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(54) **FUEL INJECTOR**

(57) A fuel injector (101) for an internal combustion engine comprising an injector housing comprising an injector body (102), provided with an injector body bore (103), and a valve body (111) for housing a control valve (110); a needle valve (104) which is movable within the injector body bore (103), under the control of the control valve (110), towards and away from a needle valve seating (106), to control fuel injection; an electrically insulating plate (112) located between the injector body (103) and the valve body (111) to electrically insulate the injector body (103) from the valve body (111); wherein the electrically insulating plate (112) is provided with an opening for receiving at least one positioning element (123b, 124b) which also extends into the valve body (111); an electrical current path (134) defined, at least in part, through the electrically insulating plate (112) and the needle valve (104); and an electrical circuit to measure the current flow through the electrical current path (134) so as to determine the position of the needle valve (104).

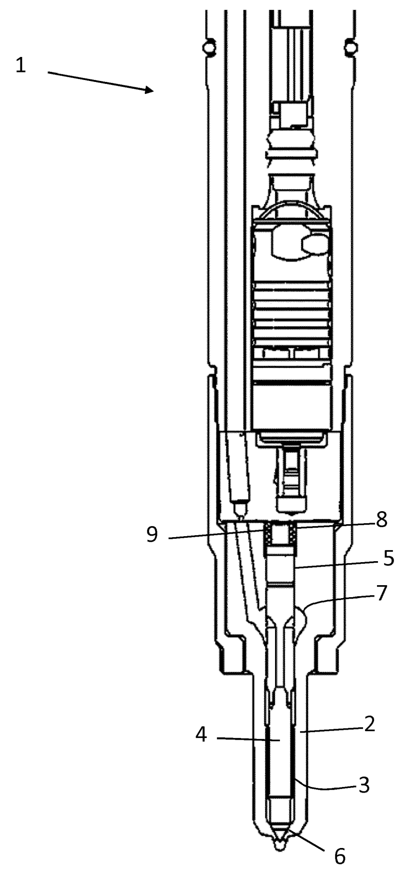

Fig. 1

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Description

FIELD OF THE INVENTION

[0001] This invention relates to a fuel injector for use in an internal combustion engine. In particular, the invention relates to a fuel injector for use with an electrical circuit for determining the position of a needle valve of the injector.

BACKGROUND

[0002] It is known to use fuel injectors for the delivery of high-pressure fuel from a common rail fuel supply system to a cylinder of an associated internal combustion engine. In particular, for such purposes it is known to use a fuel injector of a type illustrated in Figure 1.

[0003] For the purpose of the following description it will be appreciated that references to above, below, upper, lower, upward, downward, above and below, for example, are not intended to be limiting and relate only to the orientation of the fuel injectors as shown in the illustrations.

[0004] As shown in Figure 1, the fuel injector 1 is formed from an assembly of bodies, including a fuel delivery body, a valve body and a nozzle-like injector body 2 having one or more small injection apertures at its tip. The injector body 2 includes an injector body bore 3 and a needle valve 4 that is movable, within the injector body bore 3, relative to a valve seat 6 so as to control the injection of diesel fuel into the engine cylinder (not shown).

[0005] With this type of fuel injector, the injector body bore 3 extends completely through the injector body 4 and defines an integrated valve guide 5. The integrated valve guide 5 takes the form of a narrowed section of the injector body bore. The narrowed section creates a guiding region that serves to centre the needle valve 4 within the injector body 2 and guide the movement of the needle valve towards or away from the valve seat. Centring of the needle valve is important in order to ensure proper functioning of the fuel injector.

[0006] A lower end or tip of the needle valve is biased into contact with the generally conical valve seat 6 by means of a compressed spring 16. In this type of fuel injector, having an integrated valve guide 5, the compressed spring is arranged between a lower surface of the valve body and a shoulder of the needle valve. The shoulder of the needle valve defines a spring seat towards an upper end of the needle valve. When seated, the needle valve 4 contacts the valve seat 6 to stop the supply of fuel through the one or more small injection apertures provided in the injector body 3.

[0007] The diesel fuel is supplied to the fuel delivery body from a high-pressure fuel supply in the form of a common fuel rail (not shown) fed by an injection pump (not shown). The fuel passes from the fuel delivery body, through a delivery path, to a fuel accumulator volume 7 arranged in the injector body bore 3. The accumulator volume 7 is arranged to accumulate pressurised fuel for injection into the engine. When filled with fuel, the accumulator volume 7 forms a high-pressure region around a tapered portion or shoulder of the needle valve 4 and urges the needle valve away from the valve seat 6.

[0008] The injection of fuel is controlled by actuating the needle valve 4 towards or away from the valve seat 6 using an electronic control unit (not shown) that operates a two-way control valve, housed within the valve body, to increase or decrease the pressure in a control chamber 8 disposed at the upper end of the needle valve, as viewed in Figure 1.

[0009] More specifically, the control valve controls the flow of fuel between the control chamber 8, the high-pressure fuel supply and a low-pressure drain. In this manner, the pressure in the control chamber 8 can be switched between relatively high pressure and a relatively low pressure according to the position of the control valve. In turn, controlling the fuel pressure in the control chamber 8 controls the position of the needle valve 4.

[0010] With fuel injectors of this type, the position of the control valve therefore relates to whether the needle valve is seated or unseated, Hence, timing information, for controlling the amount of fuel injected into the cylinders, can be determined based on the position of the control valve. However, delays that occur between the control valve being switched and the needle valve opening or closing the injection apertures, means that fuel injection control based on such timing information can be unsatisfactory.

[0011] It is against this background that the invention has been devised.

SUMMARY OF INVENTION

[0012] According to the present invention, there is provided a fuel injector for an internal combustion engine, the fuel injector comprising: an injector housing comprising an injector body, provided with an injector body bore, and a valve body for housing a control valve; a needle valve which is movable within the injector body bore, under the control of the control valve, towards and away from a needle valve seating, to control fuel injection; an electrically insulating plate located between the injector body and the valve body to electrically insulate the injector body from the valve body; wherein the electrically insulating plate is provided with an opening for receiving at least one positioning element which also extends into the valve body; an electrical current path defined, at least in part, through the electrically insulating plate and the needle valve; and an electrical circuit to measure the current flow through the electrical current path so as to determine the position of the needle valve.

[0013] It is a benefit of the invention that the injector can be provided with a means for implementing an injector closed loop control apparatus, by virtue of the electrically insulating plate which provides a route for an electrical current path which also passes through the needle valve.

[0014] The injector body bore may include a guide region which serves to guide movement of the needle valve. The guide region may be electrically insulated from a corresponding guided region of the needle valve.

[0015] At least one of the guide region and the corresponding guided region of the needle valve may be provided with an electrically insulating coating.

[0016] The fuel injector may further comprise a biasing spring which serves to urge the needle valve against the valve seat. An upper surface of the valve spring may be engaged with the electrically insulating plate.

[0017] he electrically insulating plate may include a conductive core which defines a part of the electrical current path.

[0018] The electrically insulating plate may include a conductive portion with which an upper portion of the needle valve is engaged at full lift of the needle valve.

[0019] The electrically insulating plate may define a guiding bore which serves to guide an upper portion of the needle valve. The upper portion of the needle valve may engage with the valve body at full lift of the needle valve.

[0020] At least one of the upper portion of the needle valve and the guiding bore may be provided with an electrically insulating coating.

[0021] The at least one positioning element may be formed from electrically conductive material.

[0022] At least one of the opening in the electrically insulating plate and the at least one positioning element may be coated with an electrically insulating material to ensure no electrical contact is made between the electrically insulating plate and the or each positioning element.

