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(54) **Solenoid actuator**

(57) A solenoid actuator with a double action for a fuel injector comprising an armature (39), a first electromagnetic coil (33), a second electromagnetic coil (29) and a permanent magnet (27). When the first electromagnetic coil (33) is energised in use an electromagnetic

field is produced which acts to move the armature (39) in a first direction. When the second electromagnetic coil (29) is energised in use the electromagnetic field produced is opposite to the magnetic field of the permanent magnet thereby cancelling out that field which acts to move the armature in a second direction.

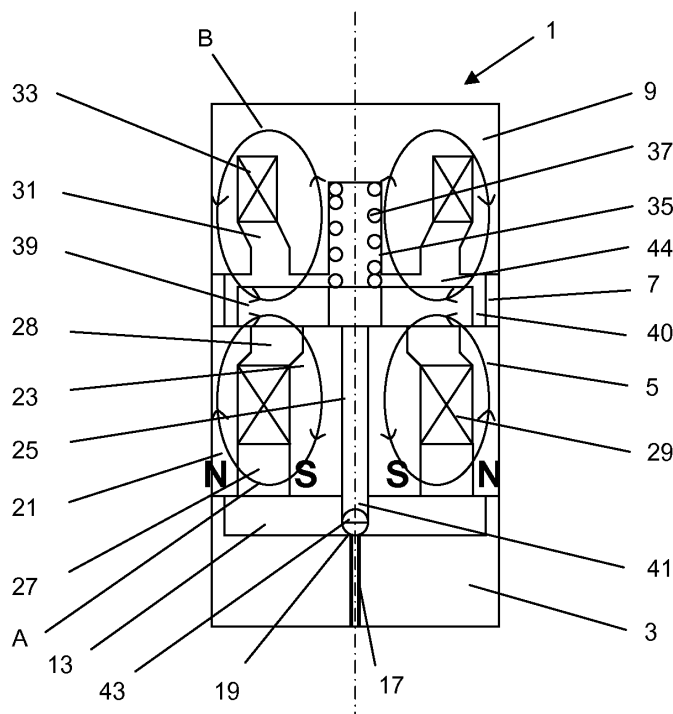


Figure 1

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Description

INTRODUCTION

[0001] The present invention relates to solenoid actuators for use in fuel injectors for internal combustion engines. In particular, the present invention relates to a double acting solenoid actuator for driving a discharge valve which is used to control the fuel pressure within a needle control chamber. The actuator provided with two electromagnetic coils used to enable movement of the actuator armature in a first direction and a permanent magnet to enable movement of the actuator armature in a second direction, opposite to the first direction.

BACKGROUND

[0002] In known fuel injectors for diesel engines a conventional solenoid actuator drives a discharge valve which is used to control the opening of the injector needle. An injector of this type is described in EP 1 163 440. The injector utilises a single acting solenoid actuator comprising an armature which passes through an electromagnetic coil and is connected to the discharge valve member. In order to open the discharge valve, an electrical current is supplied to the electromagnetic coil and the resultant electromagnetic field draws the armature into the coil such that the connected discharge valve member is moved away from the discharge valve seat. In order to close the discharge valve, the supply of electrical current to the electromagnetic coil is stopped and the armature is forced out of the coil under the action of a helical compression spring until the valve member comes to rest against the valve seat.

[0003] Development of fuel injection technology has resulted in an increase in the pressure of fuel being supplied to solenoid fuel injectors. Utilising current actuator arrangements, in order to produce the force required to keep the discharge valve closed against fuel at the increased pressure (when no fuel injection is to be made) it would be necessary to provide a much larger helical compression spring. As a consequence, the size of the actuator would need to be increased to overcome the preload of the spring. Such an increase in size cannot be tolerated because of the limitations on the overall size of the injector. Furthermore, the response time of the actuator would be increased and the actuator would be more costly.

[0004] There have been attempts to overcome this problem with different solenoid designs. EP 1 066 467 describes a solenoid actuator having an armature with an electromagnetic coil located on either side of it such that an electrical current is supplied to a first coil to move the armature and the connected discharge valve member into a closed position and an electrical current is supplied to the second coil to move the armature and the connected discharge valve member into an open position. Such an actuator can provide the necessary closing force in a

relatively small size. However, because a supply of electrical current must be provided to the first coil to maintain the discharge valve in the closed position the arrangement is not energy efficient. This is because for the greater portion of the operational life of an injector the discharge valve remains in the closed position. Consequently, there is a need for an improved solenoid actuator that is able to operate in an injector supplied with fuel at an increased pressure and that is electrically efficient.

