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(54) **Fuel injection system**

(57) A fuel injection system for use in an internal combustion engine having an engine housing comprises two or more unit pumps (18) and a plurality of fuel injectors (26), each of the unit pumps being received, in use, within a pocket provided in the engine housing and including a pumping plunger (30) that is reciprocable within a plunger bore (32) under the influence of a drive arrangement (40, 42, 46), to cause fuel pressurisation within a pumping chamber (36). Each drive arrangement includes a cam (46) that is mounted upon a cam shaft of the engine, which extends through the engine housing and which carries or is formed with the or each of the other cams. An inlet metering valve arrangement

(50) is arranged to control the rate of flow of fuel into each pumping chamber (36), thereby to control the quantity of fuel to be pressurised within the pumping chamber during a pumping cycle. An outlet valve arrangement (64) is arranged to control the delivery of pressurised fuel from the pumping chamber (36) directly to an accumulator volume (22) through an associated high pressure fuel line (70), said accumulator volume being arranged to supply pressurised fuel to all of the injectors (26) of the system. An engine installation incorporating the fuel injection system and the cam drive arrangement for each unit pump (18) is also provided by the present invention.

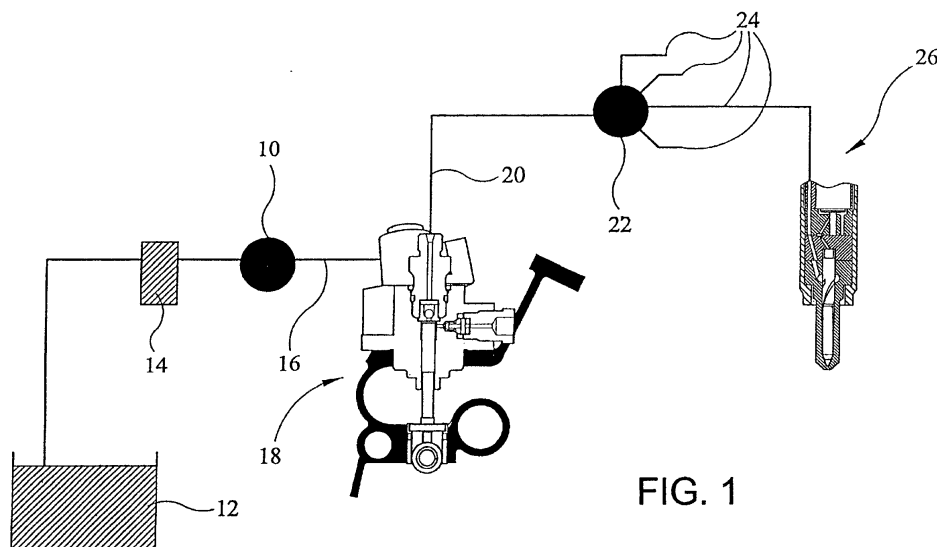


FIG. 1

Description

[0001] The invention relates to a fuel injection system for a compression ignition internal combustion engine. In particular, the invention relates to a fuel injection system including a plurality of unit pumps, each of which has a pumping plunger that is driven by means of a cam to cause pressurisation of fuel within an associated pumping chamber. The invention also relates to an engine installation incorporating such a fuel injection system.

[0002] Fuel injection systems are known in which a plurality of unit pumps are provided, each of which delivers fuel at high pressure to a separate high pressure fuel line. Each unit pump typically includes a tappet that is driven by means of a cam to impart drive to a plunger, thereby causing the plunger to reciprocate and resulting in pressurisation of fuel within a pumping chamber of the unit. Each unit pump is arranged to supply fuel to an injection nozzle of a dedicated injector for the purpose of delivering fuel to an associated cylinder of the engine. In such fuel injection systems it is therefore necessary to provide each engine cylinder with a set of separate pump components, consisting of a cam, a tappet, a unit pump, a high pressure line and an injector, with the cams for each set of pump components being formed on a common drive shaft.

[0003] In a known engine design that is of particular interest to the Applicant, the cam of each unit pump is mounted upon and is driven by means of a cam shaft that also carries the other cams of the engine system. The unit pumps are arranged "in a line" along the axis of the cam shaft, with a drive end of each unit pump cooperating with a lobe or lobes of its associated cam and the injection nozzle end of each unit pump being arranged to deliver fuel to the associated engine cylinder. Typically, the cam shaft has three (or more) lobes associated with each engine cylinder; one for driving the associated pumping plunger and the other two for controlling engine valve timing. The cam shaft extends through an engine housing or "engine crank case" which is provided with a plurality of pockets or bores for accommodating the unit pumps. The unit pumps are all therefore effectively housed within a common engine housing.

[0004] It has now been recognised that fuel injection systems of the aforementioned design have their disadvantages. For example, each unit pump typically functions by pressurising a substantially fixed volume of fuel during a pumping cycle, and then spilling pressurised fuel that is not required for an injection event to low pressure, therefore compromising system efficiency. The system also has a high part count, and therefore is of relatively high cost, in particular as it requires one unit pump to be provided for each fuel injector.

[0005] The machining and assembly line facilities for the manufacture of engine installations of the aforementioned type are well established, and engine installations that can accommodate this type of fuel injection

system are widely used. The problem addressed by the present invention is to avoid or obviate the aforementioned disadvantages associated with fuel injection systems used in engines of this type, whilst permitting continued use of production line facilities and engine installations that are already in existence.

[0006] With a view to addressing this problem we therefore provide, in accordance with a first aspect of the invention, a fuel injection system for use in an internal combustion engine having an engine housing, the fuel injection system comprising two or more unit pumps and a plurality of fuel injectors, each of the unit pumps being mounted or received, in use, within a pocket provided in the engine housing and including a pumping plunger that is reciprocable within a plunger bore under the influence of a drive arrangement to cause fuel pressurisation within a pumping chamber, each drive arrangement including a cam, which is carried by a cam shaft extending through the engine housing, in use, and which carries the or each of the other cams, an inlet metering valve arrangement which is arranged to control the rate of flow of fuel into the pumping chamber, thereby to control the quantity of fuel to be pressurised within the pumping chamber during a pumping cycle, and an outlet valve arrangement which is arranged to control the delivery of pressurised fuel from the pumping chamber directly to an accumulator volume through an associated high pressure fuel line, said accumulator volume being arranged to supply pressurised fuel to all of the injectors of the system.

[0007] The fuel injection system of the present invention provides the advantage that it can be readily incorporated into existing engine installations that were originally intended for use with separate unit fuel injection pumps delivering fuel to dedicated fuel injectors, whilst preserving the existing engine layout. This benefit is achieved as there is no requirement to modify the existing pump mounting, cam drive shaft location or cam drives. Production costs associated with re-tooling an engine production line can therefore be avoided.

