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(54) **Fuel injector**

(57) A fuel injector (10) for use in a high-pressure fuel injection system for an internal combustion engine is described. The fuel injector comprises a high-pressure fuel volume (32) defined by at least one wall (24a), a supply passage (30) for delivering high-pressure fuel to the high-pressure fuel volume (32) from a high-pressure fuel source, a valve needle (26) arranged to control fuel injection from one or more outlets of the injector, a surface associated with the valve needle (26) being exposed to fuel pressure within a control chamber (36), in use, a return flow path for conveying fuel from the control chamber (36) to a low-pressure drain, and a control valve (40) for controlling the flow of fuel through the return flow path. The return flow path comprises a return flow volume (62) disposed, at least in part, adjacent to the wall (24a) of the high-pressure fuel volume (32), thereby to promote heat transfer from the fuel in the return flow volume (62) to the fuel in the high-pressure fuel volume (32), in use. In this way, the fuel in the return flow path is cooled to avoid thermal breakdown of the fuel.

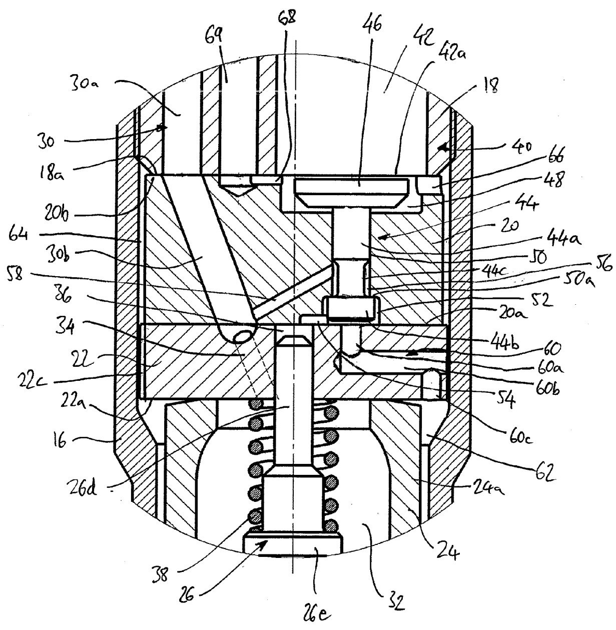

FIGURE 1(b)

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Description

Field of the invention

[0001] The present invention relates to a fuel injector. In particular, but not exclusively, the present invention relates to a fuel injector for use in a high-pressure fuel injection system for an internal combustion engine.

Background to the invention

[0002] Known fuel injection systems include a plurality of fuel injectors, each of which is arranged to inject fuel into the combustion chamber of an associated engine cylinder. Each fuel injector is supplied with high-pressure fuel from a suitable source, such as a common rail, which is charged with fuel at high pressure by a high-pressure fuel pump.

[0003] A typical fuel injector comprises a nozzle body which houses an elongate valve needle. In use, the injector is mounted so that a tip region of the nozzle body protrudes into the associated combustion chamber. A plurality of outlets is formed in the tip region of the nozzle body through which fuel can be injected into the combustion chamber at high pressure to form an atomised spray. The fuel injector also includes an accumulator volume disposed substantially within the nozzle body. The accumulator volume is arranged to receive fuel at high pressure from a suitable source, and to store the fuel at high pressure for delivery to the outlets when required for injection.

[0004] A tip of the valve needle is engageable with a seat region of the nozzle body to prevent the flow of fuel through the outlets. An end of the valve needle, opposite the tip, is received within a control chamber, such that the end of the valve needle is exposed to fuel within the control chamber, in use.

[0005] Movement of the valve needle is controlled by varying the pressure of fuel in the control chamber, by means of a nozzle control valve. The nozzle control valve connects the control chamber either to the source of high-pressure fuel, so as to raise the fuel pressure in the control chamber, or to a low-pressure drain, so as to lower the fuel pressure in the control chamber.

[0006] When the control chamber is connected to the source of high-pressure fuel, the fuel in the control chamber imparts a relatively high force to the end of the valve needle, to keep the tip of the needle engaged with the seat region of the nozzle body and to prevent injection of fuel through the outlets. When an injection is required, the control valve is operated to open the flow path between the control chamber and the low-pressure drain and to close the flow path between the control chamber and the source of high-pressure fuel. As the fuel pressure in the control chamber falls, the closing force acting on the valve needle decreases and the valve needle can move away from the seat region to permit injection through the outlets.

[0007] The nozzle control valve typically includes a control valve member which is slidable within a valve guide bore. The control valve member is moveable, under the control of an actuator, between a first position and a second position to engage with first and second valve seats respectively. In the first position, the control valve member is seated on the first seat to close the flow path between the control chamber and the low-pressure drain whilst leaving the flow path between the high-pressure fuel source and the control chamber open. In the second position, the control valve member moves into seating engagement with the second seat to close the flow path between the high-pressure fuel source and the control chamber, whilst opening the flow path between the control chamber and the low-pressure drain.

[0008] In some cases, the control valve is arranged such that the hydraulic forces acting on the control valve member due to high-pressure fuel are substantially balanced. In this way, the force required to move the control valve member between the first and second positions is relatively low, so that, advantageously, a relatively low-force actuator can be used. In such arrangements, the valve guide bore typically separates a region of high-pressure fuel from a region of low-pressure fuel, so that leakage of fuel from the high-pressure region can occur along the valve guide bore. To minimise this leakage, the outer diameter of the control valve member is closely matched to the inner diameter of the valve guide bore to give a close sliding fit.