[0023] The or each positioning element may be formed from a non-conductive material.

[0024] The electrically insulating plate may have a thickness of at least 1.0 mm.

[0025] It will be appreciated that the various features of the first aspect of the invention are equally applicable to, alone or in appropriate combination, the second aspect of the invention also.

BRIEF DESCRIPTION OF THE DRAWINGS

[0026] The above and other aspects of the invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

DETAILED DESCRIPTION

[0027] Embodiments of the invention relate to a fuel injector for an internal combustion engine and, in particular, to a fuel injector having an injector closed loop control apparatus for determining the position of a needle valve of the injector, relative to a valve seat. More specifically, the injector closed loop control apparatus includes an electrical circuit arranged to apply a voltage to at least a portion of the needle valve such that the needle valve acts as an electrical switch as it seats against, and makes electrical contact with, the valve seat. As will become clear in the description that follows, this arrangement can be used to output a signal that is indicative of the position of the needle valve, providing useful timing information. The engine has an associated engine control unit (ECU) which controls operation of the injector and, hence, the timing of injection of fuel into the engine cylinder.

[0028] Figure 2 shows an example fuel injector 101 for an internal combustion engine (not shown) according to an embodiment of the invention. The fuel injector 101 is of the type described in the background section of the application, such as a piezoelectric or solenoid fuel injector 1. Accordingly, the fuel injector 101 is suitable for delivering high pressure fuel, such as diesel fuel, to a combustion chamber of a compression ignition internal combustion engine.

[0029] The fuel injector 1 described in Figure 1 provides context for the invention and like reference numerals (incremented by 100) are used in the following description to indicate like-features of the fuel injector 101 of the invention.

[0030] The fuel injector 101 is shown extending along a longitudinal axis from a tip at a lower, first end of the fuel injector 101 to an upper, second end of the fuel injector. The upper end of the fuel injector 101 connects to a fuel delivery system, such as a common rail delivery system (not shown), which provides a supply of high-pressure fuel, as described previously.

[0031] The fuel injector 101 includes an injector body 102, an injector body bore 103, a needle valve 104, a guide region 105 for the needle valve 104, a valve seat 106, an accumulator volume 107 and a control chamber 108. The injector 101 also includes a fuel delivery body 116 and a control valve 110 within a control valve body or housing 111. The control valve 110 controls the pressure of fuel within the control chamber 108. An electrically insulating plate 112 separates the control valve housing 111 and the injector body 102.

[0032] Along the length of the fuel injector 101, the fuel injector therefore comprises an assembly of bodies. In longitudinal succession from the lower end of the fuel injector 101 to the upper end, the fuel injector 101 includes the injector body 102, the electrically insulating plate 112, the valve body 111 and the fuel delivery body 116.

[0033] The upper end of the needle valve 104 defines a floor of the control chamber 108 and is therefore exposed to the pressure within the control chamber 108. By controlling the pressure in the control chamber 108, the downward force acting on the needle valve 104 can be varied so as to control whether the needle valve 104 is seated against the valve seat 106 (when fuel pressure within the control chamber is relatively high) or whether it is lifted from the valve seat 106 (when fuel pressure within the control chamber is relatively low).

[0034] In particular, when a fuel demand exists, the control valve 110 is operated to connect the control chamber 108 to the low-pressure drain and the pressure of fuel in the control chamber 108 decreases. As a result, the higher pressure of fuel in the accumulator volume 107 causes the needle valve 104 to move away from the valve seat 106 of the injector body 102. This allows fuel to be sprayed through the injection apertures and enter the engine cylinder.

[0035] When there is no fuel demand, the control valve 110 moves to prevent communication between the control chamber 108 and the low-pressure drain and the pressure in the control chamber 108 increases back to the supply pressure. As a result, the needle valve 104 moves back on to the valve seat 106, under the influence of the spring 109, thereby cutting-off the fuel supply to the engine cylinder.

[0036] The injector body 102 may be of the type described above, with reference to Figure 1, and is described in that context below, featuring the injector body bore 103, the integrated valve guide 105 and needle valve 104, substantially as described previously.

[0037] The fuel delivery body 116 and the valve body 111 may also be of the type described above, with reference to Figure 1, and are described in that context below, with the valve body 111 housing the control valve 110 that functions substantially as described previously.

[0038] Notably, in the embodiments of the invention, the fuel injector differs from the fuel injector shown in Figure 1, at least by the further inclusion of an injector closed loop control apparatus. The injector closed loop control apparatus is configured to determine a signal indicative of the position of the needle valve 104 relative to the valve seat 106. For this purpose, the injector closed loop control apparatus comprises an electrical input capable of generating an electrical signal; an electronic control unit (ECU) configured to monitor the electrical signal; the electrically insulating plate 112 arranged to insulate the valve body 111 from the injector body 102; and a current path through the fuel injector to the needle valve 104.

[0039] Advantageously, determining the position of the needle valve 104 in this manner permits accurate calculation of the timing of fuel delivery into the engine cylinder when the needle valve 104 is unseated and, hence, the accurate calculation of an amount of fuel injected into the engine cylinder.

[0040] In particular, the injector closed loop control apparatus provides an electrical circuit that connects the electrical supply and the ECU to the needle valve 104 such that a voltage input can be applied to the needle valve 104 and monitored by the ECU.

[0041] The injector closed loop control apparatus takes advantage of the fact that the needle valve 104 and the valve seat 106 of the injector body 102 are electrically conductive. Therefore, when the needle valve 104 is supplied with electrical power and unseated, or moved away, from the valve seat 106, the needle valve 104 will hold a charge. However, when the needle valve 104 is supplied with the electrical signal and seated against the valve seat 106, a current path is defined through the needle valve 104 into the valve seat 106, where the circuit is effectively grounded. This current path can be used to determine signals that are indicative of the position of the needle valve 104 relative to the valve seat 106, which may provide timing information for operating the fuel injector.

[0042] For example, the ECU may be configured to monitor the voltage across the needle valve 104 and determine a voltage change or output signal, that is indicative of the position of the needle valve 104, as the needle valve 104 is seated (grounded) and unseated from the valve seat 106. In such an arrangement, the needle valve 104 effectively acts an electrical switch as it seats against, and makes electrical contact with, the valve seat 106.

[0043] To ensure accurate functioning of the injector closed loop apparatus, and to ensure that an output signal is not generated before the needle valve 104 engages or leaves the valve seat 106, the surfaces of the injector body 102, and of the adjacent guided region of the valve guide 105 in particular, are electrically insulated in areas that may contact the needle valve 104. For example, a coating layer of insulating material, such as a coating layer of metal oxide, may be applied to the surfaces of the injector body bore 103 to prevent a conductive path forming between the needle valve 104 and the injector body 102 before the needle valve 104 contacts the valve seat.

[0044] Moreover, the valve body 111 is also electrically conductive. Therefore, to mitigate the risk of short-circuiting between the valve body 111 and the injector body 102, the fuel injector 101 has an advantageous arrangement in which the electrically insulating plate 112 is arranged between the valve body 111 and the injector body 102, and an electrical harness 115 connects the electrical supply and the ECU to a conductive core of the electrically insulating plate 112. In this manner, the electrically insulating plate 112 provides a current path through to the needle valve 104, whilst separating the electrically conductive valve body 111 from the injector body 102 and preventing short-circuiting therebetween, as described in more detail in reference to Figures 6 to 8.

[0045] The following description, which refers to Figures 2 to 5, describes the features of the fuel injector that are adapted to accommodate, or otherwise complement, the injector closed loop control apparatus.

