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(54) Fuel injector

(57) A fuel injector (100; 200; 300) for an internal combustion engine is disclosed. The injector includes a slave piston (130; 230; 330) provided with a control bore (144; 244; 344) and associated with a valve needle (110; 210; 310), such that movement of the slave piston causes movement of the valve needle. An end of the slave piston remote from the valve needle is exposed to fuel pressure in a control chamber (152; 252; 352) of the injector, in use. A control piston (148; 348) is operable to move relative to the slave piston so as to control fuel flow through first and second control ports that connect the control bore to a high-pressure fuel supply and a low-pressure drain respectively. By suitable positioning of the control piston, the valve needle can be biased in an opening direction and in a closing direction and, optionally, the valve needle can be held in one or more intermediate positions between its fully-lifted and fully-seated positions. Proportional control of the position and velocity of the valve needle is possible, and a low-force actuator can be used to control the valve needle.

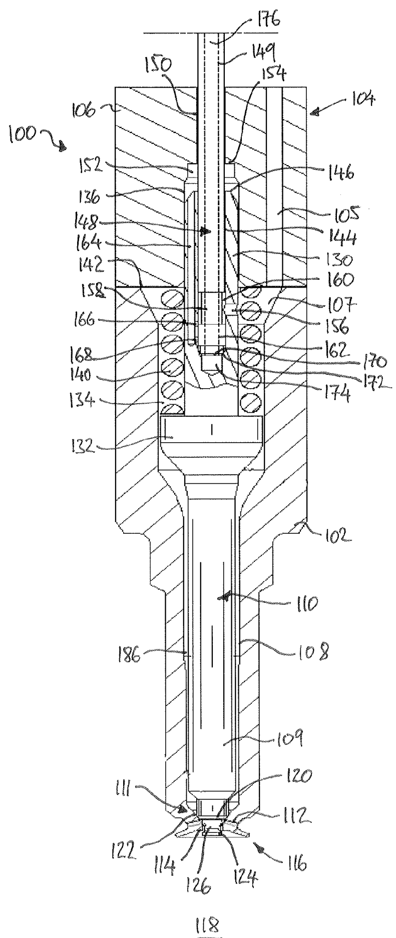

FIGURE 2

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Description

[0001] The present invention relates to a fuel injector suitable for use in an internal combustion engine. In particular, the invention relates to the control of a valve needle in a fuel injector.

Background to the invention

[0002] In an internal combustion engine, it is known for a fuel pump to supply fuel to a high-pressure accumulator, or common rail, from which it is delivered into each cylinder of the engine by means of a dedicated fuel injector. Typically, a fuel injector has an injection nozzle that is received within a bore provided in a cylinder head of the cylinder; and a valve needle that is actuated to control the release of high-pressure fuel into the cylinder from spray holes provided in the nozzle. It is also known to use fuel injectors of this type in other types of fuel injection systems, such as electronic unit injector and electronic unit pump systems.

[0003] Common rail fuel injectors have historically used a hydraulic servo mechanism (e.g. a power assistance) in order to open and close the needle. Examples of such mechanisms are described in the present Applicant's European Patent Application Publication EP-A-0647780 and European Patent Publication EP-B-0740068.

[0004] A solenoid-actuated hydraulic servo fuel injector such as that described in EP-B-0740068 is illustrated in Figure 1. The fuel injector 1 comprises a nozzle body 3 defining a blind bore 5 that terminates at a nozzle region 7; and an elongate valve needle 9 having a tip region 11 that is slidable within the bore 5, such that the tip region 11 can engage and disengage a valve seat 13 defined by an inner surface of the nozzle 7. The nozzle 7 is provided with one or more apertures (or spray holes; not shown) in communication with the bore 5. Engagement of the tip 11 with the valve seat 13 prevents fluid escaping from the nozzle body 3 through the apertures, and when the tip 11 is lifted from the valve seat 13, fluid may be delivered through the apertures into an associated engine cylinder (not shown).

[0005] A control chamber 21 for the valve needle 9 communicates with a high pressure fuel line 17 through a restrictor 23, with an end of the valve needle 9 being exposed to fuel pressure in the control chamber 21. A control valve for the control chamber 21, including a valve member 37, is operable to control whether fuel pressure within the control chamber 21 is at a relatively high level, in which case the valve needle 9 remains seated against the valve seat 13 and no injection takes place, or whether fuel pressure is reduced to a sufficiently low level to allow the valve needle 9 to lift from the valve seat 13 to commence injection through the apertures. As the fuel passes through the apertures, the pressure drop across the apertures causes the fuel to become atomised, which is advantageous for efficient combustion. A solenoid actuator 45 is provided to control movement of the valve member 37 via an armature (not labelled in Figure 1).

[0006] A solenoid-actuated hydraulic servo mechanism such as that of Figure 1 means that a low force control valve 37 can be used to switch the high forces on the valve needle 9. With low forces on the control valve 37, a relatively inexpensive, compact and simple solenoid can give a suitably fast enough response in the injector. It is also possible to use an actuator other than a solenoid actuator, such as a piezoelectric actuator, in an injector of the type shown in Figure 1.

[0007] In such an injector, the valve needle operates in a bi-polar manner. In other words, when movement of the valve needle is required, a hydraulic force imbalance is created that rapidly drives the needle in one direction or the other until movement of the needle is arrested. Opening movement of the valve needle is arrested at a full lift position by an abutment or lift stop (embodied as a plate 25 in the injector of Figure 1). Closing movement of the valve needle is arrested when the tip engages with the valve seat.

[0008] Such an arrangement is advantageous when it is desirable to open and close the valve needle both quickly and completely. For example, when the valve needle is inwardly opening and the apertures are downstream of the valve seat, as is the case in the known injector of Figure 1, when the valve needle is in close proximity to the valve seat, the flow of fluid through the apertures can be throttled. This can result in inadequate atomisation of the fuel. The servo arrangement shown in Figure 1 helps to ensure that the valve needle does not linger close to the valve seat, so as to avoid this problem.

[0009] To effect fuel delivery from such an injector, the pressure in the control chamber must be switched rapidly between the high pressure and low pressure states in order to achieve the necessary hydraulic force imbalance. This is typically achieved by venting the control chamber to a drain passage (denoted 27 in Figure 1) using the control valve. A drain passage in the fuel injector is therefore required. Furthermore, in venting pressurised fuel to drain, the energy expended in pressurising that quantity of fuel is effectively wasted. Also, the fuel flowing into the drain passage is generally at a high temperature, so it must be cooled before it can be returned to the fuel supply system.

[0010] Furthermore, in some fuel injector applications, it would be desirable to provide a degree of control over the lift position of the needle. For example, it may be desirable to be able to arrest movement of the valve needle at an intermediate position between the closed and full-lift positions. One example of such an application is described in the Applicant's European Patent Application Publication EP-A-2065590, which describes a fuel injector having a nozzle arrangement in which fuel flow through respective radial and axial apertures in a nozzle body is selectively controlled by a valve needle having first and second lift positions.

[0011] It is also expected that controlling the velocity of the valve needle during opening and/or closing movement may be desirable, for example to reduce injector noise and to ensure low-emission combustion. Currently, servo mechanisms such as that shown in Figure 1 are capable of opening and closing the valve needle at speeds of around 1 metre per second. Although the needle velocity may be influenced by the pressure of fuel in the injector, such influence is not readily controllable.

[0012] Against this background, it would be desirable to provide a fuel injector having an improved actuator arrangement that alleviates or overcomes some of the above-mentioned problems.

Summary of the invention

[0013] The present invention resides in a fuel injector for an internal combustion engine, the fuel injector comprising an injection nozzle having a nozzle body provided with a nozzle bore, a valve needle being received within the nozzle bore and engageable with a seat region to control fuel delivery through at least one nozzle outlet, and a slave piston provided with a control bore and associated with the valve needle such that movement of the slave piston causes movement of the valve needle. An end of the slave piston remote from the valve needle is exposed to fuel pressure in a control chamber of the injector, in use, the control chamber being connectable to a source of relatively high-pressure fuel by way of a first control port in the slave piston, and to a drain passage at relatively low pressure by way of a second control port in the slave piston. The first and second control ports are arranged to communicate with the control bore. A control piston is operable to move relative to the slave piston and the nozzle body so as to control fuel flow through the first and second control ports.

[0014] According to the invention, the control piston is positionable so as to allow, in a first mode of operation, fuel flow through the first control port and to prevent fuel flow through the second control port, thereby to bias the valve needle in a first direction. The control piston is also positionable so as to allow, in a second mode of operation, fuel flow through the second control port and to prevent fuel flow through the first control port, thereby to bias the valve needle in a second direction opposite to the first direction.

[0015] With this arrangement, the volume of fuel that flows to the drain passage through the second control port in the second mode of operation is approximately equal to the volume displaced in the control chamber by the movement of the slave piston in the second direction. Because fuel flow through the first control port is prevented in the second mode of operation, fuel cannot flow from the source of relatively high-pressure fuel directly to the drain passage. Advantageously, therefore, the volume of fuel that flows to drain during movement of the valve needle is very low compared to a prior art injector of the type shown in Figure 1. Furthermore, when the valve needle reaches the end of its travel in the second direction, no fuel flows to the drain passage.

[0016] In one embodiment of the invention, in the first mode of operation the valve needle is biased in the first direction towards its seat region, and in the second mode of operation the valve needle is biased in the second direction away from its seat region. In other words, the injector is of the inwardly-opening type. In another embodiment of the invention, the first and second directions are reversed, so that the injector is of the outwardly-opening type.

[0017] Preferably, the control piston is positionable so as to prevent, in a third mode of operation, fuel flow through both the first and second control ports, thereby to maintain the valve needle in a substantially static equilibrium position relative to the control piston. In this way, the valve can be held in an intermediate position between a fully-seated position and a fully-lifted position. The ability to hold the valve needle in such an intermediate position can be advantageous in controlling fuel injection through nozzle outlets of a suitable design.

[0018] Furthermore, by provision of the third mode of operation, in some embodiments of the invention the position of the valve needle can be proportionately or continuously controlled across the full range of movement from its fully-seated position to its fully-lifted position by moving the control piston to an appropriate position. The slave piston, and hence the valve needle, follows the position of the control piston. Thus the valve needle can, for example, be halted at a desired intermediate location to achieve a particular fuel injection characteristic. Furthermore, the speed of movement of the valve needle can be controlled by controlling the speed of movement of the control piston.

[0019] In one embodiment of the invention, the control piston is received within the control bore, in which case the control piston may comprise an annular piston member slidable within the control bore so as to selectively occlude the control ports.

[0020] The control ports may comprise radial passages in the slave piston. Preferably, the first and second control ports may be spaced apart along a longitudinal axis of the injector, and the piston member has a length along the longitudinal axis that is sufficient to prevent fuel flow through both the first and second control ports simultaneously. In this way, operation of the injector in the third mode of operation can be achieved.

[0021] The control piston may comprise a necked portion to define an internal gallery for high-pressure fuel, the internal gallery being connectable to the first control port in use of the injector.

[0022] Advantageously, the control piston comprises a tubular member having a central bore, the central bore comprising the drain passage. By providing the drain passage in the control piston, there is no need to accommodate a separate drain passage in the body of the fuel injector. Furthermore, because the drain passage is contained within the control piston, leakage of fuel to the drain passage from other components of the injector can be minimised.

[0023] In another arrangement, however, the drain passage comprises a passage through the slave piston.

[0024] The injector may comprise a valve assembly that is operable to prevent the flow of fuel from the control bore to the drain passage. Although the flow of fuel from the control chamber to the drain passage through the second control port is prevented in the first mode of operation, the provision of the valve assembly provides an additional sealing means to prevent leakage of fuel to the drain passage, from the second control port or otherwise. In one example, when the control piston is received within the control bore, the valve assembly may comprise a valve element being a tip region of the control piston and a seat region formed in the slave piston at an end of the control bore upstream of the drain passage, the valve element being arranged to engage with the seat region so as to prevent the flow of fuel from the control bore to the drain passage.

[0025] In one embodiment of the invention, the slave piston comprises a portion of the valve needle. In other words, the slave piston and the valve needle are formed as a single component. Alternatively, the slave piston and the valve needle may be separate components, in which case the slave piston may be biased to abut an end of the valve needle.

[0026] The fuel injector may further comprise a spring means to bias the valve needle towards the seating region. The spring means may be provided in the control chamber to act on an upper end of the slave piston. Alternatively, or in addition, a spring means may be arranged to act on the valve needle.

[0027] The control chamber may be connectable to the source of relatively high-pressure fuel by way of two or more first control ports in the slave piston, and to the drain passage by way of two or more second control ports in the slave piston. In this case, the control ports may be equi-angularly spaced around the slave piston, so as to balance the hydraulic forces acting on the control piston.

[0028] The control piston is preferably operable by means of an actuator arrangement comprising a linear-movement actuator. The actuator arrangement may, for example, comprise a Lorentz coil (voice coil), a piezoelectric stack, or a solenoid actuator arrangement including a single solenoid actuator or multiple solenoid actuators.