[0009] The control valve is typically operated by a piezoelectric actuator or an electromagnetic (solenoid) actuator. An electromagnetic actuator for a fuel injector commonly includes a disc-shaped armature coupled to an end of the control valve member, and a solenoid coil disposed around a core member and energisable to attract the armature towards a pole face of the core member. The armature is typically housed within a chamber that forms part of the return flow path from the control chamber to the low-pressure drain, such that the armature is immersed in fuel, in use. The gap between the armature and the pole face is generally relatively small, so as to minimise the diameter of the solenoid coil required to move the control valve member. Typically, the gap is of the order of 30 microns.

[0010] In view of the close tolerance between the control valve member and the valve guide bore, the relatively small gap between the armature and the pole face, and the control valve being designed to operate at relatively low forces, it is desirable to keep the fuel in the injector free from solid deposits or other contaminants that could affect the operation of the control valve. Even a thin layer of deposit on the nozzle control valve components, such as the control valve member, the armature or the pole face, can restrict the fuel flow and slow down or hinder the operation of the valve.

[0011] One source of contaminants arises when fuel in the injector becomes sufficiently hot to undergo thermal breakdown. Although the normal operating temperature of the injector is generally low enough to avoid overheating the fuel, when the nozzle control valve is operated to exhaust the high-pressure fuel from the control chamber into the low-pressure drain, the energy release associated with the pressure change can cause localised heating of the fuel flowing into the return path and the surrounding injector components. In particular, in modern diesel fuel injection systems, which operate at very high pressures (typically 3000 bar or higher), the fuel flowing into the return flow path can become sufficiently heated to undergo thermal breakdown. The thermal breakdown products can deposit on the nozzle control valve components, for example in the form of a film or lacquer. Such deposits can restrict the fuel flow and slow down or hinder the operation of the control valve, for example by causing sticking of the control valve member.

[0012] This problem is compounded by the trend towards the addition of various additives and biodiesels such as fatty acid methyl esters (FAME) to diesel fuels for automotive fuel injection systems. These additives tend to decrease the stability of fuels at high temperatures. This increased instability means that the fuel in the injector is more susceptible to thermal breakdown, so that undesirable deposits are more likely to form.

[0013] Against that background, it would be desirable to provide a fuel injector which avoids or mitigates the problems described above.

Summary of the invention

[0014] According to one aspect of the present invention, there is provided a fuel injector for use in a high-pressure fuel injection system for an internal combustion engine. The fuel injector comprises a high-pressure fuel volume defined by at least one wall, a supply passage for delivering high-pressure fuel to the high-pressure fuel volume from a high-pressure fuel source, and a valve needle arranged to control fuel injection from one or more outlets of the injector. A surface associated with the valve needle is exposed to fuel pressure within a control chamber, in use. The fuel injector further comprises a return flow path for conveying fuel from the control chamber to a low-pressure drain and a control valve for controlling the flow of fuel through the return flow path. The return flow path comprises a return flow volume disposed, at least in part, adjacent to the wall of the high-pressure fuel volume, thereby to promote heat transfer from the fuel in the return flow volume to the fuel in the high-pressure fuel volume, in use.

[0015] Because at least part of the return flow volume is located adjacent to the wall of the high-pressure fuel volume, fuel in the return flow volume is cooled by heat transfer through the wall of the high-pressure fuel volume. The cooled fuel can then flow through the return flow path towards the low-pressure drain at a temperature low enough to avoid thermal breakdown of the fuel.

[0016] To optimise the heat transfer from the fuel in the return flow volume to the fuel in the high-pressure fuel volume, the return flow volume may be directly adjacent to the wall of the high-pressure volume. For example, the return flow volume may be defined, at least in part, by the wall of the high-pressure fuel volume.

[0017] In one embodiment, the wall of the high-pressure fuel volume is generally tubular, and the return flow volume is disposed annularly around the wall. In this way, the surface area of the return flow volume that is exposed to the wall of the high-pressure fuel volume can be maximised. In one example, the high-pressure fuel volume comprises a high-pressure fuel chamber defined within the bore of the generally tubular wall.

[0018] The high-pressure fuel volume and the return flow volume are preferably housed in a region of the fuel injector that is disposed between the control valve and the outlets. The fuel injector may further comprise a nozzle body for housing the valve needle and, conveniently, the high-pressure fuel volume may be disposed within the nozzle body. The return flow volume may be defined, in part, by a wall of the nozzle body.

[0019] The return flow volume may be defined, in part, by a capnut of the fuel injector. For example, in one embodiment, the return flow volume is defined in part by a wall of a nozzle body and in part by the capnut, such that the return flow volume comprises a clearance between the nozzle body and the capnut. The fuel injector may further comprise an injector body having at least one generally cylindrical injector body portion received within the capnut, and the return flow path may include at least one passage defined in part by an outer surface of the injector body portion and in part by the capnut. In this case, the outer surface of the injector body portion may comprise a flat that defines, in part, the passage.

[0020] To improve the heat transfer between the fuel in the return flow volume and the fuel in the high-pressure fuel volume, the fuel injector may further comprise vortex-inducing means to induce a vortex in the fuel in the high-pressure fuel volume, in use. The vortex gives rise to a high fuel velocity close to the wall of the high-pressure fuel volume, which improves the heat transfer and encourages cooler fuel to move towards the wall of the high-pressure fuel volume. The rotational inertia of the fuel means that the vortex can persist between injections, even though the fuel flow through the high-pressure fuel volume is interrupted when the injector is not injecting.

[0021] The vortex-inducing means may comprise a transfer passage that conveys fuel from the supply passage to the high-pressure fuel volume. The high-pressure fuel volume may be elongate to define an axis, and the transfer passage may be inclined with respect to and/or offset from the axis, thereby to impart a non-axial flow velocity to the fuel entering the high-pressure fuel volume.

