil 44b. The flange 44f of the sleeve 44c is dimensioned so that the outer pole face 44e overlaps with the armature 36a, thereby ensuring that the magnetic field is directed from the sleeve 44c to the armature 36a in a generally axial direction. Similarly, the magnetic field is directed generally axially from the armature 36a to the core member 44a via the inner pole face 44d.

[0015] Currently, there is a trend for the injection pressures used in fuel injection systems to increase. One consequence of this trend is that the forces that act on the valve components due to the fuel pressure in a fuel injector are increased. Correspondingly, there is a need to provide actuators that can apply greater forces, so that valve components can be moved against the fuel pressure as well as providing greater sealing forces.

[0016] Several design parameters influence the maximum force available from a solenoid actuator. In general terms, these design parameters are related to the size of the actuator: a larger actuator is capable of applying a greater maximum force to an armature.

[0017] Specifically, the force that a solenoid actuator applies to the armature is proportional to the cross-sectional area of the core member. The number of turns and the gauge of the wire in the coil influence the current available to excite the core member. The diameter of the core member must be chosen carefully, since if the core member is too small for a given coil, the material of the core member may magnetically saturate, limiting the maximum magnetic flux in the core member and hence the available force of the actuator. However, if the core member is too large, the size of the coil may be compromised, so that the core member cannot be adequately energised.

[0018] In a given application, however, the overall diameter of the actuator is fixed by the design constraints of the component. For example, in a fuel injector of the type shown in Figure 1, the overall diameter of the fuel injector must be small enough to fit into a standard-size bore in the cylinder head of an engine. This limits the diameter of the actuator to a maximum of approximately 10 mm in present designs, although it would be desirable to reduce the injector diameter further in future designs. It is therefore not always possible simply to provide a larger actuator to adapt a fuel injector for use at increased pressure.

[0019] Similar considerations apply to actuators for use in other fuel injection system components, such as control actuators in fuel pumps. Consequently, it would be desirable to provide an actuator arrangement that is capable of providing a higher force for a given actuator size.

Summary of the invention

[0020] Against this background, from one aspect, the present invention resides in a solenoid actuator for use in a fuel injection system. The actuator comprises a generally cylindrical core member having a longitudinal axis and defining, at an end thereof, an inner pole face of the actuator. The actuator further comprises a wire coil disposed around the core member and arranged to be connected to a power source in use so as to generate a magnetic field around the coil, and an outer ring arranged concentrically around the end of the core member and defining an outer pole face of the actuator. The outer and inner pole faces are substantially co-planar. The actuator also comprises a support ring of non-magnetic material having a relatively low magnetic permeability, the support ring being disposed between the end of the core member and the outer ring.

[0021] By providing an outer ring defining an outer pole face of the actuator, instead of a sleeve as in the prior art actuator of Figures 1 to 3, there is more space within the diameter of the actuator for the coil and the core member. Thus, for a given actuator diameter, in the invention a core member with a larger diameter can be used to give a greater actuator force than in the prior art design.

[0022] In one embodiment of the invention, the actuator is receivable within a housing. Preferably, the actuator is arranged such that, in a part of a magnetic circuit defined by the magnetic field, substantially all of the magnetic flux is guided to pass between the outer ring and the housing in use of the actuator.

[0023] The housing is used to carry or guide the magnetic circuit around the outside of the actuator. It is not therefore necessary to provide a sleeve or similar component within the space available for the actuator itself, so that a relatively large core member and coil can be employed.

[0024] Preferably, the outer ring and/or the core member are made from a soft magnetic material having a relatively high magnetic permeability. The support ring may be of a non-magnetic metallic material, or may be a plastics or ceramic material. In one embodiment, the wire coil may be wound on a coil former, and the support ring may comprise a portion of the coil former.

[0025] Preferably, the outer ring is fixed to the core member by way of the support ring. The support ring therefore serves to attach the outer ring to the actuator.

[0026] The support ring and/or the outer ring may be fixed to the support ring by way of an interference fit, a screw fit, welding, moulding, sintering, or adhesive. Specifically, the support ring may be an interference fit on the core member. Alternatively, the support ring could be a screw fit on the core member, or could for example be welded or glued to the core member. Similarly, the outer ring may be an interference fit on the support ring, or could for example be screw-fitted, welded or glued to the support ring. In another embodiment, the support ring is fixed to the core member and/or the outer ring as part of a sintering process during manufacture of the actuator.

[0027] The actuator may further comprise an armature moveable in a direction parallel to the longitudinal axis in response to the magnetic field in use of the actuator. The outer ring may be disposed substantially between the coil and the armature. In use of the actuator, the magnetic field preferably flows between the armature and the inner and outer pole faces in a direction substantially parallel to the longitudinal axis. With this arrangement, the force applied to the armature in the direction parallel to the longitudinal axis can be maximised.

[0028] The magnetic field may be directed into the armature by the support ring. In this way, the non-magnetic support ring prevents the magnetic field from describing a circuit that does not pass through the armature.

[0029] In one embodiment of the invention, the outer ring is spaced from the wire coil in a direction parallel to the longitudinal axis. In another embodiment, the outer ring overlaps only a minor portion of the wire coil in a direction parallel to the longitudinal axis.

[0030] The support ring may comprise a former upon which the coil is wound. In this case, the support ring may comprise a part of the former.