Brief description of the drawings

[0029]

Figure 1 of the accompanying drawings, which has already been referred to above, is a part-sectional view of a known fuel injector. The present invention will now be described, by way of example only, with reference to the remaining drawings in which like reference numerals are used for like parts and in which:

Figure 2 is a part-sectional view of part of a fuel injector according to a first embodiment of the present invention, in a first mode of operation;

Figure 3 is an enlarged view of Figure 2, showing the fuel injector of the first embodiment in the first mode of operation in greater detail;

Figure 4 is a part-sectional view of part of the fuel injector of Figure 2 in a second mode of operation;

Figure 5 is an enlarged view of Figure 4, showing the fuel injector of the first embodiment in the second mode of operation in greater detail;

Figure 6 is a part-sectional view of part of the fuel injector of Figure 2 in a third mode of operation;

Figure 7 is an enlarged view of Figure 6 showing the fuel injector of the first embodiment in the third mode of operation in greater detail;

Figure 8(a) is a part-sectional view of part of a fuel injector according to a second embodiment of the present invention, and Figure 8(b) is an end view of a slave piston of the fuel injector of Figure 8(a);

Figure 9 is an enlarged view of Figure 8(a) showing the fuel injector of the second embodiment in greater detail;

Figure 10 is a part-sectional view of part of a fuel injector according to a third embodiment of the present invention; and

Figure 11 is an enlarged view of Figure 10 showing the fuel injector of the third embodiment in greater detail.

[0030] Throughout the remainder of this document, terms such as 'upper', 'lower', 'upward', 'downward' and so on are used with reference to the orientation of the fuel injector in the accompanying drawings. However, it will be appreciated that a fuel injector according to the present invention could be used in any orientation. Terms such as 'upstream' and 'downstream' are used with reference to the direction of fuel flow in use of the injector, either during an injection event or otherwise as the context demands.

[0031] Figure 2 shows part of a fuel injector according to a first embodiment of the present invention. The fuel injector 100 comprises an elongate nozzle body 102. The nozzle body 102 is clamped on to an injector body 104 by a cap nut (not shown), as is known in the art.

[0032] The injector body 104 is generally elongate and comprises a control chamber block 106 that abuts the nozzle body 102, and one or more further blocks that house an actuator arrangement (not shown). For simplicity, only the control chamber block 106 of the injector body 104 is shown in Figure 2.

[0033] The nozzle body 102 is provided with a nozzle bore 108, which receives high-pressure fuel from a fuel supply passage 105 provided in the injector body 104, via an annular gallery 107 at the uppermost end of the nozzle bore 108. A valve needle 110 is slidably received within the nozzle bore 108.

[0034] The configuration of the valve needle 110 and the nozzle body 102 in a tip region 116 of the nozzle body is substantially as described in the Applicant's European Patent Application Publication EP-A-2065590, the contents of which are incorporated herein by reference. Only a brief description of the arrangement will be given here, and reference should be made to EP-A-2065590 for a detailed description.

[0035] A set of radial fuel outlets or spray holes 112 and an axial fuel outlet or spray hole 114 are provided at the tip region 116 of the nozzle body 102. In use, the injector 100 is mounted in a cylinder head (not shown) of an internal combustion engine, so that the tip region 116 of the nozzle body 102 extends into a combustion chamber 118 of the engine. Each of the fuel outlets 112, 114 passes through the wall of the nozzle body 102, so as to provide radial and axial flow paths to allow fuel to flow from a delivery chamber 186, defined by the nozzle bore 108, through the nozzle body 102 and into the combustion chamber 118, in use.

[0036] A lower portion of the valve needle 110 comprises a shaft 109 having a tip 111. The tip 111 comprises a frusto-conical valve member 120. The valve member 120 is of complementary shape to a valve seat 122 provided in the nozzle bore 102.

[0037] At its end-most extremity, the valve needle 110 is shaped so as to form an obturator piston 124. An inwardly-curving spray shaping region 126 spaces the obturator piston 124 from the valve member 120.

[0038] The obturator piston 124 is arranged to cooperate with the axial outlet 114 so that, when the valve member 120 is seated on the valve seat 122, the valve needle 110 extends through the axial outlet 114 and the obturator piston 124 is positioned beyond the axial outlet 114. The obturator piston has a diameter that is slightly smaller than the diameter of the axial outlet 114, such that the obturator piston 124 can slide relative to the axial outlet 114.

[0039] As described in EP-A-2065590, the fuel injector is arranged so that the valve needle 110 can take up one of three positions within the nozzle bore 102, namely a first, fully lowered position, a second, intermediate position, and a third, fully lifted position.

[0040] In the first position, the valve needle 110 is fully lowered and the valve member 120 is seated on the valve seat 122. The valve member 120 covers the radial outlets 112 so as to prevent fuel flow out of the injector 100 in a radial direction. In this position, the valve member 120 also blocks fuel flow to the axial outlet 114. Hence, no injection can occur through either the radial outlets 112 or the axial outlet 114.

[0041] In the second position, the valve needle 110 occupies a position intermediate the fully-lowered and fully-lifted positions, in which the valve member 120 is lifted away from the valve seat 122, and a flow path is open between the nozzle bore 108 and the radial outlets 112 and the axial outlet 114. An injection event occurs through the axial outlet 114, because the obturator piston 124 is not fully withdrawn into the axial outlet 114. A small amount of fuel may also be injected through the radial outlets 112.

[0042] In the third position, the valve needle 110 is fully lifted. The valve member 120 is lifted fully away from the valve seat 122, and the obturator piston 124 is drawn fully within the axial outlet 114. This decreases the injection flow through the axial outlet 114, and increases flow through the radial outlets 112.

[0043] By virtue of the arrangement of the valve needle 110 and the provision of three needle lift positions, the nature of the fuel injection provided by the injector can advantageously be controlled as described further in EP-A-2065590.

[0044] The mechanism by which the lift position of the valve needle 110 is controlled in the present invention will now be described.

[0045] As shown additionally in Figure 3, an upper portion of the nozzle bore 108 has an enlarged diameter so as to form a spring chamber 134. The valve needle 110 passes through the spring chamber 134 and into a lower, relatively large diameter bore 136 formed in the control chamber block 106. An upper portion of the valve needle 110 comprises a slave piston 130. The slave piston is a sliding fit in the lower bore 136 in the control chamber block 106.

[0046] Intermediate the slave piston 130 and the shaft 109, the valve needle 110 is provided with an annular collar 132. The spring chamber 134 houses a biasing spring 140 arranged annularly around the slave piston 130. The biasing spring 140 is held in compression between a lower end face 142 of the control chamber block 106 and the collar 132 of the valve needle 110. In this way, the biasing spring 140 acts to bias the valve needle towards the first, fully lowered position.

[0047] The slave piston 130 is provided with a bore, known hereafter as the control bore 144, extending from the uppermost end 146 of the slave piston 130 towards the collar 132. The control bore 144 receives a control piston 148, which is a sliding fit within the control bore 144. The control piston 148 is a tubular member that comprises, at its upper end, a stem 149 that extends through an upper, relatively small diameter bore 150 in the control chamber block 106 to cooperate with an actuator arrangement (not shown).

[0048] An annular control chamber 152 is located between the lower bore 136 and the upper bore 150 in the control chamber block 106. The control chamber 152 is defined in part by the walls of the lower bore 136, in part by a shoulder 154 where the lower bore 136 meets the upper bore, in part by the outer surface of the control piston stem 149, and in part by the uppermost end 146 of the slave piston 130.

[0049] As will be explained below, in use of the injector, the control chamber 152 is supplied with fuel. The pressure of the fuel in the control chamber 152 is controlled by the position of the control piston 148 relative to the slave piston 130. The uppermost end 146 of the slave piston 130 is subject to the changes in fuel pressure in the control chamber 152, such that the position of the slave piston 130, and hence the valve needle 110, can be controlled by modifying the position of the control piston 148.

[0050] As shown most clearly in Figure 3, the slave piston 130 comprises a side drilling 156 which allows fuel to flow from the gallery 107 into the control bore 144. The side drilling 156 coincides with the position of a necked portion 158 of the control piston, so that the side drilling opens into an annular internal gallery 160 defined by the necked portion 158 and the wall of the control bore 144.

[0051] The internal gallery 160 is closed at its upper end by the control piston stem 149. The control piston stem 149 is a close fit in the control bore 144, so that leakage of fuel from the internal gallery 160 to the control chamber 152 past the control piston stem 149 is minimised. The internal gallery 160 is closed at its lower end by a piston member 162 of the control piston 148 that is likewise a close fit in the control bore 144.

[0052] It will be appreciated that the high-pressure fuel in the internal gallery 160 imparts an upward force on the control piston stem 149, and a downward force of approximately equal magnitude on the piston member 162. There is therefore substantially no net force on the control piston 148 due to the fuel pressure in the internal gallery 160, which means that the control piston 148 can be moved using a relatively low-force actuator.

[0053] A transfer passage 164 is provided in the slave piston 130. The transfer passage 164 comprises a blind bore that communicates with the control chamber 152 and extends downwardly from the uppermost end 146 of the slave piston 130, adjacent and parallel to the control bore 144. A first, upper control port 166 and a second, lower control port 168 extend radially from the control bore 144 into the transfer passage 164. Thus the control chamber 152 is in communication with the control bore 144 by way of the transfer passage 164 and the upper and lower control ports 166, 168.

[0054] As will be described in more detail later, the upper and lower control ports 166, 168 are arranged such that the piston member 162 of the control piston 148 can adopt one of three positional configurations with respect to the control ports 166, 168. Specifically, the distance between the upper port 166 and the lower port 168 is slightly shorter than the longitudinal length of the piston member 162. Thus, the piston member 162 can block or occlude both ports 166, 168 simultaneously (as shown in Figures 4 and 5, to be described below). Alternatively, the piston member 162 can be positioned to block fuel flow through the upper port whilst allowing flow through the lower port only (see Figures 6 and 7), or to block fuel flow through the lower port whilst allowing flow through the upper port only (as shown in Figures 2 and 3).

[0055] At the lowermost end of the control bore 144, a drain chamber 174 is provided. The drain chamber 174 has a smaller diameter than the control piston 148 and the control bore 144. The lowermost end or tip of the control piston 148 comprises a frusto-conical valve element 170 arranged to seat on a seating region 172 of complementary shape. The seating region 172 is formed as a shoulder in the slave piston 130 where the drain chamber 174 meets the control bore 144.

[0056] The control piston 148 is tubular to define a drain passage 176 that runs axially through the bore of the control piston 148. The lower end of the drain passage 176 communicates with the drain chamber 174, while the upper end of the drain passage 176 communicates with a fuel drain at low pressure (not shown). When the valve element 170 is seated on the seating region 172, as shown in Figure 3, flow of fuel into the drain chamber 174, and hence the drain passage 176, is prevented.

[0057] As noted above, the stem 149 of the control piston 148 cooperates with an actuator arrangement (not shown). The actuator arrangement is of a type capable of moving the control piston 148 up and down within the control bore 144 in response to control signals from an engine control unit. In particular, in this embodiment of the invention, the actuator arrangement is of a type that is capable of positioning the control piston 148 in at least three positions, namely a lower end-stop position, in which the control piston 148 is fully extended downwards, an upper end-stop position, in which the control piston 148 is retracted upwards, and an intermediate position between the upper and lower end-stop positions.

[0058] In one suitable actuator arrangement (not shown), the control piston stem 149 is arranged to cooperate with first and second independently-controlled solenoid actuators, each being arranged to apply an upward movement to the control piston 148. The first actuator is configured to decouple from the control piston 148 in response to the upward movement, for example by providing the first actuator with an armature that can slide on the control piston stem 149. The second actuator comprises an armature that is fixed on an upper end of the control piston stem 149.

[0059] A collar on the control piston stem 149 is provided so that, when the first actuator is energised, the collar couples to the armature of the first actuator to move the control piston 148 from a lower end-stop position to a well-defined intermediate position. Then, on energisation of the second actuator, the collar decouples from the armature of the first actuator and the control piston 148 is drawn from the intermediate position to an upper end-stop position by the action of the second actuator alone. Reference should be made to the present applicant's co-pending European Patent Application No. EP 09166712.1, the contents of which are incorporated herein by reference, for more details of such an actuator arrangement.

[0060] Figures 2 and 3 illustrate a first mode of operation of the fuel injector 100. In this first mode, the control piston 148 is positioned such that the upper control port 166 is not occluded by the piston member 162, so that a fuel flow path is open between the internal gallery 160 and the control chamber 152, via the upper control port 166 and the transfer drilling 166. Thus, fuel at high pressure flows from the supply passage 105 into the control chamber 152 via the gallery 107, the side drilling 156, the internal gallery 160, the first control port 166, and the transfer passage 164.

[0061] The lower control port 168, meanwhile, is closed by the piston member 162 so as to prevent the flow of fuel from the control chamber 152 to the drain chamber 174.

[0062] Consequently, in this first mode of operation, the control chamber 152 contains fuel at relatively high pressure. This high-pressure fuel acts on the upper end 146 of the slave piston 130 to apply a downwardly-directed force to the slave piston 130. The valve needle 110 is therefore subject to downwardly-acting forces via the slave piston 130 and the spring 140.