[0046] In Figures 2 to 5, the fuel injector 101 is shown to include a fuel delivery path and an electrical harness path. The electrical harness path accommodates the electrical connection to the needle valve 104 and acts as a guide for the electrical harness 115, which includes one or more electrical wires coated in an electrically insulating layer.

[0047] The fuel delivery path defines a channel, through the fuel injector 101, from the common rail fuel supply to the accumulator volume 107. The fuel delivery channel includes a first delivery channel 113a through the fuel delivery body 116, a second delivery channel 113b through the valve body 111, a fuel delivery opening 114 at the electrically insulating plate 112 and a third delivery channel 113c arranged in the injector body 102. In use, the third delivery channel 113c supplies high-pressure fuel to the accumulator volume 107 for injection into the engine cylinder.

[0048] The electrical supply and/or the ECU may, for example, be mounted on the fuel delivery body 116 or separately to the fuel injector body 102. In such embodiments, the electrical harness path defines a bore, through the fuel injector, from the electrical supply (and the ECU) to the electrically insulating plate 112. The electrical harness path may include a first cable route and a second cable route (not shown in Figure 2). The first cable route passes through the fuel delivery body 116, while the second cable route passes through the valve body 111, where the electrical harness path meets the electrically insulating plate 112.

[0049] As noted previously, the fuel injector 101 differs from the example described in Figure 1 in that the electrically insulating plate 112 is disposed between the injector body 102 and the valve body 111. Hence, to function in the same manner, the spring 109 that biases the needle valve 104 into contact with the valve seat 106 is arranged to abut against a lower surface of the electrically insulating plate 112, instead of the lower surface of the valve body as noted in the previous example. With this arrangement, an upper end of the spring 109 abuts against the electrically insulating plate 112 and a lower end of the spring 109 is compressed against the shoulder on the needle valve 104, which serves to bias the needle valve 104 towards the valve seat 106.

[0050] The needle valve 104 is then selectively movable towards or away from the valve seat 106 by operating the control valve 110. As in the previous example, the control valve 110 is operable to control the flow of fuel between the control chamber 108, the high-pressure fuel supply and the low-pressure drain (not shown).

[0051] To make this possible, the electrically insulating plate 112 includes an inlet channel 117 that connects the high-pressure supply to the control chamber 108 and a drain channel 118 that connects the control chamber 108 to the low pressure drain.

[0052] If the control valve 110 is actuated so that the control chamber 108 communicates with the low pressure drain (not shown), fuel flows out of the control chamber 108 through the drain channel 118 and the pressure in the control chamber 108 is reduced. Consequently, the pressure in the accumulator volume 107 (which acts on various upwardly-directed thrust surfaces of the needle valve 104) causes the needle valve 104 to move away from the valve seat 106, which allows fuel to be sprayed into the engine cylinder through the injection apertures.

[0053] If the control valve 110 is moved so that communication between the control chamber 108 and the low pressure drain is broken, high-pressure fuel flows through the inlet channel 117 of the electrically insulating plate 112 into the control chamber 108 from the high-pressure fuel supply. As a result, high pressure is reestablished in the control chamber 108 and the needle valve 104 moves back on to the valve seat 106, sealing the injector body 102 and cutting-off the fuel supply to the engine.

[0054] It is important that the various bodies of the fuel injector 101 are correctly aligned and held firmly together. For example, correct angular alignment is required to maintain effective seals between bodies that convey diesel fuel, at extremely high pressure, from one body to another.

[0055] For this purpose, the fuel injector 101 includes a plurality of positioning elements that locate the injector body 102, electrically insulating plate 112, valve body 111 and fuel delivery body 116 with respect to one another, and a cap nut 119 that forces the bodies together.

[0056] Each positioning element is an elongate member, such as a dowel pin, that extends from an opening in one body into a respective opening in an adjacent body. The positioning elements are configured to positionally align, and angularly constrain, the bodies with respect to one another. For this purpose, the openings, referred to as positional openings, have a low tolerance relative to the respective positioning elements. For example, there may be a maximum tolerance of less than 0.5mm, and optionally less than or equal to 0.2mm, between the diameters of any particular positional opening and the diameter of the respective positioning element.

[0057] The positioning elements are electrically insulated to prevent short circuiting from one conductive body to another through the positioning elements. For example, the positioning elements may be made of non-conductive materials, such as plastic materials. Alternatively, the positioning elements may be made from a conductive material, such as a metal material, and coated in an insulating layer, such as a layer of metal oxide. For example, each positioning element may be coated in a layer of Aluminium Oxide.

[0058] The cap nut 119 fastens onto a lower end of the fuel delivery body 116 and bears against a shoulder of the injector body 102 to clamp the assembly together. This arrangement substantially inhibits fuel leakage and ensures correct alignment between adjacent bodies of the injector.

[0059] Figures 3 to 5 show each of the valve body 111, the electrically insulating plate 112 and the injector body 102 in isolation such that they can be described in more detail.

[0060] First considering the valve body 111, shown in Figures 3a and 3b, the valve body 111 is a cylindrical member that extends from an upper surface shown in Figure 3a to a lower surface shown in Figure 3b. The upper surface is configured to mate with an opposing surface of the fuel delivery body 116 such that there is substantially no leakage at the interface. For this purpose, the upper surface may include one or more formations that are complementary to respective formations on the opposing surface of the fuel delivery body 116. For example, the formations on the upper surface may be recessed formations that receive protruding formations on the fuel delivery body 116 to seal the interface, or vice versa.

[0061] The upper surface also features first and second positional openings 120a, 121a that extend axially into the valve body 111 to receive first and second positioning elements 120b, 121b, as described previously. The first and second positioning elements 120b, 121b, which may take the form of first and second dowel pins, further engage respective openings in the fuel delivery body 116 so as to positionally align, and constrain, the valve body 111 relative to the fuel delivery body 116.

[0062] As shown in Figure 3a, in this example, the first and second positional openings 120a, 121a are disposed either side of the centre of the valve body 111 and may, for example, be symmetric about a transverse axis passing through the centre of the valve body 111. The arrangement should substantially mitigate any misalignment between the valve body 111 and the fuel delivery body 116.

[0063] Also shown on the upper surface is an upper opening of the second delivery channel 113b, which conveys fuel through the valve body 111, a housing portion 122 for the control valve 110 and an upper opening of the second cable route 115b, which extends through the valve body 111 and receives a portion of the electrical harness 115.

[0064] With reference now to Figure 3b, the lower surface of the valve body 111 is configured to mate with an upper surface of the electrically insulated plate 112. Although not shown in this example, the lower surface of the valve body 111 may feature one or more formations that are complementary to respective formations on the electrically insulated plate 112, shown in Figure 4a, so as to substantially inhibit leakage at an interface between the valve body 111 and the electrically insulated plate 112. For example, the formations on the lower surface of the valve body 111 may be recessed formations that receive protruding formations on the upper surface of the electrical plate 112 so as to seal the interface, or vice versa.

[0065] The lower surface also features third and fourth positional openings 123a, 124a that extend axially into the valve body 111 to receive third and fourth positioning elements 123b, 124b, as described previously. The third and fourth positioning elements 123b, 124b are configured to ensure angular alignment between the valve body 111, the electrically insulating plate 112 and the injector body 102 and may also take the form of dowel pins, as shown in Figure 3b.

[0066] The third and fourth positional openings 123a, 123b are disposed either side of the centre of the valve body 111 and may, for example, be symmetric about a transverse axis passing through the centre of the valve body 111.

[0067] Also shown on the lower surface of the valve body 111 are openings of various flow drillings that allow the flow of fuel into and out of the control chamber 108, under the control of the control valve 110.

