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(54) Fuel system

(57) A fuel system for use in supplying high pressure fuel to an injector of an internal combustion engine comprises a first fuel pump (12) for supplying fuel at a first injectable pressure level to a first accumulator volume (16), a second fuel pump (14) for supplying fuel at a second injectable pressure to a second accumulator volume (18) and control valve means (25) for selecting which of the first or second accumulator volumes (16; 18) supplies fuel to the injection nozzle.

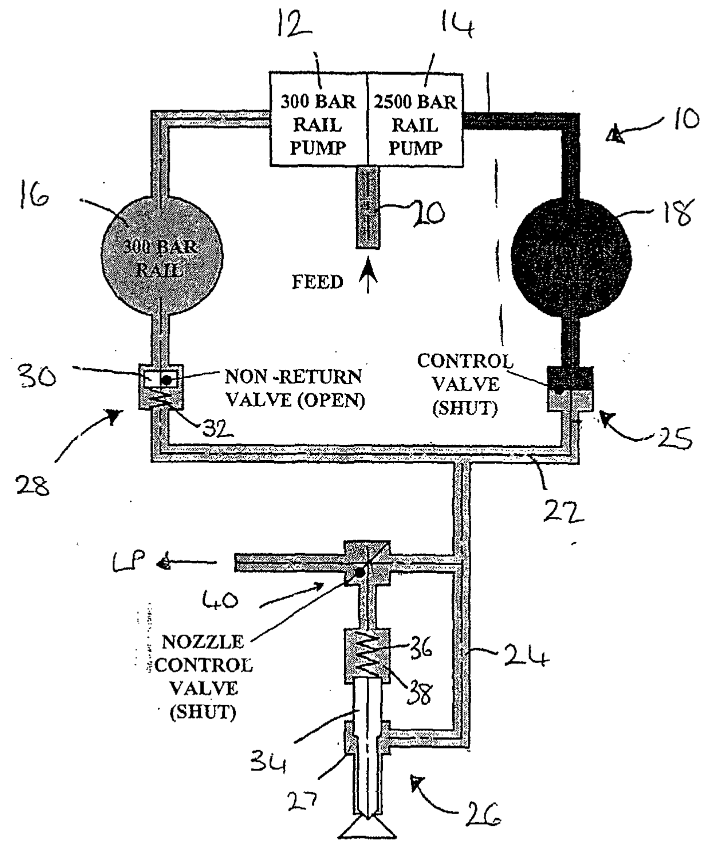

FIGURE 1

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Description

[0001] The invention relates to a fuel system for use in supplying high pressure fuel to an injection nozzle of a compression ignition internal combustion engine.

[0002] Known common rail fuel systems include an accumulator volume or rail which is charged with fuel at high pressure by means of a high pressure fuel pump. Fuel at high pressure is supplied by the common rail to a plurality of injectors, for injecting fuel into an associated cylinder of the engine.

[0003] It is desirable to be able to vary the injection characteristic of the injected fuel spray, for example the injection rate and pressure. In particular, for emissions purposes it is beneficial to provide a pilot injection of fuel followed by a main injection of fuel, wherein the pressure of fuel injected for the pilot injection is relatively low compared to that for the main injection. A so-called "boot-shaped" main injection of fuel is thought to be particularly beneficial, and requires injection at a relatively low rate, for a short period of time, followed by injection at a higher rate.

[0004] The transient response of the high pressure pump determines how quickly the peak pressure supplied to the rail can be achieved. One problem therefore with existing common rail systems is that it is difficult to achieve a relatively low injection rate for the pilot injection of fuel, followed by a higher injection rate for the main injection of fuel. It is also difficult to achieve an injection of fuel having a boot-shaped characteristic. Moreover, to achieve a relatively low pressure injection for idling conditions it is necessary to spill fuel from the high pressure rail, and this leads to system inefficiencies.

[0005] It is one object of the present invention to overcome or alleviate at least one of the aforementioned problems.

[0006] According to the present invention there is provided a fuel system for supplying fuel to an injector of an internal combustion engine, the fuel system comprising;

> a first fuel pump for supplying fuel at a first injectable pressure level to a first accumulator volume,
>
> a second fuel pump for supplying fuel at a second injectable pressure level to a second accumulator volume, and
>
> control valve means for selecting which of the first or second accumulator volumes supplies fuel to the injector.

[0007] The fuel system may, but need not, include a plurality of fuel injectors.

[0008] The system may further comprise third (or further) fuel pumps, for supplying fuel at a third (or further) injectable pressure level to a third (or further) accumulator volume.

[0009] Each injector typically includes a valve needle which is engageable with a seating to control fuel injection and a three way nozzle control valve for controlling fuel pressure within a control chamber of the injector so as to control movement of the valve needle away from the seating.