[0063] In the first mode of operation, when the fuel in the control chamber 152 is at high pressure, the downwardly-acting forces on the valve needle 110 are greater than the upwardly-acting forces, and therefore the valve needle 110 is biased to move towards its fully-lowered or seated position.

[0064] Figures 2 and 3 show the valve needle 110 in its fully-lowered position, in which the control piston 148 is also fully lowered to its lower end-stop position. In this position of the control piston 148, the valve element 170 is seated on the seating region 172. By virtue of the valve element 170 being seated on the seating region 172, any leakage of fuel past the piston member 162, for example from the internal gallery 160, the upper control port 166 or the lower control port 168, does not result in leakage of fuel into the drain chamber 174 or the drain passage 176 when the valve needle 110 is fully lowered.

[0065] It will be appreciated, however, that seating movement of the valve needle 110 can arise in the first mode of operation even when the valve element 170 is not seated on its seating region 172, because the blocking of the lower control port 168 by the piston member 162 is sufficient to prevent fuel flow from the control chamber 152 to drain.

[0066] Indeed, the first mode of operation will arise whenever the relative positions of the control piston 148 and the slave piston 130 are such that the piston member 162 is positioned so as to block the lower control port 168 whilst leaving the upper control port 166 clear for fuel flow. Thus, movement of the valve needle 110 towards its seat 122 can be effected by moving the control piston 148 in a downward direction.

[0067] Figures 4 and 5 illustrate a second mode of operation of the injector 100. In this second mode, the control piston 148 is positioned so that the upper control port 166 is occluded by the piston member 162, while the lower control port 168 is open. Furthermore, the valve element 170 is not seated on its seating region 172.

[0068] In this mode, the piston member 162 prevents the flow of high-pressure fuel from the internal gallery 160 to the control chamber 152 through the upper control port 166. The control chamber 152 instead communicates with the drain chamber 174 via the open lower control port 168. Fuel in the control chamber 152 can therefore flow to the low-pressure drain by way of the drain passage 176.

[0069] Consequently, in this second mode of operation, the fuel pressure in the control chamber 152 is caused to drop. The downwardly-acting force on the upper end 146 of the slave piston 130 is correspondingly reduced to a sufficient extent that the total downwardly-acting force on the valve needle 110 becomes less than the total force that acts upwardly on the needle, for example as a result of the fuel in the delivery chamber 186 acting on downwardly directed surfaces of the valve needle 110 such as the valve member 120. The valve needle 110 therefore experiences a net upward force and moves in an upward, unseating direction.

[0070] The second mode of operation comes about whenever the relative positions of the control piston 148 and the slave piston 130 are such that the upper control port 166 is occluded by the piston member 162 and the lower control port 168 is open. Movement of the valve needle 110 away from its seat 122 can therefore be effected by moving the control piston 148 in an upward direction.

[0071] In Figures 4 and 5, the injector is shown with the valve needle 110 in its fully-lifted position and the control piston 148 in its upper end-stop position. In this configuration, the upper end 146 of the slave piston 130 abuts a shoulder 155 in the wall of the control chamber 152. The shoulder 155 therefore acts as a full-lift end-stop for the valve needle 110.

[0072] Figures 6 and 7 illustrate a third mode of operation of the fuel injector 100. In this third mode, the control piston 148 is positioned intermediate its upper and lower end-stop positions, and both the upper control port 166 and the lower control port 168 are blocked by the piston member 162. Again, the valve element 170 is not seated on its seating region 172.

[0073] In this configuration, the control chamber 152 is connected neither to the high-pressure fuel supply in the internal gallery 160, nor to the drain chamber 174. Thus fuel neither flows into nor out of the control chamber 152, and the fuel pressure in the control chamber 152 remains constant. For as long as both the upper and lower control ports 166, 168 remain covered, the volume of the control chamber 152 is essentially fixed, and the slave piston 130 (and hence the valve needle 110) cannot move with respect to the control chamber block 106.

[0074] In this third mode, therefore, the position of the valve needle 110 is hydraulically locked with respect to the injector body 104. In this way, the valve needle 110 can be held in a substantially static intermediate position with respect to the valve seat 120. Advantageously, in this example, fuel injection through the axial outlet can take place when the valve needle 110 is in the intermediate position.

[0075] The third mode of operation of the injector comes about when the control piston 148 is held stationary at a position intermediate its upper and lower end stops. It will be appreciated that, if the pressure in the control chamber 152 falls, for example due to leakage past the control piston stem 149, the slave piston 130 may migrate upwards. In this event, the upper control port 166 will become uncovered, such that operation of the valve needle reverts to the first mode. The control chamber 152 becomes re-pressurised by virtue of fuel flow from the internal gallery 160 via the upper control port 166, and the slave piston 130, and therefore the valve needle 160, returns to its static intermediate position in the third mode of operation. In this way, the third mode of operation can be considered as a self-regulating or equilibrium state of operation.

[0076] Similarly, movement of the control piston 148 to a different position will cause the operation of the injector 100 to revert either to the first mode or the second mode until the slave piston 130 once again comes to rest in its equilibrium position with respect to the control piston 148.

[0077] Specifically, if the injector 100 is operating in the third mode of operation with the control piston in a starting position, the valve needle 110 will be held in a static intermediate position. If the control piston 148 is then displaced downwards from the starting position, the injector 100 will revert to the first mode of operation: the upper control port 166 will open so as to allow fuel to flow into the control chamber 152, thereby causing downwards movement of the slave piston 130 and hence the valve needle 110 as described above until the upper control port 166 is closed once again by the piston member 162 and the valve needle 110 adopts a new static intermediate position displaced downwardly from its original intermediate position.

[0078] If the control piston 148 is instead displaced upwards from the starting position, the injector 100 will revert to the second mode of operation: the lower control port 168 will open, allowing fuel to flow from the control chamber 152 to the low-pressure drain passage 176, and causing upward movement of the valve needle 110 as described above until the lower control port 168 is closed once again by the piston member 162 and the valve needle 110 adopts a new static intermediate position displaced upwardly from its original intermediate position.

[0079] In this way, the movement of the valve needle 110 follows the movement of the control piston 148. Depending on the actuator arrangement provided, the valve needle 110 could be positionable in an intermediate position defined by an intermediate stop of the actuator arrangement. Advantageously, only a relatively low-force actuator need be provided to move the control piston 148 in the present invention, in common with a servo-type injector. Furthermore, by controlling the speed of movement of the control piston 148, the speed of movement of the valve needle 110 can be controlled.

[0080] It will be appreciated that the third mode of operation occurs only within a limited range of the full movement of the control piston 148. When the valve needle 110 is fully seated, the control piston 148 is advantageously positioned such that the valve element 170 is seated on the seating region 172 to prevent leakage to the drain chamber 174 as shown in Figures 2 and 3. In this case, the piston member 162 occludes only the lower control port 168, leaving the upper control port open 166. Thus, in this position, the injector 100 is in the first mode of operation while the valve needle 110 is static. This is advantageous because any leakage of fuel from the control chamber 152, for example past the control piston stem 149, is immediately corrected by flow of fuel from the internal gallery 160 with no appreciable reduction in fuel pressure in the control chamber 152. The valve needle 110 is therefore held firmly closed.

[0081] Similarly, when the valve needle 110 is in its fully-lifted position, such that the upper end 146 of the slave piston 130 abuts the shoulder 155, the control piston 148 is advantageously retracted as shown in Figures 4 and 5 so that the piston member 162 occludes only the upper control port 166, leaving the lower control port 168 open. In this position, the injector 100 is in the second mode of operation while the valve needle 110 is static. This is advantageous because any leakage of high-pressure fuel into the control chamber 152, for example from the internal gallery 160, is vented to the drain chamber 174 without causing movement of the valve needle 110. The valve needle 110 is therefore held stationary in its fully-lifted position.

[0082] It will be understood, therefore, that the range of movement of the control piston 148 between its upper and lower end-stop positions is greater than the range of movement of the valve needle 110 between its fully-lifted and fully-lowered end-stop positions. The lower end-stop position of the control piston 148 is defined as the position where both the valve element 170 of the control piston and the valve needle 110 are seated on their respective seats 172, 122. The upper end-stop position of the control piston 148 is preferably defined by the actuator arrangement (not shown), as is known in the art.

[0083] It will be appreciated that, during operation of the injector 100, the amount of fuel that is discharged to drain (excluding any leakage) corresponds to the volume displaced during upward movement of the slave piston 130 in the second mode of operation. Thus the amount of fuel that is discharged to drain during operation of the injector is much lower than for a conventional fuel injector having a hydraulic servo mechanism such as that shown in Figure 1, in which high-pressure fuel is discharged constantly to drain while the valve needle is lifted.

[0084] A fuel injector 200 according to second embodiment of the invention will now be described with reference to Figures 8(a), 8(b) and 9.

[0085] As in the first embodiment, the fuel injector 200 comprises a nozzle body 202 and an injector body 204. The injector body 204 includes a control block 206, in which a high-pressure fuel supply line 205 is provided. A nozzle bore 208 in the nozzle body 202 receives a valve needle 210. A frusto-conical valve member 220 of the valve needle 210 is engageable with a valve seat 222 at the tip region 216 of the nozzle body. The arrangement of the valve needle 210 and the nozzle body 202 at the tip region 216 is as described above with reference to the first embodiment of the invention, so that fuel can selectively be injected through radial or axial outlets for fuel.

[0086] A slave piston 230 is formed integrally with the valve needle 210. Unlike in the first embodiment, in this second embodiment of the invention, there is no collar between the slave piston 230 and the shaft 209 of the valve needle 210, and there is no spring chamber. Instead, the slave piston 230 is a close sliding fit within an upper needle guide 280 and a lower needle guide 282 of the nozzle bore 208. In this way, the slave piston 230 defines a guide portion 285 of the valve needle, which cooperates with the upper and lower needle guides 280, 282.

[0087] The high-pressure fuel supply line 205 communicates with an annular gallery 207 in the nozzle body 202. The gallery 207 is situated in the nozzle bore 208 between the upper and lower guide portions 280, 282.

[0088] A nozzle path orifice 284, formed as a flat on the guide portion 285 of the valve needle 210 adjacent to the lower guide portion 282 of the nozzle bore 208, provides a restricted flow path for fuel between the gallery 207 and a delivery chamber 286 formed by the nozzle bore 208 downstream of the lower guide portion 282.

[0089] The control chamber block 206 comprises a control chamber 252 that receives the upper end 246 of the slave piston. As in the first embodiment of the invention, the slave piston 230 includes a blind control bore 244. A lower end of a control piston 148 is received within the control bore 244, and the upper end of the control piston 148 passes up through the control chamber 252 and the control chamber block 206 to cooperate with an actuator arrangement (not shown).

[0090] The control piston 148 is as described above with reference to the first embodiment of the invention. Furthermore, as in the first embodiment, the slave piston 230 is provided with a side drilling 256 to allow fuel to flow from the gallery 207 to an internal chamber 260 defined by the necked portion 158 of the control piston 148. The control chamber 252 communicates with the control bore by way of three transfer passages 264 (only one of which is shown in Figure 8(a)) and respective upper and lower control ports 266, 268 in the slave piston 230. The valve element 170 at the tip of the control piston 148 is cooperable with a valve seat 272 in the slave piston 230, so as to control the flow of fuel into a drain chamber 274 and thereby into the drain passage 176 defined by the bore of the control piston 148.

[0091] In this second embodiment, the control chamber 252 is defined, in part, by a shoulder 254 in the control chamber block 206. The control chamber 252 houses a biasing spring 288 that acts between the upper end of the slave piston 230 and the shoulder 254. The biasing spring 288 therefore acts to bias the slave piston 230 in a downward direction, and hence acts to bias the valve needle 210 towards its seated position.

[0092] An upper lift stop for the slave piston 230, and hence the valve needle 210, is provided in the form of an annular washer 253 situated in the control chamber 252. The control piston 148 is a clearance fit through a central hole in the washer 253. The washer 253 abuts a shoulder 255 formed in the wall of the control chamber 252. Upward movement of the slave piston 230, and hence the valve needle 210, is arrested when the upper end 246 of the slave piston 230 abuts the washer 253.

[0093] So as to ensure that the washer 253 does not obstruct the flow between the control chamber 252 and the transfer passages 264, flats or relief regions 265 are provided at the upper end 246 of the slave piston 230, as shown in Figure 8(b). By virtue of the relief regions 265, fuel can flow radially out of the transfer passages 264 when axial flow is restricted by the washer 253.

[0094] As described above for the first embodiment of the invention, movement of the control piston 148 causes the control ports 266, 268 to open or close to control the fuel pressure in the control chamber 252.

[0095] In a first mode of operation (not shown), the control piston 148 is positioned such that the upper control ports 266 are open and the lower control ports 268 are closed. The control chamber 252 therefore contains fuel at a relatively high pressure. The force of fuel acting on the upper end 246 of the slave piston, plus the force of the biasing spring 288, create a net downward force on the valve needle 210 that is greater than the total upward force on the valve needle caused by fuel pressure in the delivery chamber 286 . Thus, in the first mode of operation, the net force on the valve needle 210 acts to bias the valve needle 210 towards its seated position.

