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(74) Representative: **Gregory, John David Charles**
Delphi Diesel Systems
Patent Department
Courteney Road
Gillingham
Kent ME8 0RU (GB)

(71) Applicant: **Delphi Technologies Holding S.à.r.l.**
4940 Bascharage (LU)

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(72) Inventor: **McHattie, James**
Faversham, Kent ME13 7QA (GB)

(54) Pumping head

(57) A pumping head (200;300) for a high-pressure fuel pump is disclosed. The pumping head comprises a head housing (204) having a bore (206), a pumping element (202) arranged for reciprocal linear movement along a pumping axis (Q), a first pumping chamber (240) and a second pumping chamber (242), inlet means (290; 314) for delivering fluid to the first pumping chamber (240), outlet means (246,248) for conveying fluid from the second pumping chamber (242) to an outlet (244) of the pumping head, and transfer means (260,262) for conveying fluid from the first pumping chamber (240) to the second pumping chamber (242). Each forward stroke of the pumping element (202) increases a volume of the first pumping chamber (240) and decreases a volume of the second pumping chamber (242), thereby to cause fluid to flow into the first pumping chamber (240) from the inlet means (290;314) and to cause fluid to flow out of the second pumping chamber (242) to the outlet means (246,248). Each return stroke of the pumping element (202) decreases the volume of the first pumping chamber (240) and increases the volume of the second pumping chamber (242), thereby to cause fluid to flow from the first chamber (240) to the second chamber (242) through the transfer means (260,262).

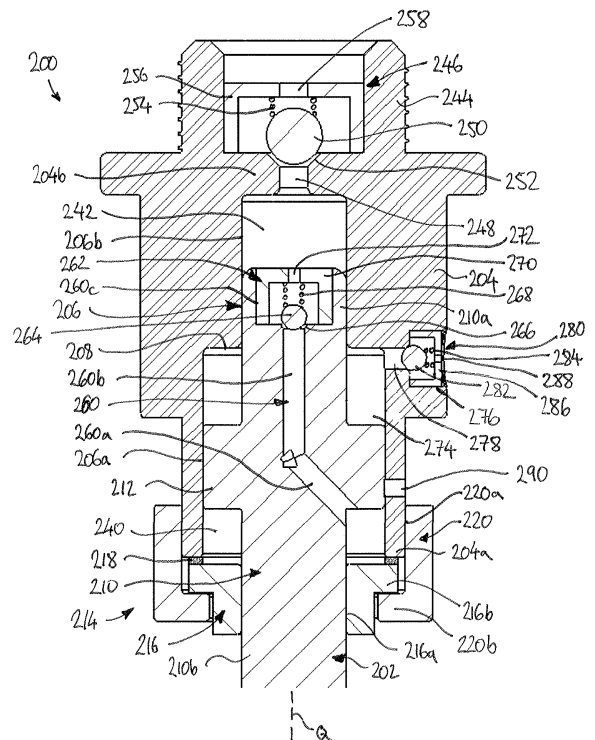


FIGURE 4

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Description

Field of the invention

[0001] This invention relates to a pumping head for a fluid pump. In particular, but not exclusively, the invention relates to a pumping head suitable for use in a high-pressure fuel pump of a fuel injection system for an internal combustion engine.

Background to the invention

[0002] Figure 1 of the accompanying drawings is a schematic diagram of a conventional fuel injection system 10 for an internal combustion engine.

[0003] The fuel injection system 10 comprises a plurality of fuel injectors 12. Each injector 12 is arranged to deliver an atomised spray of high-pressure fuel to a respective combustion chamber (not shown) of the engine. The injectors 12 receive fuel at high pressure from an accumulator volume or rail 14, by way of high-pressure supply lines 16. The rail 14 comprises a reservoir for high-pressure fuel.

[0004] Delivery of fuel from the injectors 12 is controlled by an electronic control unit 18. When a fuel injection from one of the injectors 12 is required, the electronic control unit 18 sends an actuation signal to the injector 12, which causes actuation of a delivery valve (not shown) of the injector 12.

[0005] Fuel is pumped to the rail 14 from a storage tank 20 by a fuel pump assembly 22. The fuel pump assembly 22 includes a low-pressure transfer pump 24, which serves to convey fuel from the tank 20 to the pump assembly 22, and a high-pressure pump 26 which elevates the pressure of the fuel to the injection pressure, typically of the order of 2000 bar. Fuel is conveyed from the tank 20 to the pump assembly 22 by way of a low-pressure fuel line 28, and from the pump assembly 22 to the rail by way of a high-pressure fuel line 30.

[0006] An inlet metering valve 32, under the control of the engine control unit 18, is provided between the transfer pump 24 and the high-pressure pump 26 of the pump assembly 22. The inlet metering valve 32 determines how much fuel reaches the high-pressure pump 26, for subsequent pressurisation and delivery to the rail 14. The fuel pressure in the rail 14 is regulated to a target value by the electronic control unit 18. A pressure-limiting valve 36 and return line 38 prevent the rail pressure exceeding a pre-determined acceptable level.