STATEMENTS OF INVENTION

[0005] According to a first aspect of the present invention there is provided a solenoid actuator with a double action for a fuel injector comprising, an armature, a first electromagnetic coil which, when energised in use, has an electromagnetic field which acts to move the armature in a first direction and a second electromagnetic coil, characterised in that the polarity of the second electromagnetic coil when it is energised in use is opposite to the magnetic field of a permanent magnet which magnetic field acts to move the armature in a second direction. This arrangement is advantageous because the permanent magnet can be used to retain the actuator in one position without the need for application of current to an electromagnetic coil, thereby yielding benefits in reduced electrical consumption.

[0006] In a preferred embodiment, the solenoid actuator further comprises a first core associated with the first electromagnetic coil and a second core associated with the second electromagnetic coil and the permanent magnet, wherein, in use, the magnetic fields pass through the first and second cores and wherein there is provided an air gap between the first and second cores, within which air gap the armature is located.

[0007] Also, the solenoid actuator may further comprise a valve member attached to the armature, wherein, in use, movement of the armature moves the valve member and causes a valve to be opened or closed.

[0008] According to a second aspect of the present invention there is provided a method of operating a solenoid actuator wherein the polarity of the electromagnetic field generated by the first electromagnetic coil is identical to the polarity of the electromagnetic field generated by the second electromagnetic coil. In this method of operation, the solenoid actuator is characterised by having a relatively high operating force.

[0009] According to a third aspect of the present invention there is provided an alternative method of operating a solenoid actuator wherein the polarity of the electromagnetic field generated by the first electromagnetic coil is opposite to the polarity of the electromagnetic field generated by the second electromagnetic coil. In this method of operation, the solenoid actuator is characterised by having a relatively high operating speed.

FIGURES

[0010] Two embodiments of the present invention will now be described with reference to the accompanying drawings in which:

Figure 1 is a schematic cross-sectional view of an actuator according to a first preferred embodiment of the present invention configured to produce a high force; and

Figure 2 is a schematic cross-sectional view of an actuator according to a second preferred embodiment of the present invention configured to have a high speed of operation.

SPECIFIC DESCRIPTION

[0011] Figure 1 illustrates a solenoid actuated discharge valve assembly 1, according to the first preferred embodiment of the present invention. The assembly 1 is cylindrical and it is split into four cylindrical sections. In this description the term 'upper' will be used to describe a part of the assembly 1 located distally from the nozzle of the fuel injector into which it is to be fitted and the term 'lower' will be used to describe a part of the assembly 1 that is located proximally to the nozzle of that fuel injector.

[0012] The assembly 1 comprises, in axial order from the lower side to the upper side, a discharge valve housing 3; a lower electromagnetic coil housing 5; a spacer 7; and an upper electromagnetic coil housing 9.

[0013] The discharge valve housing 3 is provided on its upper face with a cylindrical recess 13. A fuel outlet passage 17 passes through the valve housing 3, from the upper face to the lower face. The fuel outlet passage 17 is aligned coaxially with the longitudinal axis of the assembly 1 and is provided at its upper end with a valve seat 19.

[0014] The lower electromagnetic coil housing 5 comprises two parts. A hollow, circular cross-section, tubular part 21 and a circular cross-section cylindrical core 23 which is located within the tubular part 21 and aligned coaxially with the longitudinal axis of the assembly 1. The core 23 is provided with a co-axially aligned bore 25 from its upper face to its lower face. When the core 23 is located within the tubular part 21 there is an annular space 24 between them. Located within the annular space 24, between the tubular part 21 and the core 23 is a hollow cylindrical permanent ring magnet 27. The radially outer face of the permanent ring magnet 27 mates with the radially inner face of the tubular part 21 and the radially inner face of the permanent ring magnet 27 mates with the radially outer face of the core 23. The lower face of the permanent ring magnet 27 is aligned with the lower faces of the tubular part 21 and the core 23. The permanent ring magnet 27 extends in an axial direction towards the upper face of the lower coil housing 5. The distance by which it extends, i.e. its thickness, is dependent upon

the flux concentration that is required from the permanent ring magnet 27 in order to be able to close the discharge valve against the fuel pressure and to maintain the discharge valve in a closed position.

