(19) Europäisches Patentamt / European Patent Office / Office européen des brevets

(11) **EP 2 722 518 A1**

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
23.04.2014 Bulletin 2014/17

(21) Application number: **12189470.3**

(22) Date of filing: **22.10.2012**

(51) Int Cl.:
F02M 45/12 *(2006.01)* ***F02M 61/10*** *(2006.01)*
F02M 61/12 *(2006.01)* ***F02M 61/20*** *(2006.01)*

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME

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(54) **Fuel Injection nozzle having a flow restricting element**

(57) An injection nozzle (10) for injecting fuel into a combustion chamber of an internal combustion engine is disclosed. The injection nozzle comprises a nozzle body (12) having a valve needle (16) received in a bore (14) and a restrictive element (28) being moveable with the needle (16). In use, fuel passes through a throttle restriction (54) in the bore (14) defined by a clearance (R_A, R_B) between the restrictive element (28) and a wall portion (14d) of the bore (14). The clearance (R_A, R_B) increases progressively as the valve needle (16) lifts from its closed position. The restrictive element (28) may be a colar press-fitted on the needle shaft and can be adjusted according to measured parameters.

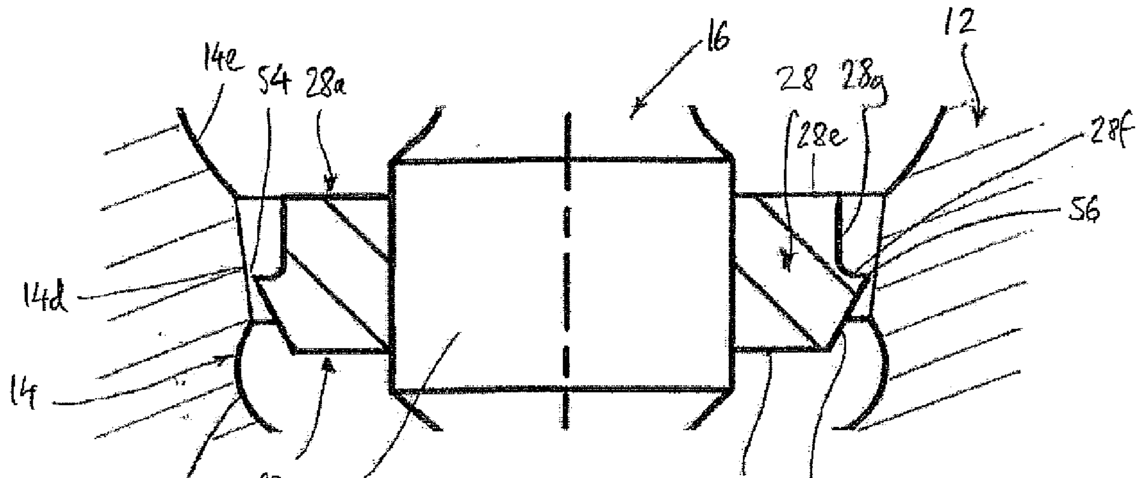

FIGURE 2

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Description

Field of the invention

[0001] The invention relates to an injection nozzle for use in a fuel injector for injecting fuel into a cylinder of an internal combustion engine. In particular, the invention relates to an injection nozzle arranged to provide improved control of an injector needle.

Background to the invention

[0002] EP 0 844 383 relates to a high-pressure fuel injector for an internal combustion engine. The fuel injector has an injection nozzle defining a bore. The bore provides a flow path for high-pressure fuel between a fuel inlet and a plurality of outlets, the fuel being received from a high-pressure fuel supply passage. The fuel injector includes a valve needle which is slidable within the bore and engagable with a seating at the lower end of the bore to control fuel delivery through the outlets, which are disposed downstream of the seating. When the valve needle is lifted from the seating, fuel is able to flow through the outlets for injection into an associated combustion chamber of the engine.

[0003] The valve needle includes at least one downstream-facing thrust surface which is exposed to high-pressure fuel in the bore. The high-pressure fuel in the bore acts on the thrust surface to apply a lifting or opening force to the needle. An upper end of the needle is exposed to fuel pressure in a control chamber, so that the fuel pressure in the control chamber acts to apply a closing force to the needle. The fuel pressure in the control chamber can be varied under the control of a nozzle control valve to adjust the balance of forces acting on the needle.

[0004] The control chamber receives fuel at high pressure from the supply passage, and the nozzle control valve is operable between a first position in which communication between the control chamber and a low-pressure drain is closed, and a second position in which communication between the control chamber and the low-pressure drain is open. In this way, the fuel pressure in the control chamber can be held at a relatively high value, when the nozzle control valve is in its first position such that the communication to drain is closed, or reduced to a relatively low value by moving the nozzle control valve into its second position to allow fuel to flow from the control chamber to drain.

[0005] When the nozzle control valve is in its first position, the pressure of fuel in the control chamber is high enough so that the net force on the needle acts in a closing direction. When the nozzle control valve is operated to move into its second position, the pressure of fuel in the control chamber falls and the closing force is no longer sufficient to overcome the opening force due to fuel pressure in the bore acting on the downstream-facing thrust surface of the needle, and the needle moves away from its seating to allow fuel injection through the outlets. To end the fuel injection, the nozzle control valve is operated to move back into its first position and the pressure of fuel in the control chamber rises so that the closing force acting on the end of the needle overcomes the opening force on the thrust surface and the needle moves back into engagement with the seating.

[0006] A restriction, in the form of a small radial clearance between the valve needle and a portion of the bore, is provided for restricting the flow of fuel through the bore between the fuel inlet and the outlets. The restriction gives rise to a pressure differential in the flow path from the inlet to the outlets, which means that, when an injection is occurring and the control valve is operated to move into its first position to terminate injection, the opening force acting on the downstream-facing thrust surface of the needle is lower than would be the case if a restriction were not present. This ensures that the increasing pressure of fuel in the control chamber is sufficient to overcome the opening force due to the fuel pressure in the bore, downstream of the restriction, acting on the downstream-facing thrust surface. Also, by virtue of the restriction, the increasing pressure of fuel in the control chamber overcomes the opening force earlier, which increases the speed of needle closure.

[0007] US 6 499 467 discloses an arrangement in which a restriction of this type takes the form of an orifice through a piston-type needle guide portion of the valve needle. The needle guide portion is situated near the injecting end of the nozzle and is remote from the control chamber. EP 0 971 118 discloses an arrangement in which the restriction is defined between an annular collar carried on the valve needle and the wall of the bore.

[0008] One disadvantage of known arrangements such as those described above is that a relatively large drop in pressure occurs across the restriction as fuel flows from the inlet to the outlets. In practice, this means that the injection pressure is lower than the pressure of fuel supplied to the injector. Hence, energy is wasted pumping the fuel to a higher pressure than is available for injection.

[0009] A further possible disadvantage of known injectors in which a restriction is formed between the needle and the bore is that the machining required to achieve the desired pressure drop has to be very accurate. Such accuracy, particularly on such small scales, means that such injectors are both time consuming and costly to manufacture.

[0010] Furthermore, in these prior art arrangements, the rate of fuel through the restrictions is sensitive to the viscosity, and hence the temperature, of the fuel. In use, the temperature of the fuel varies considerably over the operating phases of the engine, which can result in unpredictable needle behaviour.