[0010] Each injector may further comprise a delivery passage for high pressure fuel supply to the injector. The nozzle control valve is operable between an open position in which the control chamber communicates with a low pressure drain and communication between the delivery passage and the control chamber is broken, and a closed position in which the control chamber communicates with the delivery passage and communication between the low pressure drain and the control chamber is broken.

[0011] The present invention provides the advantage that the injection characteristic, for example the injection rate, can be varied by controlling the control valve means to select which of the first or second accumulator volumes delivers fuel to the injector.

[0012] Typically, each of the first and second accumulator volumes takes the form of a common rail.

[0013] Typically, the first fuel pump is arranged to supply fuel to the first accumulator volume at a pressure of around 300 bar, and the second fuel pump is arranged to supply fuel at a pressure of between 2000 and 2500 bar to the second accumulator volume.

[0014] The fuel system may further comprise a third fuel pump for supplying fuel at a third injectable pressure level to a third accumulator volume, and wherein the control valve means is operable to selectively supply fuel at a first, second or third injectable pressure level to the injector.

[0015] Another object of the present invention is to provide an improved control valve means suitable for use in the aforementioned fuel system.

[0016] From another aspect, therefore, the present invention resides in a control valve to control the flow of high pressure fuel in an injection system of an internal combustion engine, the control valve including a valve member which is engagable with a valve seating to control fuel flow through the control valve, wherein the valve member is shaped so as to be substantially pressure balanced when seated against the valve seating in a seated position, and being provided with a balancing arrangement to ensure the valve member is also substantially pressure balanced when in an unseated position.

[0017] The valve member may include an enlarged diameter region and a reduced diameter region wherein a region intermediate the enlarged and reduced diameter regions defines a seatable surface of the valve member for engagement with the valve seating.

[0018] The balancing arrangement includes a balance piston received within an internal chamber defined within the valve member, wherein one end of the balance piston is exposed to fuel pressure within a pressure balance volume defined within the valve member and operable to react against a surface fixed relative to the valve member so as to provide a balancing force to the valve member when in the unseated position.

[0019] In order to provide a flow path for fuel between a valve outlet passage (i.e. downstream of the valve seat) and the pressure balance volume when the valve member is in its unseated position, the valve member is provided with at least one radially extending passage.

[0020] The surface against which the balance piston reacts is preferably defined by a first valve housing part, wherein the valve member is movable within a second valve housing part located adjacent to the first valve housing part.

[0021] It will be appreciated that the preferred and/or optional features of the control valve of the second aspect of the invention may also be incorporated in the fuel system of the other aspect of the invention, alone or in appropriate combination.

[0022] The invention will now be described, by way of example only, with reference to the accompanying drawings in which:

Figure 1 is a schematic diagram of the present invention when in a first operating condition,

Figure 2 is a schematic diagram of the fuel system in Figure 1 when in a second operating condition,

Figure 3 is a schematic diagram of the fuel system in Figures 1 and 2 when in a third operating condition,

Figure 4 is an enlarged sectional view of the control valve for use in the fuel system in Figures 1 to 3, and

Figures 5 and 6 show the injection characteristics which may be achieved using the fuel system of the present invention when in operating conditions 2 and 3 respectively.

[0023] Referring to Figure 1, the fuel system, referred to generally as 10, includes first and second pumps 12, 14 for supplying fuel at first and second pressure levels respectively to first and second accumulator volumes or rails 16, 18. The first and second pumps 12, 14 are supplied through a common supply line 20 from a relatively low pressure feed line 20. Typically, the first pump 12 is arranged to charge fuel to a first pressure level of around 300 bar for supply to the first rail 16 and the second pump 14 is arranged to charge fuel to a second pressure level of between 2000 and 2500 bar for supply to the second rail 18.

[0024] The first and second rails 16, 18 supply fuel through a high pressure supply line 22 to a delivery line or delivery passage 24 of an associated injector 26. The first rail 16 has an associated non return valve 28 including a valve member 30 which is biased towards a closed position by means of a spring 32. When in the closed position, fuel flow from the first rail 16 into the high pressure supply line 22 is prevented, and the return flow of fuel between the high pressure supply line 22 and the first rail 16 is prevented. The second rail 18 is provided with an associated control valve 25 which is actuable between a closed position in which fuel supply from the second rail 18 to the high pressure supply line 22 is prevented and the return flow of fuel from the high pressure supply line 22 to the second rail 18 is prevented, and an open position in which the second rail 18 supplies fuel at the second pressure level to the high pressure supply line 22 for delivery to the delivery line 24 of the injector 26.

[0025] The injector 26 includes a valve needle 34 which is biased towards a valve needle seating by means of a spring 36 and fuel pressure within a control chamber 38, both of which are arranged at the back end of the needle 34. The valve needle 34 is engageable with the seating to control fuel flow between an injector delivery chamber 27 and outlet openings (not shown) of the injector, wherein the delivery chamber 27 receives high pressure fuel from the delivery line 22. The fuel injector 26 is provided with a three-way nozzle control valve 40 which is actuable between a closed position in which the control chamber 38 communicates with the delivery line 24, and an open position in which the control chamber 38 communicates with a low pressure drain and communication between the delivery line 24 and the control chamber 38 is broken.