[0096] In a second mode of operation (not shown), the upper control ports 266 are closed while the lower control ports 268 are open to connect the control chamber 252 to the drain passage 176. The pressure in the control chamber 252 is therefore reduced, and the corresponding downward force acting on the upper end 246 of the slave piston 230 is reduced. The upward force on the valve needle 210 due to fuel pressure in the delivery chamber 286 becomes sufficient to overcome the downwardly-acting forces resulting from the control chamber pressure 252 and the biasing spring 288, and the valve needle 210 is biased to move in an unseating direction.

[0097] Figures 8(a) and 9 show the injector in a third mode of operation, in which the upper and lower control ports 266, 268 are all blocked, and the pressure in the control chamber 252 is held constant. The slave piston

230, and therefore the valve needle 210, are held in a static, unseated position intermediate the fully-seated and fully-lifted positions of the valve needle 210. As in the first embodiment of the invention, leakage of fuel from the control chamber 252 causes the injector to revert to the first mode of operation, thereby to restore the control chamber pressure 252 and return the valve needle 210 to the desired position.

[0098] As described for the first embodiment of the invention, the slave piston 230 follows the movement of the control piston 148, such that the valve needle 210 can be positioned in substantially any intermediate position between its fully-seated and fully-lifted positions, and so that the velocity of the valve needle 210 can be controlled.

[0099] When the valve needle 210 is lifted and a fuel injection is taking place, the area of the valve needle 210 that is subjected to upward forces due to fuel pressure in the delivery chamber 286 is greater than the area of the upper end of the slave piston 230 exposed to fuel pressure in the control chamber 252.

[0100] To ensure that the valve needle 210 can return to its seated position, fuel flow into the delivery chamber 286 is restricted by the nozzle path orifice 284. This means that, during an injection event, the fuel pressure in the delivery chamber 286 is somewhat lower than the fuel pressure in the gallery 207. This arrangement ensures that, once the pressure in the control chamber 252 has been restored to a relatively high level in the first mode of operation, there is a sufficient net downward force on the valve needle 210 to re-seat the needle 210 without the need for a high-force return spring (such as the spring 140 of the first embodiment of the invention). Instead, only a low-force biasing spring 288 is required. A known fuel injector having a nozzle path orifice with the same function of restricting fuel flow into the delivery chamber of the fuel injector is described in European Patent Publication No. EP-B-0767304, the contents of which are incorporated herein by reference.

[0101] A fuel injector 300 according to a third embodiment of the invention is shown in Figures 10 and 11. The third embodiment of the invention shares many features with the second embodiment, and only the differences will be described.

[0102] In the third embodiment, a valve needle 310 and a slave piston 330 are formed as two separate components. A lower end 353 of the slave piston 330 abuts an upper end 361 of the valve needle 310, and a biasing spring 388 received within a control chamber 352 biases the slave piston 330 against the valve needle 310. In this way, the slave piston 330 and the valve needle 310 are associated with one another and coupled together such that movement of the slave piston 330 causes movement of the valve needle 310. The position of the valve needle 310 controls fuel delivery through a tip region 316 of the injector 300, in the same way as in the first and second embodiments of the invention.

[0103] The slave piston 330 is housed substantially within a control chamber block 306, in a slave piston bore 390 having a diameter closely matched to the diameter of the slave piston 330. The control chamber 352 is located at the top end of the slave piston bore 390 and, where the control chamber 352 meets the slave piston bore 390, a shoulder 355 is provided which acts as a full-lift end-stop for the slave piston 330.

[0104] High-pressure fuel is supplied to the slave piston bore 390 from a first branch 305a of a fuel supply passage 305. As in the first and second embodiments of the invention, the slave piston 330 includes a control bore 344 and a side drilling 356 to allow high-pressure fuel to flow into the control bore 344. In this embodiment, however, the side drilling 356 communicates with a gallery 392 formed by an annular recess in the outer wall of the slave piston 330, such that fuel from the supply passage branch 305a flows around the slave piston 330 in the gallery 392 before entering an internal gallery 360 defined by a necked 358 portion of the control piston 348.

[0105] The control chamber 352 communicates with the control bore 344 by way of a transfer passage 364, an upper control port 366 and a lower control port 368. The control ports 366, 368 are arranged to be opened or closed by a piston member 362 of the control piston 348, as in the previous embodiments of the invention, so as to control movement of the valve needle in first, second and third modes of operation as previously described.

[0106] In this embodiment of the invention, the piston member 362 includes two annular grooves 362a, 362b arranged so that, when the piston member 362 is positioned so as to occlude both the upper and lower control ports 366, 368 (as shown in Figures 10 and 11), an upper one of the grooves 362a is aligned with the upper control port 366 and a lower one of the grooves 362b is aligned with the lower control port 368. Fuel entering the control bore 344 via the control ports 366, 368 is held in the annular spaces defined by the grooves 362a, 362b, so as to ensure that the forces acting on the control piston 348 are radially balanced.

[0107] Furthermore, in this embodiment, the control piston 348 is solid, rather than tubular. When the lower control port 368 is open, fuel flows from the control chamber 352 into a drain chamber 374 which is, in turn, connected to a drain conduit 394 in the slave piston 330. The drain conduit 394 communicates with an annular drain space 396 at the lower end of the slave piston bore 390, between the nozzle body 302 and the slave piston 330. A drain passage 398 extends parallel to the slave piston bore 390 in the control chamber block 305 to connect the drain space 396 to a low-pressure fuel drain (not shown). As in the first and second embodiments of the invention, in this third embodiment fuel flow to the drain chamber 374 is prevented by cooperation of a valve element 370 of the control piston 348 and a seating surface 372 of the slave piston 330 when the control piston 348 is in its lowermost position.

[0108] The valve needle 310 comprises a guide portion 385 at its upper end. The guide portion 385 is a close fit within a needle guide 382 defined by the nozzle bore 308. An axially diagonal groove 399 is provided in the guide portion 385 to allow fuel to flow from an annular gallery 307 to a delivery chamber 386 which, in turn, communicates with the tip region 316 of the injector. The annular gallery 307 is supplied with fuel from a second branch 305b of the supply passage 305.

[0109] Unlike the nozzle path orifice 284 in the second embodiment of the invention, the groove 399 in this third embodiment does not appreciably restrict the flow of fuel to the delivery chamber 386. However, the area of the slave piston 330 that is exposed to fuel pressure in the control chamber 352 is arranged to be greater than the area of the valve needle 310 that is exposed to fuel in the delivery chamber 386 when the needle 310 is not seated, and therefore downward movement of the valve needle 310 can occur when the control chamber 352 is at high pressure.

[0110] Many of the features described above with reference to a specific embodiment of the invention could also be applied to the other embodiments of the invention.

[0111] For example, grooves such as the upper and lower grooves 362a, 362b on the piston member 362 of the injector 300 of the third embodiment of the invention could also be provided on the piston members of the first and second embodiments of the invention, thereby to balance the radial pressure on the control piston and reduce friction between the control piston and the walls of the control bore.

[0112] A tubular control piston having a drain passage therethrough, such as the control piston 148 of the first and second embodiments of the invention, could also be used in the third embodiment of the invention. Using a tubular control piston to provide a drain passage, rather than providing a drain space external to the slave piston, advantageously avoids leakage of fuel from the delivery chamber and from the slave piston bore to drain. However, this arrangement typically requires a control piston of relatively large diameter to accommodate the drain passage.

[0113] In any embodiment of the invention, the valve needle and the slave piston could be formed as a single component, as illustrated by the first and second embodiments of the invention, or as separate components, as illustrated by the third embodiment. Advantageously, when the valve needle and slave piston are formed as separate components, the invention can be deployed using valve needle and nozzle body components known from prior art injectors. For example, it will be noted that the valve needle and nozzle body of the fuel injector 300 of the third embodiment of the invention are substantially identical to the equivalent components in the injector described in EP-A-2065590.

[0114] It will be appreciated that, in all embodiments of the invention, it is preferable that the control piston is a close sliding fit within the control bore of the slave piston in the vicinity of the control ports, so as to avoid leakage from the ports when the ports are closed. However, a larger clearance can be provided between the control piston stem and the control piston bore, above the necked portion of the control piston since, between injection events, the control chamber and the internal gallery are at approximately the same fuel pressure, thereby obviating the effect of leakage in that area.

[0115] It may be desirable to modify the valve assembly as shown comprising the valve element at the end of the control piston and the seating region of the slave piston so as to ensure that any leakage of fuel into the space between the piston member and the valve element does not result in a significant upward force on the control piston. For example, in one embodiment (not shown), the diameter of the valve element and seating region is arranged to be as close as possible to the diameter of the piston member.

[0116] It is also preferred that the distance between the upper and lower control ports is closely matched to the length of the piston member of the control piston, so that only a small movement of the control piston is required to open a respective one of the ports. In this way, the slave piston, and hence the valve needle, can be made to follow accurately the movement of the control piston.

[0117] Similarly, it is advantageous to ensure that the bores in which the control piston and the slave piston respectively reciprocate are of high concentricity, so as to avoid sticktion during operation of the injector. Conceivably, a low-friction coating could be provided on the bores and/or the pistons so as to ensure reliable operation of the injector.

[0118] Although only one transfer passage having two control ports is illustrated for the first and third embodiments of the invention, it will be appreciated that, in any embodiment, several transfer passages, radially spaced around the slave piston, could be provided, as exemplified by the second embodiment of the invention Providing several transfer passages in this way helps to balance the forces on the control piston, and to increase the flow rate of fuel in and out of the control chamber, thereby improving the operating speed of the injector. In one preferred example, as shown in Figure 8(b) three transfer passages are provided in the slave piston at a radial spacing of 120° to one another, each transfer passage having an associated upper and lower control port, and the side drilling for supply of high-pressure fuel to the internal gallery is positioned equi-angularly between two of the transfer passages.

[0119] Each transfer passage could communicate with associated upper and lower control ports or, conceivably, a transfer passage could communicate with just an upper or a lower control port. It is also conceivable that a control port could be embodied as an annular groove in the wall of the control bore, arranged so that the groove intersects one or more transfer passages.

[0120] Although the invention has been described with reference to the arrangement of fuel outlets and the valve needle tip described in EP-A-2065590, it should be noted that the present invention finds application in fuel injectors having other arrangements at the tip of the injector. The present invention is suitable for substantially any design of injector tip where it is necessary, or desirable, to provide one or more intermediate valve needle lift positions, and/or to control the velocity of the valve needle.

[0121] For example, the present invention could be used to control the valve needle position in a so-called variable orifice nozzle, such as that described in the applicant's European Patent Publication EP-B-1626173.

[0122] As noted above, any suitable actuator arrangement could be provided, and the choice of actuator arrangement will depend in part upon the design of the injector tip. Generally, the actuator arrangement should be capable of effecting linear movement of the control piston between a first end-stop position and a second end-stop position. Where a well-defined intermediate valve needle position is required, a two-solenoid actuator arrangement such as that described above is preferred, since a physical intermediate lift stop position can be provided.

[0123] Another example of an actuator arrangement that could be used in the present invention is a piezoelectric actuator comprising a piezoelectric stack. The piezoelectric stack comprises layers of poled piezoelectric material and an arrangement of electrodes configured so as to cause the piezoelectric stack to lengthen or shorten. In the injector, the piezoelectric stack is coupled to the control piston stem. The length of the stack, and hence the position of the control stem, can be controlled by applying an appropriate energisation level to the electrodes of the stack. Such an actuator is capable of varying the control piston position over a continuous intermediate range, rather than being limited to a single intermediate position such as is the case for a two-solenoid actuator arrangement. Furthermore, such an actuator can be used where it is desirable to control the velocity of the control piston, and hence the valve needle.

[0124] A Lorentz coil or voice coil can also be used as the actuator arrangement in the present invention. Again, such an arrangement is capable of controlling the position and velocity of the control piston, and hence the valve needle, over a continuous range of movement from fully-seated to fully-lifted.

[0125] It is conceivable that a single solenoid actuator with no intermediate lift position, such as that described with reference to Figure 1, could be used to drive the control piston. In this case, the injector would operate in only the first and second modes of operation, since the actuator would not be capable of positioning the control piston in an intermediate position. Nevertheless, the invention would still offer the benefit of reduced drain flow compared to prior art injectors.

[0126] Although the invention has been described with reference to inwardly-opening fuel injectors, the invention is equally applicable to outwardly-opening fuel injectors in which the valve needle is moved downwardly to cause a fuel injection event.

[0127] As will be appreciated by a person skilled in the art, further modifications and variations of the invention not explicitly described above are possible within the scope of the present invention, as defined in the appended claims.