[0011] Against this background, it would therefore be desirable to provide a fuel injector in which a higher injection pressure can be achieved for a given fuel supply pressure, which is less sensitive to fuel viscosity, and which is simpler to manufacture than the arrangements of the prior art.

Summary of the invention

[0012] From a first aspect, the present invention resides in an injection nozzle for injecting fuel into a combustion chamber of an internal combustion engine, the injection nozzle comprising a nozzle body having a bore for receiving fuel from a supply line for pressurised fuel, an outlet from the bore for delivering fuel to the combustion chamber, in use, and a valve needle received in the bore and defining a valve needle axis. The valve needle is moveable between a closed position in which fuel flow through the outlet into the combustion chamber is prevented, and a fully-open position in which fuel flow through the outlet into the combustion chamber is enabled. Movement of the needle is controllable by varying the fuel pressure within a control chamber, in use.

[0013] The injection nozzle further comprises a restrictive element having an upstream side and a downstream side. The restrictive element is moveable with the needle. In use, fuel that reaches the outlet passes through a restriction in the bore defined by a clearance between the restrictive element and a wall portion of the bore. The clearance increases progressively as the valve needle lifts from its closed position.

[0014] The restrictive element restricts the flow of fuel so that, when the needle is lifted from its closed position and fuel flows through the bore, the fuel pressure downstream of the restrictive element is less than the fuel pressure upstream of the restrictive element. The fuel pressure acting on the upstream side of the restrictive element provides an additional force on the valve needle that acts in a closing direction, thereby to reduce the rate of opening of the valve needle at the beginning of an injection event.

[0015] The clearance between the restrictive element and the wall portion of the bore increases progressively or continuously as the valve needle lift increases. In its closed position, the valve needle is engaged with a seating region of the nozzle body, and the valve needle lift is the axial distance between the valve needle and the seating region that increases as the needle is lifted from its closed position towards its fully-open position. The clearance between the restrictive element and the wall portion of the bore is therefore relatively small at low needle lifts, when the valve needle is close to its closed position, and increases as soon as the valve needle starts to move towards its fully-open position.

[0016] By virtue of the varying clearance, the additional force acting on the needle due to the restrictive element is relatively high at low needle lifts, thereby improving control of the valve needle for small-volume injection events, such as pilot/pre-injections and post-injections. Furthermore, because the clearance that defines the restriction is at a minimum size when the needle is closed, the arrangement provides maximum damping of pressure waves in the bore and elastic oscillations in the valve needle between injections. At higher needle lifts, as the valve needle approaches its fully-open position, the increased clearance reduces the pressure drop across the restrictive element, which in turn increases the pressure at which fuel can be injected from the outlet.

[0017] In one embodiment, the clearance increases progressively as the valve needle lifts from its closed position to its fully-open position. Said another way, the clearance preferably varies continuously over the whole range of movement of the valve needle. The clearance may increase continuously in proportion to the lift of the valve needle. The wall portion of the bore may be generally frustoconical, such that the clearance is linearly proportional to the lift of the valve needle. The clearance is preferably non-zero when the needle is in its closed position.

[0018] The size of the clearance for a given needle position can be defined as the minimum distance between the restrictive element and the wall portion of the bore. For example, when the wall portion of the bore is generally frustoconical, the size of the clearance is the distance between the restrictive element and the wall portion of the bore measured along a direction that is perpendicular to the surface of the wall portion of the bore.

[0019] Preferably, a radial component of the direction along which the size of the clearance is defined increases progressively as the valve needle lifts from its closed position. For example, the restrictive element may be separated from the wall portion of the bore by a radial distance which increases progressively as the valve needle lifts from its closed position. Accordingly, the radial component or the radial distance may increase progressively as the valve needle lifts from its closed position to its fully-open position. The radial component or the radial distance may increase continuously in proportion to the lift of the valve needle.

[0020] The needle may comprise a needle guide portion arranged to guide sliding movement of the needle within the bore. The restrictive element is preferably disposed upstream of the needle guide portion. Providing a restrictive element that is moveable with the needle and separate from, or spaced apart from, the guide portion of the needle helps to improve the dynamic characteristics of the needle during opening and closing of the needle. Furthermore, providing the restrictive element upstream of the needle guide portion allows for the needle guide to be arranged as close to the tip of the injector as possible, which increases the mechanical stability of the needle in use. The restrictive element may have a larger diameter than the needle guide portion of the needle.

[0021] When the needle is lifted away from its closed position, the pressure of fuel at the outlet is preferably substantially the same as the pressure of fuel in the bore immediately downstream of the restrictive element. Said another way, any pressure drop that occurs across the guide portion of the needle is minimal in comparison to the pressure drop across the restrictive element.

[0022] The injection nozzle may further comprise a control piston associated with the needle and having a control surface exposed to fuel pressure within the control chamber. In this case, the collar may have a larger diameter than the piston. When the collar has a larger diameter than the needle guide portion and/or the control piston, the collar is particularly effective in both damping the opening movement of the needle and assisting the closing movement of the needle.

[0023] The injection nozzle may comprise a first bore volume upstream of the restriction and arranged to receive fuel from the supply line, and a second bore volume downstream of the restriction and arranged to receive fuel from the first bore volume through the restriction. The needle guide portion of the needle is preferably disposed within the second bore volume. The restrictive element may comprise an upstream-facing thrust surface which is exposed to fuel pressure in the first bore volume in use. Advantageously, in this arrangement, during an injection event, the upstream-facing thrust surface of the restrictive element applies an additional component of force to the valve needle that acts in a closing direction.

[0024] In this way, the pressure acting on the upstream-facing thrust surface of the restrictive element serves to assist closing movement of the needle, resulting in a faster needle closure speed. In contrast, when the needle is caused to move away from its closed position towards its fully-open position by a change in pressure in the control chamber, the pressure acting on the upstream-facing thrust surface of the restrictive element serves to reduce the net opening force on the needle during opening, resulting in damping of the needle opening movement and therefore a slower needle opening speed. Both a faster needle closure speed and a slower needle opening speed are advantageous in improving injection control.

[0025] The clearance may comprise an annular clearance between the bore and a peripheral edge of the restrictive element. In one embodiment, at least a part of the downstream side of the restrictive element comprises a bevelled surface that extends to the peripheral edge, the bevelled surface being non-perpendicular to the axis of the valve needle.

[0026] The bevelled surface on the downstream side of the restrictive element, downstream of the peripheral edge, serves to maximise the turbulence of fuel downstream of the restrictive element as the fuel flows through the restriction. Advantageously, this arrangement reduces the sensitivity to fuel viscosity of the flow characteristics through the restriction, such that the effect of temperature changes on the performance of the injector is minimised. This further improves the control of the valve needle, particularly for small-volume injection events. To maximise the turbulence, in some arrangements the bevelled surface may lie at an angle of between approximately 15° and 45° with respect to the needle axis. In one embodiment, the bevelled surface lies at an angle of approximately 30° with respect to the needle axis.

[0027] The downstream side of the restrictive element may comprise a downstream face that is normal to the needle axis, and the bevelled surface may be formed as a chamfer at the periphery of the downstream face. The bevelled surface may be frustoconical.

[0028] In one embodiment, the bevelled surface lies at an angle of between approximately 15° and 45° with respect to the needle axis. Preferably, the bevelled surface lies at an angle of approximately 30° with respect to the needle axis.