[0031] In a second aspect of the invention, there is provided a solenoid actuator for use in a fuel injection system comprising a generally cylindrical core member having a longitudinal axis and defining, at one end thereof, an inner pole face of the actuator, a wire coil disposed around the core member and arranged to be connected to a power source in use so as to generate a magnetic field around the coil, an outer ring arranged concentrically around the core member and defining an outer pole face of the actuator, the outer and inner pole faces being substantially co-planar, and a support ring of non-magnetic material having a relatively low magnetic permeability, the support ring being disposed between the core member and the outer ring. Preferably, the outer ring is spaced from the wire coil in a direction parallel to the longitudinal axis.

[0032] A third aspect of the invention resides in the combination of an actuator according to the first or second aspects of the invention and a housing comprising the recess for receiving the actuator.

[0033] The housing may be made from a material with relatively low magnetic permeability. A wall of the housing is preferably sufficiently thick so as to accommodate the magnetic field generated by the coil without saturating. In this way, the relevant part of the magnetic circuit around the energised coil can be accommodated within the wall of the housing.

[0034] The outer ring may cooperate with a wall of the recess, so as to align, locate or secure the actuator radially within the recess. The housing may include a guide portion of the recess having an inside diameter substantially equal to the outside diameter of the outer ring such that the outer ring is a sliding fit in the guide portion. The guide portion helps to align the actuator within the recess.

[0035] The actuator may be received in the housing such that only the outer ring of the actuator abuts the housing. In this way, the outer ring of the actuator supports the other components of the actuator within the recess, and insertion of the actuator into the recess is straightforward. To this end, the housing may comprise a shoulder at an end of the recess, and the outer pole face of the actuator may abut the shoulder. The actuator is preferably biased against the shoulder.

[0036] In a further aspect of the invention, a fuel injector is provided. The fuel injector comprises an actuator according to the first or second aspects of the invention, or the combination of the third aspect of the invention.

[0037] The when the fuel injector comprises the combination of the third aspect of the invention, the housing may comprise a nozzle holder body of the fuel injector, and the recess may be provided in the nozzle holder body. A significant part of the magnetic circuit of the actuator is preferably carried by the nozzle holder body. The housing may further comprise a valve block and/or a cap nut of the fuel injector, and a part of the magnetic circuit may be carried by the valve block and/or the cap nut.

[0038] Preferred and/or optional features of each of the aspects of the invention may be included in the other aspects also, alone or in appropriate combination.

Brief description of the accompanying drawings

[0039] Reference has already been made to Figures 1 to 3 of the accompanying drawings, in which like reference numerals are used for like parts and in which:

Figure 1 is a schematic cross-sectional view of a known fuel injector having a known solenoid actuator of the dual-pole type;

Figure 2 is an enlargement of a portion of Figure 1, showing the known actuator in greater detail; and

Figure 3 is a schematic cross-sectional view of part of a fuel injector of the type shown in

Figure 1, showing the magnetic field generated in use of the known actuator in the form of magnetic flux lines.

[0040] Preferred embodiments of the present invention will now be described with reference to the remaining accompanying drawings, in which like reference numerals are used for like parts and in which:

Figure 4 is a schematic cross-sectional view of an actuator according to one embodiment of the invention, disposed within a fuel injector; and

Figure 5 is an enlarged, schematic view of part of an actuator according to the invention of the type shown in Figure 4, showing the magnetic field generated in use of the actuator in the form of magnetic field lines.

[0041] Throughout this description, the terms 'upper', 'lower' and so on are used with reference to the orientation of the components in the accompanying drawings. However, it will be appreciated that the actuators described herein can be used in any orientation.

Detailed description of preferred embodiments of the invention

[0042] Referring to Figure 4, in one embodiment of the present invention there is provided a solenoid actuator 200 comprising a generally cylindrical core member 202, having a longitudinal axis labelled 'A'. The core member 202 is made from a soft magnetic material, such as a ferritic iron alloy.

[0043] A first, uppermost portion 204 of the core member 202 has a relatively wide diameter, and a second, intermediate portion 206 of the core member 202 has a relatively narrow diameter. A third, lowermost portion 207 of the core member has a diameter that is slightly smaller than that of the second portion 206. A blind bore 208 extends upwardly from the lower end of the core member 202 towards the first portion 204. The lower end of the core member 202 defines an annular inner pole face 210 of the actuator.

[0044] A wire coil 212, also known in the art as a field coil or winding, is wound around a former 214 carried on the second portion 206 of the core member 202. The former 214 is a sleeve-like element having a U-shaped cross-section, and is preferably of a plastics material so as to insulate the coil 212 from the core member 202. The coil 212 is connected to a power supply (not shown) to supply current to the coil.

[0045] A support ring 216 of non-magnetic material is provided on the third portion 207 of the core member 202 adjacent to the inner pole face 210. The support ring 216 is an interference fit on the core member 202. In the illustrated embodiment, the support ring 216 is of a non-magnetic metallic material, such as austenitic stainless steel. In other embodiments of the invention, the support ring 216 may be of ceramic or plastics material.

[0046] An outer ring 218, also known as a pole piece or pole tip, of soft magnetic material is provided around the support ring 216. The outer ring 218 is fixed to the support ring 216 by an interference fit. In this way, the outer ring 218 is firmly held on the core member 202. A lower surface of the outer ring 218 defines a ring-shaped outer pole face 220 of the actuator 200.

[0047] In this embodiment, the support ring 216 and the outer ring 218 are spaced from the coil 212 and the coil former 214 along a direction parallel to the longitudinal axis A. However, in another embodiment (not shown), the support ring 216 and the outer ring 218 abut the coil former 214. However, in both of these embodiments, the outer ring 218 does not overlap or enshroud the coil 212 in a radial direction.