[0008] The compatibility of the fuel injection system of the present invention with existing engine layouts is further advantageous in that efficiency improvements are achieved, as only that quantity of fuel required for an injection event is pumped during a pumping cycle of each of the unit pumps. In existing fuel injection systems associated with this type of engine installation, it is known to pump an excess quantity of fuel on each pumping stroke, with the excess being spilled to low pressure prior to delivery to the injectors. The fuel injection system of the present invention provides improved mechanical efficiency over such known systems due to the quantity of fuel that is pumped within a pumping cycle being controlled by the inlet metering valve arrangement.

[0009] It is recognised fuel injection pumps are known in which a plurality of pumping elements or plungers are incorporated within a unitary housing. Such arrange-

ments are commonly referred to as "in line" pump arrangements, as the pumping elements are mounted in a line parallel to the axis of a camshaft axis. Such systems require a set of tappets and a set of pumping plungers to be provided (one of each for each engine cylinder), with each tappet and its associated plunger being arranged within the associated unitary housing. As in unit pump arrangements, each pumping element has an associated pumping chamber which is connected to its associated injector through a separate high pressure fuel line. One pumping element or plunger is provided for each engine cylinder and so, again, the costs of such systems are relatively high.

[0010] Common rail fuel injection systems are also known and typically include a common rail fuel pump having a plurality of pumping plungers driven by a common eccentric cam surface. The cam surface is rotatable by means of a drive shaft, and it is common for such pumps to include three (or more) plungers radially spaced around the shaft. An example of this type of fuel injection system is described in JP 2001-003791. The cam surface of the pump is co-operable with all three of the plungers to cause phased, cyclical movement of the plungers and, hence, pressurisation of fuel within their associated pumping chambers. Whilst common rail systems such as this avoid the need for one pumping element per engine cylinder, such radial pump arrangements are incompatible with existing in-line cam drive arrangements such as that described previously and hence a totally different engine layout is required to accommodate the system.

[0011] The present invention overcomes the drawbacks and incompatibilities of such known systems, and permits pre-existing engine designs and production tooling equipment to be utilised, thus providing the manufacturer with significant cost benefits.

[0012] In the present invention, the accumulator volume of the fuel injection system preferably takes the form of a "common rail" for containing fuel at high pressure for delivery to a plurality of injectors. The common rail may be of tubular configuration (i.e. axially extending), or may be of generally spherical configuration (i.e. of the type having a central hub from which radially extending delivery flow paths extend to the injectors).

[0013] In a preferred embodiment, each unit pump has a pump outlet that is remotely spaced from an inlet to the accumulator volume or common rail. The unit pumps therefore deliver fuel to the injectors indirectly, with each unit pump delivering fuel to the separate, intermediate fuel volume (in the form of the common rail) through its associated high pressure fuel line from where fuel is delivered to all of the injectors of the system. This is a novel implementation of unit pumps, which are only known for use in fuel injection systems in which they supply fuel directly to a dedicated fuel injector.

[0014] The fuel injection system preferably includes high pressure delivery lines through which fuel is delivered from the common rail to the injectors. The injectors

of the fuel system are therefore spaced apart from the unit pumps.

[0015] In a preferred embodiment, the pumping plunger is arranged such that it can move axially relative to a drive member that is driven by the rotating cam, wherein the drive member typically takes the form of a tappet.

[0016] The high pressure fuel line associated with each unit pump communicates with the associated pumping chamber through the associated outlet valve arrangement and preferably at least a portion of the high pressure fuel line is substantially coaxially aligned with the associated pumping plunger.

[0017] Preferably, each unit pump includes a plunger bore provided in a unit pump housing, and the high pressure fuel line associated with each unit pump is preferably defined within an insert member mounted, at least in part, within the unit pump housing.

[0018] Preferably, the inlet metering valve arrangement includes a valve housing which is adapted to be mounted to the unit pump housing. Alternatively, the inlet metering valve arrangement may be housed in a common housing with the pumping plunger and other components of the unit pump.

[0019] The inlet metering valve arrangement may be of the type that is controlled by electrical, and preferably electronic, means.

[0020] In a preferred embodiment, the fuel injection system includes a number of fuel injectors that is greater than the number of unit pumps. For example, if there are four engine cylinders, and hence four fuel injectors, there may only be two or three unit pumps. It will be appreciated that in this case the existing cam shaft of the engine, which was designed for use with four unit pumps (and hence four fuel injection system cams) will have at least one redundant cam. In general, the cam shaft may be formed with or may carry a number of cams, at least one of which does not have an associated unit pump and is thus redundant.

[0021] The fuel injection system may be incorporated within an engine installation, in accordance with a second aspect of the invention, which includes the engine housing, typically the engine crank case. The engine housing is preferably provided with a plurality of pockets, each of which receives a respective one of the unit pumps. Preferably, the engine housing defines an axially extending opening through which the cam shaft extends, in use, and the pockets are arranged to extend radially from the opening. The opening may be defined in an integral or unitary engine housing or, alternatively, may be defined by adjacently mounted engine housing parts.

[0022] In accordance with a third aspect of the invention, a fuel injection system for use in an internal combustion engine having an engine housing comprises two or more unit pumps and a plurality of fuel injectors, each of the unit pumps being received, in use, within a pocket provided in the engine housing and including a pumping

plunger that is reciprocable under the influence of a drive arrangement to cause pressurisation of fuel within a pumping chamber and an outlet valve arrangement which is arranged to control the delivery of pressurised fuel from the pumping chamber directly to an accumulator volume through an associated high pressure fuel line, said accumulator volume being arranged to supply pressurised fuel to both or all of the fuel injectors and each drive arrangement including a cam that is mounted upon a cam shaft, which extends into the engine housing and which carries the or each of the other cams, and wherein only one of the unit pumps includes an inlet metering valve arrangement which is arranged to control the rate of flow of fuel into the associated pumping chamber, and wherein the or each of the other unit pumps is provided with an inlet in communication with the inlet metering valve arrangement of the first unit pump such that said inlet metering valve arrangement controls the quantity of fuel to be pressurised within the pumping chambers of all of the unit pumps.

[0023] The fuel injection system of this third aspect of the invention may include three or more unit pumps, wherein a first one of the unit pumps is provided with an inlet metering valve arrangement and each of the other unit pumps is arranged to receive a metered flow of fuel from the inlet metering valve arrangement of the first unit pump.

[0024] The fuel injection system of the third aspect of the invention is advantageous in that it permits an increased quantity of fuel to be supplied to the common rail. Additionally, the assembly is efficient as only the quantity of fuel required during an injection event is pumped by virtue of the inlet metering valve arrangement. A further advantage is obtained in that only a single inlet metering valve arrangement is required to control the fuel flow rate to a plurality of pumping chambers.