[0007] The high-pressure pump 26 comprises a pumping head 50, shown schematically in Figure 2, which is arranged to receive a reciprocable pumping plunger or pumping element 52. The pump 26 further comprises a drive assembly 100, shown in Figure 3, for driving reciprocal movement of the pumping element 52 along a pumping axis Q.

[0008] The pumping head 50 comprises a housing 56 that includes a blind bore 58. The pumping element 52

is slidably received within the bore 58. A pumping chamber 60 at the blind end of the bore 58 is defined in part by the pumping member 52 and in part by the bore 58. As the pumping element 52 is driven in reciprocal linear motion along the pumping axis Q by the drive assembly, the volume of the pumping chamber 60, and hence the pressure in the pumping chamber 60, increases and decreases accordingly.

[0009] The pumping head 50 further comprises a spring-biased inlet valve 62 and a spring-biased outlet valve 64. When the pumping element 52 moves downwards (referred to as a filling stroke or return stroke of the pumping element 52), the volume of the pumping chamber 60 increases, the outlet valve 64 closes, and the inlet valve 62 opens when the pressure differential across it reaches a first predetermined level. Fuel is then admitted to the pumping chamber 60 from a fuel supply port 63, through the inlet valve 62. The fuel supply port 63 is fed with fuel from the inlet metering valve (32 in Figure 1).

[0010] When the pumping element 52 moves upwards (referred to as a pumping stroke or forward stroke of the pumping element 52), the volume of the pumping chamber 60 decreases, the inlet valve closes 62, and the pressure of fuel in the pumping chamber 60 increases. The outlet valve 64 is arranged to open at a second pre-determined pressure. Fuel is then delivered through the outlet valve 64 from the pumping chamber 60 at the second pre-determined pressure, for delivery to the fuel rail 14 through an outlet port 65. By setting the second pre-determined pressure at a high level, for example 2000 bar or more, pressurisation of the fuel rail 14 to the desired level can be achieved.

[0011] The pumping head 50 is generally 'T'-shaped, so that the housing 56 comprises a vertically-extending portion 56a and first and second horizontally-extending portions 56b, 56c that extend in opposite directions from the vertically-extending portion 56a. The bore 58 extends within the vertically-extending portion 56a of the housing 56, and the inlet and outlet valves 62, 64 are received in the first and second horizontally-extending portions 56b, 56c, respectively.

[0012] A first high-pressure seal 70 is provided to prevent leakage of fuel from the pumping chamber 60 past the inlet valve 62, and a second high-pressure seal 72 is provided to prevent leakage of fuel from the pumping chamber 60 past the outlet valve 64.

[0013] The first horizontally-extending portion 56b of the housing 56 includes an inlet passage 74 that extends laterally from the pumping chamber 60. The inlet passage 74 opens into an enlarged-diameter inlet valve bore 76 that houses the inlet valve 62, so that, when the inlet valve 62 is open, fuel can flow from the supply port 63, through the inlet valve 62 and the inlet passage 74 into the pumping chamber 60. A first internal shoulder 78 of the housing 56 is defined where the relatively large diameter inlet valve bore 76 meets the relatively small diameter inlet passage 74.

[0014] At its outside end, the inlet valve bore 76 includes an internally-threaded region 76a. The inlet valve 62 has an externally-threaded region that engages with the threaded region 76a of the inlet valve bore 76 to secure the inlet valve 62 in the housing 56. In use, an end face of the generally cylindrical inlet valve 62 is clamped against the first shoulder 78 of the housing 56 to form the first high-pressure seal 70.

[0015] A similar arrangement is present in the second horizontally-extending portion 56c of the housing 56. The outlet valve 86 comprises a generally cylindrical end member 64a, a valve ball 64b, and a spring 64c that acts between the valve ball 64b and the end member 64a. An outlet passage 84 extends laterally from the pumping chamber 60 to open into an enlarged-diameter outlet valve bore 86 that houses the end member 64a of the outlet valve 64. The outlet passage 84 includes a first portion 84a adjacent to the pumping chamber 60, and a second portion 84b with a larger diameter than the first portion 84a. A valve seat 84c for the valve ball 64b is provided in the outlet passage 84, where the first portion 84 meets the second portion 84b.

[0016] When the outlet valve 64 is open (i.e. when the valve ball 64b is lifted off the valve seat 84c), fuel can flow from the pumping chamber 60, through the outlet passage 84 and the outlet valve 64 and out of the housing 56 via the outlet port 65. A second internal shoulder 88 of the housing 56 is defined where the relatively large diameter outlet valve bore 86 meets the relatively small diameter outlet passage 84. At its outside end, the outlet valve bore 86 includes an internally-threaded region 86a that engages with an externally-threaded region of the outlet valve 64 to secure the outlet valve 64 in the housing 56.