[0026] In use, with the fuel system in an operating position in which the control valve 25 is closed and the nozzle control valve 40 is closed (as shown in Figure 1), the first rail 16 supplies fuel at the first pressure level through the open non return valve 28 into the high pressure supply line 22. It will be appreciated that the force of the spring 32 is selected to ensure that, when the pressure of fuel within the first rail 16 exceeds a desired, predetermined amount, the hydraulic force acting on the valve member 30 is sufficient to overcome the spring force to open the non return valve 28 and to permit fuel flow between the first rail 16 and the high pressure supply line 22. As the control valve 25 is closed, fuel at the second pressure level from the second rail 18 is unable to flow through the control valve 25 into the high pressure supply line 22.

[0027] With the nozzle control valve 40 in the closed position, fuel at the first pressure level within the delivery line 24 is able to flow into the control chamber 38 at the back of the valve needle 34 and the valve needle 34 is urged against its seating, in which position injection to the engine is prevented.

[0028] In order to inject fuel at the first pressure level, the nozzle control valve 40 is opened (as shown in Figure 2) to close communication between the delivery line 24 and the control chamber 38 and to open communication between the control chamber 38 and the low pressure drain. Fuel pressure within the control chamber 38 is therefore reduced, and a point will be reached at which the hydraulic force due to high pressure fuel within the delivery chamber 27 acting on the valve needle is sufficient to overcome the force due to the spring 36 and reduced fuel pressure within the control chamber 38 and the valve needle 34 starts to lift from its seating. In such circumstances, a relatively low rate of injection is achieved.

[0029] When injection is to be terminated, the nozzle control valve 40 is moved into its closed position to break communication between the control chamber 38 and the low pressure drain and to reopen communication between the delivery line 24 and the control chamber 38. High fuel pressure is re-established within the control chamber 38 and a point will be reached at which the force due to the spring 36 acting in combination with fuel pressure within the control chamber 38 is sufficient to reseat the valve needle 34.

[0030] If it is required to inject fuel at the second pressure level, the control valve 25 is moved into its open position to permit fuel within the second rail 18 to flow into the high pressure supply line 22. The valve member 30 of the non return valve 28 is urged into its closed position due to higher pressure fuel within the supply line 22, thereby preventing a return flow of fuel at the second pressure level from the high pressure supply line 22 into the first rail 16. In addition to opening the control valve 25, the nozzle control valve 40 is opened to close communication between the delivery line 24 and the control chamber 38 and to permit fuel within the control chamber 38 to flow to low pressure. As fuel pressure within the control chamber 38 is reduced, the hydraulic force acting on the valve needle due to fuel at the second pressure level within the delivery chamber 27 is sufficient to lift the valve needle 34 from its seating to commence injection at the second pressure level.

[0031] In order to terminate injection at the second pressure level, the nozzle control valve is closed to close communication between the control chamber 38 and the low pressure drain, thereby causing re-pressurisation of the control chamber 38 to seat the valve needle, as described previously.

[0032] The fuel system in Figures 1 to 3 permits a pilot injection of fuel to be followed by a main injection of fuel within the same injection event. For the pilot injection of fuel, the fuel system is in the second operating condition (as shown in Figure 2) in which the control valve 25 is shut and the nozzle control valve 40 is open to permit injection into the engine at the first moderate pressure level. To achieve the main injection of fuel at a higher pressure level the fuel system adopts the third operating condition, as shown in Figure 3, in which the control valve 25 is open and the nozzle control valve 40 is open.

[0033] Figure 4 shows an enlarged view of the control valve 25 of the fuel system in Figures 1 to 3. The valve 25 takes the form of a two position valve having only one control seat and including a valve pin, or valve member 136, having an upper region 136a of reduced diameter ("reduced diameter region") and a lower region 136b of enlarged diameter ("enlarged diameter region"). The valve member 136 is movable within a bore 138 provided in a first valve housing 140, and is engageable with the valve control-seat, or valve seating 142, to control whether fuel is able to flow through the valve 25 between a valve inlet passage 19 in communication with the second rail 18 and a valve outlet passage 21 in communication with the high pressure supply line 22.

[0034] When the valve 25 is opened, high pressure fuel within the valve inlet passage 19 is able to flow past the valve seating 142 into the valve outlet passage 21 and, hence, to high pressure supply line 22 (via a drilling in the housing 140). When the valve 25 is closed, the valve seating 142 is closed off and, thus, communication between the second rail 18 and the high pressure supply line 22 is broken.