[0068] It is envisaged that the precise arrangement of flow drillings may vary in different embodiments of the invention. Nonetheless, at least first and second flow drillings are provided in the valve body 111 that open into respective openings at the lower surface of the valve body 111.

[0069] The first drilling defines a drain path from the control chamber 108, through which fuel flows to the low pressure drain when the control valve 110 is actuated to a first position. The opening at the lower surface, defined by the first drilling, may be referred to as the drain orifice 118a. The drain orifice 118a is arranged to align with the drain channel 118 through the electrically insulating plate 112.

[0070] The second flow drilling defines a further path into the control chamber 108 for the high pressure fuel supply. The opening at the lower surface, defined by the second drilling, may be referred to as the inlet orifice. The inlet orifice 117a is arranged to align with the inlet channel 117 through the electrically insulating plate 112.

[0071] The references to "orifice" derive from the presence of restrictions or orifices provided in each of the flow paths to restrict the rate of flow of fuel through the flow path.

[0072] Further shown on the lower surface of the valve body 111 is a lower opening of the second delivery channel 113b and a lower opening of the second cable route 115b. The lower opening of the second delivery channel 113b aligns with the delivery opening in the electrically insulating plate 112 and conveys high-pressure fuel thereto. The lower opening of the second cable route 115b aligns with a conductive portion of the electrically insulating plate 112, as shall be described in more detail below.

[0073] As shown in Figures 4a and 4b, the electrically insulating plate 112 is a substantially circular plate-like member comprising an electrically conductive core, a coating layer of electrically insulating material and a plurality of openings that extend through the electrically insulating plate 112 from an upper surface, shown in Figure 4a, to a lower surface, shown in Figure 4b.

[0074] The conductive core may be metallic, for example. The thickness and stiffness of the conductive core is such that there is negligible deformation in use. More specifically, the thickness and stiffness of the conductive core is such that there is negligible deformation when the electrically insulating plate 112 is subjected to pressures up to around 3000 bar. The thickness of the conductive core may, for example, be greater than 1mm. Optionally, the thickness of the conductive core may be greater than or equal to 1.5mm. In this embodiment, the thickness of the conductive core is 1.5mm.

[0075] The coating layer may, for example, comprise a layer of metal oxide such as aluminium oxide. The coating layer may substantially cover the outer surfaces of the conductive core. However, conductive portions of the core are left uncoated so as to provide locations for forming electrically conductive connections to the electrical devices in the injector closed loop control apparatus.

[0076] In particular, a first conductive portion 125a is featured on the upper surface of the electrically insulating plate 112, as shown in Figure 4a. The first conductive portion 125a is arranged to align with the lower opening of the second cable route so as to provide a location for connecting the electrical harness 115 to the electrically conductive core.

[0077] A second conductive portion 125b is featured on the lower surface of the electrically insulating plate 112, as shown in Figure 4b. The second conductive portion 125b is arranged such that, in use, the spring 109, which biases the needle valve 104 towards the valve seat 106, abuts against the second conductive portion 125b so as to form an electrical connection therewith.

[0078] In this manner, a current path is defined, in which current travels into the electrically insulating plate 112 at the first conductive portion 125a; the current conducts through the core of the electrically insulating plate 112 to the second conductive portion 125b, where the current leaves the electrically insulating plate 112 and conducts along the length of the spring 109 into the needle valve 104, as shall be described in more detail in a later section that refers to Figures 6 and 7.

[0079] The various openings through the electrically insulating plate 112 include an opening for the drain channel 118, an opening for the inlet channel 117, the fuel delivery opening 114 and first and second positional openings 126, 127 that correspond to, and align with, the third and fourth positional openings 123a, 124a in the valve body 111. The first and second positional openings 126, 127 may be disposed either side of the centre of the electrically insulating plate 112 and may, for example, be symmetric about a transverse axis passing through the centre of the electrically insulating plate 112.

[0080] As shown in Figures 4a and 4b, the drain channel 118 and the inlet channel 117 are centrally disposed with respect to the electrically insulating plate 112. At the upper surface, the drain channel 118 is aligned with the drain orifice 118a of the valve body 111 and the inlet channel 117 is aligned with the inlet orifice 117a of the valve body 111. At the lower surface, both the drain channel 118 and the inlet channel 117 are aligned with the larger opening of the injector body bore 103. In this manner, the drain channel 118 and the inlet channel 117 permit the flow of fuel to and from the control chamber 108, as necessary to actuate the needle valve 104.

[0081] The fuel delivery opening 114 is radially spaced from the drain channel 118 and the inlet channel 117. The fuel delivery opening 114 may, for example, be positioned equidistantly from each of the drain channel 118 and the inlet channel 117. At the upper surface of the electrically insulating plate 112, the fuel delivery opening 114 aligns with the lower opening of the second delivery channel 113b and, at the lower surface of the electrically insulating plate 112, the fuel delivery opening 114 aligns with the third delivery channel 113c in the injector body 102. The injector body 102, shown in Figure 5, is an elongate nozzle-shaped member having an upper surface and a lower end or tip 130. It follows from the above that the upper surface features first and second positional openings 128, 129 that correspond to, and align with, the first and second positional openings 126, 127 in the electrically insulating plate 112 and the third and fourth positional openings 123a, 124a in the valve body 111. These openings are arranged to receive the third and fourth positioning elements 123b, 124b and positionally align, and angularly constrain, the valve body 111, electrically insulating plate 112 and the injector body 102 relative to one another.

[0082] Furthermore, the upper surface of the injector body 102 also features an upper opening for the third delivery channel 113c and an upper opening of the injector body bore 103 that extends through the injector body 102.

[0083] The assembled fuel injector 101 is configured to provide controlled injection of high-pressure diesel fuel into an engine cylinder. To provide enhanced injection control, the ECU for the fuel injector 101 is configured to operate the injector closed loop control apparatus to determine the position of the needle valve 104 with respect to the valve seat 106. This provides information relating to the opening and closing of the injection apertures, which can be used as timing information for actuating the needle valve 104, as shall be described in more detail below in reference to Figures 6 to 8.

[0084] Figure 6 shows the operation of the injector closed loop control apparatus for determining the position of the needle valve 104.

[0085] As noted previously, the injector closed loop control apparatus takes advantage of the fact that the needle valve 104 and the injector body 102 are made from electrically conductive material and the injector closed loop control apparatus is arranged to apply a voltage input to the needle valve 104 and to monitor the voltage signal to determine whether the needle valve 104 is seated (grounded) or unseated from the valve seat 106.

[0086] As shown in Figure 6, when a voltage is applied from the electrical supply, a current path 134 is defined in which current travels along the electrical harness 115 to the first conductive portion 125a of the electrically insulating plate 112. The current is then conducted through the conductive core of the electrically insulating plate 112 to the second conductive portion 125b where the current leaves the electrically insulating plate 112 and conducts into an upper end of the spring 109. From there, the current conducts along the spring 109 and into the needle valve 104, where the lower end of the spring 109 abuts against the shoulder of the needle valve 104.

[0087] The electrical circuit is closed when the tip of the needle valve 104 makes contact with the valve seat 106 defined in the injector body 102. In this instance, the voltage applied to the needle valve 104 decreases as the current flows through the closed circuit to ground (including the needle valve 104 contacting the valve seat 106). This voltage decrease indicates the precise moment at which the needle contacts the valve seat 106, which is valuable data for optimising control of the nozzle in ongoing operation.

[0088] Conversely, when the needle valve 104 is lifted from the valve seat 106, the electrical circuit opens which prevents a current from flowing, thereby causing the voltage on the needle valve 104 to increase. Each change in the needle valve 104 voltage can therefore be considered as an output signal that is indicative of the state of the needle valve 104, i.e. whether the needle valve 104 is engaged with the valve seat 106, or lifted to some extent.