[0048] In the illustrated embodiment, the support ring 216 has a chamfer on its uppermost inside edge, so as to allow the support ring 216 to be push-fitted on to the third portion 207 of the core member 202 during manufacture of the actuator 200. The core member 202 is provided with an inclined shoulder 222 where the second portion 206 meets the third portion 207. The shoulder 222 is of complementary shape to the chamfer of the support ring 216. The outer ring 218 also has a chamfer 219 on its uppermost inside edge, which assists in allowing the outer ring 218 to be push-fitted onto the support ring 216 during manufacture of the actuator 200. In other embodiments of the invention, the core member 202, the support ring 216 and the outer ring 218 may be connected to one another using alternative connection methods, such as by screw fitting, welding, moulding, sintering, adhesives and so on.

[0049] In Figure 4, the actuator is illustrated in use in a housing comprising a fuel injector 300. In this illustrative embodiment, the fuel injector 300 is of a known type that will be familiar to those skilled in the art, for example from the present applicant's granted European Patent No. EP-B-0767304. The details of the injector 300 will not be described here.

[0050] The fuel injector 300 comprises a nozzle holder body 302 and a valve block 304, together defining a housing for the actuator. A fuel supply line 306 extends through the nozzle holder body 302 and the valve block 304 to convey fuel at high pressure to a tip region (not shown) of the injector 300. In use, the valve block 304 is clamped against the nozzle holder body 302 by way of a cap nut 316. The cap nut 316 can also be considered to be part of the housing.

[0051] The actuator 200 is received within a recess 308 in the nozzle holder body 302. The actuator is a close clearance fit within the majority of the recess 308. However, at the lowermost end of the recess 308, adjacent to the valve block 304, the diameter of the recess 308 is slightly reduced so as to form a guide region 310 for the actuator 200. The outer ring 218 of the actuator 200 is a sliding fit against the guide region 310, so that the longitudinal axis A of the actuator 200 remains parallel to a corresponding longitudinal axis of the injector 300.

[0052] The valve block 304 includes a chamber 312 in an upper end thereof, which opens into the recess 308 in the nozzle holder body 302. The chamber 312 has a diameter that is slightly smaller than the diameter of the guide portion 310, so as to define a shoulder 314 between the valve block 304 and the nozzle holder body 302.

[0053] When the actuator 200 is in place within the recess 308, a peripheral portion of the outer pole face 220 abuts the shoulder 314. Thus the core member 202 of the actuator 200 is supported in position in the recess 308 by virtue of the outer ring 218 and the support ring 216. The actuator 200 is held in place in the recess 308 by a biasing arrangement (not shown), such as a spring or a threaded cap. The biasing arrangement acts on the uppermost end of the core member 202 to apply an axial force to the actuator 200 that presses the outer ring 218 against the shoulder 314.

[0054] The chamber 312 in the valve block 304 houses a disc-shaped armature 230. The armature 230 is rigidly connected to a control element comprising a valve element 232 of the injector 300. The armature 230 is moveable within the chamber 312 along the longitudinal axis A of the actuator 200, and may be guided in such movement by the valve element 232. The armature 230 is biased away from the actuator 200 by biasing means 234 that act on the armature and/or on the valve element 232. The valve element 232 extends into the bore 208 in the core member 202, and the biasing means 234 is housed in the bore 208. If the chamber 312 is filled with fuel in use, the armature 230 may include axial vent holes (not shown) to reduce the drag on movement of the armature 230.

[0055] The inner pole face 210, outer pole face 220 and the lowermost face 224 of the support ring 216 together define a bottom face 226 of the actuator 200. In one embodiment, the inner and outer pole faces 210, 220 and the support ring face 224 are coplanar. This can be achieved by, for example, grinding the bottom face 226 of the actuator 200 during manufacture. In another embodiment, the support ring face 224 may protrude slightly beyond the inner and outer pole faces 210, 220, so as to provide a lift-stop for upward movement of the armature 230. In either case, the support ring face 224, being of more wear-resistant material than the surrounding pole faces 210, 220, prevents excessive wear of the bottom face 226 of the actuator 200 in arrangements where the armature 230 contacts the bottom face 226 at the upper extremity of its movement. Typically, the working distance between the bottom face 226 of the actuator 200 and the uppermost face of the armature 230 is approximately 0.1 mm or less.

[0056] On energisation of the coil 212, a magnetic field is established around the coil 212. Figure 5 shows, schematically and in reduced detail, the distribution of the magnetic flux lines F around the coil 212 in one half of an injector 300 having an actuator 200 of the type shown in Figure 4. Figure 5 represents a cross-sectional view through the injector in a different plane to that shown in Figure 4, so the fuel supply line 306 is not visible in Figure 5. Furthermore, the coil former 214, the biasing means 234 and the cap nut 316 have been omitted from Figure 5 for clarity.

[0057] As is apparent from Figure 5, the magnetic field describes a generally toroidal circuit within the injector 300. The circuit passes axially along a central region of the core member 202, then radially between the first portion 204 of the core member into the nozzle holder body 302. The circuit then follows an axial path within the nozzle holder body 302 and the cap nut (not shown in Figure 5). Some magnetic flux passes in a generally radial direction between the nozzle holder body 302 where it meets the outer ring 218, while some flux passes in a generally axial direction between the outer pole face 220 and the shoulder 314. A substantial portion of the magnetic field is concentrated through the outer ring 218. Said another way, in the relevant part of the magnetic circuit, substantially all of the flux is guided to pass between the housing (comprising the nozzle holder body 302 and the valve block 304) and the outer ring 218.