[0035] The valve member 136 also includes a neck region 136c, arranged between the reduced and enlarged diameter regions 136a, 136b, which defines, together with the valve housing bore 138, an upstream annular chamber. A part-conical surface of the valve member 136, between the neck region 136c and the enlarged diameter region 136b, defines a seatable valve surface 144 of part-conical form which is engageable with the valve seating 142 to control fuel flow through the valve. The surfaces 142, 144 are shaped so that the valve member 136 seats on its inner diameter (i.e. the valve seat diameter). As a consequence of this the valve member 136 is substantially pressure balanced to fuel pressure in the valve inlet passage 19 (i.e. within the second rail 18) when in its closed state.

[0036] An end surface 146 of the enlarged diameter region 136b of the valve member 136 is engageable with a further seating surface 148 defined by a second housing part 150 so as to limit the extent of opening movement of the valve member 136 away from the valve seating 142. It will be appreciated that the further seating surface 148 does not define a control seat of the control valve 25, as whether the end of the valve member 136 is engaged or disengaged from the seating surface 148 does not directly control a fuel flow through the valve 25.

[0037] The valve member 136 includes an internal chamber 152 defined at the end of the enlarged diameter region 136b, the chamber 152 communicating, at one end, with an additional drilling or blind bore 157 provided in the valve member 136. A return spring 154 is received within the internal chamber 152 and serves to urge the valve member 136 towards its closed position in which the valve surface 144 seats against the valve seating 142. A balance arrangement is provided in the form of a balance piston 156, which is received within the drilling 157 so that it extends into the internal chamber 152 and abuts, at its lowermost end, an abutment surface defined by the seating surface 148 of the housing 150.

[0038] The blind end of the drilling 157 and the end surface of the balance piston 156 together define a fuel volume, or "pressure balance volume" 158. A flow path for fuel exists between the pressure balance volume 158 and a downstream annular chamber, which is defined between the outer surface of the valve member 136 and the bore 138 in the valve housing 140. The flow path is defined by radial extending passages 160, or cross drillings, provided in the valve member 136.

[0039] At its uppermost end, the valve member 136 is attached or otherwise coupled to an armature 162 of an electromagnetic actuator arrangement. The actuator arrangement includes a winding or solenoid 164 which is energisable so as to cause movement of the armature 162, and hence of the valve member 136, to move the valve member 136 between seated (closed) and unseated (open) positions. The armature 162 is provided with a through drilling 166 through which a region of the housing 140 defining a portion of the delivery passage 19 extends.

[0040] In use, when the actuator is de-energised, the force due to the spring 154 is sufficient to seat the valve member 136 so that the co-operable valve and seating surfaces 144, 142 respectively are engaged with one another. In this position fuel flow between the second rail 18 and the high pressure supply line, through passages 19, 21, is prevented.

[0041] When the winding 164 is de-energised, the armature 162 is caused to move against the return spring force (i.e. in a downward direction in the illustration shown), causing the valve member 136 to be urged away from the valve seating 142. As a result, high pressure fuel is able to flow from the second rail 18, into the inlet valve delivery passage 19, through the valve and into the valve outlet passage 21 to the high pressure supply line 22. As the valve member 136 starts to move away from its seating, a hydraulic force acts on the valve member 136 in the opening direction due to high pressure fuel flowing past the disengaged surfaces 142, 144.

[0042] The magnitude of this hydraulic force is determined by the difference in cross sectional area between the valve seat diameter (that of the region 136a) and the diameter of the enlarged region 136b. This hydraulic force would provide an out-of-balance force on the valve member 136 when in its unseated, open position, but for the provision of the balance arrangement 156, 158, 160. When the valve member 136 is spaced from the valve seating 142, a balancing or opposing force acts on the valve member 136 due to fuel flowing into the passages 160 in the valve member 136 and, hence, into the pressure balance volume 158. The balance piston 156 reacts against the (fixed) abutment surface 148 whilst the valve member 136 can move or slide relative to the balance piston 156. The pressure balance volume 158 is shaped and dimensioned so that any out of balance force acting on the open valve member 136 in an opening direction (i.e. due to the difference in cross sectional area between the seat diameter and the enlarged diameter region 136b) is substantially balanced or counter-acted by fuel pressure within the pressure balance volume 158 acting in the closing direction. This is achieved by careful selection of the pressure balance volume 158 to ensure the net effective area of the valve member experiencing a hydraulic force in one direction is substantially equal to the net effective area of the valve member experiencing a hydraulic force in the other direction. Selection of the diameter of the balance piston 156 is therefore dependent upon the difference in cross sectional area between the seat diameter of the valve member 136 and the enlarged diameter region 136b.

[0043] The benefit of provide a two-position, single control-seat valve 36 of the type shown in Figure 4 is that the valve member 136 remains substantially pressure balanced to high pressure fuel in the inlet passage 19 and in the outlet passage 21 under all operating conditions. Importantly, therefore, when it is required to reseat the valve member 136 against the valve seating 142, only the force due to the spring 154 must be overcome, and no other out of balance hydraulic force. The actuator can therefore be relatively small, providing a cost, weight and size benefit.