[0089] The current path 134 through the electrically insulating plate 112 is shown in more detail in the cross-section shown in Figure 7. As noted previously, the core of the electrically insulating plate 112 is substantially covered in an electrically insulating layer and the surfaces of the injector body 102, and the valve guide 105 in particular, are electrically insulated in areas that may contact the needle valve 104. This means that electrical current can only pass between the first and second conductive portions 125a, 125b of the plate 112 and the current path 134 is defined from the electrical harness 115 to the needle valve 104, as described previously.

[0090] In this manner, when the needle valve 104 is in contact with the valve seat 106, the current is conducted through to the injector body 102, causing a voltage drop across the needle valve 104, which is indicative that the needle valve 104 is seated against the valve seat 106 and that the injection apertures are closed. When the needle valve 104 is moved away from the valve seat 106, the insulation around the needle valve 104 ensures that a charge is held in the needle valve 104 and a voltage increase is indicative that the injection apertures are open.

[0091] It will be appreciated by a person skilled in the art that the invention could be modified to take many alternative forms to that described herein, without departing from the scope of the appended claims.

[0092] For example, Figure 8 shows a further embodiment of the fuel injector 101 and, in particular, the electrically insulating plate 112. In this embodiment, the electrically insulating plate 112 further includes a guiding bore 131 that extends through the electrically insulating plate 112 and aligns with the needle valve 104. The guiding bore 131 is configured to receive an upper portion 132 of the needle valve 104 and allows the upper portion 132 of the needle valve 104 to pass through the thickness of the electrically insulating plate 112 and contact the lower surface of the valve body 111.

[0093] To mitigate the risk of short circuiting between the valve body 111 and the electrically insulating plate 112, the guiding bore 131 is coated in an insulating material and, as in the previous example, the second conductive portion 125b is arranged on the lower surface of the electrically insulating plate 112. However, in this example, the second conductive portion 125b is arranged around the circumference of the bore such that current passes through the electrically insulating plate 112, along the abutting spring 109 and into the injector needle.

[0094] As shown in Figure 8, when the needle valve 104 is seated against the valve seat 106, current flows through the electrically insulating plate 112 and the needle valve 104 into the injector body 102, as described in the previous embodiment. Similarly, when the needle valve 104 is moved away from the valve seat 106, the circuit is broken and the needle valve 104 holds a charge causing a measurable increase in the voltage across the needle valve 104.

[0095] However, at full lift, i.e. when the needle valve 104 is moved away from the valve seat 106 to a fully open position, the upper portion 132 of the needle valve 104 passes through the guiding bore 131 to contact the lower surface of the valve body 111. Accordingly, a new current path 134 is defined which passes from the electrical harness 115 to the first conductive portion 125a, through the conductive core of the electrically insulating plate 112 to the second conductive portion 125b, where the current is conducted along the abutting spring 109 and into the needle valve 104. With the needle valve 104 at full lift, the current then passes up the needle valve 104 to the upper portion 132 that seats against, and makes electrical contacts with, the lower surface of the valve body 111. Accordingly, current flows through the upper portion 132 of the needle valve 104, into the valve body 111, where the circuit is effectively grounded. In this instance, the voltage applied to the needle valve 104 decreases again as the current flows through the closed circuit to ground. This voltage decrease indicates the precise moment at which the needle contacts the valve body 111, and reaches full lift, which is valuable data for optimising control of the nozzle in on-going operation.

[0096] Advantageously, the embodiment shown in Figure 8 can use the increases and decreases in the voltage signal across the needle valve 104 to determine the precise moments at which: the needle valve 104 is seated against the valve seat 106; moved away from the valve seat 106; and at which the needle valve 104 reaches at full lift.

REFERENCES:

Prior Art

[0097]

1 - Injector

2 - Injector body

3 - Injector body bore

4 - Needle valve

5 - Integrated guide region

6 - Valve seat

7 - Accumulator volume

8 - Control chamber

9 - Spring

Invention

[0098]

101 - Injector

102 - Injector body

103 - Injector body bore

104 - Needle valve

105 - Integrated valve guide

106 - Valve seat

107 - Accumulator volume

108 - Control chamber

109 - Spring

110 - Control valve

111 - Valve body/housing

112 - Electrically insulating plate

113a - First delivery channel

113b - Second delivery channel

113c - Third delivery channel

114 - Fuel delivery opening

115 - Electrical harness

116 - Fuel delivery body

117 - Inlet channel

117a - Inlet orifice

118 - Drain channel

118a - Drain orifice

120a - First positional opening (of valve body)

120b - first positioning element

121a - Second positional opening (of valve body)

121b - Second positioning element

122 - Housing portion

123a - Third positional opening

123b - Third positioning element

124a - Fourth positional opening

124b - Fourth positioning element

125a - First conductive portion

125b - Second conductive portion

126 - First positional opening (of electrically insulating plate)

127 - Second positional opening (of electrically insulating plate)

128 - First positional opening (of injector body)

129 - Second positional opening (of injector body)

130 - Tip (of injector body)

131 - Guiding bore

132 - Upper portion of the needle valve

134 - Current path

Claims

1. A fuel injector (101) for an internal combustion engine, the fuel injector (101) comprising:

an injector housing comprising an injector body (102), provided with an injector body bore (103), and a valve body (111) for housing a control valve (110);
a needle valve (104) which is movable within the injector body bore (103), under the control of the control valve (110), towards and away from a needle valve seating (106), to control fuel injec-

tion;
an electrically insulating plate (112) located between the injector body (103) and the valve body (111) to electrically insulate the injector body (103) from the valve body (111); wherein the electrically insulating plate (112) is provided with an opening for receiving at least one positioning element (123b, 124b) which also extends into the valve body (111);
an electrical current path (134) defined, at least in part, through the electrically insulating plate (112) and the needle valve (104); and
an electrical circuit to measure the current flow through the electrical current path (134) so as to determine the position of the needle valve (104).

2. The fuel injector (101) as claimed in claim 1, wherein the injector body bore (103) includes a guide region (105) which serves to guide movement of the needle valve (104), and wherein the guide region (105) is electrically insulated from a corresponding guided region of the needle valve (104).

3. The fuel injector (101) as claimed in claim 2, wherein at least one of the guide region (105) and the corresponding guided region of the needle valve (104) is provided with an electrically insulating coating.

4. The fuel injector (101) as claimed in any of claims 1 to 3, further comprising a biasing spring (109) which serves to urge the needle valve (104) against the valve seat (106), wherein an upper surface of the valve spring (109) is engaged with the electrically insulating plate (112).

5. The fuel injector (101) as claimed in any of claims 1 to 4, wherein the electrically insulating plate (112) includes a conductive core which defines a part of the electrical current path (134).

6. The fuel injector (101) as claimed in any of claims 1 to 5, wherein the electrically insulating plate (112) includes a conductive portion (125b) with which an upper portion of the needle valve (104) is engaged at full lift of the needle valve (104).

7. The fuel injector (101) as claimed in any of claims 1 to 5, wherein the electrically insulating plate (112) defines a guiding bore (131) which serves to guide an upper portion (132) of the needle valve (104), and wherein the upper portion (132) of the needle valve (104) engages with the valve body (111) at full lift of the needle valve (104).

8. The fuel injector as claimed in claim 7, wherein at least one of the upper portion (132) of the needle valve (104) and the guiding bore (131) is provided with an electrically insulating coating.

9. The fuel injector as claimed in any of claims 1 to 8, wherein the at least one positioning element (123b, 124b) is formed from electrically conductive material.