[0058] The magnetic circuit is completed by the armature 230. The magnetic field lines lie in a generally axial direction between the outer pole face 220 and the armature 230, and between the armature 230 and the inner pole face 210. Since the support ring 216 has relatively low magnetic permeability compared to the outer ring 218 and the core member 202, the amount of magnetic flux in the support ring 216 is very low. Thus the support ring 216 advantageously serves to direct the magnetic field generated by the coil 212 into the armature 230, and prevents a magnetic short circuit in which the magnetic field would pass directly from the support ring 216 back to the core member 202. The chamfer 219 on the inside edge of the outer ring 218 also helps to help direct the magnetic circuit towards the armature 230.

[0059] When the coil 212 is energised, the armature 230 is biased to move towards the bottom face 226 of the actuator 200, so as to reduce the length of the magnetic circuit. The support ring 216 may serve as a lift stop for upward movement of the armature 230. When the current supplied to the coil 212 is stopped, the armature 230 is free to move away from the actuator 200 under the action of the biasing means 234. In this way, by energising and de-energising the coil, the position of the armature 230 and hence the control member 232 can be controlled.

[0060] It will be appreciated that, since the magnetic field lines between the actuator 200 and the armature 230 are substantially in the axial direction, the actuator 200 is optimised to maximise the force applied to the armature 230 on energisation of the coil 212.

[0061] It is to be noted that the nozzle holder body 302 is not made from a material that is optimised for carrying a magnetic field. Typically, the nozzle holder body 302 is made from a hard steel material with a relatively low magnetic permeability. Use of a mechanically strong material for the nozzle holder body 302 is required in order to prevent rupture of the holder body 302 around the high-pressure fuel supply line 306 (not shown in Fig 5).

[0062] However, by virtue of the design of the actuator 200 of the invention, the nozzle holder body 302 is utilised to carry the magnetic field around the circuit. It is not therefore necessary to provide the actuator 200 with a sleeve of magnetic material between the coil 212 and the nozzle holder body 302. It will be appreciated that, because the material of the nozzle holder body 302 has a lower magnetic permeability compared to the material of the core member 202, the cross-sectional area of the nozzle holder body 302 through which the magnetic circuit passes must be correspondingly larger than the area of the inner pole face 210. This is achieved by virtue of the greater radius, and hence circumference, of the respective part of the nozzle holder body 302 compared to the inner pole face 210, thereby providing greater cross-sectional area per unit of radial thickness at that radius.

[0063] Advantageously, therefore, the size of the coil 212 and the core member 202 can be maximised and optimised to provide the maximum force to the armature 230 within the constraints imposed by the size of the recess 308. In one example, the diameter of the recess is 10 mm, and the diameter of the inner pole face 210 in an actuator according to the invention is approximately 1 mm larger than would be possible in a known actuator of the type shown in Figures 1 to 3 having the same overall outer diameter. In another example, the core member diameter is approximately 20% larger than would be possible in the actuator of Figures 1 to 3. Thus the cross-sectional area of the core member is approximately 40% larger, and the force applied to the armature is at least approximately 25% greater than in the prior art actuator.

[0064] The increased force available from an actuator 200 of the present invention can, for example, be utilised to provide a greater lift force to a valve member attached to the armature 230 without increasing the outside diameter of the actuator 200. Such an arrangement can be useful in fuel injectors operating at particularly high pressure, where it may be necessary to overcome the high biasing load necessary to keep the valve member in a closed position against the high pressure, or to provide a greater sealing load.

[0065] In another example, when it is not necessary to provide an increased force to a control element, the increased magnetic field available from the actuator 200 can be exploited by allowing an armature 230 of reduced thickness to be used to transfer the specified amount of force to the control element. In this case, the moving mass of the armature 230 can be reduced, which in turn allows the armature 230 and hence the control element to move more rapidly. Such an arrangement can be advantageous in fuel injectors where it is desirable to achieve fine control of small injection volumes.

[0066] It is desirable to ensure that the outer ring 218 abuts the guide region 310 of the nozzle holder body 302 as closely as possible, so as to maximise the connection of magnetic flux between the nozzle holder body 302 and the outer ring 218. However, it is not necessary to provide a mechanical connection between the outer ring 218 and the nozzle holder body 302 to achieve sufficient connection of flux from the nozzle holder body 302 to the outer ring 218. Advantageously, this means that the actuator 200 can be easily fitted into the recess 308 during manufacture of the injector 300.

[0067] In the illustrated embodiment, the armature 230 can be considered to be part of the actuator arrangement 200, but it will be appreciated that the armature 230 is not connected to the actuator arrangement 200 and may conveniently be manufactured as part of the injector 300.

[0068] In an alternative embodiment of the invention (not shown), the coil 212 is encapsulated in a plastics material so as to provide electrical insulation for the coil 212. In some circumstances, the plastics material can soften due to the relatively high temperatures and pressures that prevail in the actuator, in use. However, since there are no gaps between the core member 202, the support ring 216 and the outer ring 218 at the bottom face 225 of the actuator, there is no possibility of the plastics material being extruded from the bottom face 226 of the actuator as might otherwise occur, which might interfere with armature movement.

[0069] The coil former 214 is made from a non-magnetic material. Therefore, in another conceivable embodiment of the invention, the coil former 214 includes a part that extends to the bottom face 226 of the actuator, and the support ring 216 comprises this downwardly-extending part of the coil former 214.

[0070] In a further variant of the invention, the coil 212 and/or the coil former 214 may be shaped so as to abut or cooperate with the chamfer 219. In such a case, the coil 212 and/or the coil former 214 may have a generally trapezoidal cross-section. In this variant, a minor portion only of the coil 212 may partially overlap the outer ring 218 in a direction parallel to the longitudinal axis A of the injector. Nevertheless, substantially all of the magnetic circuit around the coil 212 still passes through the nozzle holder body 302.