[0015] Above the permanent ring magnet 27, within the annular space 24 is the lower electromagnetic coil 29. The lower surface of the lower electromagnetic coil 29 contacts the upper surface of the permanent ring magnet 27.

[0016] Abutting the upper surface of the lower electromagnetic coil housing 5 and the lower surface of the upper electromagnetic coil housing 9 is a spacer 7. The spacer 7 is a hollow cylindrical ring and is made of a non-magnetic material, to prevent magnetic flux, from the lower electromagnetic coil 29 and the permanent ring magnet 27, passing through the lower electromagnetic coil housing 5 and into the upper electromagnetic coil housing 9.

[0017] The upper electromagnetic coil housing 9 is provided with a coaxially aligned blind annular recess 31 which passes from the lower face towards the upper face of the upper electromagnetic coil housing 9. Within the annular recess 31 is contained the upper electromagnetic coil 33. The upper face of the upper electromagnetic coil 33 is located adjacent to the upper, blind, face of the recess 31. The lower surface of the coil 33 is spaced away from the lower surface of the upper electromagnetic coil housing 9, such that an air gap 32 is created within the recess 31. The upper electromagnetic coil housing 9 is also provided with a blind cylindrical recess 35 which extends coaxially from the lower surface of the upper electromagnetic coil housing 9. Within the recess 35 there is located a helical compression spring 37 which in an uncompressed state extends outside of the recess 35. At its upper end, the spring 37 presses against the upper, blind, face of the recess 35. At its lower end the helical compression spring 37 presses against an armature 39.

[0018] The armature 39 is cylindrical and is aligned coaxially within the assembly 1. The armature 39 is located within a cylindrical recess 40 created between the lower electromagnetic coil housing 5 and the upper electromagnetic coil housing 9 by the spacer 7. The thickness of the armature 39 is less than the axial distance between the upper face of the lower electromagnetic coil housing 5 and the lower face of the upper electromagnetic coil housing 9.

[0019] A cylindrical discharge valve member 41 is attached to the lower surface of the armature 39. The discharge valve member 41 is coaxially aligned within the assembly 1 and is slideable within the bore 25 provided in the core 23 of the lower electromagnetic coil housing 5. At its lower end the discharge valve member 41 is provided with a hemi-spherical discharge valve face 43 that is shaped to fit against the discharge valve seat 19, that is provided on the valve housing 3, such that when the discharge valve face 43 is seated against the discharge valve seat 19 a fluidtight seal is created which

prevents the flow of fuel through discharge passageway 17.

[0020] In order to avoid magnetic leaks, there is a non-magnetic area below the permanent ring magnet 27, provided by the recess 13, and a non-magnetic area above the magnet 27, provided by the non-magnetic spacer 7.

[0021] In operation, when there is no injection of fuel being made from the fuel injector, the armature 39 is held in its lowermost position by the force resulting from the magnetic field created by the permanent ring magnet 27. The magnetic field from the permanent ring magnet is shown in the lower half of Figures 1 and 2 and identified with the letter A. In the lowermost position, the discharge valve face 43 is seated against the discharge valve seat 19 and no fuel passes through the discharge passageway 17. As a result there is no decrease in the fuel pressure within the needle control chamber, and the injector needle remains in a closed position.

[0022] The permanent ring magnet 27 is configured so that it produces a magnetic field in a first magnetic circuit A which passes through the armature 39 and the air gap 42. The magnetic field in the magnetic circuit A produces the force which, acting downwardly and in combination with the downwards force from the helical compression spring 37, holds the armature 39 in the lowermost position, as shown in Figure 1 (although, it should be noted that the magnetic field alone can provide the necessary force to move the armature into the lowermost position and retain it in that position). In this preferred embodiment the direction of the magnetic circuit A in the permanent ring magnet 27 is from the radially outer side of the permanent ring magnet 27 to the radially inner side of the permanent ring magnet 27, the flux travelling upwardly on the radially outer side. The magnetic circuit A passes through the armature 39 and the air gap 44, wherein the magnetic flux is travelling upwardly on the radially outer side.