10. The fuel injector as claimed in any of claims 1 to 9, wherein at least one of the opening in the electrically insulating plate (112) and the at least one positioning element (123b, 124b) is coated with an electrically insulating material to ensure no electrical contact is made between the electrically insulating plate (112) and the or each positioning element (123b, 124b).

11. The fuel injector as claimed in any of claims 1 to 8, wherein the or each positioning element (123b, 124b) is formed from a non-conductive material.

12. The fuel injector as claimed in any of claims 1 to 11, wherein the electrically insulating plate (112) has a thickness of at least 1.0 mm.

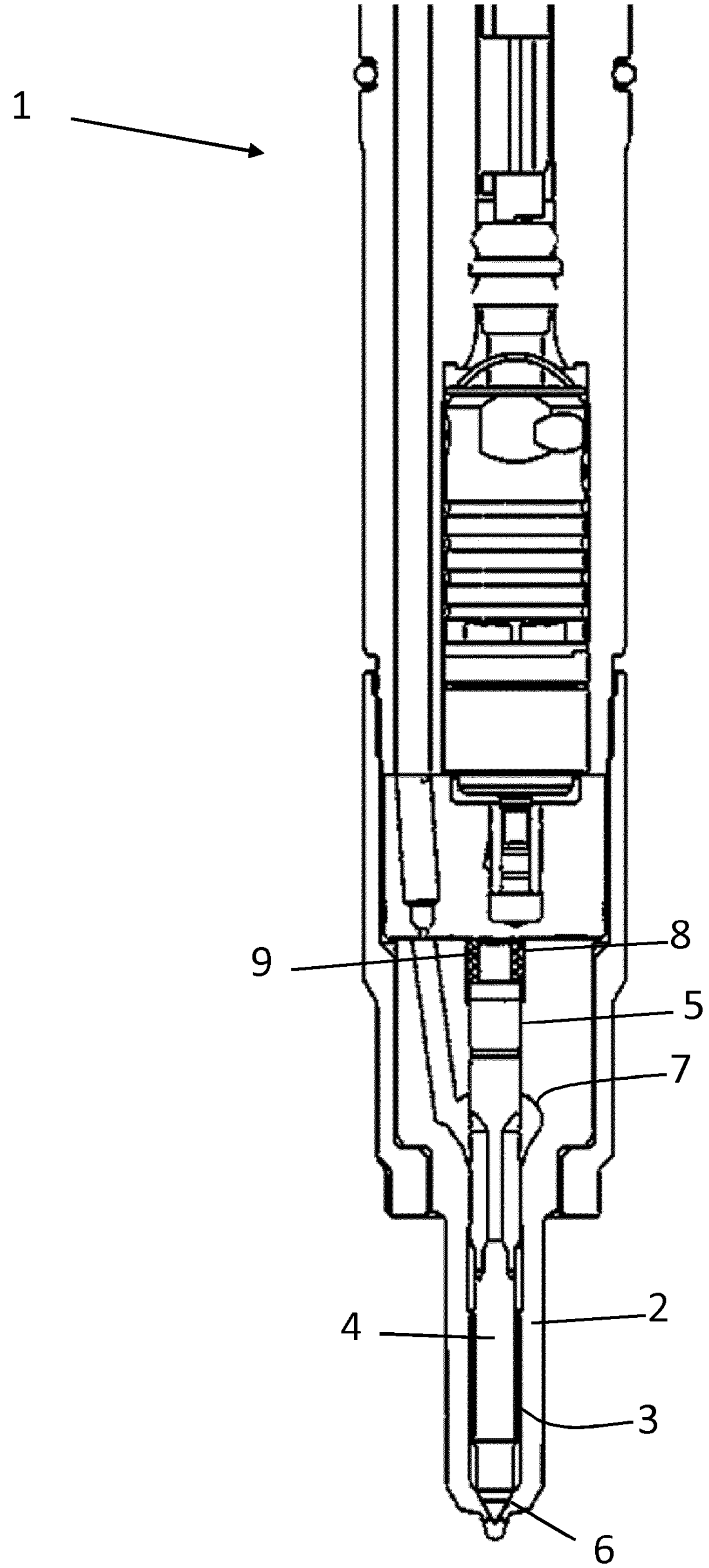

Fig. 1

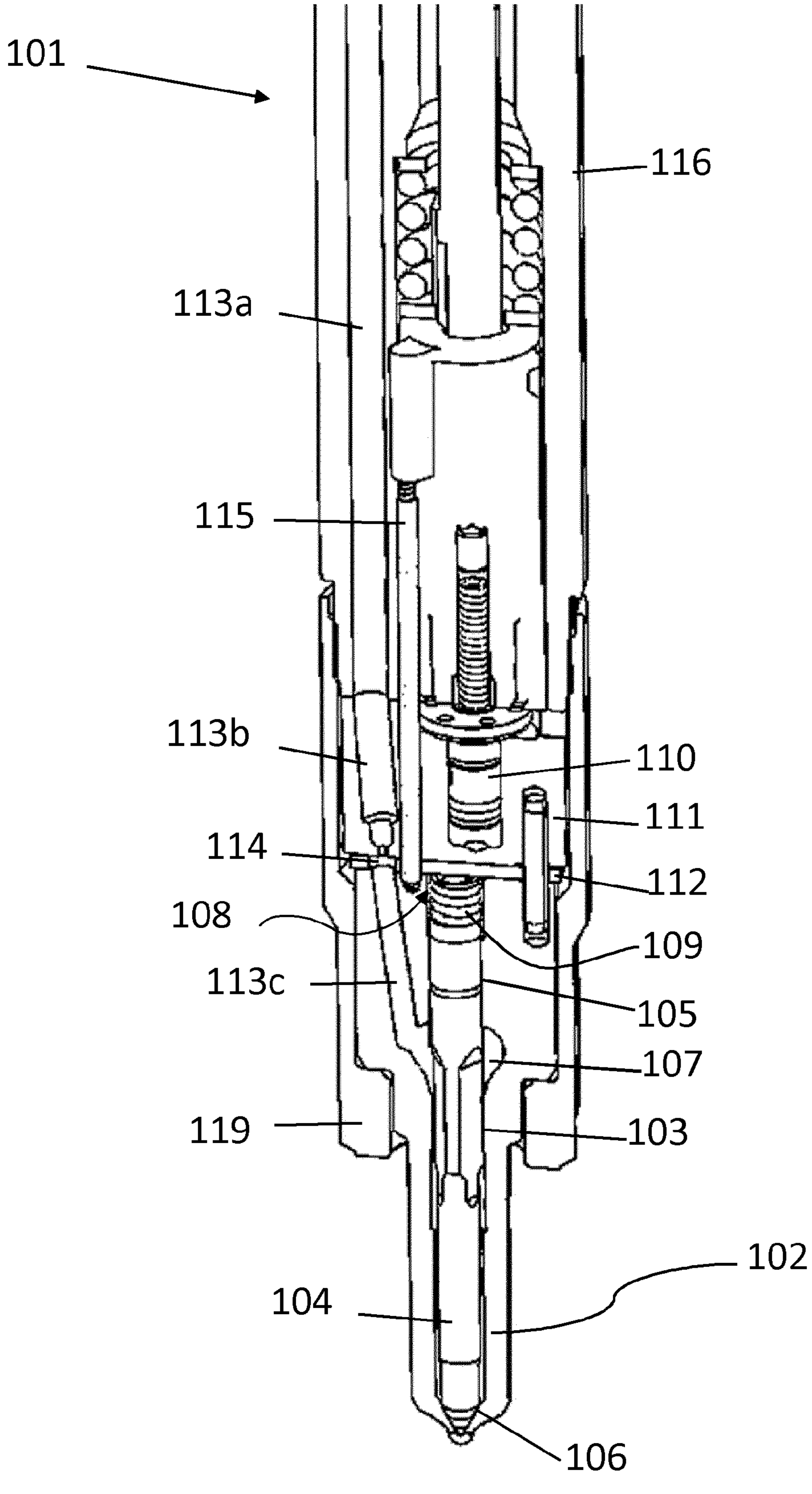
101
116
113a
115
113b
110
111
114
112
108
109
113c
105
107
119
103
102
104
106