[0029] The upstream side of the restrictive element may comprise an upstream edge face that extends to the peripheral edge of the restrictive element. In one embodiment, for example, the upstream side of the restrictive element comprises a central face, and the upstream edge face is annularly disposed around the central face. The upstream edge face may be recessed from the central face to define a step between the upstream edge face and the central face.

[0030] Preferably, the upstream edge face is normal to the needle axis. The peripheral edge of the restrictive element may be defined where the upstream edge face and the bevelled surface meet. In this way, the peripheral edge can take the form of a sharp edge at the intersection between the upstream edge face and the bevelled surface, such that the restriction has fluid flow characteristics approaching those of a theoretical sharp-edged orifice, with minimal sensitivity to viscosity.

[0031] It general, is desirable that the length of the restriction in the flow direction within the bore, and hence the length of the peripheral edge in the direction of the needle axis, is as short as possible. This arrangement minimises the sensitivity of the flow to viscosity, and reduces the moving mass of the valve needle. For example, the peripheral edge may have a length of approximately 0.2 mm or less in a direction parallel to the needle axis. Preferably, the peripheral edge has a length of approximately 0.1 mm or less in the direction parallel to the needle axis. The peripheral edge may comprise a generally cylindrical surface that extends parallel to the needle axis. Instead of a generally cylindrical surface, the peripheral edge may comprise a curved or barrelled surface or may be formed with knife-edge geometry.

[0032] The valve needle may comprise a downstream-facing thrust surface disposed downstream of the restrictive element. The downstream-facing thrust surface may also be disposed downstream of the needle guide portion. The restrictive element may be located in a relatively large-diameter region of the bore, upstream of a relatively small-diameter region of the bore.

[0033] The restrictive element is preferably disposed at a downstream end portion of the region of relatively large diameter. For example, the restrictive element may be disposed in a downstream third of the region of relatively large diameter or, more preferably, in a downstream quarter of the region of relatively large diameter.

[0034] In another arrangement, the bore includes a region of relatively large diameter upstream of the restrictive element, a region of relatively small diameter in which the needle guide portion of the valve needle is disposed, and an intermediate region in which the restrictive element is disposed. The intermediate region may be of intermediate diameter.

[0035] By locating the restrictive element at a downstream end portion of a region of relatively large diameter, or in an intermediate-diameter region downstream of a region of relatively large diameter, the volume of the bore above the restrictive element is maximised and the volume below it is minimised. This helps to maximise the accumulator volume available for high-pressure fuel in the large-diameter region of the bore, upstream of the restriction.

[0036] In use of the injection nozzle, pressure waves can arise in the fuel within the bore. Such pressure waves have characteristic wavelengths that depend on the geometry of the bore. Such waves are undesirable because they can disturb the opening and closing movement of the needle and the pressure of injected fuel, giving rise to uncertainty in the quantity of fuel injected. Advantageously, the restrictive element can be arranged on the needle so that, in use, it is positioned at or close to an antinode of one or more such pressure waves, thereby damping the waves and reducing their undesirable effect. For example, the restrictive element may be positioned at an antinode of a characteristic standing wave in the bore.

[0037] The injection nozzle may further comprise a spring for urging the needle towards the closed position. The spring can be arranged to engage with an upper surface of the restrictive element. Alternatively, the needle may comprise a spring seat that is spaced from and disposed upstream of the restrictive element. To enable the injection nozzle to operate at low pressures, a relatively low-load spring may be required, and providing a separate spring seat upstream of the restrictive element allows a relatively short low-load spring to be used to minimise the risk of buckling. Furthermore, in this arrangement, the volume of the bore upstream of the restrictive element that is occupied by the spring is relatively low, maximising the volume available for fuel.

[0038] The restrictive element may comprise a collar disposed annularly around a shaft portion of the valve needle. The collar and the needle are preferably formed as separate components that are joined together during manufacture of the injection nozzle. The collar is preferably an annular component mounted on the shaft portion. For example, the collar may be press-fitted on the shaft portion of the valve needle. Advantageously, with such an arrangement, the position of the collar with respect to the needle can be adjusted during assembly of the injection nozzle so that a desired clearance between the collar and the wall portion of the bore can be obtained when the needle is in its closed position.

[0039] The present invention therefore extends to a method of assembling such an injection nozzle, comprising measuring a parameter relating to fuel flow through the restriction, and adjusting the position of the collar with respect to the valve needle to achieve a target value of the measured parameter. In this way, the collar can be adjusted into a suitable position to ensure that the restriction at a given needle lift is the correct size, corresponding to the target value of the measured parameter. The adjustment of the position of the collar could be made whilst simultaneously measuring the parameter, or the adjustment could be made after measuring the parameter. The measurement and adjustment steps could be repeated several times to achieve the target value.

[0040] The measured parameter may, for example, comprise the size of the clearance that defines the restriction, or the radial distance between the collar and the wall portion of the bore.

[0041] In another example, the method may include passing a fluid through the bore at a known flow rate, and the measured parameter may comprise a pressure drop across the restriction. Similarly, the measured parameter may comprise a pressure of fluid downstream of the restriction. The method may comprise passing a fluid through the bore at a known feed pressure, and the measured parameter may comprise a flow rate of fluid through the bore. In another variant, the method comprises passing a fluid through the bore at a known feed pressure and/or a known flow rate, and the measured parameter comprises a force on the valve needle. In other words, the force that acts on the needle as a result of the restrictive element can be measured.

[0042] It will be appreciated that preferred and/or optional features of each aspect of the invention can also be included in the other aspects of the invention, alone or in appropriate combination.

Brief description of the drawings

[0043] Embodiments of the present invention will now be described, by way of example only, with reference to the accompanying drawings, in which like reference numerals refer to like parts, and in which:

Figure 1 is a schematic cross-sectional view of part of an injection nozzle according to an embodiment of the present invention;

Figure 2 is an enlarged schematic cross-sectional view of the injection nozzle of Figure 2; and

Figure 3 is a schematic cross-sectional view of part of an injection nozzle according to another embodiment of the present invention.

[0044] Throughout this specification, terms such as 'upper' and 'lower' are used with reference to the orientation of the injection nozzle as shown in the accompanying drawings, although it will be appreciated that the injection nozzle could be used in any suitable orientation. Terms such as 'upstream' and 'downstream' refer to the general direction of fuel flow within the injection nozzle during injection in normal use (i.e. downwards in the accompanying drawings).

Detailed description of embodiments of the invention

[0045] Figures 1 and 2 show part of an injection nozzle 10 according to a first embodiment of the invention. The injection nozzle 10 forms part of a fuel injector for injecting fuel into a combustion chamber (not shown) of an associated engine.

[0046] Referring to Figure 1, the injection nozzle 10 comprises a generally tubular nozzle body 12 having a bore 14. A valve needle 16 is received in the bore 14. The valve needle 16 is engageable with a seating region 20 formed at a downstream tip 22 of the nozzle body 12.

[0047] One or more outlets 24 are formed in the tip 22 of the nozzle body 12, downstream of the seating region 20, and the needle 16 is moveable between a closed position, in which the needle 16 is engaged with the seating region 20 to prevent fuel in the bore 14 from reaching the outlets 24, and an open position, in which the needle 16 is lifted away from the seating region 20 to allow fuel to flow from the bore 14 through the outlets 24 for injection.