[0071] Although the invention has been described with reference to application in a fuel injector, it will be appreciated that an actuator according to the present invention could be employed in other applications where an actuator is housed in a housing with some degree of magnetic permeability, even though the housing is not specifically designed to be part of a magnetic circuit. Rather, the actuator is designed to utilise the housing to complete the magnetic circuit, thereby allowing the size of the coil and the core member to be maximised. The invention is particularly useful where it is desirable to provide the actuator as a separate component to be inserted into a housing during assembly of a device.

[0072] In one specific further example, an actuator according to the invention is used in a fuel injection pump, for example to actuate a control valve of the pump.

[0073] It will be appreciated by a person skilled in the art that the present invention is not limited to the specific embodiments and exampled described herein, and that many variations and modifications could be made without departing from the scope of the invention as defined in the appended claims.

Claims

1. A solenoid actuator (200) for use in a fuel injection system, the actuator (200) comprising:

    a generally cylindrical core member (202) having a longitudinal axis (A) and defining, at an end thereof, an inner pole face (210) of the actuator;
    a wire coil (212) disposed around the core member (202) and arranged to be connected to a power source in use so as to generate a magnetic field around the coil;
    an outer ring (218) arranged concentrically around the end of the core member (202) and defining an outer pole face (220) of the actuator, the outer and inner pole faces (210, 220) being substantially co-planar; and
    a support ring (216) of non-magnetic material having a relatively low magnetic permeability, the support ring (216) being disposed between the end of the core member (202) and the outer ring (218).

2. The actuator of Claim 1, being receivable within a housing (302, 304) and being arranged such that, in a part of a magnetic circuit defined by the magnetic field, substantially all of the magnetic flux is guided to pass between the outer ring (218) and the housing (302, 304) in use of the actuator.

3. The actuator of Claim 1 or Claim 2, wherein the outer ring (218) and/or the core member (202) are made from a soft magnetic material having a relatively high magnetic permeability.

4. The actuator of any preceding Claim, wherein the outer ring (218) is fixed to the core member (202) by way of the support ring (216).

5. The actuator of any preceding Claim, further comprising an armature (230) moveable in a direction parallel to the longitudinal axis (A) in response to the magnetic field in use of the actuator.

6. The actuator of Claim 5, wherein, in use of the actuator, the magnetic field passes between the armature (230) and the inner and outer pole faces (210, 220) in a direction substantially parallel to the longitudinal axis (A).

7. The actuator of Claim 5 or Claim 6, wherein the magnetic field is directed into the armature (230) by the support ring (216).

8. The actuator of any preceding Claim, wherein the outer ring (218) is spaced from the wire coil (212) in a direction parallel to the longitudinal axis (A).

9. In combination, an actuator (200) according to any preceding claim, and a housing (302, 304) comprising a recess (308) for receiving the actuator.

10. The combination of Claim 9, wherein the housing (302, 304) is made from a material with relatively low magnetic permeability.

11. The combination of Claim 9 or Claim 10, wherein the housing (302, 304) includes a guide portion (310) of the recess (308) having an inside diameter substantially equal to the outside diameter of the outer ring (218) such that the outer ring (218) is a sliding fit in the guide portion (310).

12. The combination of any of Claims 9 to 11, wherein the actuator (200) is received in the housing (302, 304) such that only the outer ring (218) of the actuator abuts the housing (302, 304).

13. The combination of Claim 12, wherein the housing (302, 304) comprises a shoulder (314) at an end of the recess (308), and wherein the outer pole face (220) of the actuator (200) abuts the shoulder (314).

14. A fuel injector (300) comprising an actuator according to any of Claims 1 to 9 or the combination of any of Claims 10 to 13.

15. A fuel injector (300) comprising the combination of any of Claims 10 to 13, wherein the housing comprises a nozzle holder body (302), and wherein the recess (308) is provided in the nozzle holder body (302).