Claims

1. A fuel injector (100; 200; 300) for an internal combustion engine, the fuel injector comprising:

an injection nozzle having a nozzle body (102; 202; 302) provided with a nozzle bore (108; 208; 308);

a valve needle (110; 210; 310) being received within the nozzle bore (108; 208; 308) and engageable with a seat region (122; 222) to control fuel delivery through at least one nozzle outlet (112, 114);

a slave piston (130; 230; 330) provided with a control bore (144; 244; 344) and associated with the valve needle (110; 210; 310) such that movement of the slave piston (130; 230; 330) causes movement of the valve needle (110; 210; 310);

a control chamber (152; 252; 352), an end of the slave piston (130; 230; 330) remote from the valve needle (110; 210; 310) being exposed to fuel pressure in the control chamber (152; 252; 352) in use of the injector, the control chamber (152; 252; 352) being connectable to a source (105; 205; 305) of relatively high-pressure fuel by way of a first control port (166; 266; 366) in the slave piston (130; 230; 330), and to a drain passage (176; 394) at relatively low pressure by way of a second control port (168; 268; 368) in the slave piston (130; 230; 330), the first and second control ports being arranged to communicate with the control bore; and

a control piston (148; 348) operable to move relative to the slave piston (130; 230; 330) and the nozzle body (102; 202; 302) so as to control fuel flow through the first and second control ports (166, 168; 266, 268; 366, 368);

wherein the control piston (148; 348) is positionable so as to allow, in a first mode of operation, fuel flow through the first control port (166; 266; 366) and to prevent fuel flow through the second control port (168; 268; 368), thereby to bias the valve needle (110; 210; 310) in a first direction;

and wherein the control piston (148; 348) is positionable so as to allow, in a second mode of operation, fuel flow through the second control port (168; 268; 368) and to prevent fuel flow through the first control port (166; 266; 366), thereby to bias the valve needle (110; 210; 310) in a second direction opposite to the first direction.

2. A fuel injector according to Claim 1, wherein the control piston (148; 348) is positionable so as to prevent, in a third mode of operation, fuel flow through both the first and second control ports (166, 168; 266, 268; 366, 368), thereby to maintain the valve needle (110; 210; 310) in a substantially static equilibrium position relative to the control piston (148; 348).

3. A fuel injector according to Claim 1 or Claim 2, wherein the control piston (148; 348) is received within the control bore (144; 244; 344).

4. A fuel injector according to Claim 3, wherein the control piston (148; 348) comprises an annular piston member (162; 362) slidable within the control bore (144; 244; 344) so as to selectively occlude the control ports (166, 168; 266, 268; 366, 368).

5. A fuel injector according to Claim 4, wherein the first and second control ports (166, 168; 266, 268; 366, 368) are spaced apart along a longitudinal axis of the injector, and wherein the piston member (162; 362) has a length along the longitudinal axis that is sufficient to prevent fuel flow through both the first and second control ports (166, 168; 266, 268; 366, 368) simultaneously.

6. A fuel injector according to any of Claims 3 to 5, wherein the control piston (148; 348) comprises a necked portion (158; 358) to define an internal gallery (160; 260; 360) for high-pressure fuel, the internal gallery (160; 260; 360) being connectable to the first control port (166; 266; 366) in use of the injector.

7. A fuel injector according to any of Claims 3 to 6, wherein the control piston (148) comprises a tubular member having a central bore, the central bore comprising the drain passage (176).

8. A fuel injector according to any of Claims 1 to 6, wherein the drain passage (394) comprises a passage through the slave piston (130; 230; 330).

9. A fuel injector according to any preceding Claim, further comprising a valve assembly (170, 172; 272; 370, 372) operable to prevent the flow of fuel from the control bore (144; 244; 344) to the drain passage (176; 394).

10. A fuel injector according to Claim 9, wherein the control piston (148; 348) is received within the control bore (144; 244; 344) and wherein the valve assembly comprises a valve element (170; 370) being a tip region of the control piston (148; 348), and a seat region (172; 272; 372) formed in the slave piston (130; 230; 330) at an end of the control bore (144; 244; 344) upstream of the drain passage (174; 394), the valve element (170; 370) being arranged to engage with the seat region (172; 272; 372) so as to prevent the flow of fuel from the control bore (144; 244; 344) to the drain passage (174; 394).

11. A fuel injector according to any preceding Claim, wherein the slave piston (130; 230) comprises a portion of the valve needle (110; 210).

12. A fuel injector according to any preceding Claim, further comprising a spring means (140; 288; 388) to bias the valve needle (110; 210; 310) towards the seating region.

13. A fuel injector according to Claim 12, wherein the spring means (288; 388) is provided in the control chamber (252; 352) to act on an upper end of the slave piston (230; 330).

14. A fuel injector according to any preceding Claim, wherein the control chamber is connectable to the source of relatively high-pressure fuel by way of two or more first control ports in the slave piston, and to the drain passage by way of two or more second control ports in the slave piston.

15. A fuel injector according to any preceding Claim, wherein the control piston (148; 348) is operable by means of an actuator arrangement comprising a linear-movement actuator.

Amended claims in accordance with Rule 137(2) EPC.

1. A fuel injector (100; 200; 300) for an internal combustion engine, the fuel injector comprising:

an injection nozzle having a nozzle body (102; 202; 302) provided with a nozzle bore (108; 208; 308);
a valve needle (110; 210; 310) being received within the nozzle bore (108; 208; 308) and engageable with a seat region (122; 222) to control fuel delivery through at least one nozzle outlet (112, 114);
a slave piston (130; 230; 330) provided with a control bore (144; 244; 344) and associated with the valve needle (110; 210; 310) such that movement of the slave piston (130; 230; 330) causes movement of the valve needle (110; 210; 310);
a control chamber (152; 252; 352), an end of the slave piston (130; 230; 330) remote from the valve needle (110; 210; 310) being exposed to fuel pressure in the control chamber (152; 252; 352) in use of the injector, the control chamber (152; 252; 352) being connectable to a source (105; 205; 305) of relatively high-pressure fuel by way of a first control port (166; 266; 366) in

the slave piston (130; 230; 330), and to a drain passage (176; 394) at relatively low pressure by way of a second control port (168; 268; 368) in the slave piston (130; 230; 330), the first and second control ports being arranged to communicate with the control bore; and

a control piston (148; 348) operable to move relative to the slave piston (130; 230; 330) and the nozzle body (102; 202; 302) so as to control fuel flow through the first and second control ports (166, 168; 266, 268; 366, 368);

wherein the control piston (148; 348) is positionable so as to allow, in a first mode of operation, fuel flow through the first control port (166; 266; 366) and to prevent fuel flow through the second control port (168; 268; 368), thereby to bias the valve needle (110; 210; 310) in a first direction; and wherein the control piston (148; 348) is positionable so as to allow, in a second mode of operation, fuel flow through the second control port (168; 268; 368) and to prevent fuel flow through the first control port (166; 266; 366), thereby to bias the valve needle (110; 210; 310) in a second direction opposite to the first direction;

characterised in that the fuel injector further comprises a valve assembly (170, 172; 272; 370, 372) operable to prevent the flow of fuel from the control bore (144; 244; 344) to the drain passage (176; 394) in the first mode of operation, thereby to prevent leakage of fuel into the drain passage.

2. A fuel injector according to Claim 1, wherein the control piston (148; 348) is positionable so as to prevent, in a third mode of operation, fuel flow through both the first and second control ports (166, 168; 266, 268; 366, 368), thereby to maintain the valve needle (110; 210; 310) in a substantially static equilibrium position relative to the control piston (148; 348).

3. A fuel injector according to Claim 1 or Claim 2, wherein the control piston (148; 348) is received within the control bore (144; 244; 344).

4. A fuel injector according to Claim 3, wherein the control piston (148; 348) comprises an annular piston member (162; 362) slidable within the control bore (144; 244; 344) so as to selectively occlude the control ports (166, 168; 266, 268; 366, 368).

5. A fuel injector according to Claim 4, wherein the first and second control ports (166, 168; 266, 268; 366, 368) are spaced apart along a longitudinal axis of the injector, and wherein the piston member (162; 362) has a length along the longitudinal axis that is sufficient to prevent fuel flow through both the first and second control ports (166, 168; 266, 268; 366, 368) simultaneously.

6. A fuel injector according to any of Claims 3 to 5, wherein the control piston (148; 348) comprises a necked portion (158; 358) to define an internal gallery (160; 260; 360) for high-pressure fuel, the internal gallery (160; 260; 360) being connectable to the first control port (166; 266; 366) in use of the injector.

7. A fuel injector according to any of Claims 3 to 6, wherein the control piston (148) comprises a tubular member having a central bore, the central bore comprising the drain passage (176).

8. A fuel injector according to any of Claims 1 to 6, wherein the drain passage (394) comprises a passage through the slave piston (330).

9. A fuel injector according to any preceding Claim, wherein the control piston (148; 348) is received within the control bore (144; 244; 344) and wherein the valve assembly comprises a valve element (170; 370) being a tip region of the control piston (148; 348), and a seat region (172; 272; 372) formed in the slave piston (130; 230; 330) at an end of the control bore (144; 244; 344) upstream of the drain passage (174; 394), the valve element (170; 370) being arranged to engage with the seat region (172; 272; 372) so as to prevent the flow of fuel from the control bore (144; 244; 344) to the drain passage (174; 394).

10. A fuel injector according to any preceding Claim, wherein the slave piston (130; 230) comprises a portion of the valve needle (110; 210).

11. A fuel injector according to any preceding Claim, further comprising a spring means (140; 288; 388) to bias the valve needle (110; 210; 310) towards the seating region, wherein the spring means (288; 388) is provided in the control chamber (252; 352) to act on an upper end of the slave piston (230; 330).

12. A fuel injector according to any preceding Claim, wherein the control chamber is connectable to the source of relatively high-pressure fuel by way of two or more first control ports in the slave piston, and to the drain passage by way of two or more second control ports in the slave piston.

13. A fuel injector according to any preceding Claim, wherein the control piston (148; 348) is operable by means of an actuator arrangement comprising a linear-movement actuator.

14. A fuel injector according to any preceding Claim, wherein the slave piston (130; 230; 330) includes a transfer passage (164; 264; 364) that communicates with the control chamber (152, 252, 352), such that the control chamber (152; 252; 352) is in communication with the control bore (144; 244; 344) by way of the transfer passage (164; 264; 364) and the first and second control ports.

15. A fuel injector according to Claim 14, wherein the first and second control ports (166, 168; 266, 268; 366, 368) extend radially from the control bore (144; 244; 344) into the transfer passage (164; 264; 364).