Fig. 2

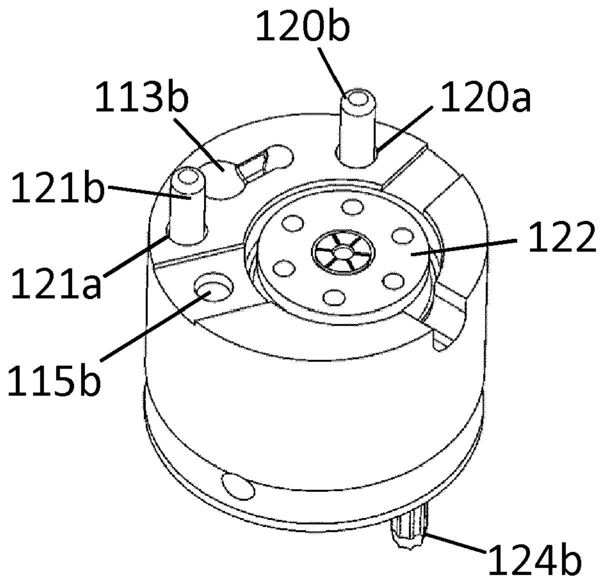
120b
113b
120a
121b
122
121a
115b
124b

Fig. 3a

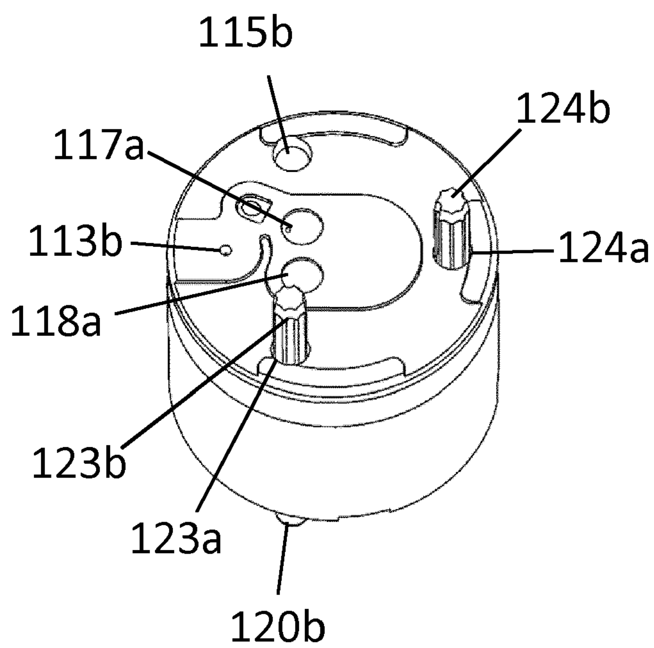
115b
124b
117a
113b
124a
118a
123b
123a
120b