[0044] Further benefits of the fuel system described with reference to Figure 1 to 3 will now be described, with reference to Figures 5 and 6. Figures 5 and 6 illustrate a pilot injection of fuel and a subsequent main injection of fuel, wherein the main injection of fuel has a "boot-shaped" characteristic, which is known to have particular benefits for emissions levels. In order to achieve a boot-shaped injection characteristic, the fuel system adopts the second operating condition (as shown in Figure 2) immediately followed by the third operating condition (as shown in Figure 3). The boot-shaped injection characteristic is achieved by switching the control valve 25 between its closed and open states, whilst the nozzle control valve 40 remains open. In existing systems, it is difficult to achieve this sequence of injection events as the transient response time of the high pressure common rail pump imposes a limitation on injection timing.

[0045] The sequence of events described previously may be reversed so that the main injection event is followed by a post injection of fuel, which also provides emissions benefits, or a late post injection of fuel for after treatment purposes.

[0046] It will be appreciated that the fuel system of the present invention may be used to supply fuel to an alternative type of injector to that shown in the multiple pump arrangement for supplying fuel at different injectable pressures, and control valve means 25, 30 for selectively supplying fuel at the different injectable pressures to the associated injector(s). Thus, the invention also extends to a three pump system, whereby each pump supplies fuel to a different one of three accumulator volumes or rails, and wherein control valve means are provided for selectively supplying fuel at first, second or third injectable pressure levels to an associated fuel injector 26. Higher multiplicity pump systems are also envisaged.

Claims

1. A fuel system for supplying fuel to an injector (26) of an internal combustion engine, the fuel system comprising;

    a first fuel pump (12) for supplying fuel at a first injectable pressure level to a first accumulator volume (16),

    a second fuel pump (14) for supplying fuel at a second injectable pressure level to a second accumulator volume (18), and

    control valve means (25) for selecting which of the first or second accumulator volumes (16, 18) supplies fuel to the injection nozzle (26),

2. The fuel system as claimed in Claim 1, including a plurality of fuel injectors (26).

3. The fuel system as claimed in Claim 2, wherein each injector (26) includes a valve needle (34) which is engageable with a seating to control fuel injection, a delivery passage (24) for high pressure fuel supply to the injector (26) and control chamber (38) for fuel, arranged to apply a force to the valve needle to urge the valve needle towards a closed position, and further comprising a nozzle control valve (40) which is operable between an open position in which the control chamber (38) communicates with a low pressure drain and communication between the delivery passage (24) and the control chamber (38) is broken and a closed position in which the control chamber (38) communicates with the delivery passage (24) and communication between the low pressure drain and the control chamber (38) is broken.

4. The fuel system as claimed in any one of Claims 1 to 3, further comprising a third fuel pump for supplying fuel at a third injectable pressure level to a third accumulator volume, and wherein the control valve means is operable to selectively supply fuel at a first, second or third injectable pressure level to the injector.

5. The fuel system as claimed in any one of Claims 1 to 4, wherein each of the first and second accumulator volumes (16, 18) takes the form of a common rail.

6. The fuel injection system as claimed in any one of Claims 1 to 5, wherein the first fuel pump (12) is arranged to supply fuel to the first accumulator volume (16) at a pressure of around 300 bar.

7. The fuel system as claimed in any one of Claims 1 to 6, wherein the second fuel pump (14) is arranged to supply fuel at a pressure of between 2000 and 2500 bar to the second accumulator volume (18).

8. The fuel system as claimed in any one of Claims 1 to 7, wherein the control valve means (25) includes a valve member (136) which is engagable with a valve seating (142) to control fuel flow through the control valve means (25), and wherein the valve member (136) is shaped and configured to be substantially pressure balanced when in both a seated position, in which it is engaged with the valve seating (142), and an unseated position, in which it is disengaged from the valve seating (142).

9. The fuel system as claimed in Claim 8, wherein the valve member (136) has a seatable surface (144) of part-conical form for engagement with the valve seating (142), and wherein the valve seating (142) is of part-conical form.

10. The fuel system as claimed in Claim 8 or Claim 9, wherein the control valve means (25) includes a balance arrangement (156, 158, 160) to counteract out of balance forces acting on the valve member (136) in an opening direction when it is spaced away from the valve seating (142), thereby to ensure the valve member (136) is substantially pressure balanced when in the unseated position.

11. The fuel system as claimed in Claim 10, wherein the balance arrangement includes a balance piston (156) received within an internal chamber (152) defined within the valve member (136), wherein one end of the balance piston (156) is exposed to fuel pressure within a pressure balance volume (158) defined within the valve member (136) and is operable to react against a surface (148) fixed relative to the valve member (136) so as to provide the balancing force to the valve member (136) when in the unseated position.

12. The fuel system as claimed in Claim 11, wherein the pressure balance volume (158) communicates with at least one radially extending passage (160) defined in the valve member (136) to provide a flow path for fuel between the delivery passage (19) and the pressure balance volume (158).