[0048] An upper portion of the nozzle body 12 is mounted to a housing part (not shown) by means of a capnut (not shown). The housing part includes a supply line (not shown) which, in use, supplies fuel at high pressure to the bore 14 of the nozzle body 12. An upper portion of the valve needle 16 forms a control piston 26. The upper end of the control piston 26 is exposed to fuel pressure within a control chamber (not shown) defined in the housing part. As will be familiar to those skilled in the art, movement of the valve needle is controlled by varying the fuel pressure in the control chamber by means of a nozzle control valve (not shown) which is operable to connect the control chamber to a low-pressure drain to reduce the pressure in the control chamber, or to allow the control chamber to fill with high-pressure fuel from the supply line.

[0049] A restrictive pressure reduction element, in the form of a collar 28, is disposed annularly around the needle 16. The collar 28 is mounted on a cylindrical shaft portion 30 of the needle 16. The collar 28 extends radially outwards from the needle 16, and has a relatively large diameter in comparison with the diameter of the needle 16. A stem portion 32 of the needle 16, upstream of the cylindrical shaft portion 30, has a smaller diameter than the cylindrical shaft portion 30.

[0050] The uppermost end of the stem portion 32 is formed into a collar defining an enlarged-diameter spring seat 34 for a biasing spring 36. The spring 36 urges the needle 16 towards its closed position. The control piston 26 is slidable within a bore 38 of a spacer piece 40. The spacer piece 40 serves as an upper seat for the spring 36, and spaces the spring 36 from the housing part (not shown). The spacer piece 40 is held against the housing part by the force of the spring 36. The spacer piece 40 can slide sideways to accommodate misalignment of the needle 16 with the housing part, such as might occur due to tolerances in manufacturing.

[0051] The spring 36 is maintained in concentric alignment with the axis of the valve needle 16 by way of a spring guide portion 42 of the valve needle 16, disposed above the spring seat 34. The spring guide portion 42 is dimensioned such the spring 36 is slidingly guided on the spring guide portion 42. In addition, the lower surface of the spacer piece 40 is formed with a raised locating ring 44 around the entrance to the bore 38. The locating ring 44 is dimensioned such that it can be received within the inside diameter of the spring 36. In this way, the locating ring 44 locates the spring 36 in a concentric position with respect to the needle axis.

[0052] The bore 14 includes a relatively large-diameter region 14a, and a relatively small-diameter region 14b. The large-diameter and small-diameter regions 14a, 14b are separated by an intermediate region 14c. The intermediate region 14c comprises a frustoconical wall portion 14d of the bore 14, the diameter of which increases moving away from the tip 22 of the nozzle body 12. The frustoconical wall portion 14d is linked to the large-diameter and small-diameter regions 14a, 14b respectively by first and second radiussed transition regions 14e, 14f. The large-diameter region 14a, small diameter region 14b and restriction region 14c together define an accumulator volume 48 for high-pressure fuel.

[0053] The small-diameter region 14b of the bore 14 of the nozzle body 12 includes a guide region 14g, with a decreased inside diameter that is matched to the outside diameter of a guide portion 50 of the needle 16. Downstream of the guide region 14g, the small-diameter region 14b of the bore 14 includes a further reduced-diameter portion 14h, close to the tip 22 of the nozzle body 12, to reduce the volume of the bore 14 downstream of the collar 28.

[0054] The needle guide portion 50 provides a generally cylindrical guiding surface that is arranged to slidingly engage with the guide region 14g of the bore 14, to guard against lateral movement of the needle 16 within the bore 14. A plurality of helical grooves 52 are formed in the surface of the needle guide portion 50 to allow fuel to flow past the needle guide portion 50 with no appreciable pressure drop. The pressure of fuel at the outlets 24 is therefore substantially equal to the pressure immediately downstream of the collar 28. The diameter of the collar 28 in this embodiment of the invention is approximately twice the diameter of the needle guide portion 50.

[0055] The needle guide portion 50 is disposed within the small-diameter region 14b of the bore 14, close to the tip 22 of the nozzle body 12, to provide good stability to the tip of the needle 16. In particular, restricting the lateral movement of the tip of the needle 16 ensures that the tip of the needle 16 forms a reliable seal with the seating region 20 when the needle 16 is in its closed position.

[0056] As shown most clearly in Figure 2, the collar 28 is positioned on the needle 16 such that it registers or overlaps with the frustoconical wall portion 14d of the bore 14 over the whole range of movement of the needle 16.

[0057] An annular passage or clearance 54 is defined between a peripheral edge 56 of the collar 28 and the frustoconical wall portion 14d of the bore 14. The cross-sectional area of the annular clearance 54, through which fuel flows towards the outlets 24 during an injection event, is relatively small, so that the annular clearance 54 acts as a restriction in the fuel flow path through the bore 14 between the supply passage and the outlets 24.

[0058] As will be explained below, the restriction 54 is sufficiently small in cross-sectional area to result in a pressure drop across the collar 28 when the needle 16 is lifted from the seating region 20 and fuel is flowing through the bore 14 to the outlets 24. The collar 28 therefore divides the accumulator volume 48 into two separate pressure control volumes, referred to hereafter as bore volumes. Referring back to Figure 1, a first or upper bore volume 48a is defined upstream of the collar 28, and a second or lower bore volume 48b is defined downstream of the collar 28. When the needle 16 is in the open position, the fuel pressure in the first bore volume 48a is greater than the fuel pressure in the second bore volume 48b, by virtue of the restriction 54.

[0059] A downstream-facing thrust surface 60 of generally frustoconical form is provided on the valve needle 16, downstream of the needle guide portion 50. The thrust surface 60 is therefore exposed to fuel pressure within the second bore volume 48b. Because the thrust surface 60 is downstream-facing (i.e. a normal vector of the thrust surface 60 has a component parallel to the needle axis and directed towards the tip 22 of the nozzle body 12), the fuel pressure acting on the thrust surface 60 applies a force to the valve needle 16 in the lifting or opening direction.

[0060] An upstream side 28a of the collar 28 is exposed to fuel pressure in the first bore volume 48a. The upstream side 28a of the collar 28 therefore forms an upstream-facing thrust surface, and the fuel pressure acting on the upstream side 28a of the collar 28 applies a force to the valve needle 16 in the closing direction. Similarly, a downstream side 28b of the collar 28 is exposed to fuel pressure in the second bore volume 48b and forms a downstream-facing thrust surface. The fuel pressure acting on the downstream side 28b of the collar 28 applies a force to the valve needle 16 in the lifting direction.

[0061] The operation of the injection nozzle 10 will now be described. When the injection nozzle 10 is in a non-injecting state, communication between the control chamber and drain is closed by the nozzle control valve, so that the fuel pressure in the control chamber is relatively high. The downward or closing force acting on the needle 16 due to fuel pressure in the control chamber acting on the control piston 26 combined with the closing force provided by the spring 36 is greater than the upward or opening force acting on the needle 16 due to fuel acting on the thrust surface 60 of the needle 16. Therefore, there is a net downward or closing force on the needle 16, which retains the needle 16 in the closed position. The tip of the needle 16 is engaged with the seating 20 in order to prevent flow of fuel out of the outlets 24.

[0062] It will be appreciated that, when the valve needle 16 is held in its closed position, the respective pressures of fuel in the first and second bore volumes 48a, 48b equalise and the forces applied to the valve needle 16 due to fuel pressure acting on the respective upstream and downstream sides 28a, 28b of the collar 28 cancel out.