[0017] In use, an end face of the generally cylindrical outlet valve 64 is clamped against the second shoulder 88 of the housing 56, with sufficient clamping force being applied to ensure that no fuel leaks past the second high-pressure seal 72. A further high-pressure seal (not shown) is required to seal the connection between the outlet port 65 and a fuel line (30 in Figure 1) that connects the head 50 to the fuel rail (14 in Figure 1), in use.

[0018] Referring to Figure 3, the drive assembly 100 comprises a housing 102, also known as a cam box, which houses a cylindrical cam 104. The housing 102 is only partially shown in Figure 3. The cam 104 is driven in eccentric rotational movement by a drive shaft (not shown in Figure 3) that extends through the housing 104, so that the cylinder axis C of the cam 104 describes a circular path around the axis A of the drive shaft (which extends normal to the drawing plane in Figure 3) as the drive shaft rotates. The path described by the edge of the cam 104 as it rotates is indicated by the dashed line P in Figure 3. The drive shaft has a smaller diameter than the cam 104.

[0019] The cam 104 carries a cam ring or rider 106, which includes a central cylindrical aperture 108 for receiving the cam 104. The rider 106 includes a flattened

surface region or flat 110, which is arranged to cooperate with a cam follower or tappet 112 that acts as a drive member for the pumping element 52. The cam 104 is free to rotate in the aperture 108, so that the orientation of the flat 110 of the rider 106 remains horizontal in use.

[0020] The tappet 112 is guided for reciprocal movement through an opening 114 in the housing 102, and is coupled to the pumping element 52 so that movement of the tappet 112 causes movement of the pumping element 52.

[0021] The tappet 112 includes a flat base surface 116 that is held in sliding contact with the flat 110 of the cam rider 106 by a biasing or return spring 118. The housing 102 contains a lubricant (conveniently fuel) that lubricates the sliding interfaces between the tappet 112 and the rider 106 and between the tappet 112 and the wall of the opening 114.

[0022] In operation, as the drive shaft rotates, the cam 104 carries the rider 106 in a path having an upward component, towards the opening 114 in the housing 102. By virtue of the upward component of movement of the rider 106, the tappet 112 is driven upwards by the rider 106, so as to drive the forward stroke of the pumping element (52 in Figure 2). Once the cam 104 reaches its uppermost position (top dead centre or TDC), continued rotation of the drive shaft results in the cam 104 carrying the rider 106 in a path having a downward component, away from the opening 114 in the housing 102. The biasing spring 118 keeps the tappet 112 in engagement with the flat 110 of the rider 106, so that the tappet 112 moves downwards and the pumping element (52 in Figure 2) is therefore driven by the biasing spring 114 in its return stroke. The pumping cycle repeats as the drive shaft continues to rotate.

[0023] One disadvantage of the pumping arrangement shown in Figures 2 and 3 is that only the forward stroke part of the pumping cycle is used to increase the pressure of fuel in the pumping chamber 60. The reverse stroke part of the pumping cycle is used only to re-fill the pumping chamber 60 with low-pressure fuel. Accordingly, the torque required to turn the drive shaft of the pump, and so the torque demanded from the engine, is substantially higher during the forward stroke than during the return stroke, giving rise to a torque peak or spike.

[0024] Torque spikes of this nature are undesirable, since they can cause damage to the components of the pumping arrangement and the associated drive train. In particular, the repetitive, cyclical forces to which the components are subjected can give rise to fatigue failures of the components. As pumping heads are designed for increasingly high pumping pressures to meet the demands of modern emissions legislation, correspondingly higher torque spikes occur, which increases the problem.

[0025] One approach to reducing this problem is to provide one or more further pumping heads, so that the demand for high-pressure fuel can be spread between the heads. The peak torque required by each head is therefore reduced.

[0026] For example, a second pumping head (not shown) may be mounted diametrically opposite the pumping head 50 shown in Figure 2. In this case, a pumping element (not shown) associated with the second pumping head is driven by a tappet (not shown) that cooperates with a second flat 110a provided on the rider 106. As the first pumping element 52 undergoes its forward stroke, the second pumping element undergoes its return stroke, and vice versa. Therefore the torque demand is more evenly spread in the pumping cycle.

[0027] Such a multi-head pumping arrangement, however, requires extra space to accommodate the or each additional pumping head. Furthermore, additional fuel lines or other suitable connection means must be provided to deliver low-pressure fuel to the additional head and to receive high-pressure fuel from the pumping head. Accordingly, the provision of one or more additional heads adds complexity and cost to the pumping arrangement.

[0028] Against this background, it would be desirable to provide a pumping head that addresses or overcomes the problems of the prior art.