[0022] To increase the surface area over which heat transfer can take place between the fuel in the return flow volume and the fuel in the high-pressure fuel volume, and/or to guide the fuel flow along a relatively long path within the return flow volume, the return flow volume may include grooves, flats, channels, passages or the like. For example, the wall of the high-pressure fuel volume that defines the return flow volume may include one or more flats or channels to direct fuel within the return flow volume.

[0023] A portion of the return flow path, downstream of the return flow volume, may be arranged to direct fuel that has been cooled in the return flow volume through or adjacent to the control valve, thereby to cool the control valve.

[0024] In one embodiment, the control valve includes a control valve member that is slidable within a valve guide bore. The valve guide bore may separate a high-pressure fuel region from a low-pressure fuel region, for example when the control valve member is hydraulically balanced. The low-pressure fuel region may form part of the return flow path downstream of the return flow volume. Advantageously, in such an arrangement, fuel that leaks along the valve guide bore can mix with the cooled fuel in the return flow path to avoid overheating of the fuel and the valve components.

[0025] The control valve may further comprise an electromagnetic actuator operable to move an armature associated with a control valve member of the valve, in which case the armature may be received in an armature chamber that forms part of the return flow path downstream of the return flow volume. In this way, the armature and the actuator can be cooled by the fuel in the return flow path. In one embodiment, a pole face of the actuator is exposed to fuel in the armature chamber. Similarly, the return flow path, downstream of the return flow volume, may be directed at least in part around the actuator such that heat can be transferred from the actuator components to the fuel in the return flow path. The cooling of the control valve and actuator components further mitigates the risk of thermal breakdown of the fuel in the return flow path.

[0026] In another embodiment, the fuel injector comprises a piezoelectric actuator, in which case the return flow path can be directed at least in part around the piezoelectric actuator stack.

[0027] The high-pressure fuel volume may be an accumulator volume of the injector. The accumulator volume provides a reservoir of high-pressure fuel for injection that helps to maintain a relatively constant injection pressure.

Brief description of the drawings

[0028] Embodiments of the present invention will be now described, by way of example only, with reference to the accompanying drawings in which:

Figure 1(a) is a schematic cross-sectional view of a fuel injector according an embodiment of the present invention;

Figure 1(b) is an enlarged schematic cross-sectional view of a portion of the fuel injector of Figure 1(a);

Figure 2 is a schematic sectional top-down view of the fuel injector of Figure 1(a) at the A-A plane.

[0029] Throughout this specification, terms such as 'upper', 'lower', 'top', 'bottom' and so on are used with reference to the orientation of the fuel injector as shown in Figures 1(a) and 1(b) of the accompanying drawings. It will be appreciated, however, that the fuel injector could be oriented in any suitable position, in use.

Detailed description of embodiments of the invention

[0030] Referring first to Figures 1(a) and 1(b), a fuel injector 10 for a high-pressure fuel injection system comprises a generally elongate injector body 12, a nozzle 14, and a generally tubular capnut 16 that retains the nozzle 14 against the injector body 12. The injector body 12 comprises three generally cylindrical injector body portions, namely a first injector body portion 18 forming an first, upper end of the injector body 12, an intermediate second injector body portion 20, and a third injector body portion 22 at the second, lower end of the injector body 12. The nozzle 14 comprises a nozzle body 24 that houses a valve needle 26. The nozzle body 24 and the first, second and third body portions 18, 20, 22 are clamped together in sealing engagement by the capnut 16.

[0031] The first body portion 18 comprises an inlet port 28 that is connectable, by way of a supply line (not shown), to a source of high-pressure fuel such as a common rail (not shown) of the fuel injection system. The inlet port 28 defines an entry point through which high-pressure fuel can be admitted to a supply passage 30 of the injector. A first portion 30a of the supply passage 30 extends from the inlet port 28 through the first injector body portion 18 to connect with a second portion 30b of the supply passage 30 that extends through the second injector body portion 20.

[0032] The nozzle body 24 comprises an upper, relatively large-diameter generally tubular region 24a and a lower, relatively small-diameter generally tubular region 24b, and the capnut 16 engages with a shoulder of the nozzle body 24 where the upper region 24a meets the lower region 24b.

[0033] The lower region 24b comprises a bore 28 within which a guide portion 26a of the valve needle 26 is slidably engaged. The lower generally tubular region 24b terminates at a tip region 24c of the nozzle body 24, which defines a seating region 24d for a tip 26b of the valve needle 26. A plurality of outlets (not shown) extend through the tip region 24c of the nozzle body 24. When the tip 26b of the valve needle 26 is engaged with the seating region 24d, fuel flow between the bore 28 and the outlets is prevented, and when the valve needle 26 is lifted to disengage the tip 26b from the seating region 24d, fuel can flow from the bore 28 through the outlets for injection.

[0034] At an upper end of the lower region 24b of the nozzle body 24, opposite the tip region 24c, the bore 28 opens into an accumulator volume 32 defined in part by the bore of the upper nozzle body region 24a and in part by a lower face 22a of the third injector body portion 22. In this way, the tubular upper region 24a of the nozzle body 24 defines a wall of the accumulator volume 32. The accumulator volume 32 receives high-pressure fuel from the supply passage 30 by way of a transfer passage 34 that extends through the third injector body portion 22 to open onto the lower face 22a of the third injector body portion 22, as shown in Figure 2. In Figures 1(a), 1(b) and 2, the transfer passage 34 extends behind the plane of the drawings and is indicated with dashed lines.

[0035] The valve needle 26 extends upwardly from the guide portion 26a through the accumulator volume 32. An upper end portion 26d of the valve needle 26 is slidably received within a control chamber 36 defined in part by an axial bore in the third injector body portion 22, and in part by a lower face 20a of the second injector body portion 20.