13. The fuel system as claimed in Claim 11 or Claim 12, wherein the balance piston (156) has an end surface, remote from the pressure balance volume (158), in engagement with an abutment surface (148) defined by a first valve housing part (150) and wherein the valve member (136) is movable within

a second valve housing part (140) located adjacent to the first valve housing part (150).

14. A valve for controlling the flow of high pressure fuel in an injection system of an internal combustion engine, the valve including a valve member (136) which is engageable with a valve seating (142) to control fuel flow through the valve (36), wherein the valve member (136) is shaped so as to be substantially pressure balanced when seated against the valve seating (142) in a seated position, and being provided with a balance arrangement (156, 158, 160) to ensure the valve member (136) is also substantially pressure balanced when in an unseated position.

15. The valve as claimed in claim 14, wherein the balance arrangement is dimensioned so that the surface or surfaces of the valve member (136) exposed to net fuel pressure acting in an opening direction are of equivalent area to the surface or surfaces of the valve member (136) exposed to net fuel pressure acting in a closing direction when the valve member is in the unseated position.

16. The valve as claimed in Claim 14 or Claim 15, wherein the valve member (136) includes an enlarged diameter region (136b) and a reduced diameter region (136a), and wherein a region (136c) intermediate the enlarged and reduced diameter regions (136b, 136a) defines a seatable surface (144) of the valve member (136) for engagement with the valve seating (142).

17. The valve as claimed in Claim 16, wherein the balance arrangement (156, 158, 160) includes a balance piston (156) received within an internal chamber (152) defined within the valve member (136), wherein one end of the balance piston (156) is exposed to fuel pressure within a pressure balance volume (158) defined within the valve member (136) and operable to react against a surface fixed relative to the valve member (136) so as to counteract an out of balance acting on the valve member (136) when in the unseated position.

18. The valve as claimed in Claim 17, wherein the pressure balance volume (158) communicates with at least one radially extending passage (160) provided in the valve member (136) to provide a flow path for fuel between the delivery passage (19) and the pressure balance volume (158) when the valve member is in the unseated position.

19. The valve as claimed in Claim 18, wherein the surface (148) against which the balance piston (156) reacts is defined by a first valve housing part (150) and wherein the valve member (136) is movable within a second valve housing part (140) located adjacent to the first valve housing part (150).