Summary of the invention

[0029] According to a first aspect of the invention, a pumping head for a high-pressure fuel pump is provided. The pumping head comprises a head housing having a bore, a pumping element slidably received in the bore and arranged for reciprocal linear movement along a pumping axis in alternating forward and return strokes together defining a pumping cycle, and a first pumping chamber and a second pumping chamber, each pumping chamber being defined, in part, by the pumping element, and inlet means for delivering fluid to the first pumping chamber from a source of fluid.

[0030] The pumping head further comprises outlet means for conveying fluid from the second pumping chamber to an outlet of the pumping head, and transfer means for conveying fluid from the first pumping chamber to the second pumping chamber.

[0031] Each forward stroke of the pumping element causes an increase in volume of the first pumping chamber and a decrease in volume of the second pumping chamber, thereby to cause fluid to flow into the first pumping chamber from the inlet means and to cause fluid to flow out of the second pumping chamber to the outlet means. Each return stroke of the pumping element causes a decrease in volume of the first pumping chamber and an increase in volume of the second pumping chamber, thereby to cause fluid to flow from the first chamber to the second chamber through the transfer means.

[0032] Because the pumping head is provided with two pumping chambers, the pressure of fluid is increased both on the forward stroke and on the return stroke of the pumping cycle, thereby increasing the efficiency of the pumping head. Furthermore, when used with a rotary drive mechanism, the peak drive torque required to achieve a given outlet pressure can be reduced, com-

pared to a pumping head with a single pumping chamber. Advantageously, therefore, the risk of damage to the drive mechanism for the pumping element is reduced in the present invention.

[0033] In one embodiment, fluid is delivered to the first pumping chamber at a relatively low inlet pressure. The decrease in volume of the first pumping chamber during the return stroke preferably causes an increase in fluid pressure to an intermediate pressure. The decrease in volume of the second pumping chamber during the forward stroke preferably causes a further increase in fluid pressure to a relatively high outlet pressure.

[0034] By first pressurising the fluid to an intermediate pressure before subsequently pressurising the fluid to a relatively high outlet pressure, the force required to drive the pumping element, and therefore the torque required by a rotary drive mechanism, is reduced during the forward stroke. The intermediate pressure is preferably at least approximately 25% of the outlet pressure.

[0035] The first pumping chamber may be larger in cross-sectional area in a plane normal to the pumping axis than the second pumping chamber.

[0036] The transfer means preferably comprises a transfer passage in the pumping element. Alternatively, or in addition, the transfer means may comprise a transfer valve arranged to permit fluid flow from the first chamber to the second chamber during the return stroke, and to restrict fluid flow from the second chamber to the first chamber during the forward stroke.

[0037] Relief means for providing communication between the bore and a low-pressure drain may be provided. The relief means is remote from the first chamber and the second chamber. By providing relief means, any internal leakage flows of fluid within the pumping head can be exhausted from the pumping head to the drain, thereby preventing a build-up of leakage fluid in the pumping head.

[0038] In one example, the relief means comprises a non-return valve to prevent the flow of fluid from the drain into the pumping bore. Alternatively, or in addition, the relief means may comprise a relief chamber defined, in part, by the pumping element and optionally in part by the bore.

[0039] In one embodiment of the pumping head, the pumping element comprises a shaft and a collar portion. The first chamber may be defined, in part, by a first surface of the collar portion. When present, the relief chamber may be defined, in part, by an oppositely-facing second surface of the collar portion.

[0040] The second pumping chamber may be defined, in part, by an end of the pumping element. One or more of the first pumping chamber, the second pumping chamber and, when present, the relief chamber may be defined, in part, by the bore of the housing.

[0041] The pumping head may comprise a guide member for the pumping element and a retaining member for retaining the guide member. The first pumping chamber may be defined, in part, by the guide member.

[0042] When a guide member is present, the inlet means may comprise a fluid flow path between the guide member and the retaining member, and the guide member may be engageable with the retaining member to restrict fluid flow through the fluid flow path during the return stroke. Alternatively, the inlet means may comprise an inlet passage that opens into the first chamber, and the pumping element may be arranged to occlude the inlet passage to limit flow between the first chamber and the inlet passage during a portion of the pumping cycle.

[0043] The outlet means may comprise an outlet valve, the outlet valve being configured to allow fluid to flow from the second pumping chamber to the outlet during the forward stroke. The outlet valve may be configured to allow fluid to flow only when the pressure of fluid in the second pumping chamber reaches a pre-determined outlet pressure. The outlet valve is preferably a non-return valve, to prevent the flow of fluid from the outlet into the second pumping chamber during the return stroke.

[0044] In one embodiment of the invention, the pumping head includes a third pumping chamber comprising an inlet pumping chamber, a first inlet passage for delivering fluid to the inlet pumping chamber from the source of fluid, and a second inlet passage for transferring fluid from the inlet pumping chamber to the first pumping chamber. The return stroke of the pumping element causes an increase in volume of the inlet pumping chamber, thereby to cause fluid to flow into the inlet pumping chamber from the first inlet passage. The forward stroke of the pumping element causes a decrease in volume of the inlet pumping chamber, thereby to cause fluid to flow from the inlet pumping chamber to the first pumping chamber through the second inlet passage. In this way, the fluid can be increased to a first intermediate pressure in the inlet pumping chamber, then to a second intermediate pressure in the first chamber, and then to the outlet pressure in the second chamber.