[0036] A biasing spring 38 is disposed between the lower face 22a of the third injector body portion 22 and a spring seat 26e formed on the needle 26. The biasing spring 38 biases the valve needle 26 towards a closed position, in which the tip 24d of the needle 26 is engaged with the seating region 24d of the nozzle body 24.

[0037] Movement of the valve needle 26 is controlled by varying the fuel pressure in the control chamber 36 by means of a nozzle control valve 40. In this embodiment, the control valve 40 is an electromagnetically-actuated valve comprising a solenoid actuator 42 and a movable control valve member 44. The actuator 42 is operable to control the position of the control valve member 44.

[0038] The actuator 42 is housed within the first injector body portion 18 and comprises a solenoid coil disposed around a core member (not shown). A pole face 42a of the actuator 42 is exposed at the lower face 18a of the first injector body portion 18. As shown most clearly in Figure 1(b), the control valve member 44 comprises an elongate stem portion 44a coupled, at its upper end, to a disc-shaped armature 46. The armature 46 is received within an armature chamber 48 formed as a recess in the upper face 20b of the second injector body portion 20, such that the armature 46 is disposed parallel and adjacent to the pole face 42a of the actuator 42. The stem portion 44a extends through a valve guide bore 50 that extends from the armature chamber 48 to the lower face 20a of the second body portion 20.

[0039] An enlarged-diameter end region 44b of the control valve member 44, opposite the armature 46, is received within a first valve chamber 52. The first valve chamber 52 is formed by an enlarged-diameter region of the valve guide bore 50, such that a shoulder 50a is defined in the valve guide bore 50 at the top of the first valve chamber 52. The first valve chamber 52 is in fluid communication with the control chamber 36 by way of a channel 54 formed in the lower face 20a of the second body portion 20.

[0040] A second valve chamber 56 is defined between a reduced-diameter part 44c of the control valve member 44, adjacent to the end region 44b, and the valve guide bore 50. The second valve chamber 56 is connected to the second portion 30b of the supply passage 30 by a drilling 58.

[0041] A return passage 60 is formed in the third injector body portion 22. A first portion 60a of the return passage 60 is axially aligned with the control valve member 44 and opens into the first valve chamber 52. A second portion 60b of the return passage 60 extends radially outwards from the first portion 60a to connect with a third portion 60c of the return passage 60. The third portion 60c of the return passage 60 extends parallel to the control valve axis and opens onto the lower face 22a of the third injector body portion 22 to connect with a return flow volume 62 in the form of an annular chamber disposed between the upper region 24a of the nozzle body 24 and the capnut 16. Flow from the end of the second portion 60b of the return passage is restricted at the periphery of the third injector body portion 22 by the relatively small clearance between the third injector body portion 22 and the capnut 16, such that the majority of flow is directed from the second portion 60b of the return passage 60 into the return flow volume 62 by way of the third portion 60c.

[0042] The return flow volume 62 is connected to a low-pressure drain for fuel, as will now be described.

[0043] Fuel can flow from the return flow volume 62 into an annular space 64 between the second injector body portion 20 and the capnut 16 by way of the relatively small clearance between the third injector body portion 22 and the capnut 16. The third injector body portion 22 includes a flat 22c at its peripheral edge to assist the flow of fuel from the return flow volume 62 into the annular space 64. The flat 22c is disposed diametrically opposite to the third portion 60c of the return passage 60, which helps to maximise the length of the flow path that the fuel takes through the return flow volume 62 before it reaches the annular space 64.

[0044] The annular space 64 is connected to the armature chamber 48 by means of a first channel 66 formed in the upper face 20b of the second injector body portion 20. In turn, the armature chamber 48 is connected, by means of a second channel 68 in the upper face 20b of the second injector body portion 20, to a low-pressure drain passage 69 that extends within the first injector body portion 18. As shown most clearly in Figure 1(a), the drain passage 69 terminates at an outlet port 70 that is connected in use to a low-pressure drain, such as a fuel tank (not shown).

[0045] In this way, the return passage 60, the return flow volume 62, the annular space 64, the first channel 66, the armature chamber 48, the second channel 68, the drain passage 69 and the outlet port 70 together define a return flow path for conveying fuel from the control chamber 36 to the low-pressure drain.

[0046] The control valve member 44 is movable, under the influence of the actuator 42, to open and close communication between the first valve chamber 52 and the second valve chamber 56, and to open and close communication between the first valve chamber 52 and the return passage 60.

[0047] In particular, when the control valve member 44 is in a first position, a lower face of the end region 44b of the control valve member 44 seats on the upper face 22b of the third injector body portion 22, to occlude the return passage 60 and to prevent the flow of fuel from the first valve chamber 52, and hence the control chamber 36 to the low-pressure drain. In this first position, the end region 44b is spaced from the shoulder 50a of the valve guide bore 50 to allow high-pressure fuel to flow from the second valve chamber 56 into the first valve chamber 52, and hence into the control chamber 36. Thus, when the control valve member 44 is in its first position, the pressure of fuel in the control chamber 36 is relatively high. The relatively high force thus exerted on the upper end portion 26d of the valve needle 26 is sufficient to bias the tip 24d of the needle 26 into engagement with the seating region 24d of the nozzle body 24.

[0048] When the control valve member 44 moves into a second position, in response to energisation of the actuator 42, the end region 44b of the valve member comes into engagement with the shoulder 50a as shown in Figure 1(b) to prevent the flow of high-pressure fuel from the second valve chamber 56 into the first valve chamber 52. The lower face of the end region 44b moves away from the upper face 22b of the third injector body portion 22, to open the return passage 60. In this way, the pressure of fuel in the control chamber 36 drops to a relatively low level when the control valve member 44 is moved into its second position. The force acting on the upper end portion 26d of the valve needle 26 as a result of the fuel pressure in the control chamber 36 therefore drops, to allow the tip 24d of the needle 26 to disengage from the seating region 24d of the nozzle body 24, thereby to permit injection of fuel through the outlets in the tip region 24c of the nozzle body 24.