Fig. 3b

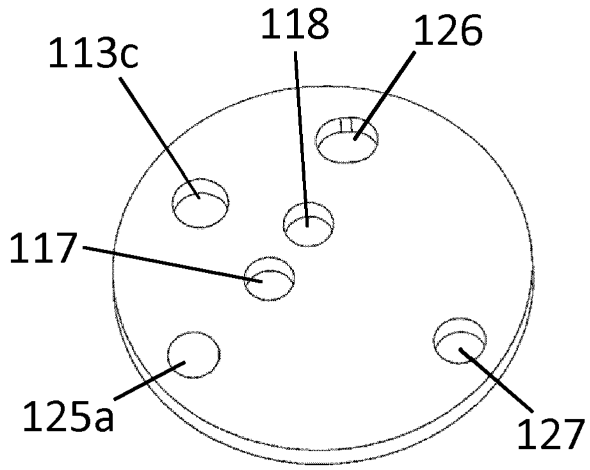

Fig. 4a

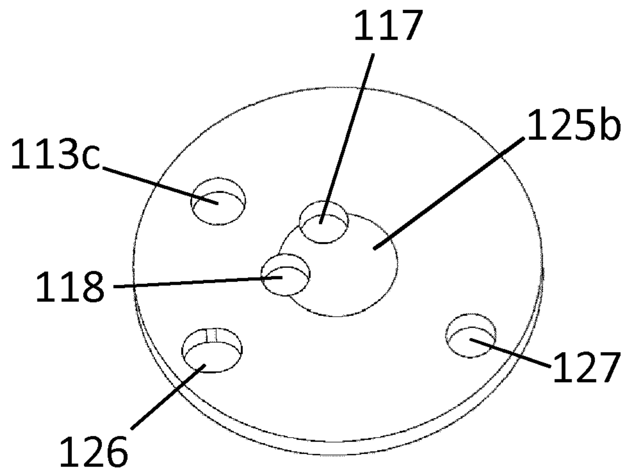

Fig. 4b

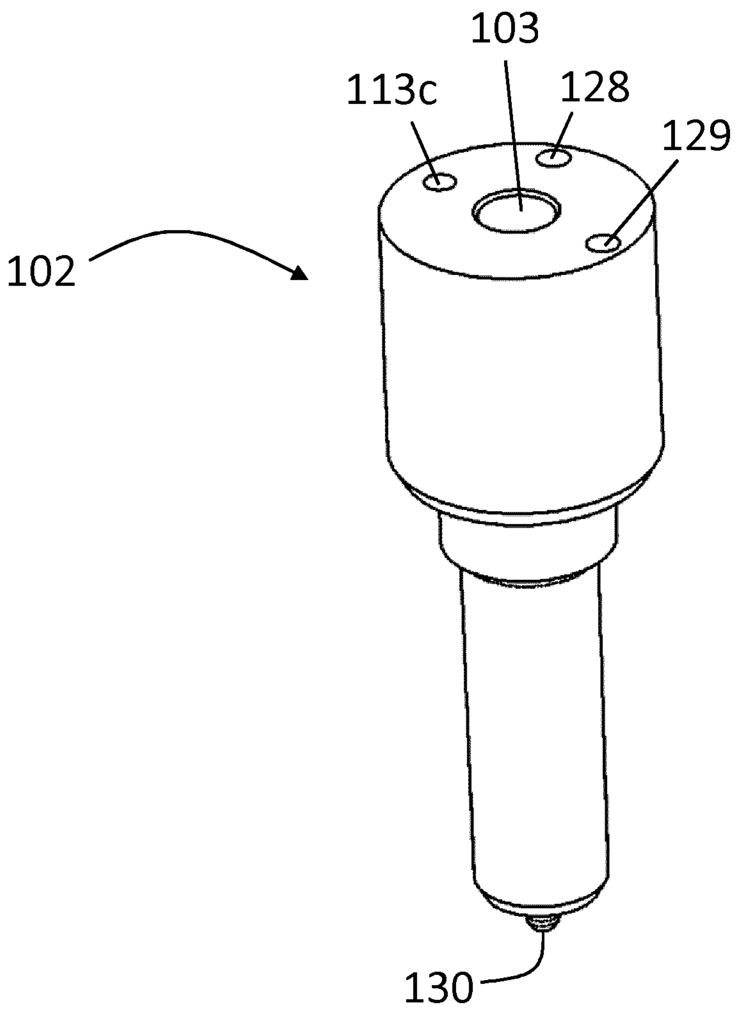

Fig. 5

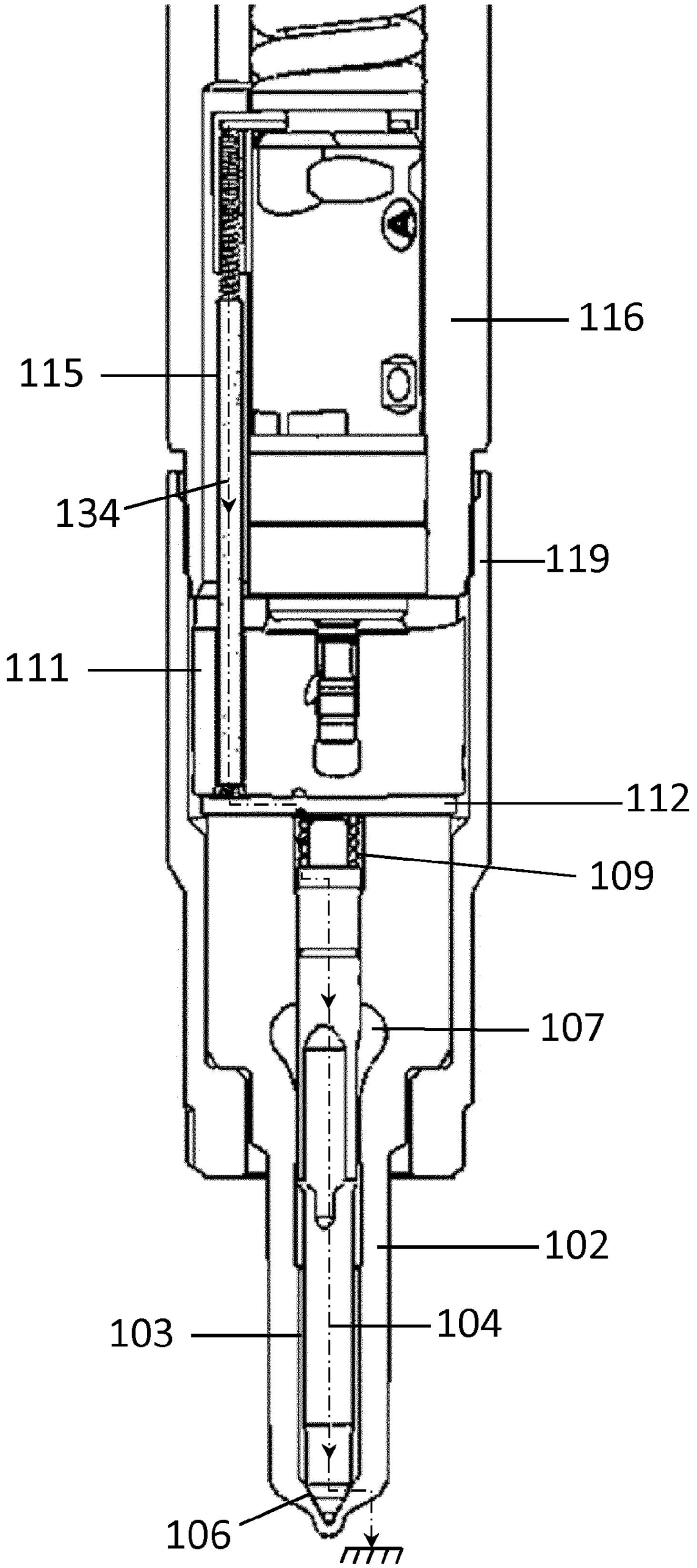

Fig. 6

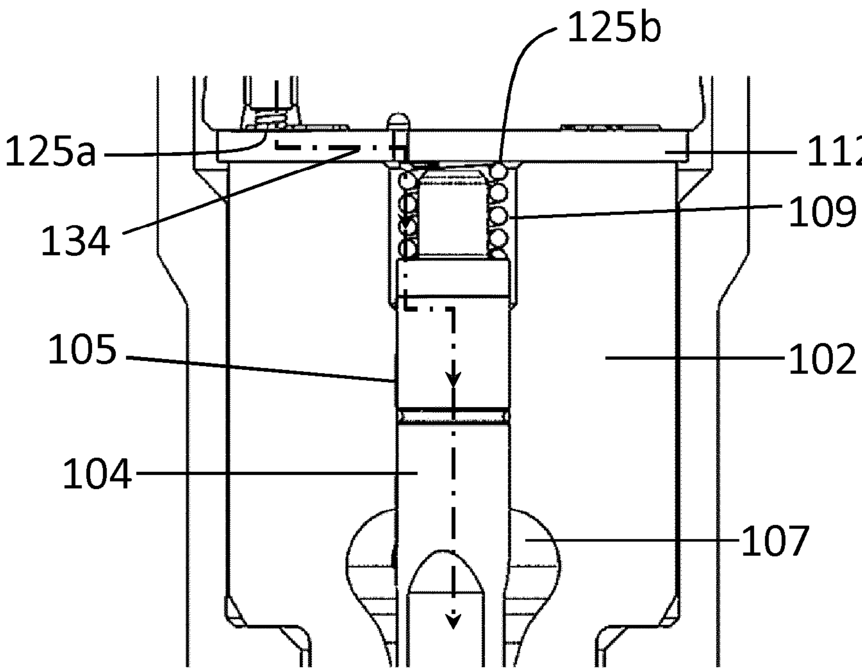
125b
125a
112
134
109
105
102
104
107

Fig. 7

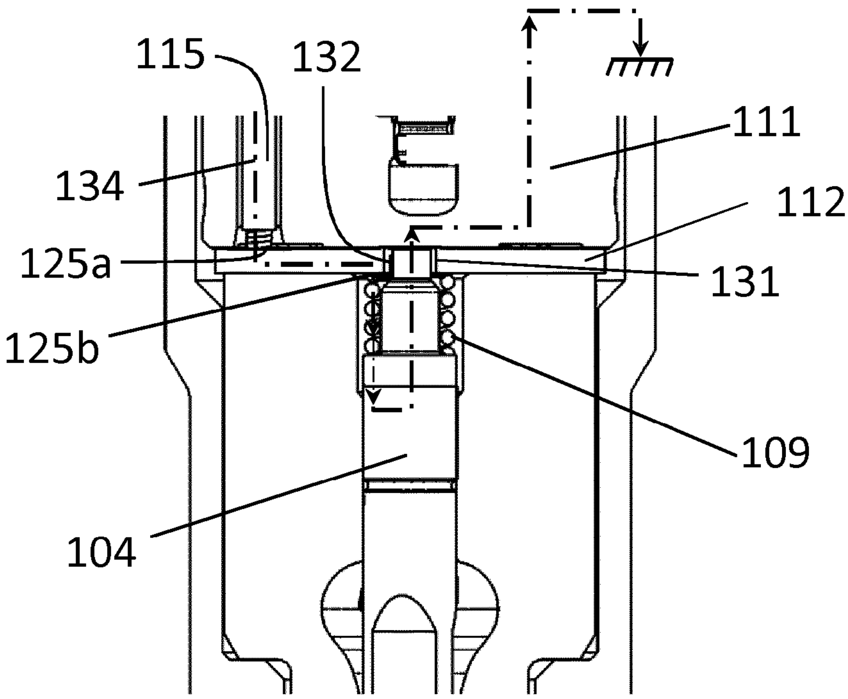
115
132
134
111
112
125a
131
125b
109
104

Fig. 8

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EUROPEAN SEARCH REPORT

Application Number
EP 20 17 8607

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1

Place of search	Date of completion of the search	Examiner
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