[0045] In a second aspect of the invention, a fuel pump for a fuel injection system is provided. The fuel pump comprises a pumping head according to the first aspect of the invention, and a drive mechanism for driving the pumping element of the pumping head in linear reciprocal movement.

[0046] From a third aspect, the invention resides in a method for pressurising fluid to a relatively high outlet pressure in a pumping head of a fluid pump. The method comprises admitting fluid to the pumping head at a relatively low inlet pressure, pressurising the fluid to an intermediate pressure during a first stage of a pumping cycle, and pressurising the fluid to the relatively high outlet pressure during a second stage of the pumping cycle.

[0047] By pressurising the fluid first to an intermediate pressure and then further to a relatively high outlet pressure, the force required to pressurise the fluid is distributed over both the first and second stages of the pumping cycle. Accordingly, the peak force required is advantageously lower than if the pressure of the fluid were to be

increased from the inlet pressure to the outlet pressure in one pumping operation.

[0048] Preferred and/or optional features of each aspect of the invention may also be used, alone or in appropriate combination, with the other aspects of the invention also.

Brief description of the drawings

[0049]

Figure 1 of the accompanying drawings, which has been referred to above, is a schematic diagram of a conventional fuel injection system of an internal combustion engine having a conventional high-pressure fuel pump.

Figures 2 and 3, which have also been referred to above, are schematic cross-sectional views of a pumping head and a drive assembly, respectively, of a conventional high-pressure fuel pump for use in the fuel injection system of Figure 1.

[0050] The present invention will now be described, by way of example only, with reference to the remaining accompanying drawings, in which like reference numerals are used for like features, and in which:

Figure 4 is a cross-sectional view of a pumping head according to the invention;

Figure 5 is a cross-sectional view of part of another pumping head according to the invention; and

Figure 6 is an inclined sectional view of the pumping head of Figure 5, sectioned on line R-S.

[0051] Throughout this description, terms such as 'upper', 'lower' and so on relate to the orientation of the components as shown in the accompanying drawings and are used for ease of reference only. It should be understood that the invention could be used in any suitable orientation.

Detailed description of embodiments of the invention

[0052] Figure 4 shows a pumping head 200 according to a first embodiment of the present invention. The pumping head 200 is suitable for use in a high-pressure fuel pump in a fuel injection system. The pumping head 200 includes a pumping element or plunger 202 that is driveable in linear reciprocal movement along a pumping axis Q by a drive mechanism (not shown) of the pump.

[0053] The pumping head 200 comprises a generally cylindrical housing 204 having a blind pumping bore 206 that extends upwardly from the lowermost end 204a of the housing 204 and receives the pumping element 202. The pumping bore 206 extends coaxially with the pump-

ing axis Q.

[0054] The pumping bore 206 comprises a relatively small diameter upper portion 206a, and a relatively large diameter lower portion 206b. An internal shoulder 208 of the pumping bore 206 is defined where the upper and lower portions 206a, 206b meet.

[0055] The pumping element 202 includes a shaft 210 and a collar portion 212 located part-way along the shaft 210. An upper end portion 210a of the shaft 210, above the collar portion 212, is slidably received in the relatively small diameter upper portion 206a of the pumping bore 206, and a lower portion 210b of the shaft 210 extends downwards out of the pumping head 200 to cooperate with the drive mechanism (not shown). The collar portion 212 has a larger diameter than the shaft 210, and is slidably received in the relatively large diameter lower 206b of the pumping bore 206.

[0056] The pumping bore 206 is closed at the lowermost end 204a of the housing 204 by a sealing arrangement 214 through which the lower portion 210b of the shaft 210 extends. The sealing arrangement 214 includes an annular guide member 216 of generally tubular form, a sealing washer 218, and a retaining member 220.

[0057] The guide member 216 includes a central bore 216a for receiving the lower portion 210b of the shaft 210. An upper end portion of the guide member 216 is provided with an outwardly-extending flange 216b. The sealing washer 218 is located between an upper face of the flange 216b and the lower end 204a of the housing 204.

[0058] The retaining member 220 is of generally tubular form, and includes a bore 220a for receiving the lowermost end 204a of the housing 204. The retaining member 220 and the lowermost end 204a of the housing 204 are provided with cooperating threaded regions (not shown), so that the retaining member 220 can be securely engaged with the end 204a of the housing 204 during assembly of the pumping head 200.

[0059] A lower end portion of the retaining member 220 is provided with an inwardly-extending flange 220b, which cooperates with the outwardly-extending flange 216b of the guide member 216. In this way, the guide member 216 is retained by the retaining member 220, and the sealing washer 218 is clamped between the guide member 216 and the lowermost end 204a of the housing 204.