[0063] To initiate fuel injection, the nozzle control valve is operated to open the connection between the control chamber and the low-pressure drain, thereby reducing the fuel pressure in the control chamber and hence the closing force acting on the control piston 26. The total force acting on the needle 16 in the closing direction is no longer sufficient to overcome the upward force acting on the needle 16 as a result of fuel pressure on the thrust surface 60 in the second bore volume 48b. At this point, a net upward or opening force acts on the needle 16, and the needle 16 begins to move upwards away from the seat 20 to move into its open position.

[0064] As the needle 16 lifts off the seat 20, fuel is injected from the outlets 24 at high pressure into the combustion chamber. The pressure at the lower end of the bore 14, in the second bore volume 48b, reduces as fuel is injected into the combustion chamber. This helps to slow the initial speed at which the needle 16 lifts, because the upward pressure exerted by the fuel on the thrust surface 60 is reduced.

[0065] Also, a pressure difference arises between the first and second bore volumes 48a, 48b due to the restriction 54 as fuel flows through the bore 14 towards the outlets 24. As a result, the fuel pressure acting on each side of the collar 21 is no longer balanced. Instead, the closing force acting on the upstream side 28a of the collar 28 exceeds the lifting force acting on the downstream side 28b of the collar 28, and the net effect of the collar 28 is to apply an additional component of force to the needle 16 that acts in the closing direction.

[0066] The collar 28 therefore also helps to reduce the speed at which the needle 16 moves upwards away from the seating region 20. In addition, the movement of the collar 28 through the fuel gives rise to a drag effect that further attenuates the opening speed of the needle 16. Hence, the collar 28 has the effect of damping the opening movement of the needle 16 against the flow of fuel in the opposite direction to the movement of the needle 16. It is noted that the downward component of force acting on the needle 16 through the collar 28 is not sufficient to overcome the upward components of force acting through the thrust surface 60, so a net upward force continues to act to open the needle 16 to carry the needle 16 to a maximum lift or fully-open position, which may be defined by a lift stop for the needle (not shown).

[0067] When the desired amount of fuel has been delivered to the combustion chamber, the nozzle control valve is operated to close the connection to drain and to allow the pressure of fuel in the control chamber to rise. As a result, the combined downward forces acting on the needle 16 once again become larger than the upward forces acting on the needle 16, resulting in a net downward force on the needle that causes the needle to move in a closing direction to engage with the seating region 20. The downward force applied to the needle 16 through the collar 28 as a result of the differential pressure created by the restriction 54 provides an additional component of closing force that increases the speed of needle closure.

[0068] It will be appreciated that the effect of the restrictive element or collar 28 on the movement of the needle 16 exhibits hysteresis. During needle opening, the collar 28 damps movement of the needle 16, allowing good control of small injection volumes. During needle closing, the collar 28 boosts the closing speed of the needle 16, which allows rapid termination of injection. The additional force applied to the needle 16 by the collar 28 also helps to damp out any mechanical oscillations in the needle movement due to force waves travelling through the length of the needle 16 in use.

[0069] As shown most clearly in Figure 2, the radial distance or spacing between the peripheral edge 56 of the collar 28 and the wall portion 14d of the bore 14 depends on the position of the valve needle 16 with respect to the nozzle body 12. The diameter of the wall portion 14d of the bore 14 increases in the upstream direction, moving away from the tip 22 of the nozzle body 12, so that the radial spacing and the size of the clearance defining the restriction 54 increases progressively as the needle 16 moves from its closed position. In this embodiment, because the wall portion 14d is frustoconical, the radial spacing increases continuously in linear proportion to the needle lift (i.e. the axial separation distance between the needle 16 and the seating 20).

[0070] In this way, the flow area of the restriction 54 defined between the peripheral edge 56 of the collar 28 and the wall portion 14d increases as the needle 16 lifts during an injection event. At the beginning of an injection, when the needle lift is small (i.e. when the needle 16 has just lifted from the seating 20), the clearance between the collar 28 and the wall portion 14d is relatively small, so that the restriction 54 causes a large pressure drop across the collar 28. As the needle lift increases, the clearance increases, and the increased flow area of the restriction 54 results in a smaller pressure drop across the collar 28.

[0071] Accordingly, at low needle lifts, the relatively large pressure drop across the collar 28 has a relatively large effect on the movement of the needle 16, and significantly slows the rate of opening movement of the needle 16 at the beginning of an injection event. As the needle lift increases, the pressure drop across the collar 28 reduces, and the effect of the collar 28 on the needle velocity diminishes.

[0072] The control of the valve needle 16 is therefore improved in the present invention during relatively short, low-volume injection events in which the needle lift remains small throughout the whole of the injection event. In such cases, the clearance that defines the restriction 54 is relatively small, resulting in a large pressure drop across the collar 28 that both reduces the opening speed of the needle 16 and increases the closing speed of the needle 16 at the end of the injection event. In this way, very small volumes of fuel can be injected accurately. In particular, good control of small pre- and/or post-injections, which are delivered before and after a main injection event respectively, can be achieved.

[0073] Also, the damping effects of the collar 28 and the restriction 54 are maximised when the needle 16 is in its closed position, because the clearance that defines the restriction 54 is minimised. In particular, residual post-injection pressure waves in the fuel in the bore 14, and any mechanical oscillations or elastic waves in the needle are most effectively damped when the needle 16 is closed, which minimises the chance of such effects having an influence on subsequent injections.

[0074] Furthermore, because the flow area of the restriction 54 increases with increasing needle lift, the pressure of fuel reaching the outlets 24 gets closer to the supply pressure as the needle lift increases than would be the case if the restriction 54 were of constant flow area. In this way, for relatively long, high-volume injection events, injection can occur at a higher pressure for a given supply pressure than would otherwise be possible.

[0075] In summary, therefore, the effect of providing a restriction 54 with a flow area that increases with needle lift on the delivery curve of the injection nozzle 10 (i.e. the rate of injection as a function of time after the control valve is operated to initiate an injection event) is both to decrease the gradient of the curve at the start of the injection event, allowing good control of small injections, and to increase the gradient of the curve as the needle 16 approaches its maximum lift or fully-open position, allowing rapid delivery of fuel at high pressure during large injections.

[0076] The collar 28 has an asymmetrical shape, so that the upstream-facing side 28a of the collar 28 has a different shape to the downstream-facing side 28b. The downstream-facing side 28b of the collar 28 has a bevelled or chamfered edge portion 28c. The chamfered edge portion 28c is a bevelled surface that extends from a lower face 28d of the collar 28 to the outer peripheral edge 56. The upstream-facing side 28a of the collar 28 comprises a flat upper central face 28e which is stepped at its outer edge to define a peripheral recess or cut-out. A flat base portion of the cut out defines an upstream edge face 28f that extends outwardly to meet the peripheral edge 56 of the collar 28. The upstream edge face 28f is therefore recessed from the central face 28e to define a step 28g.

[0077] In this way, the peripheral edge 56 of the collar

28 forms a 'sharp' edge or knife edge that defines the restriction 54. In other words, the peripheral edge 56 of the collar 28 is defined where a first surface (the chamfered edge portion 28c) meets a second surface (the upstream edge face 28f). The first surface is inclined to the axis of the needle 16, and the second surface is perpendicular to the axis of the needle 16. In this embodiment, the peripheral edge 56 is half-way between the upper and lower faces 28e, 28d of the collar 28.