[0049] When the control valve member 44 moves into its second position, the relatively high-pressure fuel in the control chamber 36 flows into the return passage 60, which is at relatively low pressure. The resultant energy change that occurs as a result of the decrease in pressure causes localised heating of the fuel flowing into the return passage 60. As will now be described, the injector 10 is adapted so that the heated fuel flowing from the return passage 60 is cooled as it flows through the injector 10.

[0050] As noted above, fuel flows from the return passage 60 into the annular return flow volume 62. The return flow volume 62 is defined in part by the outer surface of the tubular wall of the accumulator volume 32 formed by the upper region 24a of the nozzle body 24, and in part by the inner surface of the capnut 16. In this way, heat transfer between the relatively hot fuel in the return flow volume 62 and the cooler fuel in the accumulator volume 32 can occur.

[0051] Because the return flow volume 62 is directly adjacent to the wall 24a of the accumulator volume 32, and because the return flow volume 62 is annularly disposed around the accumulator volume 32, the surface area of the nozzle body 24 through which heat transfer can occur is maximised. Furthermore, the radial thickness of the return flow volume 62 is relatively small, so that all of the fuel in the return flow volume 62 is held close to the wall 24a of the accumulator volume. The relatively high temperature of the fuel entering the return flow volume 62 has a relatively low viscosity, which further assists in obtaining a high rate of heat transfer.

[0052] It will be appreciated that, during injection, the flow rate of high-pressure fuel through the accumulator volume 32 is substantially greater than the flow rate of fuel into the return flow volume 62 from the return passage 60. As a result, the temperature of the fuel in the return flow volume 62 can be reduced significantly for a relatively small increase in temperature of the fuel in the accumulator volume 32.

[0053] By transferring the heat from the fuel in the return flow volume 62 to the fuel in the accumulator volume 32, the likelihood of thermal breakdown of the low-pressure fuel that is exhausted from the control chamber 36 is significantly reduced. Accordingly, the risk of injector failure or performance degradation due to the build up of breakdown products as a deposit or lacquer on the injector components, and particularly the components of the control valve 40, is minimised.

[0054] The fuel flowing into the accumulator volume 32 through the transfer passage 34 is at a relatively low temperature, and therefore has a relatively high viscosity. Furthermore, because the accumulator volume 32 is relatively large in cross-sectional area, the fuel velocity and turbulence within the accumulator volume 32 can be low. These factors could have a negative impact on the rate of heat transfer. Accordingly, to improve the heat transfer coefficient between the fuel in the return flow volume 62 and the fuel in the accumulator volume 32, the fuel flow in the accumulator volume 32 is directed into a vortex flow pattern by the arrangement of the transfer passage 34. Referring to Figures 1(b) and 2, the transfer passage 34 enters the accumulator volume 32 at a point that is radially spaced from the axis of the valve needle 26, around which the accumulator volume 32 is symmetrically disposed. Furthermore, the transfer passage 34 is inclined with respect to the axis of the valve needle. Accordingly, the fuel enters the accumulator volume 32 from the transfer passage 34 with a component of velocity that is tangential to the wall of the accumulator volume 32, to set up a vortex or helical flow pattern in the accumulator volume 32.

[0055] The vortex within the accumulator volume 32 creates a high velocity of fuel adjacent to the wall 24a of the accumulator volume 32, which increases the heat transfer coefficient. Furthermore, as a result of the centripetal forces that arise in the vortex, relatively cold, denser fuel tends to flow towards the wall whilst relatively hot, less dense fuel tends to flow towards the centre of the accumulator volume 32. This maximises the temperature difference across the wall 24a of the accumulator volume 32, which increases further the efficiency of heat transfer.

[0056] When the injector 10 is in a non-injecting state, with the tip 26b of the valve needle 26 engaged with the seating region 24d of the nozzle body 24, fuel flow through the accumulator volume 32 stops. Advantageously, because of the inertia of the fuel, the vortex created by the orientation of the transfer passage 34 can persist between injection events, maintaining a useful degree of heat transfer, even though the fuel flow through the accumulator volume 32 is intermittent.

[0057] The cooled fuel flows out of the return flow volume 62 between the flat 22c of the third injector body portion 22 and the capnut 16 into the annular space 64 that surrounds the second injector body portion 20, and then into the armature chamber 48. In this way, the armature 46 and the pole face 42a of the actuator 42 are cooled by the fuel. In this way, the electrical efficiency of the control valve 40 is improved.

[0058] It will be appreciated that, in use, some high-pressure fuel within the second valve chamber 56 of the control valve 40 will leak along the valve guide bore 50 into the armature chamber 48, which is at low pressure. Advantageously, this leakage fuel mixes with the cooled fuel flowing into the armature chamber 48 from the return flow volume 62, such that any localised heating of the control valve components due to the pressure change in the leakage fuel is minimised.

[0059] Also, because the control valve member 44 and the surrounding injector components are cooled by the fuel from the return flow volume 62, the fuel in the second valve chamber 56 and in the valve guide bore 50 is cooler, and therefore more viscous, than would otherwise be the case. The rate of leakage is therefore advantageously reduced by virtue of the cooling of the fuel in the return flow volume 62.

[0060] More generally, because of the cooling of the fuel in the return flow volume 62, the fuel that returns to the low-pressure drain from the outlet port 70 of the injector is cooler than would otherwise be the case. This has a beneficial effect on the efficiency of the fuel injection system as a whole and, as a result of the generally higher viscosity of the fuel, the propensity for leakage within the fuel injection system is reduced.