[0025] Optional and/or preferable features of the fuel injection system or engine installation of the first and second aspects of the invention may also be incorporated, alone or in appropriate combination, within the fuel injection system of the third aspect of the invention, and this third aspect of the invention may also be incorporated within an engine installation in accordance with the second aspect of the invention.

[0026] The invention will now be described, by way of example only, with reference to the accompanying figures in which:

Figure 1 is a schematic diagram of a fuel injection system in accordance with one aspect of the present invention,

Figure 2 is a view, shown part in section, of a part of a pump for use in the fuel injection system in Figure 1,

Figure 3 is a sectional view of an inlet metering valve which may form part of the fuel injection sys-

tem in Figure 2,

Figures 4 and 5 illustrate two different cam surface profiles which may be used in a drive arrangement for the fuel injection system in Figure 2, and

Figure 6 is a schematic diagram of a fuel injection system in accordance with an alternative aspect of the present invention.

[0027] Referring to Figure 1, a common rail fuel injection system for an internal combustion engine includes a low pressure pump 10 which receives fuel from a low pressure reservoir 12 through a filter arrangement 14. The low pressure pump 10 supplies fuel through a first supply line 16 to an inlet (not shown in Figure 1) of a high pressure pump, referred to generally as 18. The high pressure pump 18 is arranged to cause pressurisation of a controllable quantity of fuel to a relatively high level, and delivers high pressure fuel through a second supply line 20 to an accumulator volume in the form of a common rail 22. The common rail 22 is of generally spherical configuration and includes a plurality (four in the illustration shown) of high pressure fuel lines 24 which extend from a central hub of the rail 22. Each one of the high pressure fuel lines 24 is arranged to supply fuel to an injector 26 of the fuel system (only one of which is shown), from where fuel is delivered to an associated engine cylinder or other combustion space. The injector may be of conventional type, the design and operation of which would be well known to a person familiar with this field of technology. For example, the injector may be of the electromagnetically or piezoelectrically actuable type, may be of the direct actuation type or may be of the type including a hydraulic amplifier arrangement for controlling injector valve needle movement.

[0028] In practice two or more high pressure pumps 18 are provided in the system, but for clarity and simplicity only one pump 18 will be described in detail with reference to Figure 2 which shows just one of the high pressure fuel pumps 18. Referring to Figure 2, it can be seen that the pump 18 includes a single pumping plunger 30 which is slideable within a plunger bore 32 provided in a pump housing 34 to cause pressurisation of fuel within a pumping chamber 36. The pumping plunger 30 is driven, in use, by means of a drive arrangement, referred to generally as 38, including a generally cylindrical tappet member 40, a roller member 42 and a cam carried by a drive shaft (not shown). The roller 42 is arranged to co-operate with a surface 46 of the cam such that, as the drive shaft rotates, the cam is driven and the roller 42 is caused to ride over the cam surface 46. The roller 42 and the tappet 40 are reciprocable within a guide bore 44 provided in an engine housing 39 which is secured to the pump housing 34. An internal surface of the tappet 40 is provided with an annular groove, within which an abutment plate 47 for a return spring 48 is mounted. The return spring 48 is arranged to urge the

tappet and roller arrangement 40, 42 outwardly from the guide bore 44 (downward in the orientation shown in Figure 2) into engagement with the cam surface and, hence, serves to allow the pumping plunger 30 to be urged outwardly from the plunger bore 32 to perform a return stroke of a pumping cycle, as described in further detail below. The tappet 40 and pumping plunger 30 are arranged such that they are able to move axially relative to one another. Thus, as the tappet 40 is urged inwardly within the guide bore 44 upon rotation of the cam surface, a point will be reached in its range of travel at which it moves into engagement with the pumping plunger 30 to urge the pumping plunger inwardly within the plunger bore 32.

[0029] The cam drive arrangement for the cam shown in Figure 2 includes a cam drive shaft (not shown) of the type used in an engine installation as described previously, originally intended to include separate unit fuel injection pumps, each for delivering fuel to a dedicated injector. In such existing engine installations the cam drive shaft is formed with a plurality of cam forms, each of which is intended to drive a plunger of an associated one of the unit fuel injection pumps. In the present invention this cam drive arrangement is utilised in a different manner, but nonetheless the requirement to re-design the engine installation is avoided.

[0030] In the present invention the unit pumps are arranged in a line substantially parallel to the axis of the cam shaft, and are accommodated within a common engine housing provided with a plurality of pockets or bores, each one of the pumps being or mounted within a respective one of the bores. Typically the engine housing may take the form of the engine crank case which is provided with an axially extending opening through which the cam shaft extends. The pockets for receiving the unit pumps extend radially from this opening, and thus define the locations for the unit pumps within the installation. The unit pumps of the fuel injection system of the present invention do not, however, supply fuel directly to just one injector, and so the operating principle of the system contrasts that of existing engine installations having this construction. By making the fuel injection system compatible with existing engine layouts, an advantage is obtained in that the need to re-design existing engine layouts and tolling equipment is avoided.

[0031] In addition to the installation and tooling advantage provided by the present invention, an efficiency advantage is also achieved by virtue of an inlet metering valve arrangement, referred to generally as 50, that is provided on each pump 18. The inlet metering valve arrangement 50 is located at the end of the pumping plunger 30 remote from the tappet 40, and is located within a separate valve housing 52 secured to a face of the pump housing 34. The inlet metering valve 50 is in communication with a pump inlet 54 which communicates with the first supply line 16 in Figure 1, such that a supply of low pressure fuel is delivered to the inlet metering valve 50 from the low pressure pump 10. The inlet

metering valve 50 is arranged to control the rate of flow of fuel delivered to the pumping chamber 36 through an inlet check valve, referred to generally as 56, under the control of an Engine Control Unit (ECU, not shown).

[0032] The inlet metering valve 50 may typically be of the type shown in further detail in Figure 3, in which a metering valve member 75 is movable under the influence of an electromagnetic actuator, referred to generally as 77, to control the extent of opening of an orifice or restriction 79 in a flow path between the pump inlet 54 and the inlet check valve 56, thereby to vary the rate of flow of fuel through the orifice 79 to the pumping chamber 36. The metering valve member 75 is movable between a closed position in which communication between the pump inlet 54 and the inlet check valve 56 through the orifice 79 is closed, and a fully open position in which a maximum rate of flow of fuel through the orifice 79 is permitted. Movement of the metering valve member 75 is effected by energising and de-energising a winding 81 of the actuator 77 under the control of the ECU. Further details of the operation of a metering valve of the type shown in Figure 3 would be familiar to a person skilled in the field of engine fuel system design.