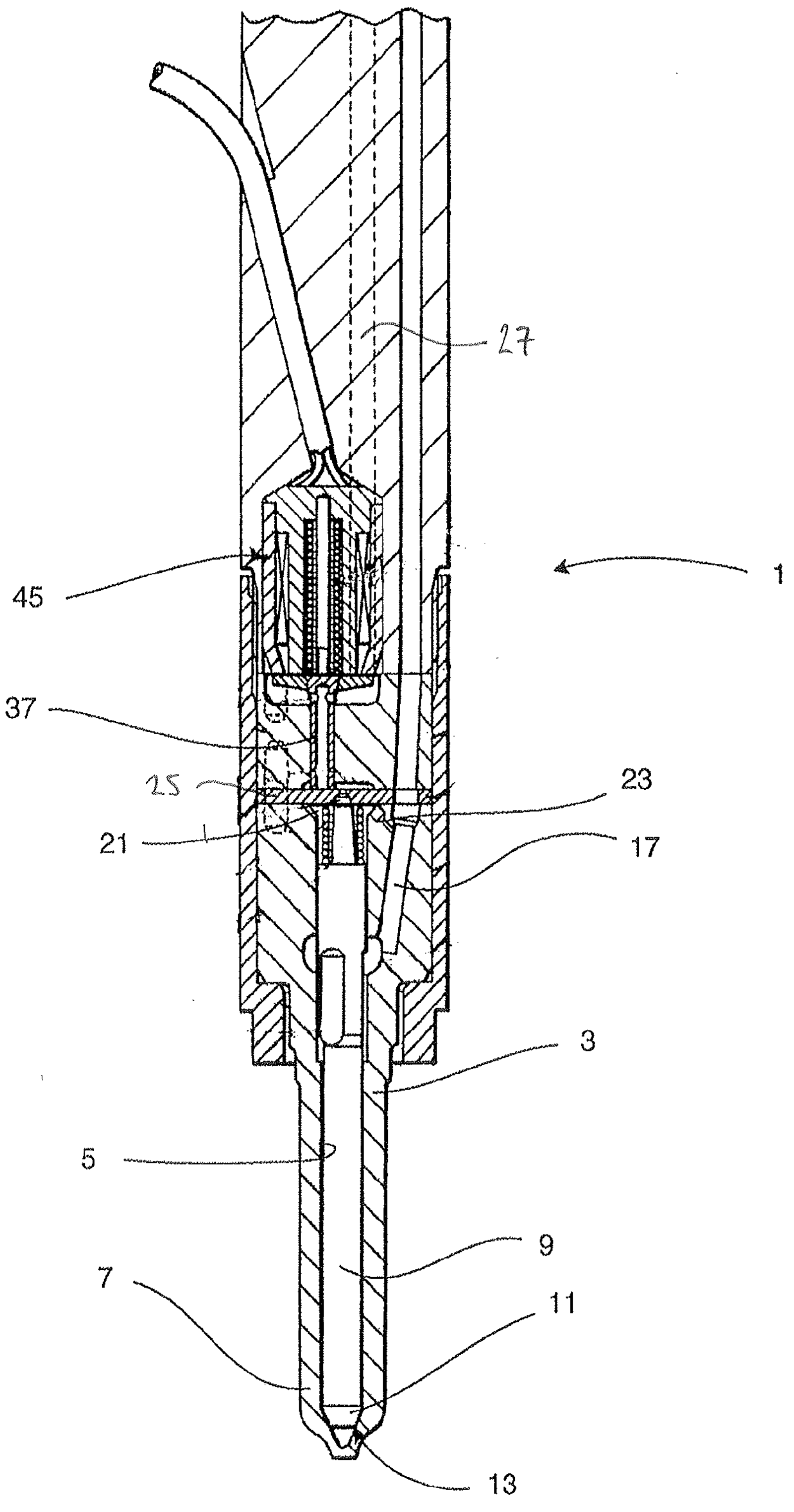

FIGURE 1

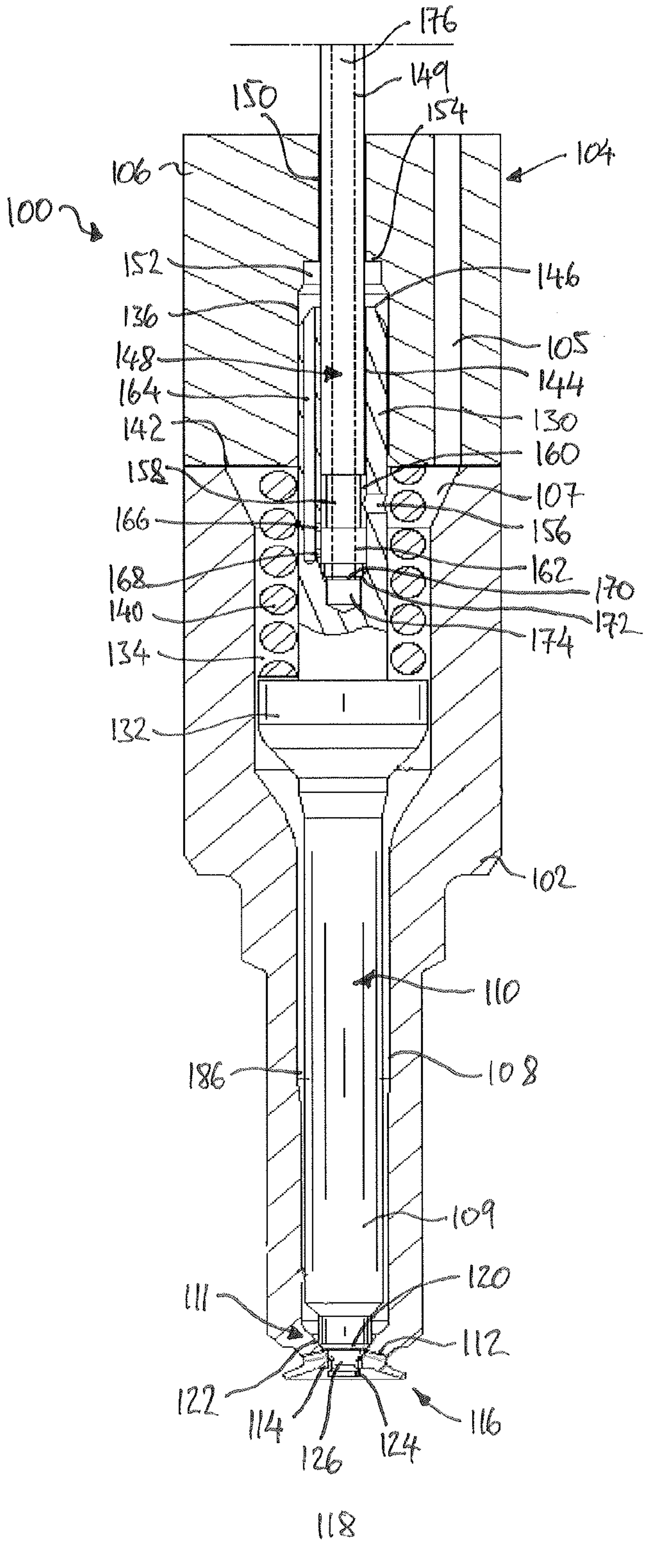
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FIGURE 2

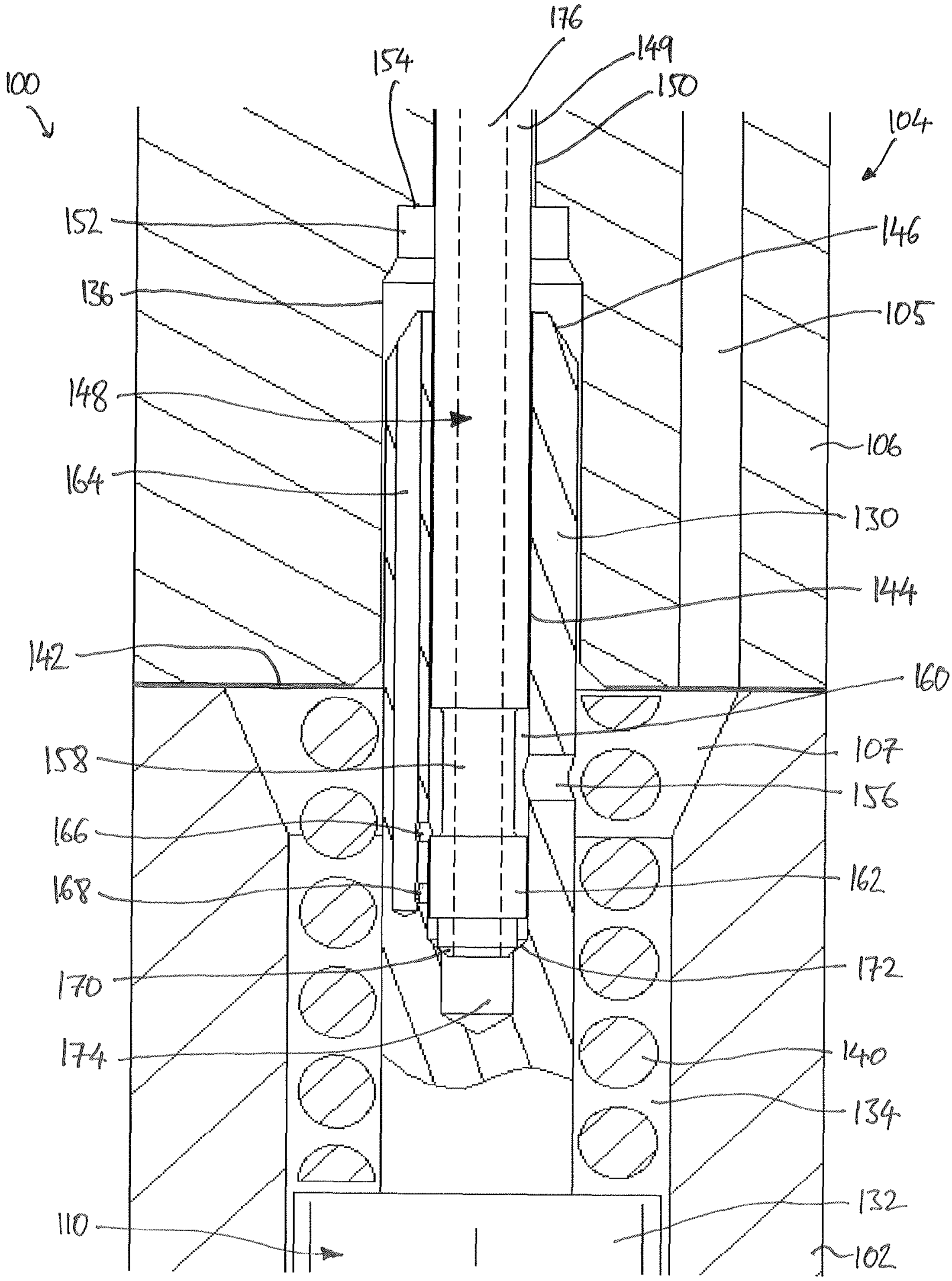
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FIGURE 3

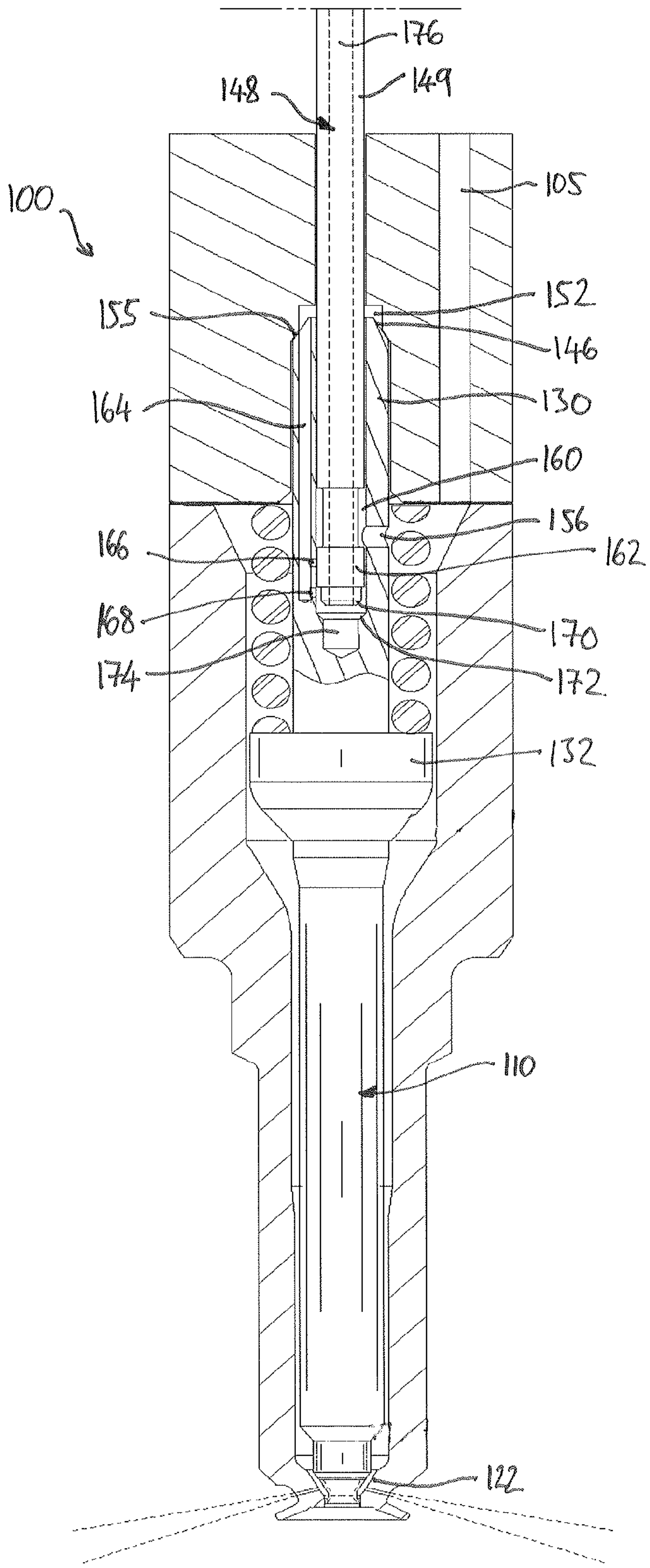
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FIGURE 4