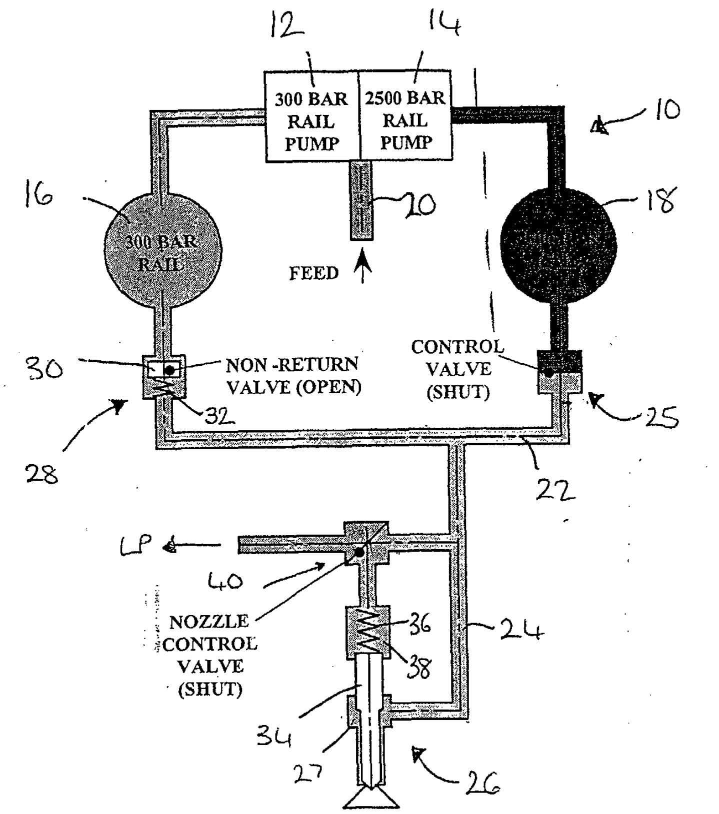


FIGURE 1

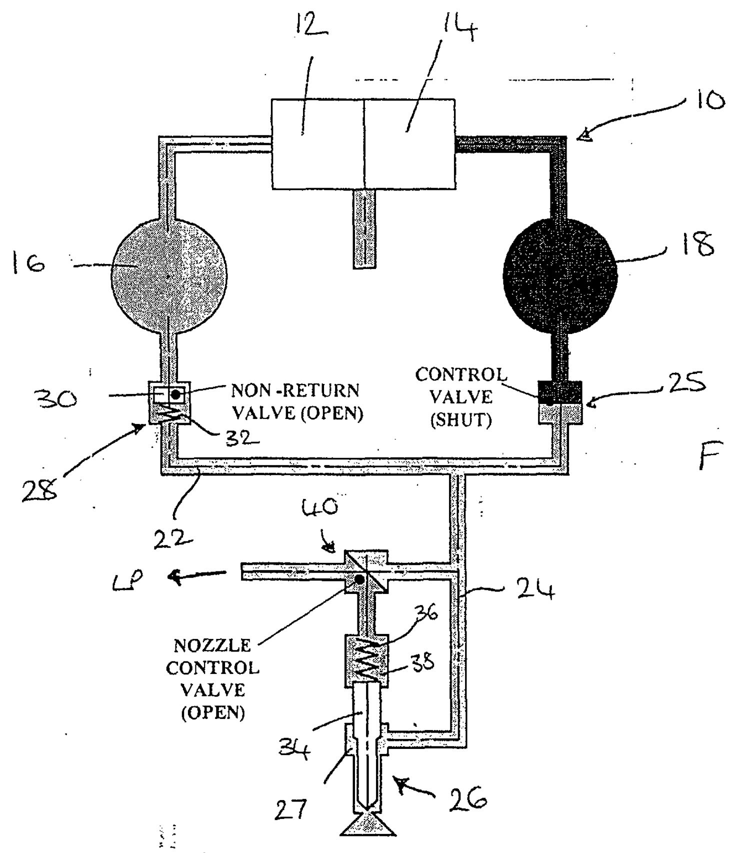
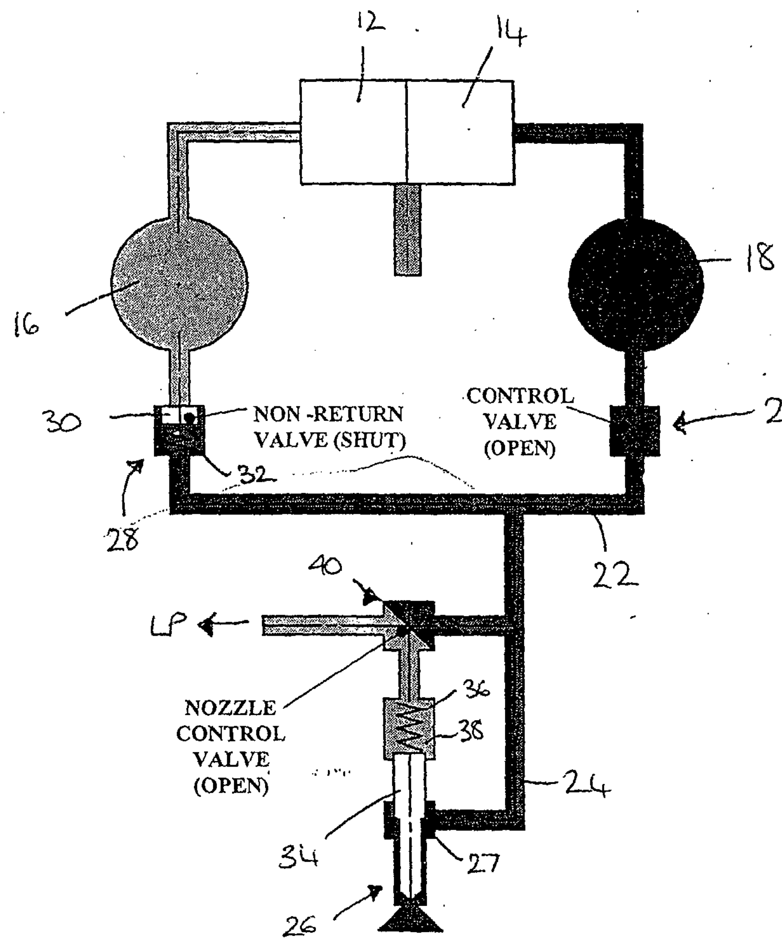