[0033] The inlet check valve 56 includes a valve abutment member 60 defining a valve seat 62 with which a check valve member 58 is engageable to control the metered flow of fuel from the inlet metering valve 50 to the pumping chamber 36. The valve abutment member 60 is provided with axially and radially extending passages which communicate with one another such that, when the check valve member 58 is caused to lift from the valve seat 62, fuel delivered to the pump inlet 54 and passing through the inlet metering valve 50 is able to flow into the radially extending passage in the valve abutment member 60, into the axially extending passage and past the valve seat 62 into the pumping chamber 36. Although not shown in Figure 2, in practice it may be desirable to provide the inlet check valve 56 with a relatively low spring pre-load to urge the check valve member 58 into a position in which it engages the valve seat 62.

[0034] Whilst the flow into the pumping chamber 36 is controlled by means of the inlet metering valve 50 and the inlet check valve 56, the flow of fuel out of the pumping chamber 36 is controlled by means of an outlet delivery valve arrangement, referred to generally as 64. The outlet valve arrangement 64 takes the form of a ball valve having a ball 66 which is engageable with a further valve seat 68 to control fuel flow between the pumping chamber 36 and a high pressure supply line 70 forming part of or being in communication with the supply line 20. The outlet valve arrangement 64 may be provided with an outlet valve spring (not shown) having a relatively low pre-load, which serves to urge the ball 66 into engagement with the further valve seat 68.

[0035] The high pressure flow line 70 is defined by a passage provided in an insert member 72 located, in part, within a further bore 73 provided within the pump

housing 34 and partially extending from the pump housing 34. The high pressure flow line 70 is substantially coaxially aligned with the pumping plunger 30 and is arranged to communicate, at its end remote from the pump housing 34, with an end of the second supply line 20 to the common rail 22. Thus, in use, high pressure fuel delivered from the pumping chamber 36 to the high pressure flow line 70 is able to flow into the second supply line 20, and into the common rail 22, for delivery to the injectors 26.

[0036] In use, as the drive shaft is rotated and the roller 42 rides over the cam surface, the tappet 40 is caused to reciprocate within the guide bore 44, thereby causing axial movement to be imparted to the pumping plunger 30 as the tappet 40 is moved into engagement with, and moves with, the pumping plunger 30. A pumping cycle consists of two phases. During a filling phase, the inlet check valve 56 is open to permit fuel delivery from the inlet metering valve 50 to the pumping chamber 36, and the outlet valve arrangement 64 is held closed by means of high pressure fuel within the high pressure flow line 70 to the common rail. During the filling phase, the pumping plunger 30 is urged outwardly from the plunger bore 32 to perform a return stroke due to the pressure exerted on the plunger 30 by the flow of fuel from the inlet metering valve 50, through the inlet check valve 56 and into the pumping chamber 36.

[0037] During a subsequent pumping phase of the pumping cycle, the inlet check valve 56 is caused to close due to increasing fuel pressure within the pumping chamber 36 as the plunger 30 starts to move inwardly under the drive of the tappet 40, to prevent further flow of fuel into the pumping chamber 36 from the inlet metering valve 50. Additionally, as fuel pressure within the pumping chamber 36 increases further, the outlet valve arrangement 64 is caused to open to permit pressurised fuel within the pumping chamber 36 to flow into the high pressure flow line 70. During the pumping phase the pumping plunger 30 is urged inwardly within the plunger bore 32, under the influence of the tappet 40 co-operating with the roller 42 and the driven cam surface, to cause fuel pressurisation within the pumping chamber 36.

[0038] The sequence of events during a pumping cycle will now be described in further detail. At the start of the pumping cycle, the pumping plunger 30 adopts its innermost position within the plunger bore 32 (i.e. uppermost position in the orientation in Figure 2) and fuel pressure within the pumping chamber 36 is high due to the pressurisation caused by the previous pumping stroke. The outlet valve arrangement 64 is closed due to the equalisation of fuel pressures in the pumping chamber 36 and the high pressure flow line 70. The tappet 40 is also at its innermost position in the guide bore 44, and high fuel pressure within the pumping chamber 36 serves to urge the pumping plunger 30 into contact with the tappet 40.

[0039] Upon commencement of its return stroke, the

plunger member 30 is initially allowed to retract from the plunger bore 32 due to decompression within the pumping chamber 36 and retraction of the tappet 40 under the force of the return spring 48 as the roller 42 rides over the cam surface. As the pumping chamber 36 is decompressed, a point will be reached at which the pressure in the pumping chamber 36 falls below the pressure required to lift the check valve member 58 from the valve seat 62 due to the flow of fuel from the inlet metering valve 50, and the next filling phase commences.

[0040] Further movement of the pumping plunger 30 outwardly from the plunger bore 32 is effected by a force due to pressure within the pumping chamber 36 caused by the flow of fuel from the inlet metering valve 50, through the radially and axially extending passages in the valve abutment member 60 and through the inlet check valve 56 into the pumping chamber 36. Further retraction of the tappet 40 from the guide bore 44 (i.e. outward movement of the tappet 40 from the bore 44) occurs under the force of the return spring 48, causing the roller 42 to ride over the cam surface.

[0041] During the filling phase, the ball 66 of the outlet valve arrangement 64 remains seated against the further valve seating 68 due to high pressure fuel within the high pressure flow line 70 and due to the force of the outlet valve spring.

[0042] After the tappet 40 reaches its outermost position within the guide bore 44, the roller 42 is urged in an upward direction (in the illustration shown in Figure 2) as it follows the cam surface, and a point will be reached at which the tappet 40 moves into engagement with the plunger member 30, thereby causing the pumping plunger 30 to be driven inwardly within the plunger bore 32. As the pumping plunger 30 is driven inwardly within the plunger bore 32, fuel within the pumping chamber 36 is pressurised.

[0043] As fuel pressure within the pumping chamber 36 starts to increase, a point will be reached part way through the pumping stroke at which the check valve member 58 of the inlet check valve 56 is urged against its seating, due to increasing fuel pressure within the pumping chamber 36, to prevent further flow of fuel into the pumping chamber 36 and return flow from the pumping chamber 36 towards the inlet metering valve 50.

[0044] As the plunger pumping stroke continues, fuel within the pumping chamber 36 is pressurised to a sufficiently high level to cause the ball 66 to lift from the further valve seating 68, thereby permitting pressurised fuel to flow from the pumping chamber 36 into the high pressure flow line 70 and, hence, to the supply line 20 to the common rail 22. At the end of the pumping stroke, when the pumping plunger 30 reaches the end of its range of travel, the ball 66 will be urged against the further valve seating 68 due to high pressure fuel within the high pressure flow line 70 and the force of the outlet valve spring, thereby holding high fuel pressure within the high pressure flow line 70, the second supply line

20 and, hence, within the common rail 22.