[0061] As will be understood by a person skilled in the art, many variations and modifications to the fuel injector described with reference to Figures 1(a), 1(b) and 2 can be contemplated.

[0062] For example, it can be advantageous to guide the flow of fuel within the return flow volume 62 so that the fuel flows adjacent to the wall 24a of the accumulator volume 32 over as great a distance as practicable. For example, in some embodiments of the invention, grooves, flats, channels, passages or the like may be formed in the nozzle body 24 and/or the capnut 16 to guide the fuel flow along a relatively long path within the return flow volume 62, and/or to increase the surface area over which heat transfer can take place. Similarly, grooves, flats, channels, passages or the like may be formed on other components of the injector, such as the second and third body portions 20, 22, to guide the flow of fuel from the return flow volume 62 to the low-pressure drain.

[0063] In one variant of the invention, the flat 22c on the third injector body portion 22 is omitted. In this case, fuel flows from the return flow volume 62 into the annular space 64 through an annular clearance between the cylindrical outer surface of the third injector body portion 22 and the internal surface of the capnut 16. In another variant, one or more passages are formed through the third injector body portion 22 to convey fuel from the return flow volume 62 into the annular space 64.

[0064] In the illustrated embodiment, the transfer passage 34 acts as a vortex-inducing means for fuel flowing into the accumulator volume 32. Alternatively, or in addition, other flow-modifying means could be employed to optimise the flow of fuel within the accumulator volume 32 to maximise the heat transfer. For instance, ridges, baffles or similar features could be provided on the internal surface of the wall 24a of the accumulator volume to act as vortex-inducing means.

[0065] In the illustrated embodiment, the accumulator volume 32 is disposed within a single-piece nozzle body 24 that extends to the tip of the injector. In an alternative embodiment, the nozzle body is a two-piece component with an upper section that houses the accumulator volume, and a tubular lower section that guides the valve needle and extends to the tip of the injector. The upper section may, for example, be barrel-shaped.

[0066] Conceivably, the return flow volume may be disposed around a volume of high-pressure fuel located in any suitable location within the fuel injector, and the volume of high-pressure fuel need not act as an accumulator volume. The return flow volume and the high-pressure fuel volume may be arranged in any suitable configuration. For example, the return flow volume need not be disposed annularly around the high-pressure fuel volume, and instead the heat transfer between the two volumes could occur across a planar wall that separates the volumes.

[0067] In the illustrated embodiment of the invention, the control valve 40 is of a two-position, three-way type to control the flow of high-pressure fuel into the control chamber 36 from the supply passage 30 as well as the flow of fuel out of the control chamber 36 into the low-pressure return passage 60. The present invention could also be employed in fuel injectors having control valves of the two-position, two-way type, in which only the flow of fuel out of the control chamber to the low-pressure drain is under the control of the control valve. In the illustrated embodiment, the control valve member 44 is susceptible to leakage along the valve guide bore 50. Other embodiments, however, may include leak-free control valve designs.

[0068] The return flow path for cooled fuel that extends between the return flow volume 62 and the drain passage 69 may differ from that shown in the illustrated embodiment. For example, the return flow path may include passages or conduits through the second and third injector body portions, and/or may bypass the armature chamber. The flow path for cooled fuel may extend alongside or around the actuator for the control valve, to improve cooling of the actuator.

[0069] The control valve may be actuated by a piezoelectric actuator instead of by an electromagnetic actuator. In this case, the cooled fluid may be used to cool the piezoelectric actuator stack.

[0070] It will be appreciated that further modifications and variations not expressly described above may also be made without departing from the scope of the invention as defined in the appended claims.

Claims

1. A fuel injector (10) for use in a high-pressure fuel injection system for an internal combustion engine, the fuel injector comprising:

a high-pressure fuel volume (32) defined by at least one wall (24a);
a supply passage (30) for delivering high-pressure fuel to the high-pressure fuel volume (32) from a high-pressure fuel source;
a valve needle (26) arranged to control fuel injection from one or more outlets of the injector, a surface associated with the valve needle (26) being exposed to fuel pressure within a control chamber (36), in use;
a return flow path for conveying fuel from the control chamber (36) to a low-pressure drain; and
a control valve (40) for controlling the flow of fuel through the return flow path;
wherein the return flow path comprises a return flow volume (62) disposed, at least in part, adjacent to the wall (24a) of the high-pressure fuel volume (32), thereby to promote heat transfer from the fuel in the return flow volume (62) to the fuel in the high-pressure fuel volume (32), in use.

2. A fuel injector as claimed in Claim 1, wherein the return flow volume (62) is defined, at least in part, by the wall (24a) of the high-pressure fuel volume (32).

3. A fuel injector as claimed in Claim 1 or Claim 2, wherein the wall (24a) of the high-pressure fuel volume (32) is generally tubular, and wherein the return flow volume (62) is disposed annularly around the wall (24a).

4. A fuel injector as claimed in any preceding claim, further comprising a nozzle body (24) for housing the valve needle (26), wherein the high-pressure fuel volume (32) is disposed within the nozzle body (26).

5. A fuel injector as claimed in Claim 4, wherein the return flow volume (62) is defined, in part, by a wall (24a) of the nozzle body (26).

6. A fuel injector as claimed in any preceding claim, wherein the return flow volume (62) is defined, in part, by a capnut (16) of the fuel injector.

7. A fuel injector as claimed in Claim 6, further comprising an injector body (12) having at least one generally cylindrical injector body portion (20, 22) received within the capnut (16), wherein the return flow path includes at least one passage defined in part by an outer surface of the injector body portion (20, 22) and in part by the capnut (16).