[0023] When it is desired to make an injection of fuel from the fuel injector, an electrical current is supplied to the lower electromagnetic coil 29, such that a lower electromagnetic field is generated. The electromagnetic coil 29 is configured to produce an electromagnetic field which cancels out the magnetic field of the permanent magnet 27. At the same time, or with a specified delay, an electrical current is supplied to the upper electromagnetic coil 33, such that an upper electromagnetic field, having a second magnetic circuit B, is generated. The magnetic circuit B passes through the armature 39 and the air gap 44, wherein the flux is travelling downwardly on the radially outer side. The upper electromagnetic field produces a force which moves the armature 39 into its uppermost position, such that the discharge valve is opened. When the discharge valve is opened fuel can leave the fuel injector needle control chamber allowing the fuel injector needle to move upwards, away from a valve seat, thereby opening the fuel injection valve.

[0024] When it is desired to cease the injection of fuel through the fuel injector, the electrical supplies to the

upper and lower electromagnetic coils 33, 29 are stopped. The downwardly acting force on the armature 39 generated by the magnetic field from the permanent ring magnet 27 in combination with the helical compression spring 37 then act to move the armature downwards so that the discharge valve face 43 is located against the discharge valve seat 19, such that the discharge valve is closed. The pressure with the fuel injector needle control chamber then builds to a point at which the fuel injector needle is moved downwards, against a valve face, thereby closing the fuel injection valve.

[0025] Figure 2 illustrates the second preferred embodiment of the present invention which is structurally largely the same as the first embodiment. Equivalent features have been given the same reference numerals prefixed with the number 2.

[0026] The operation of the second embodiment differs in that a magnetic circuit C in the upper electromagnetic coil 233 passing through the armature 239 and the air gap 244, is in the opposite sense to the magnetic circuit B of the first embodiment. The magnetic circuit C passes through the armature 239 and the air gap 244, wherein the magnetic flux is travelling upwardly on the radially outer side.

Claims

1. A solenoid actuator with a double action for a fuel injector comprising, an armature (39), a first electromagnetic coil (33) which, when energised in use, has an electromagnetic field which acts to move the armature (39) in a first direction and a second electromagnetic coil (29), **characterised in that** the polarity of the second electromagnetic coil (29) when it is energised in use is opposite to the magnetic field of a permanent magnet (27) which magnetic field acts to move the armature (39) in a second direction.
2. A solenoid actuator as claimed in claim 1, further comprising a first core (9) associated with the first electromagnetic coil (33) and a second core (23) associated with the second electromagnetic coil (29) and the permanent magnet (27), wherein, in use, the magnetic fields pass through the first and second cores (9, 23) and wherein there is provided an air gap (40) between the first and second cores (9, 23), within which air gap (40) the armature (39) is located.
3. A solenoid actuator as claimed in claim 1 or claim 2 further comprising a valve member (41) attached to the armature (39), wherein, in use, movement of the armature (39) moves the valve member (41) and causes a valve to be opened or closed.
4. A method of operating a solenoid actuator according to any one of claim 1, claim 2 or claim 3, wherein the polarity of the electromagnetic field generated by the

first electromagnetic coil (33) is identical to the polarity of the electromagnetic field generated by the second electromagnetic coil (29).

5. A method of operating a solenoid actuator according to any one of claim 1, claim 2 or claim 3, wherein the polarity of the electromagnetic field generated by the first electromagnetic coil (33) is opposite to the polarity of the electromagnetic field generated by the second electromagnetic coil (29).