[0045] The extent of plunger movement during the pumping stroke will be determined by the quantity of fuel delivered to the pumping chamber 36 during a filling phase, as this determines the extent to which the pumping plunger 30 is retracted from the plunger bore 32 during the return stroke. The quantity of fuel delivered to the pumping chamber 36 during the filling phase therefore determines the point in the range of travel of the tappet 40 at which it engages the pumping plunger 30 to commence the plunger pumping stroke.

[0046] The quantity of fuel delivered to the pumping chamber 36 during one pumping cycle is therefore determined by the rate of flow of fuel through the inlet metering valve 50, and the time for which the inlet check valve 56 is held open to permit fuel flow into the pumping chamber 36. The time for which the inlet check valve 56 is held open is determined by the spring rate of the inlet valve spring (if provided), the hydraulic force acting on the check valve member 58 as fuel is pressurised within the pumping chamber 36 and the speed of the associated engine which determines the rate of movement of the tappet 40. The quantity of fuel delivered to the pumping chamber 36 can therefore be varied by adjusting the inlet metering valve setting to vary the fuel flow rate through the inlet check valve 56.

[0047] The inlet metering valve 50 is operable by means of the ECU between a fully open state, corresponding to maximum filling and a maximum pumping plunger stroke, and a fully closed state corresponding to zero filling and zero pumping plunger stroke, and has a range of settings between its fully open and closed states to vary the extent of filling of the pumping chamber 36 and, hence, the quantity of fuel delivered to the common rail 22 during any given pumping cycle.

[0048] The provision of the inlet metering valve 50 provides the advantage that only that quantity of fuel required for an injection event is pumped during a pumping cycle. In existing pump designs, it is known to pump an excess quantity of fuel on each pumping stroke, with the excess being spilled to a drain port prior to delivery to the injectors. The pump assembly of the present invention provides improved mechanical efficiency over such known pump designs.

[0049] The cam drive arrangement for the pump assembly is typically arranged to have a cam surface with one cam lobe per injection event. Figure 4 shows the cam drive arrangement of the fuel injection system of the present invention, in which the cam 80, driven by means of an engine drive shaft 82, has a cam surface provided with two cam lobes. This particular cam surface drive arrangement may be used, for example, in a two-pump system for a four cylinder engine, or in a three-pump system for a six cylinder engine. Figure 5 shows a cam drive arrangement in which the cam 80 has a three lobed cam surface, and this cam drive arrangement may be used, for example, in a two-pump system for a six cylinder engine.

[0050] Although the quantity of fuel required for an injection event may be greater than that which can be provided by a single pump 18, because two or more pumps are used fuel injection demand is satisfied. Referring to Figure 6, for example, there is shown a dual pump arrangement in which first and second pump assemblies 100a, 100b respectively are arranged to deliver fuel at high pressure through respective supply lines 20a, 20b to the common rail 22. The first pump assembly 100a has a first inlet 54a which is supplied with fuel through a first supply passage 16 (as shown in Figure 1). As described previously with reference to Figure 2, low pressure fuel delivered to the inlet check valve 56 is regulated by means of the inlet metering valve 50 to control the quantity of fuel pumped within the pumping chamber 36 during a pumping cycle.

[0051] The first and second pump assemblies 100a, 100b are structurally substantially identical, and thus this embodiment is similar to that described with reference to Figures 1 to 5, except that the second pump assembly 100b need not be provided with an inlet metering valve. Instead, the second pump assembly 100b is arranged such that an inlet 54b to its pumping chamber is supplied with fuel from the inlet metering valve 50 of the first pump assembly 100a. Conveniently, the metered flow of fuel from the first pump assembly 100a may be tapped off from an outlet 102 (also shown in Figure 2). Conveniently, a port 104 of the second pump assembly 110b which is equivalent to the inlet 54a of the first pump assembly 100a, may be used to provide a back-leak connection to low pressure. The use of a multi pump scheme such as that shown in Figure 5 is advantageous in that it permits an increased, yet controlled, quantity of fuel to be supplied to the common rail by means of the multiple pumping cycles in an efficient manner, whilst only requiring a single inlet metering valve 50 to be provided.

[0052] It will be appreciated that, although the fuel injection system of the present invention is shown to include unit pumps having a tappet drive arrangement which co-operates with its associated cam, other drive arrangements are also envisaged, for example shoe and roller arrangements.

[0053] For the purpose of this specification, any reference to the cam drive shaft "carrying" a cam is intended to include carrying or mounting of a separate cam upon the cam drive shaft, or the integral formation of the cam with the shaft.

Claims

1. A fuel injection system for use in an internal combustion engine having an engine housing, the fuel injection system comprising:

two or more unit pumps (18) and a plurality of fuel injectors (26), each of the unit pumps being

received, in use, within a pocket provided in the engine housing and including a pumping plunger (30) that is reciprocable within a plunger bore (32) under the influence of a drive arrangement (40, 42, 46), to cause fuel pressurisation within a pumping chamber (36), each drive arrangement including a cam (46), which is carried by a cam shaft extending through the engine housing, in use, and which carries the or each of the other cams, an inlet metering valve arrangement (50) which is arranged to control the rate of flow of fuel into the associated pumping chamber (36), thereby to control the quantity of fuel to be pressurised within the pumping chamber during a pumping cycle, and an outlet valve arrangement (64) which is arranged to control the delivery of pressurised fuel from the pumping chamber (36) directly to an accumulator volume (22) through an associated high pressure fuel line (70), said accumulator volume being arranged to supply pressurised fuel to all of the injectors (26) of the system.

2. The fuel injection system as claimed in Claim 1, wherein the accumulator volume takes the form of a common rail.
3. The fuel injection system as claimed in Claim 1 or Claim 2, wherein each unit pump (18) has a pump outlet that is remotely spaced from an inlet to the accumulator volume (22).
4. The fuel injection system as claimed in any one of Claims 1 to 3, including a plurality of high pressure delivery lines (24), each for delivering fuel from the accumulator volume (22) to a respective one of the injectors (26).
5. The fuel injection system as claimed in any one of Claims 1 to 4, wherein at-least a portion of the high pressure fuel line (70) associated with each unit pump (18) is substantially coaxially aligned with the associated pumping plunger (36).
6. The fuel injection system as claimed in any one of Claims 1 to 5, wherein each unit pump (18) includes a plunger bore (32) provided in a unit pump housing (34), and wherein the high pressure fuel line (70) associated with each unit pump (18) is defined within an insert member (72) mounted, at least in part, within the unit pump housing (34).
7. The fuel injection system as claimed in Claim 6, wherein the inlet metering valve arrangement (50) of each unit pump (18) includes a valve housing (52) mounted upon the unit pump housing (18).
8. The fuel injection system as claimed in any one of

Claims 1 to 7, wherein the pumping plunger (30) is arranged such that it can move axially relative to a drive member (40) that is driven by the cam.