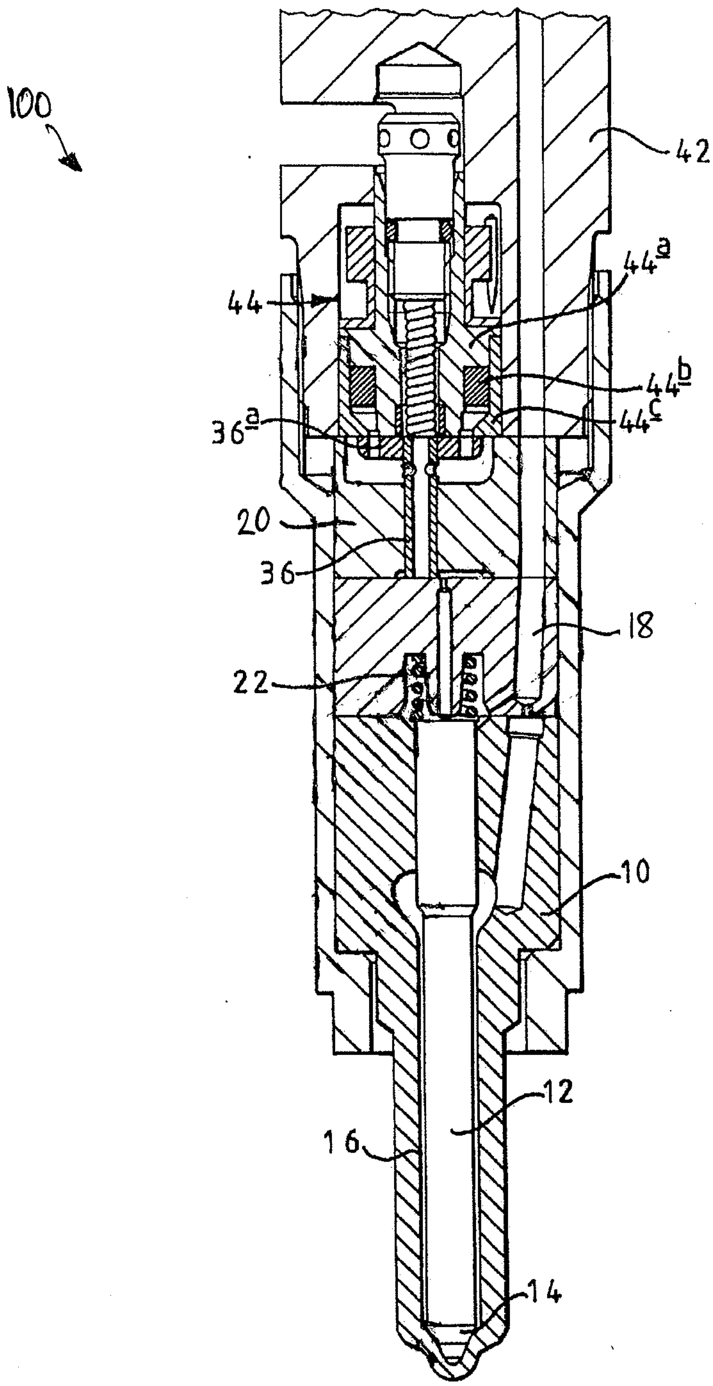

FIGURE 1

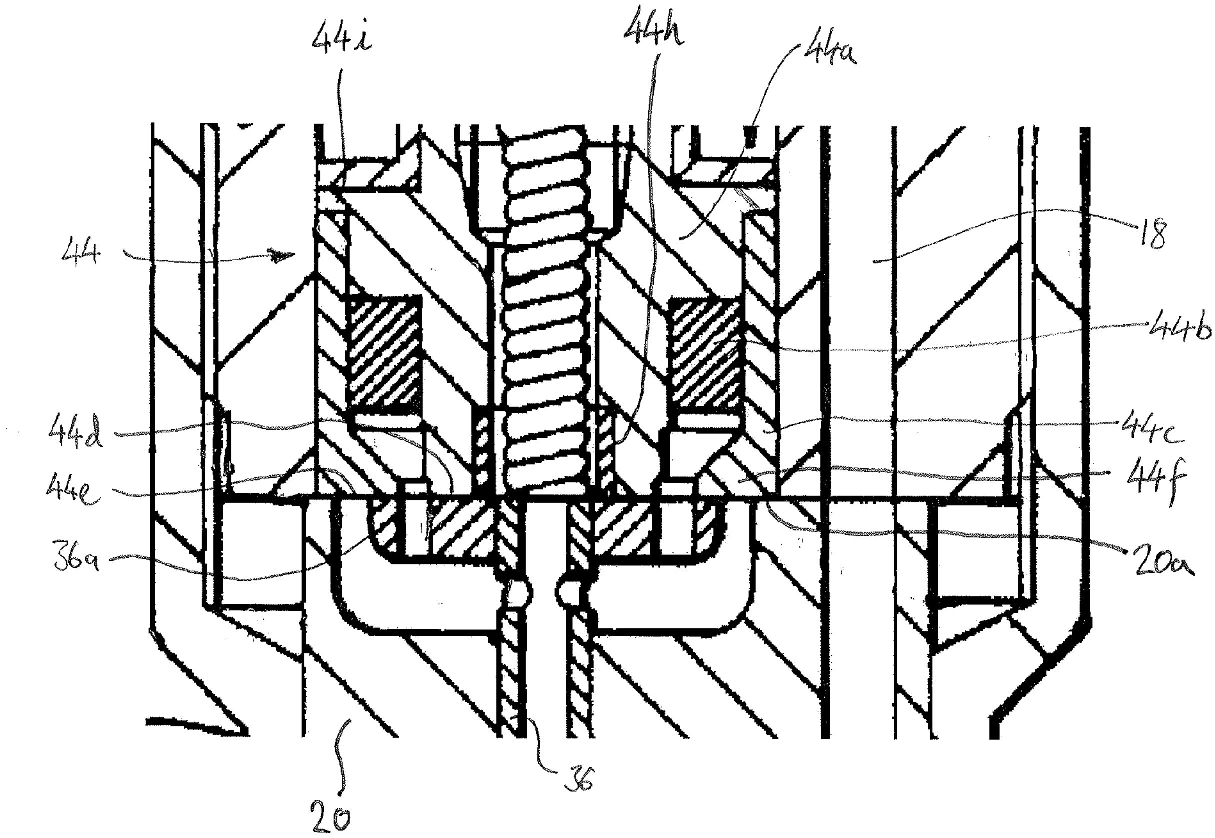

FIGURE 2

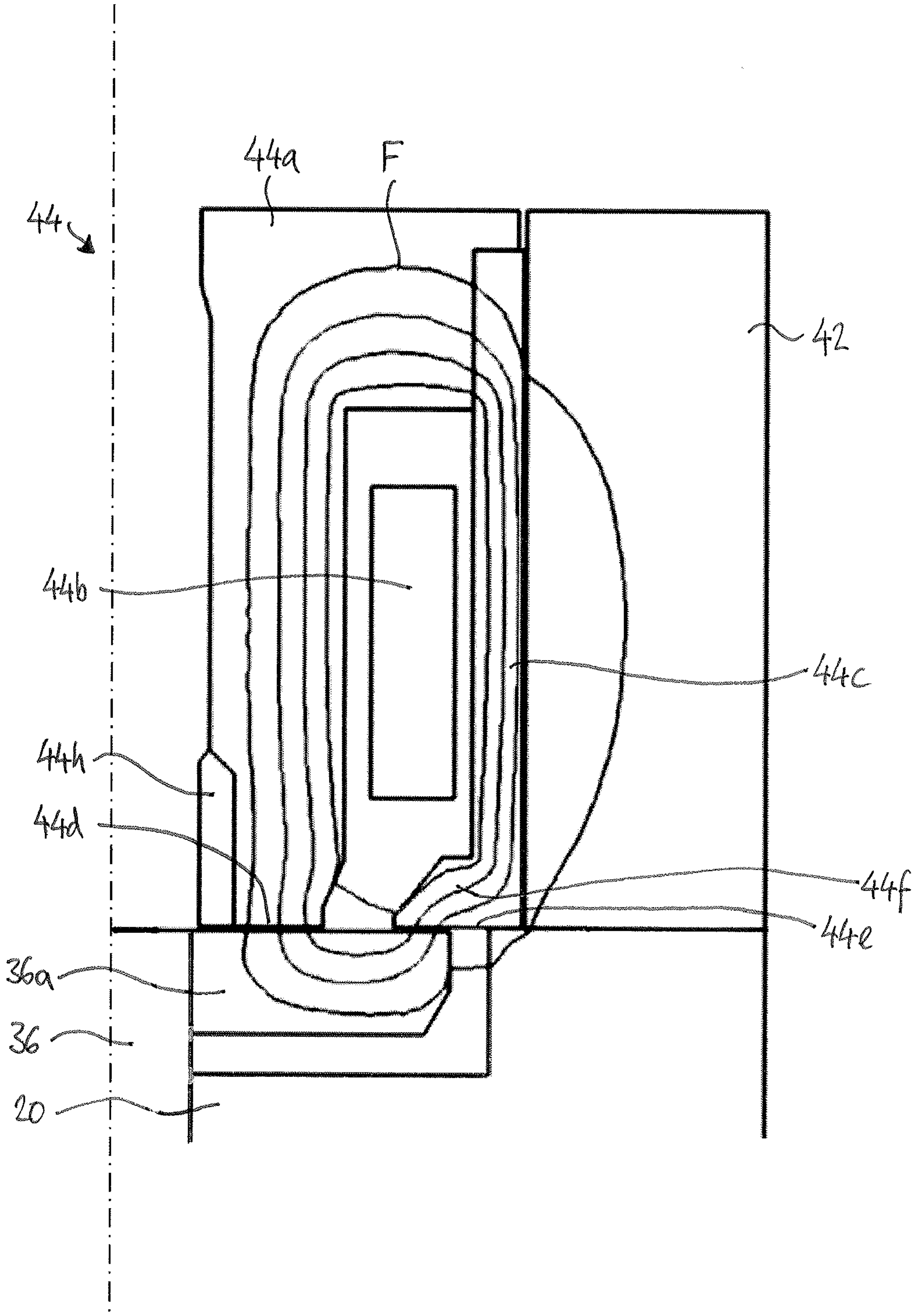