[0078] The shape of the collar 28 means that the peripheral edge 56 of the collar 28, which defines the restriction 54, is very short in the direction of the needle axis. Furthermore, the chamfered edge portion 28c of the collar 28, downstream of the peripheral edge 56, serves to maximise the turbulence of fuel downstream of the collar 28 as the fuel flows through the restriction 54. Thus, the characteristics of the restriction 54 approach those of a sharp-edged orifice, with the advantage that the sensitivity of the restriction 54 to fuel viscosity, and therefore to temperature, is particularly low. This further improves the control of the needle 16 during small injection events.

[0079] It will be appreciated that the peripheral edge 56 may not, in practice, be perfectly sharp. Instead, the peripheral edge 56 forms a generally cylindrical surface with a finite length in the direction parallel to the axis of the needle 16 which, preferably, is less than 0.2 mm. More preferably, the length of the peripheral edge 56 in the direction parallel to the needle axis is not more than 0.1 mm. In this example, the chamfered edge portion 28c of the downstream side 28b of the collar 28 is chamfered at an angle of approximately 30° with respect to the needle axis. In other examples, the chamfered edge portion 28c may preferably be chamfered at an angle of between approximately 15° and 45° to the needle axis.

[0080] The restriction 54 is disposed between the large-diameter and small-diameter regions 14a, 14b of the bore 14. This means that the bore volume 48a upstream of the collar 28 is substantially larger than the bore volume 48b downstream of the collar 28. Maximising the upstream bore volume 48a and minimising the downstream bore volume 48b helps to maximise the efficiency of the restriction 54.

[0081] The present invention is further illustrated with reference to Figure 3, which is a schematic drawing of part of an injection nozzle according to a simplified embodiment of the invention, in which only a portion of the collar 28 and a portion of the nozzle body 12 are visible.

[0082] When the valve needle is in its closed position, indicated by the solid lines in Figure 3, the collar 28 is positioned such that the radial distance or spacing R_A between the peripheral edge 56 of the collar 28 and the frustoconical wall portion 14d of the bore 14 is relatively small, to define an annular restriction 54a with a narrow width. With the valve needle in its fully open position, the collar 28 adopts the position indicated by the dashed lines on Figure 3, in which the radial distance R_B between the peripheral edge 56 of the collar 28 and the frustoconical wall portion 14d of the ball 14 is relatively large, to define an annular restriction 54b with a relatively wide flow path for fuel. It will be appreciated from Figure 3 that the clearance that defines the restriction 54a, 54b is the minimum clearance between the collar 28 and the frustoconical wall portion 14d, which corresponds to the distance along a line that extends perpendicular to the surface of the frustoconical wall portion 14d. The radial distance R_A, R_B between the collar 28 and the wall portion 14d, measured perpendicular to the valve needle axis, is indicative of the size of the restriction 54a, 54b and hence varies in the same way as the clearance that defines the restriction 54a, 54b.

[0083] Referring back to Figures 1 and 2, in the illustrated embodiments of the invention, the collar 28 and the needle 16 are manufactured as separate components that are fitted together during assembly of the injection nozzle 10. The collar 28 is arranged to be press-fitted to the shaft portion 30 of the needle 16, so that the collar 28 moves with the needle 16 as the needle 16 slides within the bore 14. One advantage of making the collar 28 separately from the needle 16 is that the bar size required for manufacturing the needle 16 can be reduced, thereby reducing manufacturing cost and waste material during manufacture.

[0084] Furthermore, referring to Figure 3, the radial clearance R_A that defines the size of the restriction 54a when the valve needle 16 is in its closed position or in another predetermined position can be set to a desired value during manufacture of the injection nozzle 10 by adjusting the axial position of the collar 28 on the valve needle 16. In this way, the initial size of the restriction 54a at the start of an injection event can be fine-tuned during manufacturing on a part-by-part basis without the need for costly machining operations. For example, dimensional variations in the diameter of the collar 28 and the bore 14 due to manufacturing tolerances can be readily compensated for. In addition, injection nozzles with different initial restriction sizes can be manufactured using identical sets of components.

[0085] To adjust the position of the collar 28 into the desired position on the valve needle 16, one or more parameters that are characteristic of the size of the restriction 54 may be measured during assembly, and the position of the collar 28 can be adjusted so as to achieve a target value of each parameter. The target value may be any value within a certain tolerance of an ideal value, for example. The adjustment of the position of the collar 18 can be made whilst simultaneously measuring and monitoring the parameter, in a direct-feedback process, or the adjustment could be made after measuring the parameter. The measurement and adjustment steps can be repeated as many times as necessary or desired, depending on the accuracy required.

[0086] In one example, the physical size of the clearance that defines the restriction 54 is measured directly. In another example, the radial distance between the peripheral edge 56 of the collar 28 and the wall portion 14d of the bore 14 could be measured. The measurements could be made by any suitable method as would be familiar to those skilled in the art.

[0087] In another method, a fluid, such as fuel, is passed through the bore 14 at a known flow rate during the assembly process. The pressure drop across the restriction 54 can then be measured, for example by measuring the fuel pressure upstream and downstream of the restriction 54. Alternatively, a measurement of the pressure of fluid downstream of the restriction 54 may be sufficient.

[0088] In another example, the fluid can be passed through the bore 14 at a known feed pressure, and the flow rate of fuel through the bore 14 can be measured to indicate the size of the restriction. Another technique measures the force acting on the valve needle when a fluid is passed through the bore at a known feed pressure and/or a known flow rate.

[0089] Several modifications and variations of the present invention can be contemplated. For example, the wall portion of the bore that defines the restriction can be shaped so as to achieve a particular variation of the restriction size as a function of needle lift. In the embodiment illustrated in Figures 1 and 2, for example, the cone angle of the wall portion is approximately 10°, but larger or smaller cone angles could be used as appropriate. For instance, the cone angle could be between approximately 5° and 30°.

[0090] The wall portion need not be frustoconical. Instead, the wall portion could have any suitable profile to achieve a desired variation of the restriction size as a function of needle lift. For instance, the wall portion could have a concave or convex profile, or a bottle-shaped surface. The clearance that defines the restriction may vary linearly or non-linearly with the needle lift. When the wall portion is frustoconical, the radial distance between the restrictive element and the wall portion is linearly proportional to the clearance that defines the restriction. In other cases, the radial distance may vary differently with respect to the size of the clearance. In general, a radial component of the direction that defines the clearance preferably increases progressively as the needle lifts from its closed position.

[0091] In another embodiment of the invention (not shown), the collar defines a spring seat to support the lower end of the spring. In this case, the number of components required in the injector is reduced and as such a simpler injector is provided. In other embodiments, the spring could be provided in the control chamber or elsewhere.

[0092] The restrictive element may differ from the collar shown in the illustrated embodiments. For example, the restrictive element may be in the form of a simple disc-shaped collar carried on the valve needle, or an annular collar with a bevelled surface at the edge of its downstream and/or upstream sides. A restrictive element with annular grooves or ridges for defining a plurality of peripheral edges could also be used, such that the restriction in the bore comprises a plurality of sub-restrictions.

[0093] The restrictive element may be formed integrally with the needle, rather than as a separate component that is mounted to the needle. Thus the needle may have an integrated collar or flange that forms the restrictive element.

[0094] It will be appreciated that the dimensions of the collar may vary from those described above. In particular, the diameter of the collar with respect to the diameter of the needle guide portion and with respect to the diameter of the control piston may be selected to adjust the behaviour of the valve needle. For instance, in the example illustrated in Figure 1, the diameter of the collar is approximately twice the diameter of the needle guide portion. In another example, the collar is approximately 1.2 times the diameter of the needle guide portion.