9. The fuel injection system as claimed in any one of Claims 1 to 8, including a number of fuel injectors (26) that is greater than the number of unit pumps (18).
10. An engine installation including the fuel injection system as claimed in any one of Claims 1 to 9 and further including the cam drive arrangement for each of the unit pumps (18).
11. The engine installation as claimed in Claim 10, including a cam shaft formed with or carrying a number of cams, at least one of which does not have an associated unit pump and is thus redundant.
12. The engine installation as claimed in Claim 10 or Claim 11, including the engine housing that is provided with a plurality of pockets, a respective one of the unit pumps (18) being received within one of the pockets.
13. The engine installation as claimed in Claim 12, wherein the engine housing defines an axially extending opening through which the cam shaft extends, in use, and wherein the pockets extend radially from the opening.
14. The engine installation as claimed in Claim 13, wherein the opening is defined in a unitary engine housing.
15. A fuel injection system for use in an internal combustion engine having an engine housing comprises two or more unit pumps (100a, 100b) and a plurality of fuel injectors, each of the unit pumps being received, in use, within a pocket provided in the engine housing and including a pumping plunger that is reciprocable under the influence of a drive arrangement (40) to cause pressurisation of fuel within a pumping chamber and an outlet valve arrangement which is arranged to control the delivery of pressurised fuel from the pumping chamber directly to an accumulator volume (22) through an associated high pressure fuel line (20a, 20b), said accumulator volume being arranged to supply pressurised fuel to both or all of the fuel injectors and wherein each drive arrangement includes a cam that is mounted upon a cam shaft, which extends into the engine housing and which carries the or each of the other cams, and wherein only one of the unit pumps (100a) includes an inlet metering valve arrangement (50) which is arranged to control the rate of flow of fuel into the pumping chamber of that

unit pump (100a), and wherein the or each of the other unit pumps (100b) is provided with an inlet (54b) in communication with the inlet metering valve arrangement (50) of the first unit pump (100a) such that said inlet metering valve arrangement (50) also controls the quantity of fuel to be pressurised within the pumping chambers of the other unit pump or pumps (100b).

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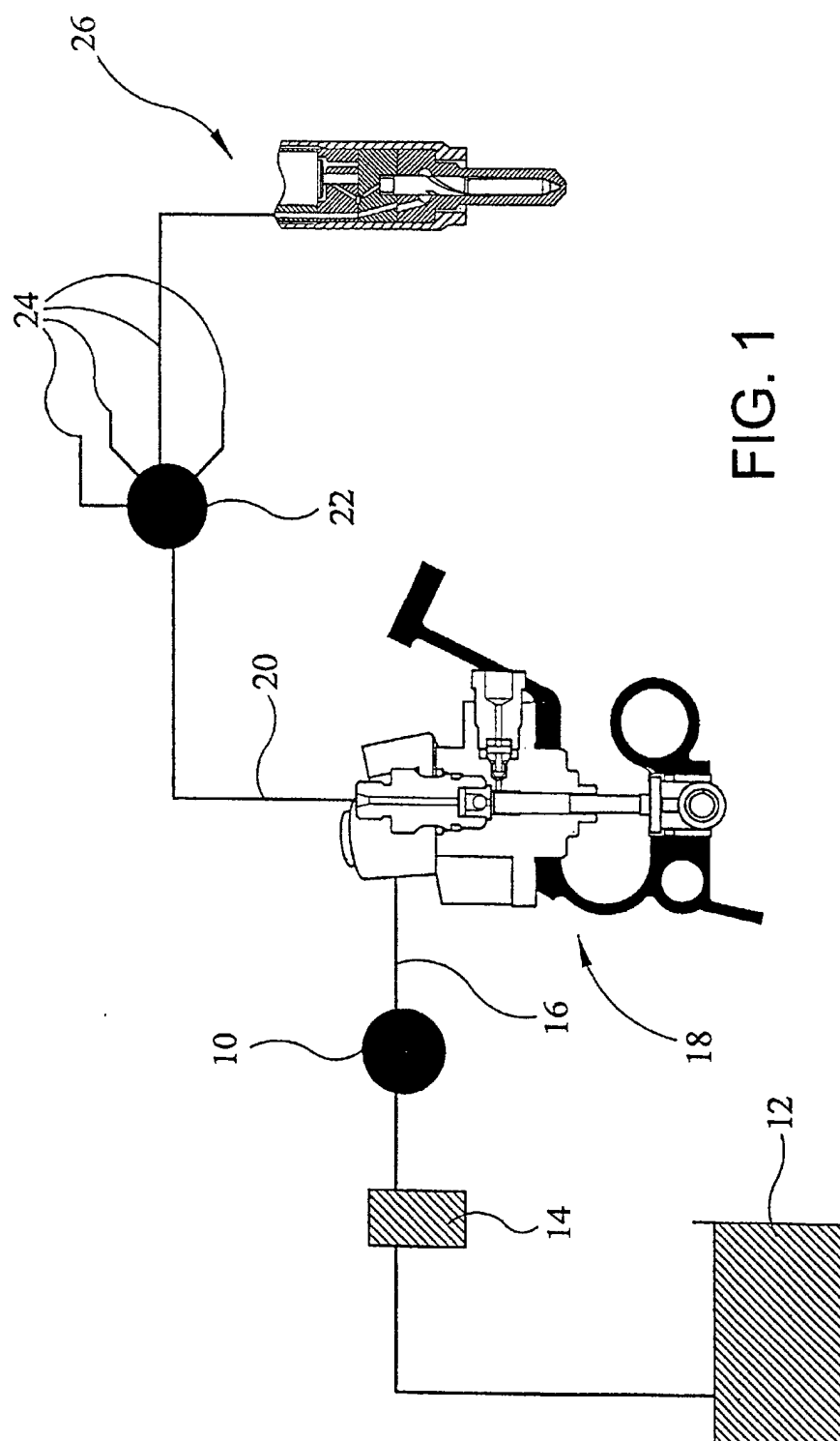