8. A fuel injector as claimed in Claim 7, wherein the outer surface of the injector body portion (22) comprises a flat (22a) that defines, in part, the passage.

9. A fuel injector as claimed in any preceding claim, further comprising vortex-inducing means (34) to induce a vortex in the fuel in the high-pressure fuel volume (32), in use.

10. A fuel injector as claimed in Claim 9, wherein the vortex-inducing means comprises a transfer passage (34) that conveys fuel from the supply passage (30) to the high-pressure fuel volume (32).

11. A fuel injector as claimed in Claim 10, wherein the high-pressure fuel volume (32) is elongate to define an axis, and wherein the transfer passage (34) is inclined with respect to and/or offset from the axis, thereby to impart a non-axial flow velocity to the fuel entering the high-pressure fuel volume (32).

12. A fuel injector as claimed in any preceding claim, wherein a portion of the return flow path, downstream of the return flow volume (62), is arranged to direct fuel through or adjacent to the control valve (40), thereby to cool the control valve (40).

13. A fuel injector as claimed in Claim 12, wherein the control valve (40) comprises a control valve member (44) that is slidable within a valve guide bore (50), wherein the valve guide bore (50) separates a high-pressure fuel region (56) from a low-pressure fuel region (48), the low-pressure fuel region (48) forming part of the return flow path downstream of the return flow volume (62).

14. A fuel injector as claimed in Claim 12 or Claim 13, wherein the control valve (40) further comprises an electromagnetic actuator (42) operable to move an armature (46), and wherein the armature (46) is received in an armature chamber (48) forming part of the return flow path downstream of the return flow volume (62).

15. A fuel injector as claimed in any preceding claim, wherein the high-pressure fuel volume is an accumulator volume (32) of the injector.

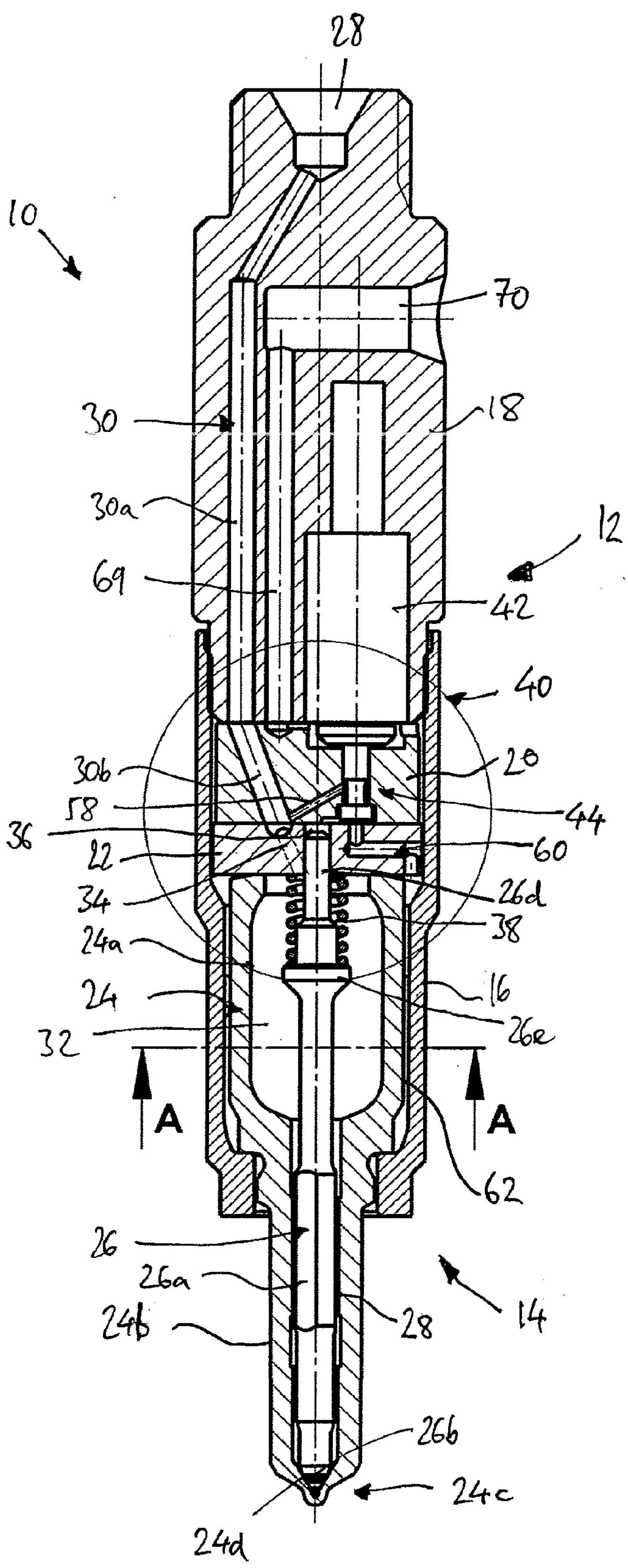
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FIGURE 1(a)