FIGURE 2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14
16
18
30
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CONTROL
VALVE
(OPEN)
25
32
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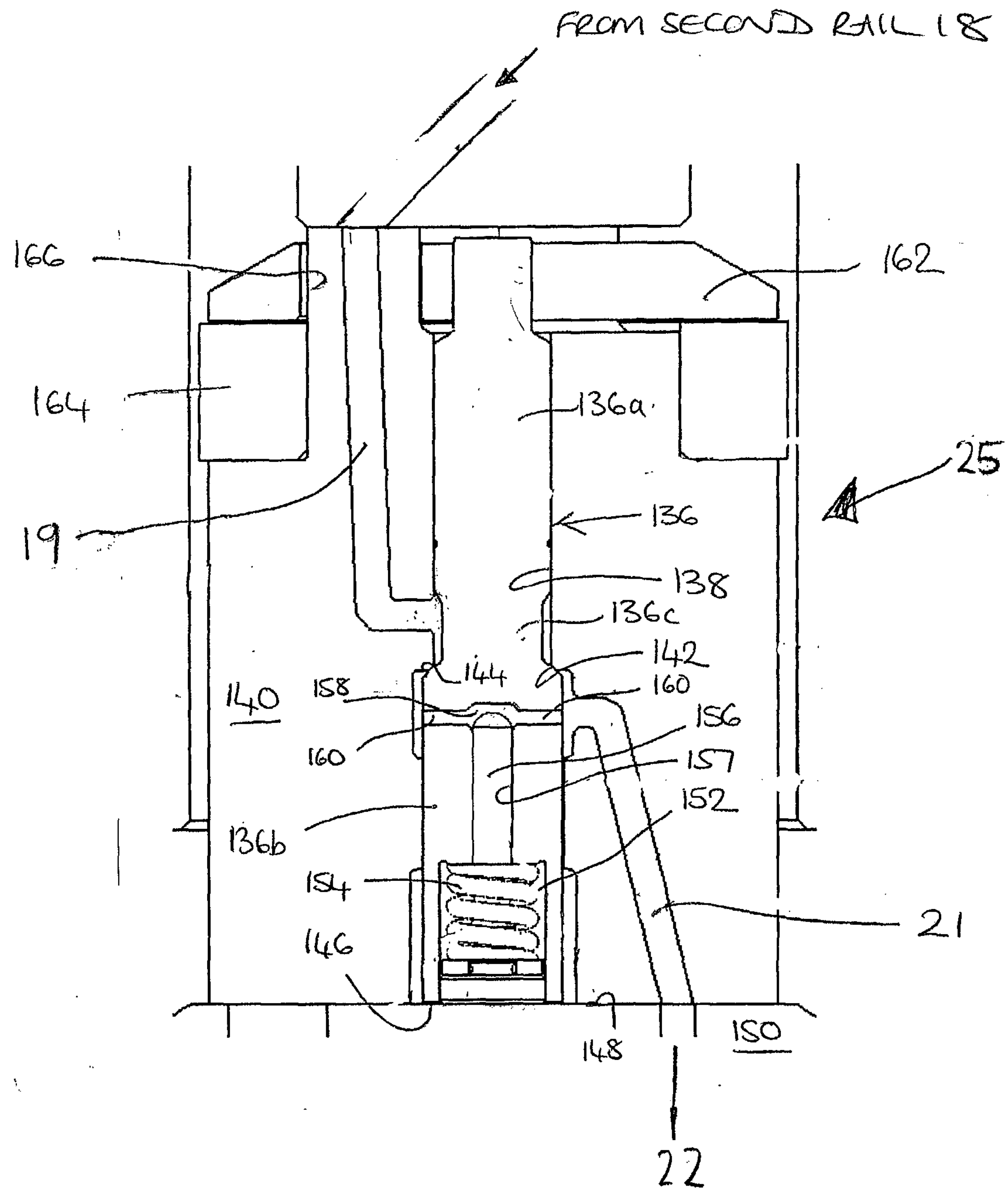
CONTROL
VALVE
(OPEN)
36
38
24
34
27
26

FIGURE 3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166
162
164
136a
19
25
136
138
136c
142
140
158
144
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156
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136b
154
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146
148
150
22

FIGURE 4

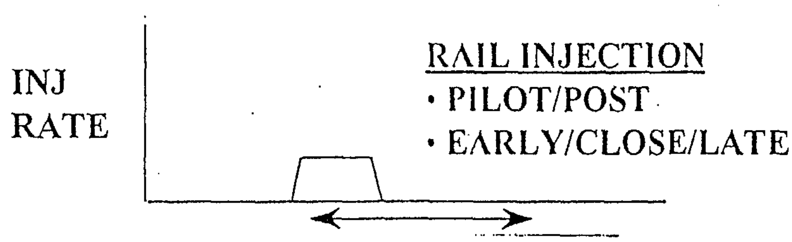

FIGURE 5

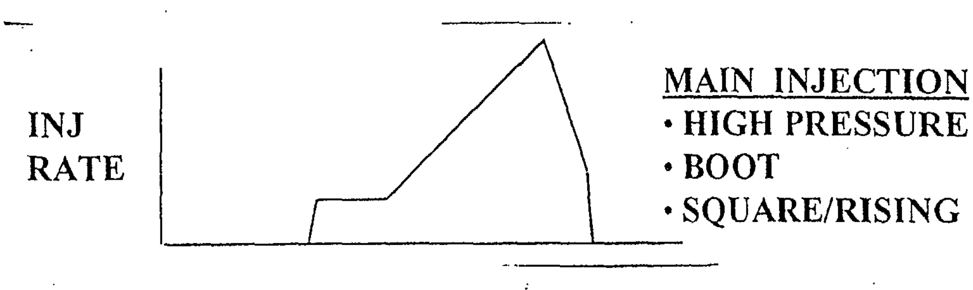

FIGURE 6