FIG. 1

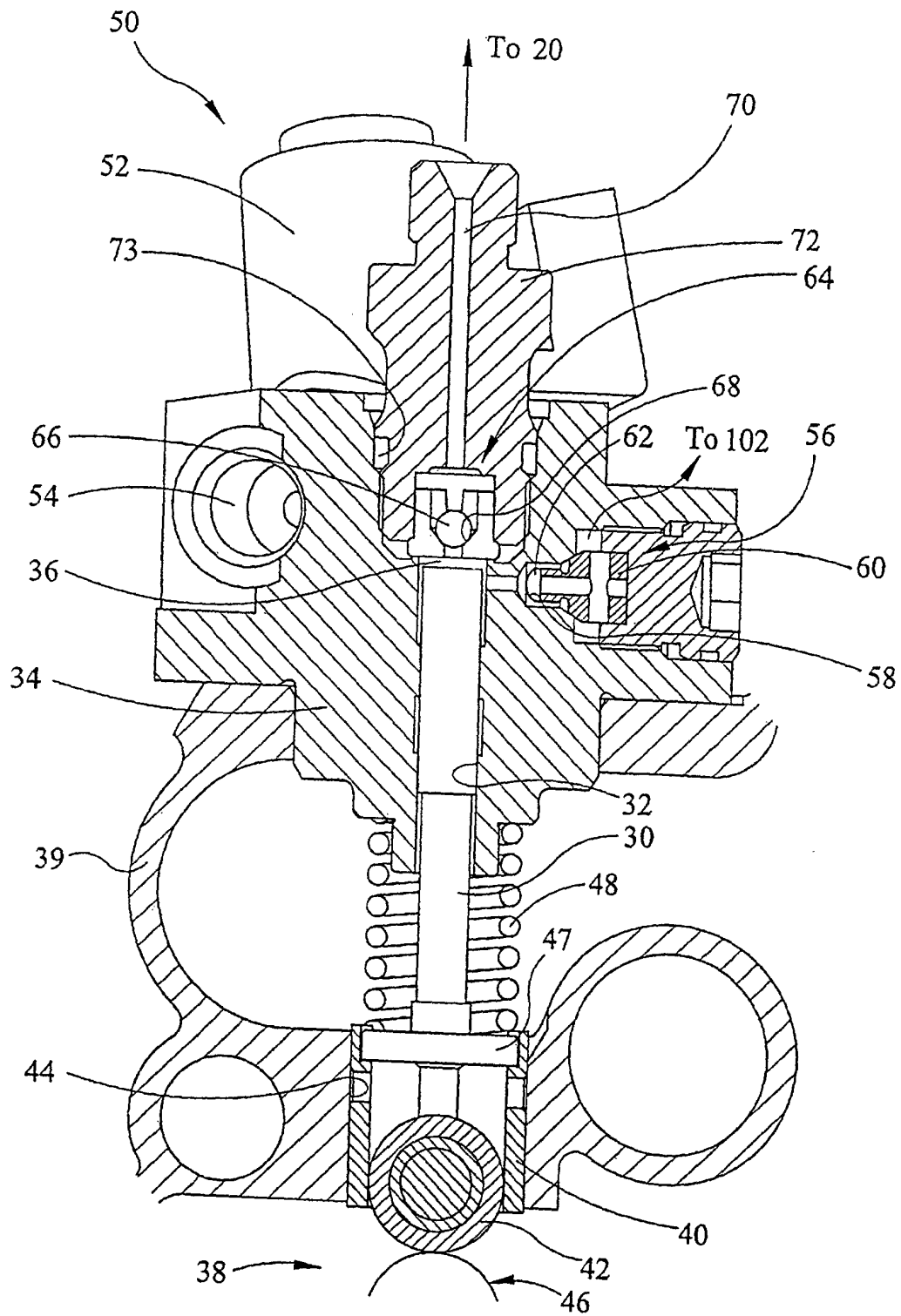


FIG. 2

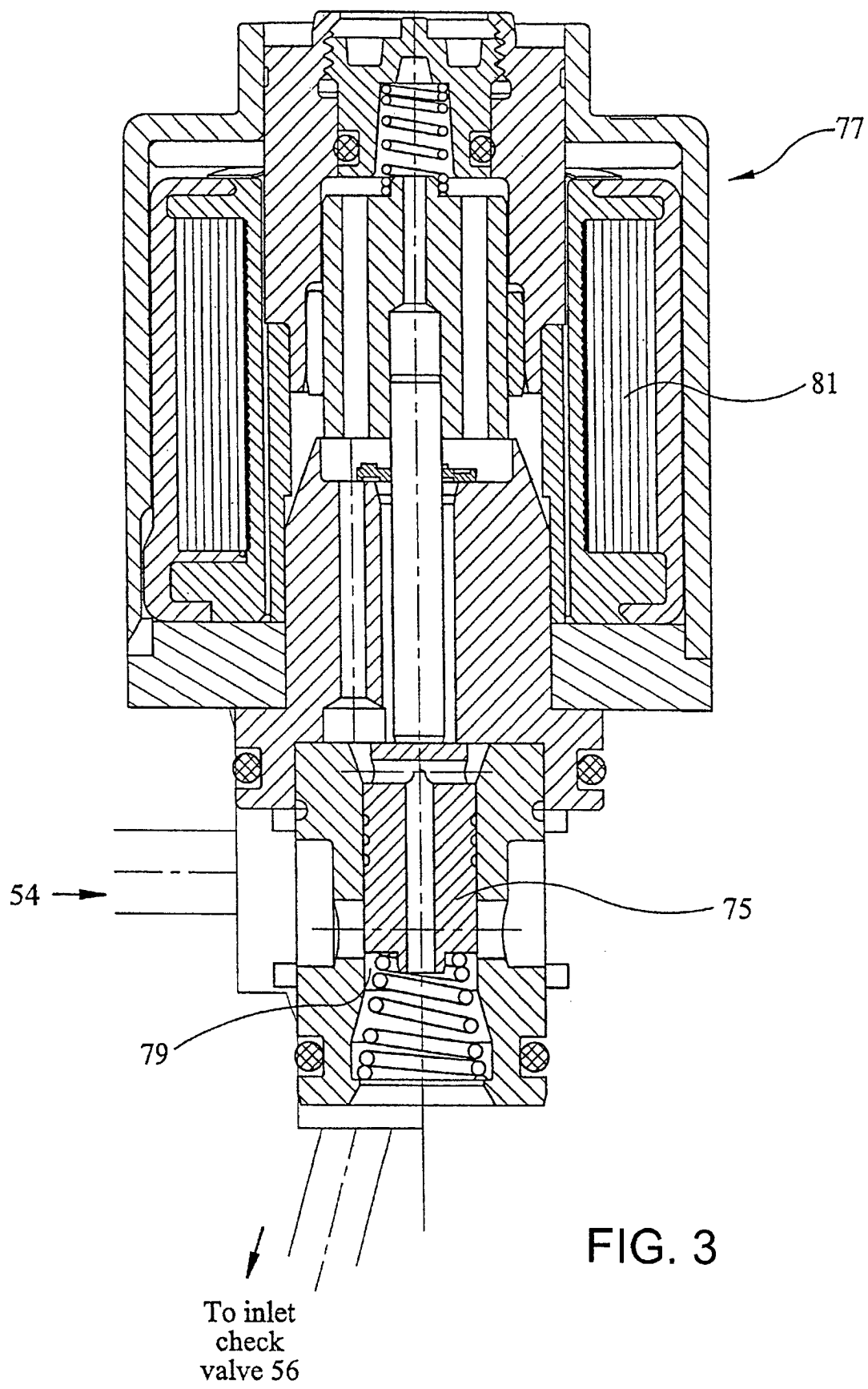


FIG. 3