FIGURE 3

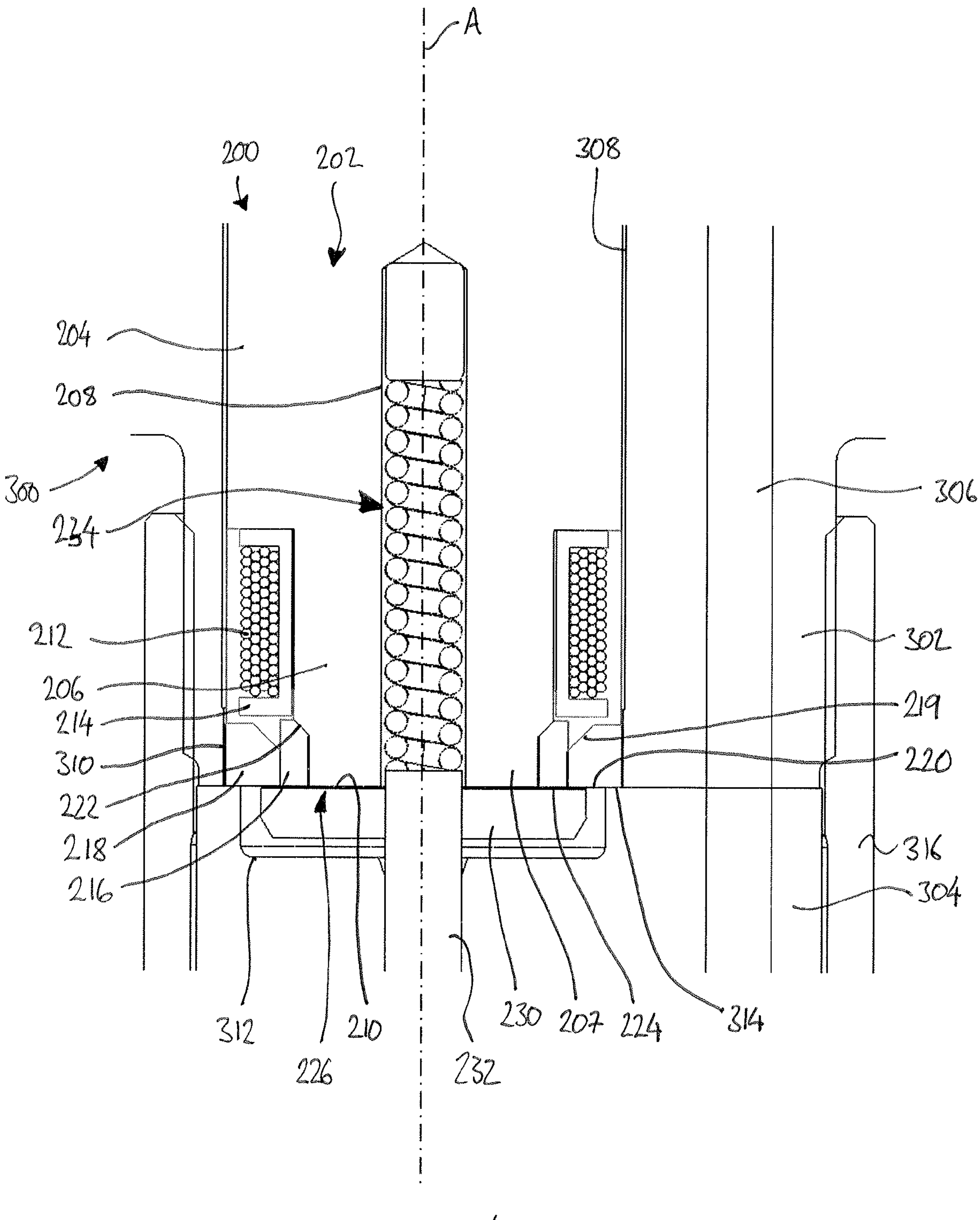
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FIGURE 4