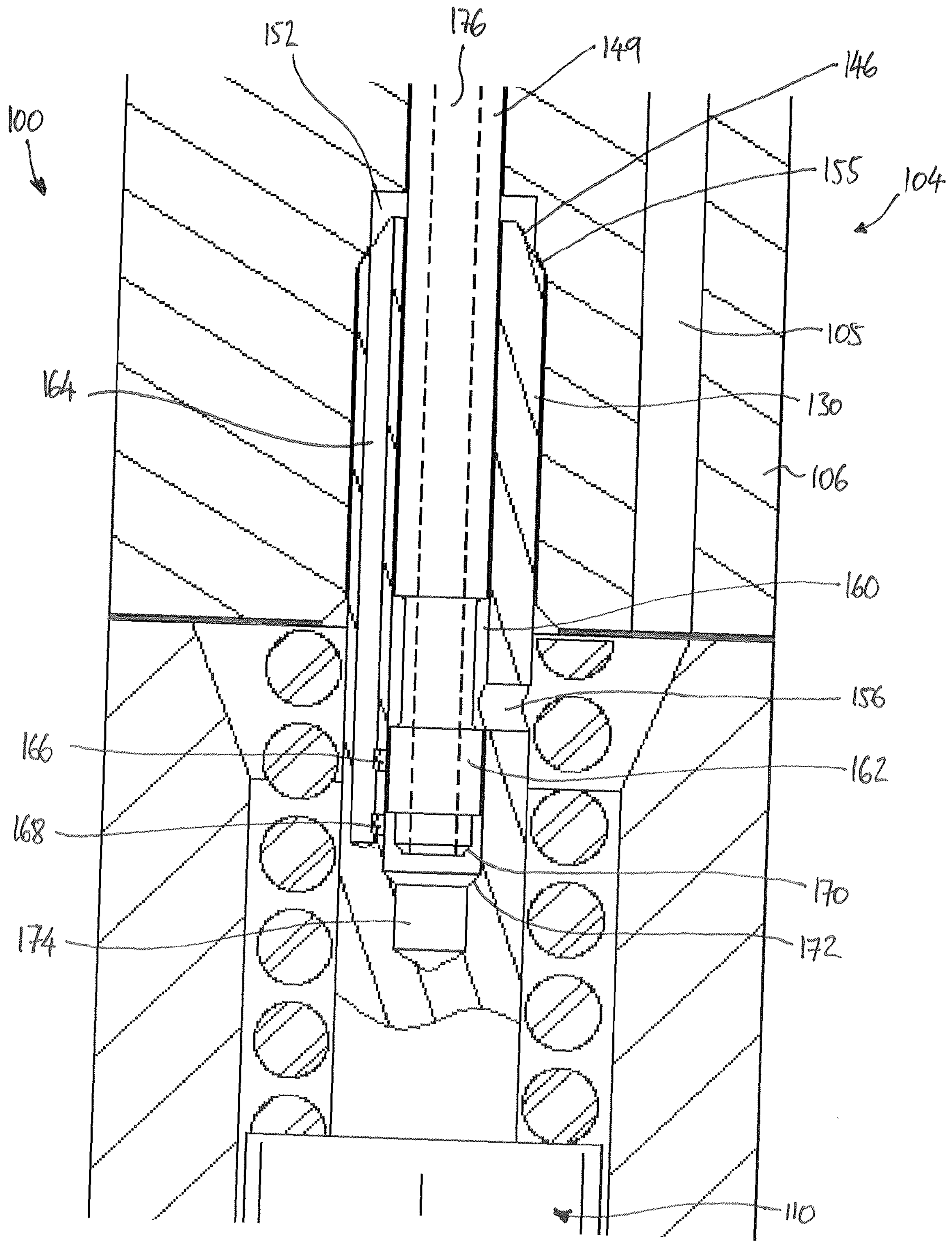
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FIGURE 5

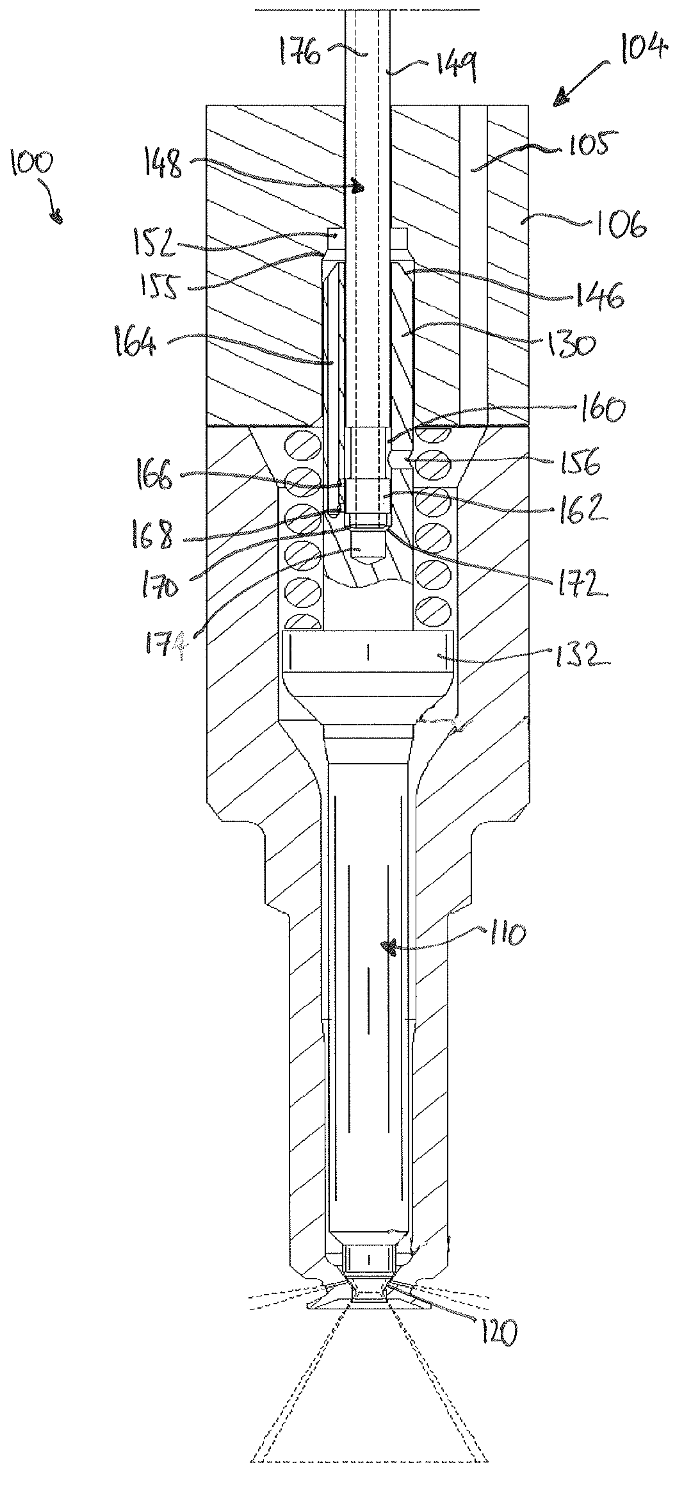
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FIGURE 6

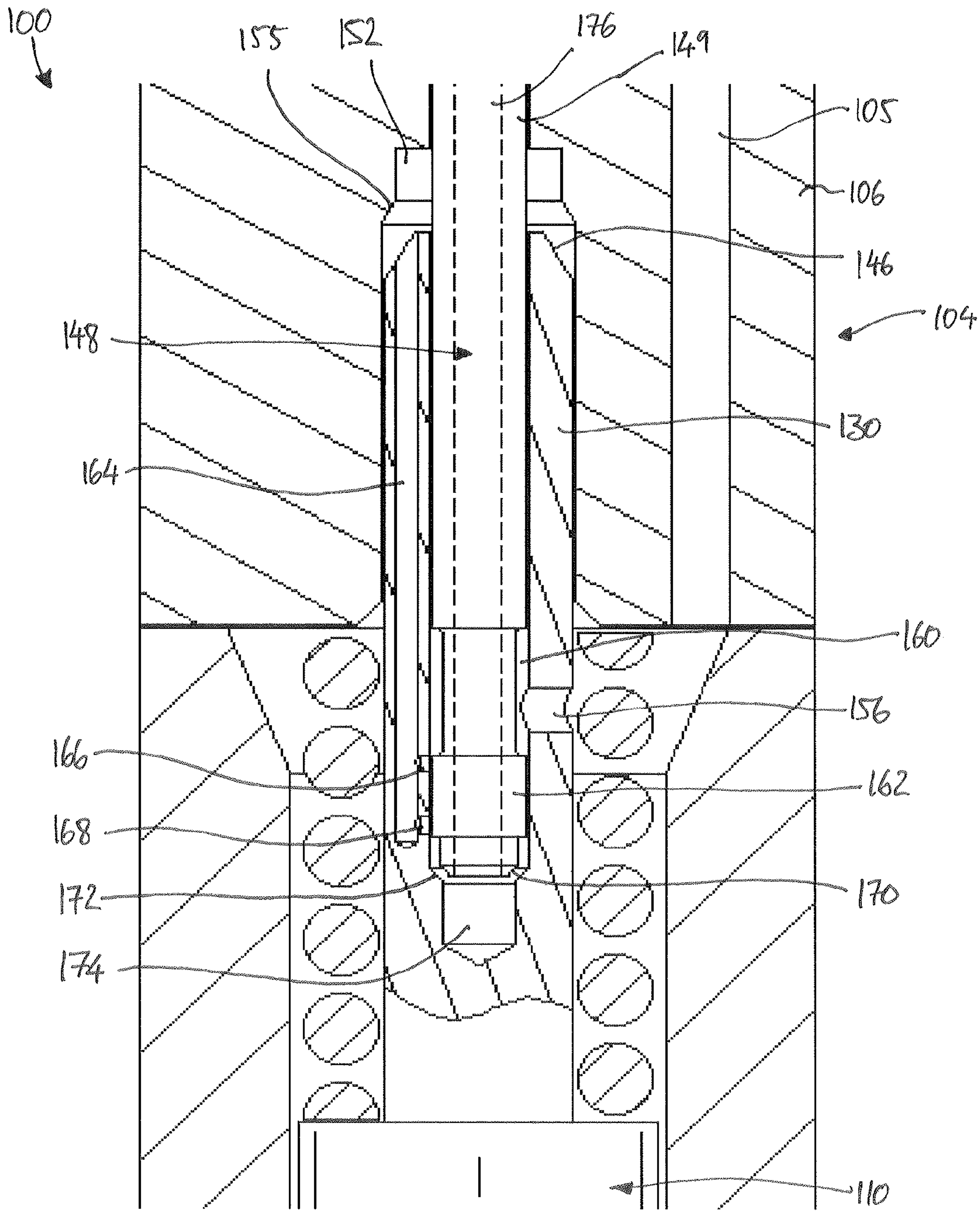
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FIGURE 7

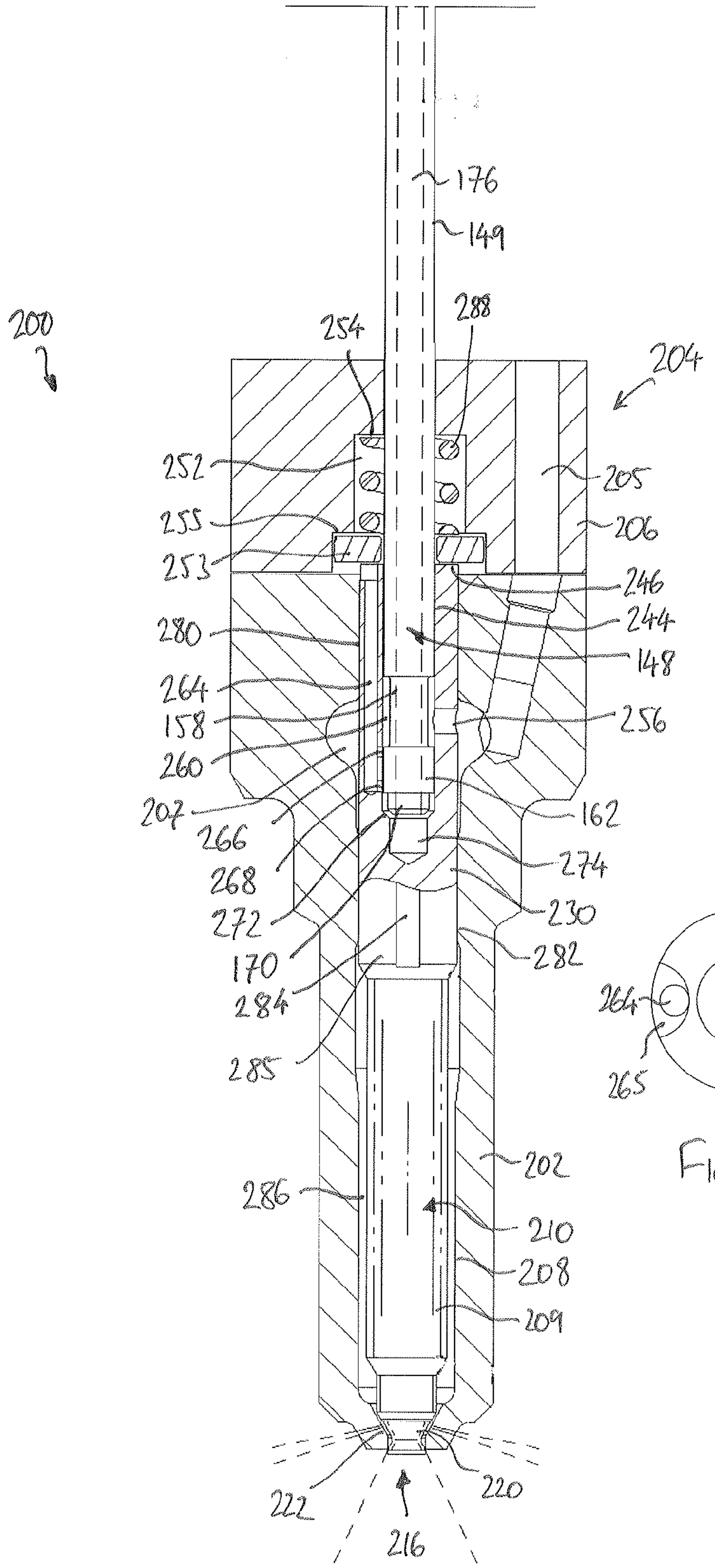

FIGURE 8(a)