[0095] In the illustrated embodiments, the needle is housed in a bore in a single-piece nozzle body. However, the needle could instead be housed in a multi-part nozzle body, in which case the bore could be formed of a plurality of coaxially-arranged bores. The bore may also extend into, or be provided in, a component upstream of the nozzle body.

[0096] The control piston may be formed as an end region of the valve needle. Alternatively, the control piston could be a separate part that is associated with the needle, such that movement of the control piston is transferred to the needle.

[0097] Further modifications and variations not explicitly described above could also be made by a person skilled in the art without departing from the scope of the invention as defined in the appended claims.

Claims

1. An injection nozzle (10) for injecting fuel into a combustion chamber of an internal combustion engine, the injection nozzle comprising:

a nozzle body (12) having a bore (14) for receiving fuel from a supply line for pressurised fuel;
an outlet (24) from the bore (14) for delivering fuel to the combustion chamber, in use;
a valve needle (16) received in the bore (14) and defining a valve needle axis, the valve needle (16) being moveable between a closed position in which fuel flow through the outlet (24) into the combustion chamber is prevented, and a fully-open position in which fuel flow through the outlet into the combustion chamber is enabled, movement of the needle (16) being controllable by varying the fuel pressure within a control chamber, in use; and
a restrictive element (28) having an upstream side (28a) and a downstream side (28b); the restrictive element (28) being moveable with the needle (16);

wherein, in use, fuel that reaches the outlet (24) passes through a restriction (54) in the bore (14) defined by a clearance (54a, 54b) between the restrictive element (28) and a wall portion (14d) of the bore (14);
and wherein the clearance (54a, 54b) increases progressively as the valve needle (16) lifts from its closed position.

2. An injection nozzle according to Claim 1, wherein the clearance (54a, 54b) increases progressively as the valve needle (16) lifts from its closed position to its fully-open position.

3. An injection nozzle according to Claim 1 or Claim 2, wherein the clearance (54a, 54b) increases continuously in proportion to the lift of the valve needle (16).

4. An injection nozzle according to Claim 3, wherein the wall portion (14d) of the bore (14) is generally frustoconical, such that the clearance (54a, 54b) is linearly proportional to the lift of the valve needle (16).

5. An injection nozzle according to any preceding claim, wherein the clearance (54a) is non-zero when the needle (16) is in its closed position.

6. An injection nozzle according to any preceding claim, wherein the restrictive element (28) is separated from the wall portion (14d) of the bore by a radial distance (R_A, R_B), and wherein the radial distance (R_A, R_B) increases progressively as the valve needle (16) lifts from its closed position.

7. An injection nozzle according to any preceding claim, wherein the needle comprises a needle guide portion (50) arranged to guide sliding movement of the needle (16) within the bore (14), and wherein the restrictive element (28) is disposed upstream of the needle guide portion (50).

8. An injection nozzle according to Claim 7, wherein the restrictive element (28) has a larger diameter than the needle guide portion (50) of the needle (16).

9. An injection nozzle according to Claim 7 or Claim 8, wherein the bore (14) includes a region (14a) of relatively large diameter upstream of the restrictive element (28), a region (14b) of relatively small diameter in which the needle guide portion (50) of the valve needle (16) is disposed, and a region (14c) intermediate the large and small diameter regions (14a, 14b) in which the restrictive element (28) is disposed.

10. An injection nozzle according to any preceding claim, wherein the clearance (54a, 54b) comprises an annular clearance (54) between the bore (14) and a peripheral edge (56) of the restrictive element (28).

11. An injection nozzle according to Claim 10, wherein at least a part of the downstream side (28b) of the restrictive element (28) comprises a bevelled surface (28c) that extends to the peripheral edge (56), the bevelled surface (28c) being non-perpendicular to the valve needle (16) axis.

12. An injection nozzle according to Claim 10 or Claim 11, wherein the upstream side (28a) of the restrictive element (28) comprises an upstream edge face (28f) that extends to the peripheral edge (56) of the restrictive element (28), the upstream edge face (28f) being perpendicular to the needle axis.

13. An injection nozzle according to any preceding claim, wherein the restrictive element comprises a collar (28) disposed annularly around a shaft portion (30) of the valve needle (16).

14. An injection nozzle according to Claim 13, wherein the collar (28) is press-fitted on the shaft portion (30) of the valve needle (16).

15. A method of assembling an injection nozzle according to Claim 13 or Claim 14, comprising:

measuring a parameter relating to fuel flow through the restriction; and
adjusting the position of the collar with respect to the valve needle to achieve a target value of the measured parameter.

16. A method according to Claim 15, wherein the measured parameter comprises the size of the clearance that defines the restriction, or the radial distance between the collar and the wall portion of the bore.

17. A method according to Claim 15, comprising passing a fluid through the bore at a known flow rate and/or a known feed pressure, and wherein the measured parameter comprises a pressure drop across the restriction, a fluid pressure downstream of the restriction, a flow rate of fluid through the bore, or a force on the valve needle.

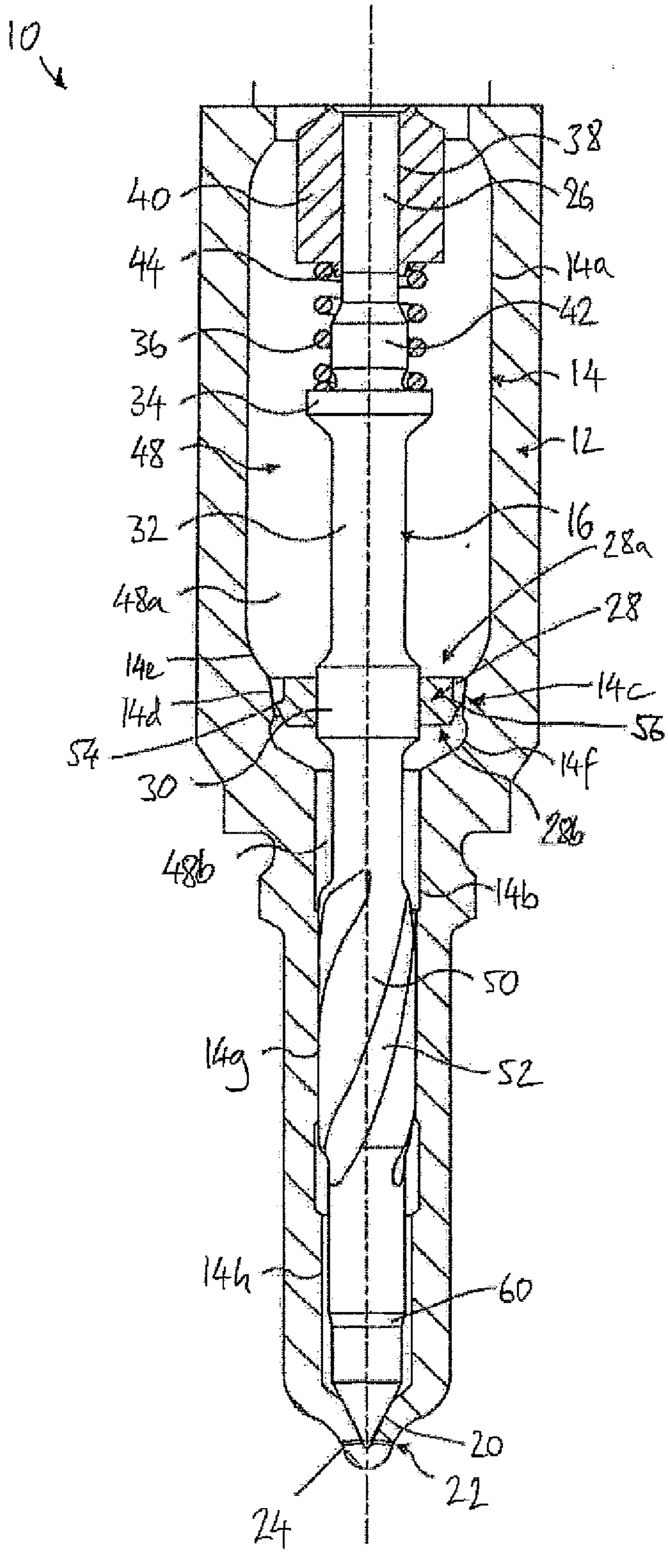
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FIGURE 1