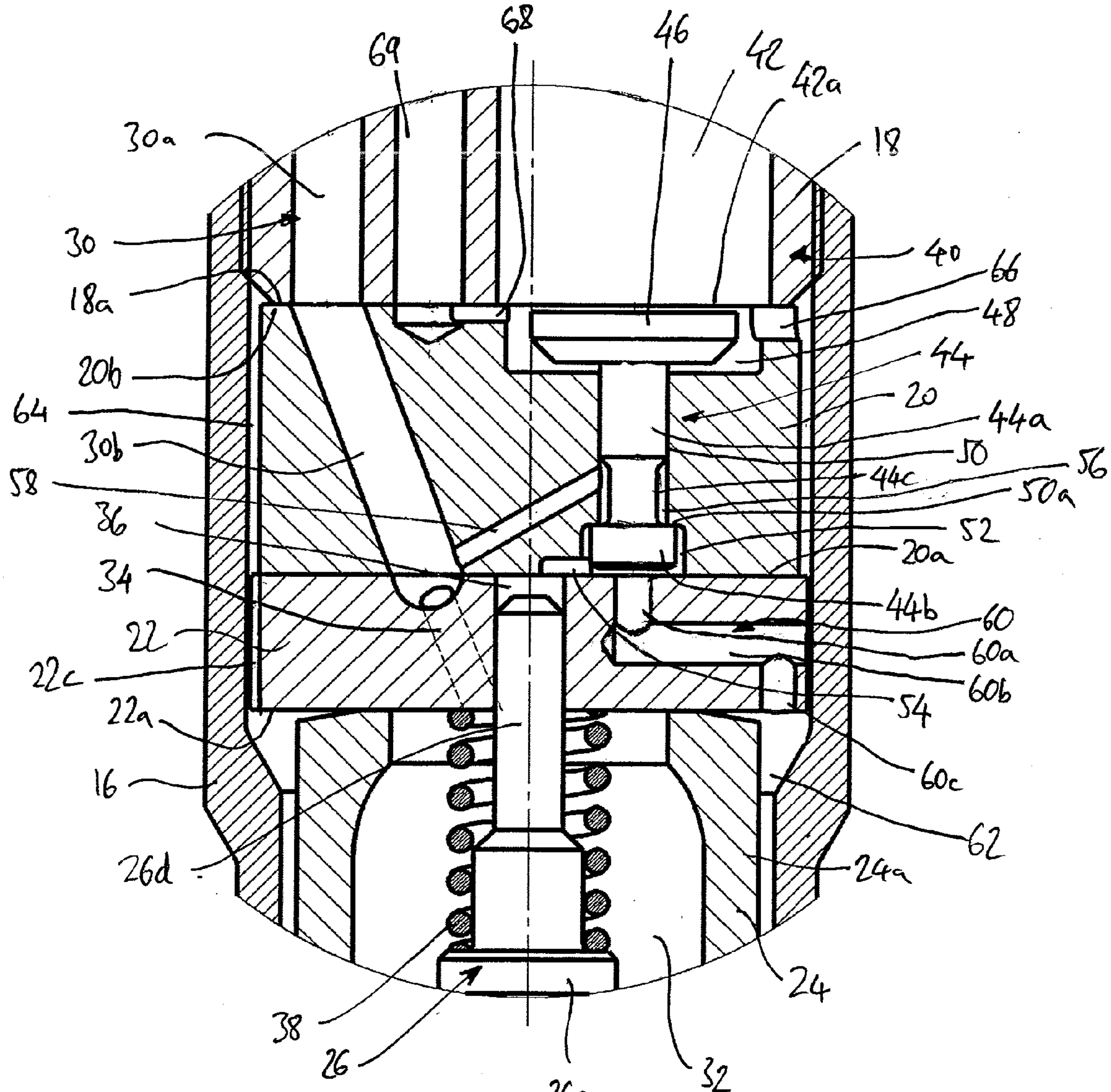
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FIGURE 1(b)

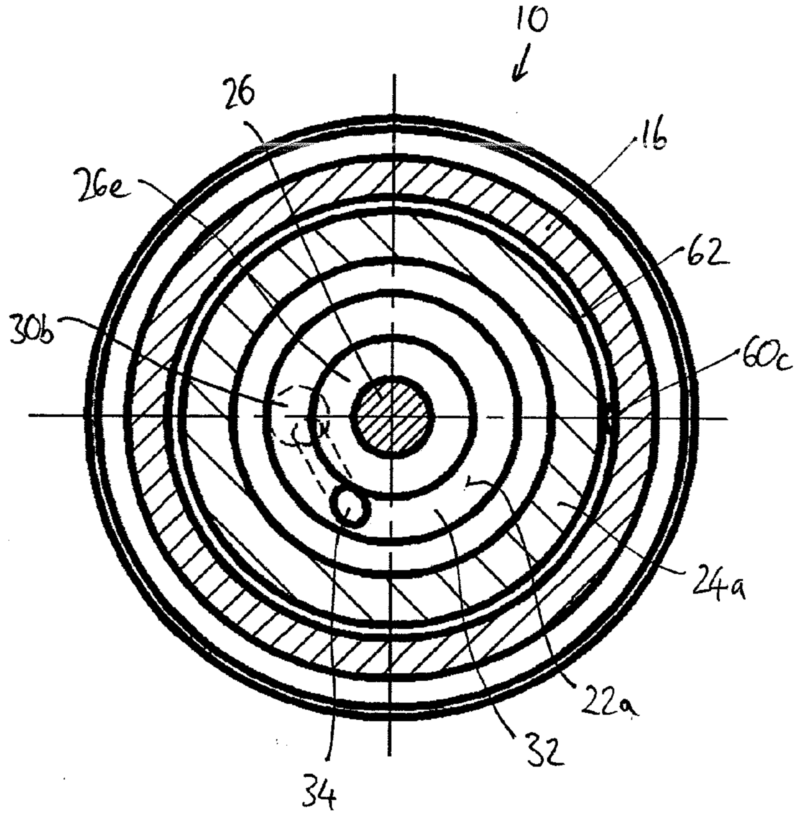

FIGURE 2

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EUROPEAN SEARCH REPORT

Application Number
EP 12 18 5936

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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
The Hague	18 January 2013	Hermens, Sjoerd

CATEGORY OF CITED DOCUMENTS

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