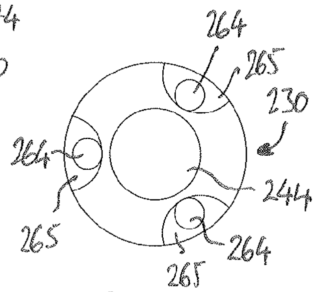

FIGURE 8(b)

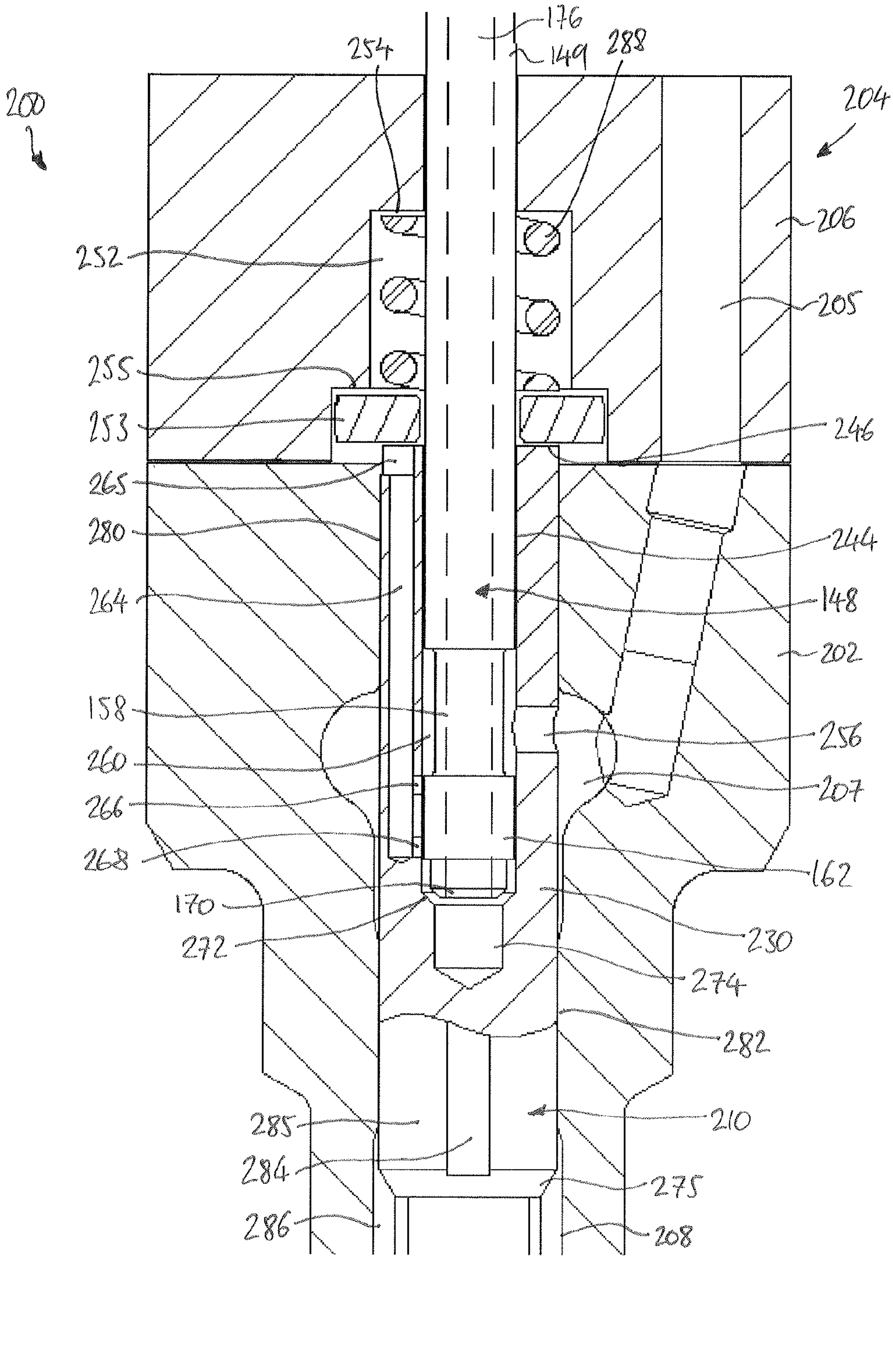

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FIGURE 9

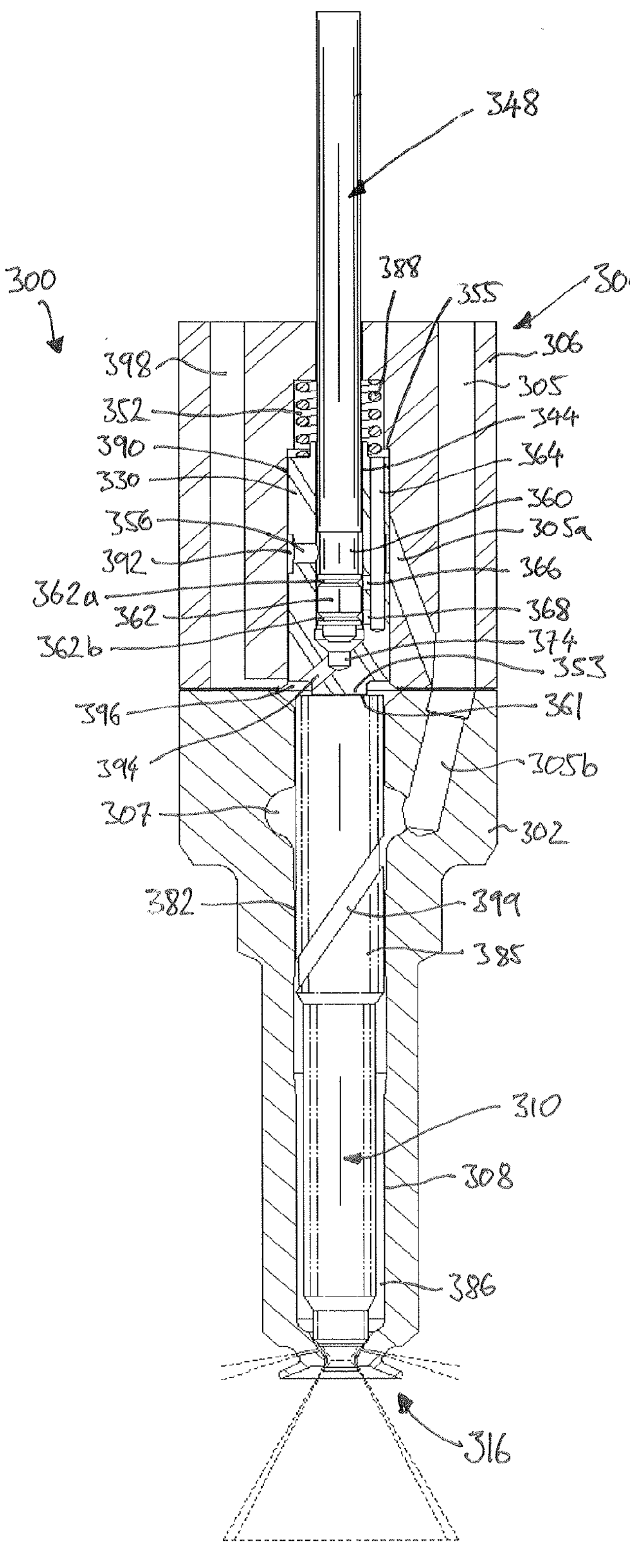
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FIGURE 10

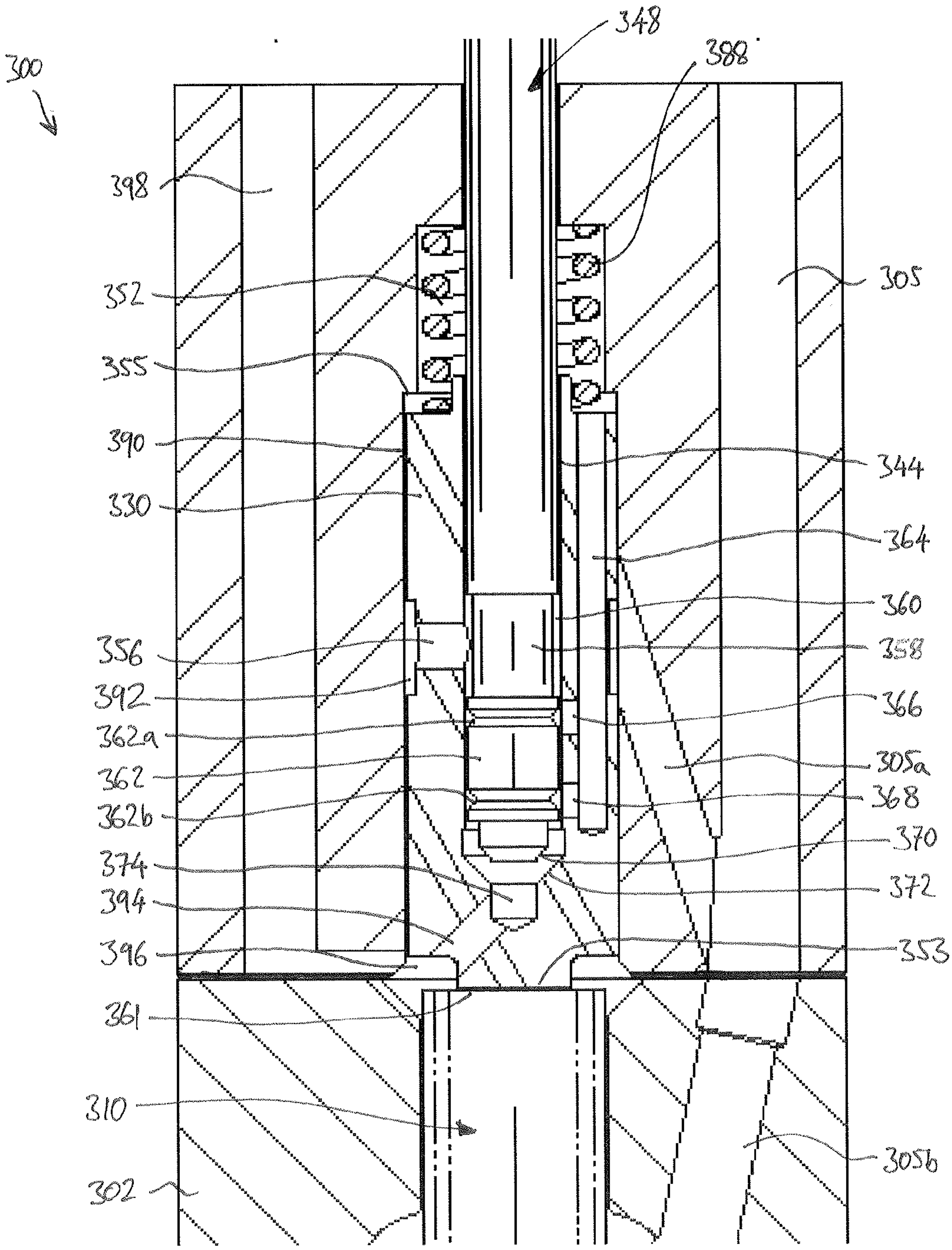
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FIGURE 11

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EUROPEAN SEARCH REPORT

Application Number
EP 09 17 5036

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 Y	US 6 024 298 A (KELLY WILLIAM W [US]) 15 February 2000 (2000-02-15) * column 5, line 13 - column 7, line 65; figure 2 *	1-6,8, 11-12,15 7	INV. F02M45/12 F02M47/02 F02M63/00
Y	US 5 860 597 A (TARR YUL J [US]) 19 January 1999 (1999-01-19) * column 6, line 55 - column 7, line 19; figure 1 *	7	
Y,D	EP 0 647 780 A2 (LUCAS IND PLC [GB]) 12 April 1995 (1995-04-12) * column 2, lines 50-58; figure 3 *	7	
Y	GB 2 341 893 A (LUCAS INDUSTRIES LTD [GB]) 29 March 2000 (2000-03-29) * page 5, paragraph 3; figure 1 *	7	
			TECHNICAL FIELDS SEARCHED (IPC)
			F02M

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
Munich	12 March 2010	Etschmann, Georg

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Patent document cited in search report		Publication date	Patent family member(s)		Publication date
US 6024298	A	15-02-2000	DE	69812001 D1	17-04-2003
			DE	69812001 T2	04-03-2004
			EP	0892171 A2	20-01-1999
			ES	2193440 T3	01-11-2003
			US	5947382 A	07-09-1999
US 5860597	A	19-01-1999	NONE		
EP 0647780	A2	12-04-1995	JP	7167005 A	04-07-1995
			US	5556031 A	17-09-1996
GB 2341893	A	29-03-2000	NONE		

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Patent documents cited in the description

- EP 0647780 A **[0003]**
- EP 0740068 B **[0003] [0004]**
- EP 2065590 A **[0010] [0034] [0039] [0043] [0113] [0120]**
- EP 09166712 A **[0059]**
- EP 0767304 B **[0100]**
- EP 1626173 B **[0121]**