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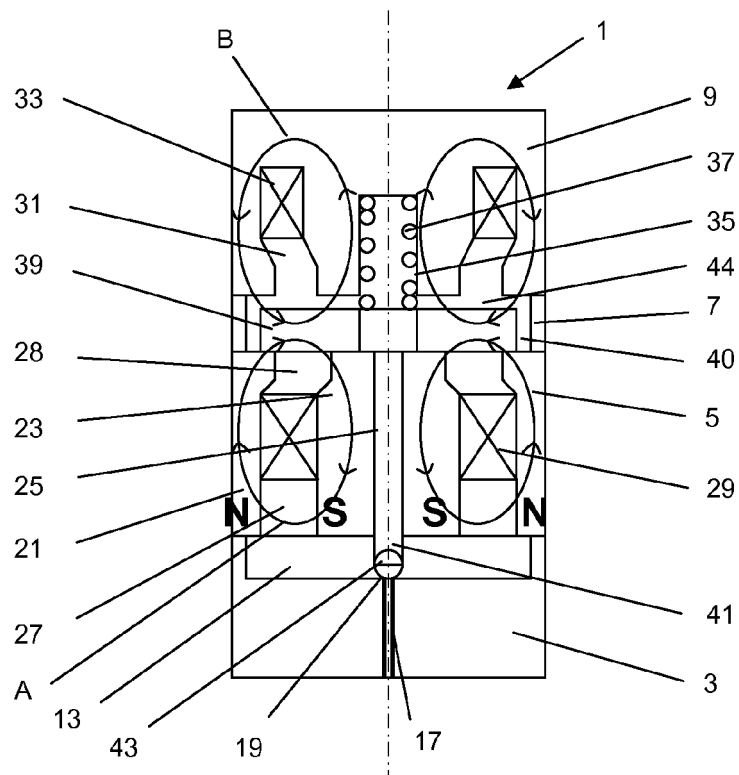


Figure 1

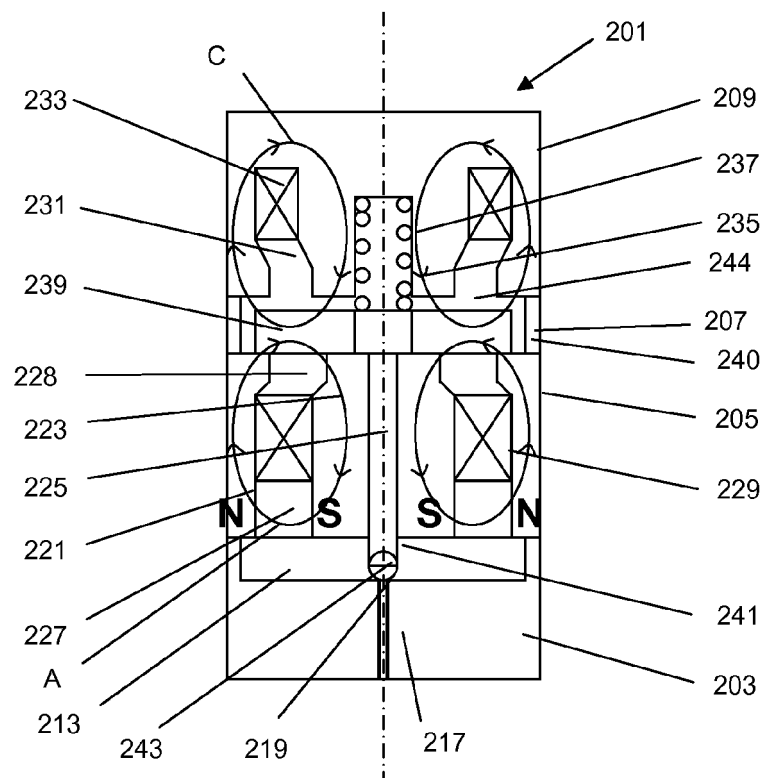


Figure 2



EUROPEAN SEARCH REPORT

Application Number
EP 08 17 0602

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	GB 2 447 769 A (BIFOLD FLUIDPOWER LTD [GB]) 24 September 2008 (2008-09-24) * abstract * * page 6, line 10 - last line ; figure 5 *	1-5	INV. H01F7/16
A	US 5 351 893 A (YOUNG NIELS O [US]) 4 October 1994 (1994-10-04) * column 8, line 4 - line 37 * * column 9, line 9 - line 16 * * column 10, line 36 - line 4; figure 1 *	1-5	ADD. H01F7/122 F02M63/00
			TECHNICAL FIELDS SEARCHED (IPC)
			H01F
The present search report has been drawn up for all claims			
Place of search The Hague		Date of completion of the search 6 March 2009	Examiner Marti Almeda, Rafael
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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EPO FORM 1503 03.82 (P4/C01)

**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

EP 08 17 0602

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06-03-2009

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
GB 2447769	A	24-09-2008	NONE	

US 5351893	A	04-10-1994	NONE	

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

REFERENCES CITED IN THE DESCRIPTION

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- EP 1066467 A [0004]