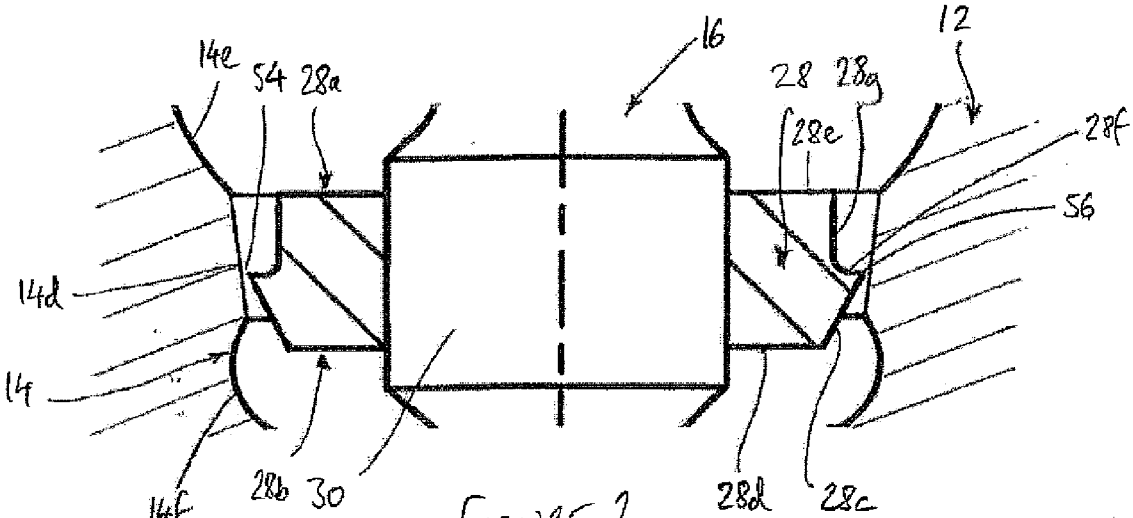

FIGURE 2

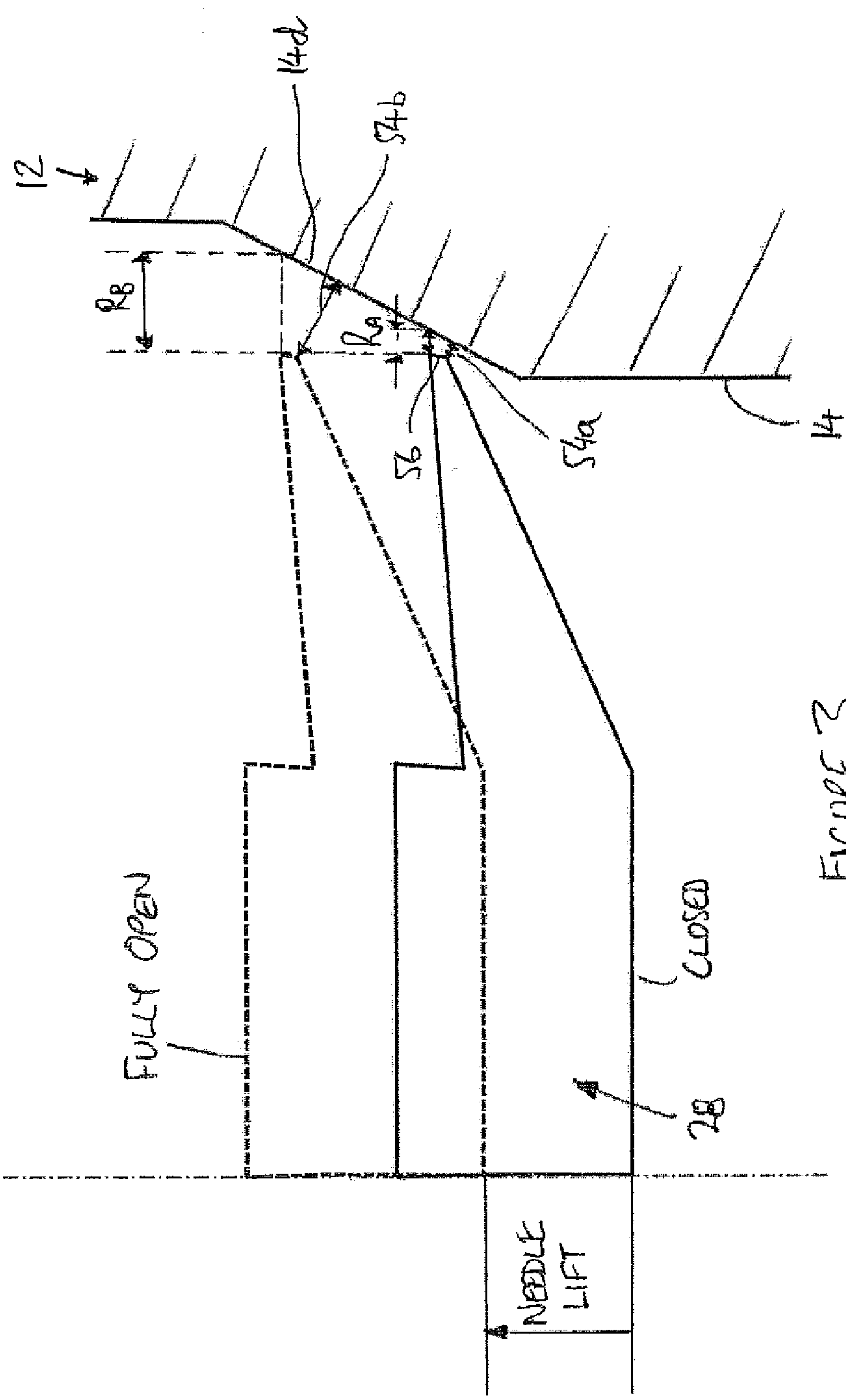

FIGURE 3

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EUROPEAN SEARCH REPORT

Application Number
EP 12 18 9470

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	DE 10 2005 061925 A1 (CATERPILLAR INC [US]) 31 August 2006 (2006-08-31)	1-6, 10-13, 15-17	INV. F02M45/12 F02M61/10 F02M61/12 F02M61/20
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The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	25 February 2013	Kolland, Ulrich

CATEGORY OF CITED DOCUMENTS

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

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