[0060] An annular first pumping chamber 240 of the pumping head 200 is defined by the lowermost face of the collar 212, part of the lower portion 210b of the shaft 210, part of the wall of the lower portion 206a of the pumping bore and the uppermost face of the guide member 216. The sealing washer 218 prevents leakage of fluid from the first pumping chamber 240 between the housing 204 and the guide member 216. The lower portion 210b of the shaft 210 is a close sliding fit in the bore 216a of the guide member 216, so that leakage from the first pumping chamber 240 between the shaft 210 and the guide member 216 is minimal.

[0061] The upper portion 206b of the pumping bore 206 ends at an end wall 204b of the housing 204. A generally cylindrical second pumping chamber 242 is defined by the uppermost end of the pumping element shaft 210, the wall of the upper portion 206b and the end wall 204b of the housing 204. The upper portion 201a of the pumping element shaft 210 is a close sliding fit in the upper portion 206b of the pumping bore 206, so that leakage from the second pumping chamber 242 between the shaft 210 and the housing 204 is minimal.

[0062] At its uppermost end, the housing 204 is provided with a tubular outlet port 244 that is threaded to connect with a high-pressure fluid line (not shown) in use of the pumping head 200. An outlet valve 246 is housed within the outlet port 244.

[0063] The outlet valve 246 provides an outlet means that controls the flow of fluid through an outlet passage 248 that extends through the end wall 204b of the housing, between the second pumping chamber 242 and the outlet port 244. The outlet valve 246 comprises a valve ball 250 that is engageable with a seating surface 252 formed at the upper end of the outlet passage 248. A biasing spring 254 biases the valve ball 250 into engagement with the seating surface 252. The biasing spring 254 acts between the valve ball 250 and a cup-shaped outlet valve body 256. The outlet valve body 256 is an interference fit in the outlet port 244, and includes an aperture 258 to allow fluid flow through the outlet valve 246 when the valve ball 250 is disengaged from the seating surface 252.

[0064] A transfer passage 260 extends between the first chamber 240 and the second chamber 242, through the pumping element 206, to provide a transfer means for fluid. The transfer passage 260 includes a first section 260a that extends inwardly from the outer surface of the pumping element 202, in a direction inclined to the pumping axis Q. The first section 260a opens into the first chamber 240 at the corner between the collar portion 212 and the lower shaft portion 210b.

[0065] Inside the pumping element 202, the first section 260a of the transfer passage 260 meets a second section 260b of the transfer passage 260 that extends in a coaxial direction with respect to the pumping axis Q. The second section 260b of the transfer passage 260, in turn, opens into a third section 260c of the transfer passage that has an increased diameter, relative to the first and second sections 260a, 260b. The third section 260c of the transfer passage 260 opens into the second pumping chamber 242 at the top end of the pumping element 202.

[0066] A transfer passage valve 262 is housed in the third section 260c of the transfer passage 260, to control the flow of fluid from the first chamber 240 to the second chamber 242 through the transfer passage 260.

[0067] The transfer passage valve 262 is of similar construction to the outlet valve 246, and comprises a valve ball 264 that is engageable with a seating surface 266 formed at the upper end of the third transfer passage

section 260c. A biasing spring 268 acts between the valve ball 264 and a cup-shaped transfer passage valve body 270 to urge the valve ball 264 into engagement with the seating surface 266. The valve body 270 is an interference fit in the third transfer passage section 260c, and includes an aperture 272 to allow fluid flow through the transfer passage valve 262 when the valve ball 264 is disengaged from the seating surface 266.

[0068] A relief chamber 274 of the pumping head 200 is defined by the uppermost face of the collar 212, part of the upper portion 210a of the shaft 210, the wall of the upper portion 206b of the pumping bore 206 and the shoulder 208 of the pumping bore 206. A relief port 276 is provided in the wall of the housing 206, and the relief port 276 communicates with the relief chamber 274 by way of a relief passage 278.

[0069] A non-return relief valve 280 is received in the relief chamber 274, to control the flow of fluid from the relief chamber 274 to the relief port 276. The relief valve 280 is similar in construction to the outlet valve 246 and the transfer passage valve 262, and comprises a valve ball 282 that engages with a seating surface 284 formed at the end of the relief passage 278, a biasing spring 284, and a valve body 286 having an aperture 288. The components of the relief valve 280 are arranged as described above with reference to the outlet valve 246 and the transfer passage valve 262.

[0070] In use, the relief port 276 is connected to a low-pressure drain (such as the internal volume of a pump housing or the fuel tank of a fuel injection system). The relief chamber 280 and the relief port 276 are remote from the first chamber 240 and the second chamber 242. In other words, the relief chamber 274 and the relief port 276 are not in communication with the first chamber 240 or the second chamber 242 by a dedicated fluid flow passage. However, fluid can leak into the relief chamber 274 from both the first chamber 240 and the second chamber 242 along the sliding interfaces between the plunger 202 and the bore 206.