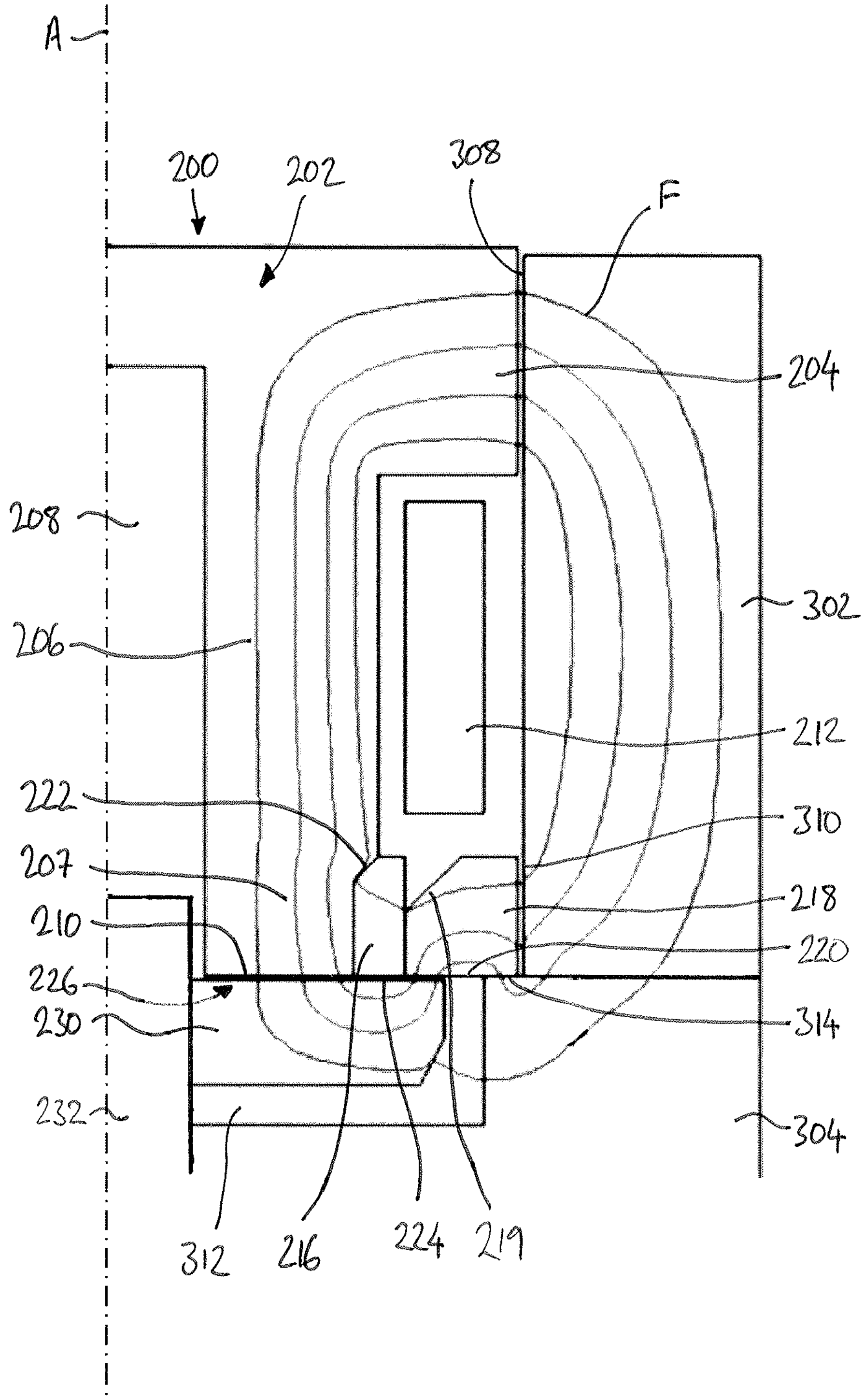
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FIGURE 5

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EUROPEAN SEARCH REPORT

Application Number
EP 09 17 5220

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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
Munich	13 April 2010	Torle, Erik

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