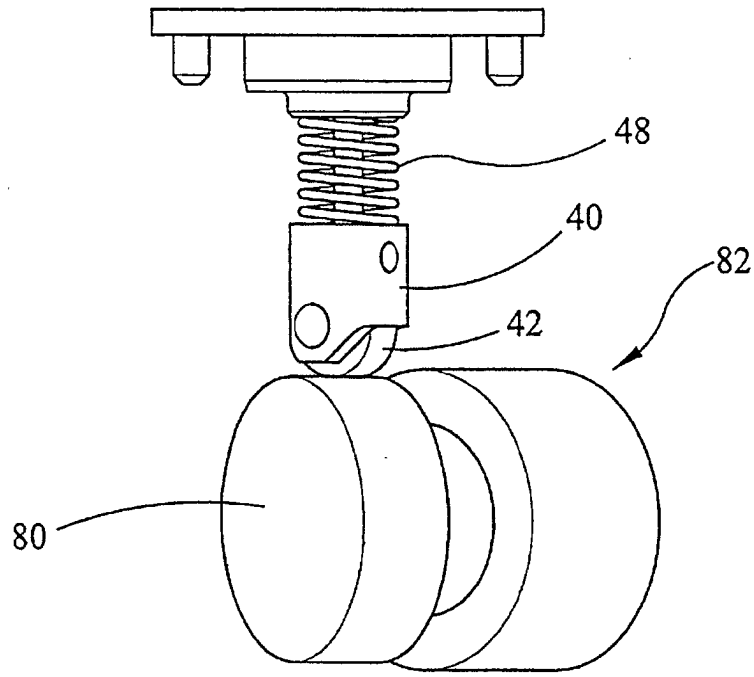


FIG. 4

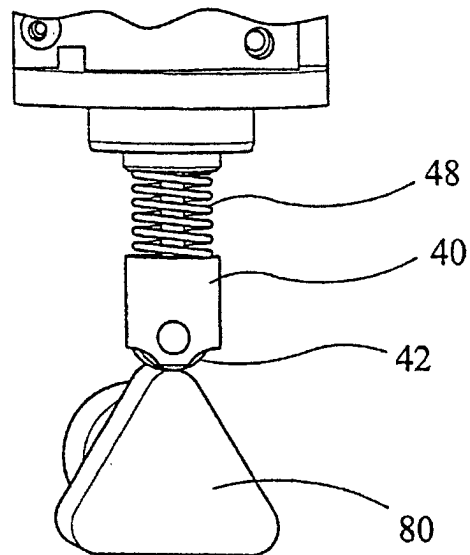


FIG. 5

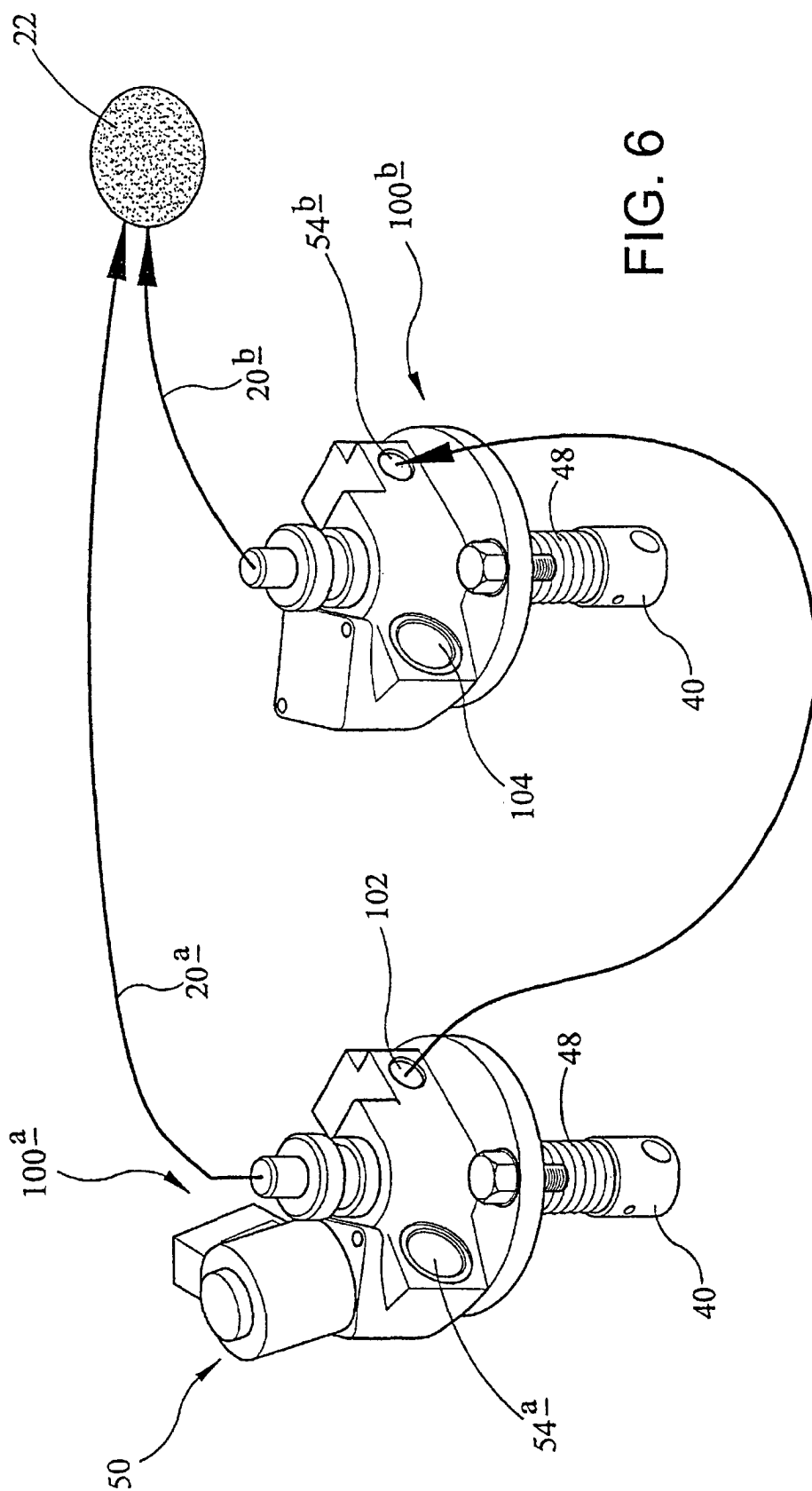


FIG. 6