[0071] Fluid is supplied to the pumping head 200 by a supply line (not shown) that communicates with an inlet means comprising an inlet passage 290 that extends through the wall of the housing 204. The inlet passage 290 is arranged so that, as the pumping element 202 reciprocates within the pumping bore 206, the inlet passage 290 is either occluded by the collar portion 212 of the pumping element 202 (as shown in Figure 4), or is open to allow fluid flow from the inlet passage 290 into the first pumping chamber 240.

[0072] Operation of the pumping head 200 will now be described. As mentioned above, the drive mechanism (not shown) drives the pumping element 202 in reciprocal linear movement. The pumping element 202 moves between a bottom dead centre (BDC) position, in which the pumping element 202 is at its furthest downward extent of travel in the pumping bore 206, and a top dead centre (TDC) position, in which the pumping element 202 is at its furthest upward extent of travel in the pumping bore

206.

[0073] Movement of the pumping element 202 from the BDC position to the TDC position is known as a forward stroke of the pumping element 202, and movement of the pumping element 202 from the TDC position to the BDC position is known as a return stroke of the pumping element 202. The forward and return strokes of the pumping element 202 together define a pumping cycle.

[0074] Starting from the BDC position, as the pumping element 202 moves upwards within the pumping bore 206 in the forward stroke of the pumping cycle, the volume of the first pumping chamber 240 increases, while the volume of the second pumping chamber 242 decreases. The transfer passage valve 262 acts as a non-return valve to prevent fluid from flowing from the second pumping chamber 242 into the first pumping chamber 240 through the transfer passage 260.

[0075] During the forward stroke of the pumping element 202, therefore, the pressure of fluid in the first pumping chamber 240 decreases as the volume of the first pumping chamber 240 increases. During a first part of the forward stroke, the inlet passage 290 is occluded by the collar portion 212 of the pumping element 202. Then, as the pumping element 202 continues to move upwards, the collar portion 212 moves past the opening of the passage 290 to allow fluid to flow from the inlet passage 290 into the first pumping chamber 240 to fill the first pumping chamber 240 with fluid at relatively low pressure, corresponding to the pressure at which fluid is supplied to the inlet passage 290.

[0076] At the same time, during the forward stroke of the pumping element 202, the pressure of fluid in the second pumping chamber 242 increases as the volume of the second pumping chamber 242 decreases. The pressure in the second pumping chamber 242 continues to rise as the pumping element 202 moves upwards within the pumping bore 206.

[0077] The outlet valve 246 is configured such the ball 250 moves away from its seating surface 252, against the action of the biasing spring 254, when the fluid pressure difference across the outlet valve 246 reaches a predetermined value. In other words, the outlet valve 246 opens when the fluid pressure in the second pumping chamber 242 reaches a sufficiently high pressure. Once the outlet valve 246 opens, fluid is ejected from the second pumping chamber 242 through the outlet port 244 at relatively high pressure.

[0078] Once the pumping element 202 reaches the TDC position, the outlet valve 246 closes and the return stroke of the pumping element 202 begins. During the return stroke, the volume of the first pumping chamber 240 decreases, and the volume of the second pumping chamber 242 increases.

[0079] Accordingly, the pressure of fluid in the first chamber 240 increases, and the pressure of fluid in the second chamber 242 decreases. The transfer passage valve 262 is configured such that, when the pressure of fluid in the first chamber 240 exceeds the pressure of the

fluid in the second chamber 242 by a pre-determined amount, the transfer passage valve 262 opens to allow fluid to flow from the first chamber 240 to the second chamber through the transfer passage 260.

[0080] During a first part of the return stroke, the inlet passage 290 remains open so some fluid may flow from the first pumping chamber 240 back out of the inlet passage 290. However, in a second part of the return stroke, the collar portion 212 of the pumping element 202 occludes the inlet passage 290 to restrict further flow through the inlet passage 290. During this second part of the return stroke, in particular, the fluid in the first pumping chamber 240 becomes pressurised, and is forced through the transfer passage 260 into the second pumping chamber 242.

[0081] The volume change that occurs in the first chamber 240 during a given linear displacement of the pumping element 202 is greater than the volume change that occurs in the second chamber 242 during the same linear displacement. As a result, the fluid pressure rises to an intermediate level as it passes from the first pumping chamber 240 to the second pumping chamber 242 during the return stroke.

[0082] The pumping cycle continues with another forward stroke, in which the first pumping chamber 240 is re-filled with fluid from the inlet passage 290, and the fluid in the second pumping chamber 242 is expelled at high pressure through the outlet port 244.

[0083] Fluid is therefore pumped through the pumping head 200 from the inlet passage 290 to the outlet port 244 in three consecutive pumping strokes of the pumping element, namely a first forward stroke, a return stroke, and a second forward stroke, as will now be described.

[0084] A quantity of fluid is drawn into the first pumping chamber 240 during the first forward stroke of the pumping element 202. During the subsequent return stroke, the quantity of fluid is pressurised to an intermediate pressure in the first pumping chamber 240 and is transferred to the second pumping chamber 242. At the end of the return stroke, therefore, the fluid in the second pumping chamber 242 is already at an elevated intermediate pressure, which is lower than the ultimate outlet pressure, but which is substantially higher than the inlet pressure. During the second forward stroke, the fluid in the second pumping chamber 242 is pressurised further to a relatively high outlet pressure, and is delivered from the pumping head 200 through the outlet port 244 at the outlet pressure.

[0085] The magnitude of the volume change that occurs in the first chamber 240 during the forward and return strokes of the pumping element 202 is greater than the magnitude of the volume change that occurs in the second chamber 242 during the forward and return strokes. Said another way, the cross-sectional area of the first chamber 240 in a plane normal to the pumping axis Q is greater than the cross-sectional area of the second chamber 242, so that the volume swept by the pumping element 202 in use is greater in the first chamber 240

than in the second chamber 242. In this way, although the linear displacement of the pumping element 202 in each chamber is the same, the increase in fuel pressure that occurs in the first chamber 240 is less than the increase in fluid pressure that occurs in the second chamber 242, in use.

[0086] It will be understood that the pumping head 200 is arranged so that the pressure of fluid is increased both on the forward stroke and on the return stroke of the pumping cycle. The torque demand on the drive mechanism, and on the drive train that drives the drive mechanism, is therefore split between the forward and return strokes, and torque spikes of lower magnitude occur than would be the case if the pressure of the fluid were elevated to the outlet pressure during only the forward stroke of the pumping element 202.

[0087] In particular, because the fluid is delivered to the second pumping chamber 242 at an elevated pressure, the second pumping chamber 242 can be reduced in volume compared to the single pumping chamber of a known pumping head, such as that shown in Figure 2, whilst achieving the same delivery volume. Accordingly, the maximum torque required to pressurise the fuel to the same outlet pressure is lower in the pumping head of the invention.

[0088] The intermediate fluid pressure to which the fluid is elevated during the return stroke of the pumping element 202 depends on, amongst other factors, the cross-sectional area of the first pumping chamber 240, the stroke of the pumping element 202, the force of the biasing spring 268 of the transfer passage valve 262.

[0089] Preferably, the pumping head 200 is arranged so that, during the return stroke of the pumping element 202, the pressure of the fluid that reaches the second pumping chamber 242 is increased to an intermediate pressure that is approximately 25% of the outlet pressure from the pumping head 200. However, it will be appreciated that the pumping head 200 could be designed so that the intermediate pressure is higher or lower than 25% of the outlet pressure.

[0090] During operation of the pumping head 200, fluid may leak between the pumping element 202 and the pumping bore 206 into the relief chamber 274. For example, during the forward stroke of the pumping element 202, fluid may leak from the second pumping chamber 242 past the upper portion 210a of the pumping element shaft 210 into the relief chamber 274, and during the return stroke of the pumping element 202, fluid may leak from the first pumping chamber past the collar portion 212 of the pumping element 202 into the relief chamber 274.

[0091] Fluid that leaks into the relief chamber 274 can flow out of the pumping head 200 through the relief valve 280, thereby preventing a build-up of leakage fluid in the pumping head 200 that could otherwise impair its operation. The relief valve 280 acts as a non-return valve to prevent fluid being drawn into the relief chamber 274 from the low-pressure drain.

[0092] A pumping head 300 according to a second embodiment of the invention will now be described with reference to Figure 5 which is a cross-sectional view of part of the pumping head 300 taken on a vertical plane containing the pumping axis Q, and to Figure 6, which is a cross-section taken on an inclined plane, along line R-S in Figure 5.

[0093] The pumping head 300 of the second embodiment differs from the pumping head 200 of the first embodiment, shown in Figure 4, in the arrangement of the inlet means and in the configuration of the sealing arrangement that closes the lowermost end of the pumping bore, and only these differences will be described in detail below. The pumping heads 200, 300 of the first and second embodiments of the invention are otherwise identical. Like reference numerals are therefore used in Figures 5 and 6 to denote like components already described with reference to Figure 4, and reference should be made to the foregoing description where appropriate for an explanation of the features of the pumping head 300 of the second embodiment that are not referred to again below.

[0094] In the pumping head 300 of the second embodiment, the pumping bore 206 is closed at the lowermost end 204a of the housing 204 by an inlet arrangement 314 that provides an inlet means to supply fluid to the first pumping chamber 240. No separate inlet passage to the pumping bore 204 need be provided.

[0095] The inlet arrangement 314 comprises an annular guide member 316 of generally tubular form, and a retaining member 320. The guide member 316 includes a central bore 316a in which the lower portion 210b of the pumping element shaft 210 is slidably received. An upper portion of the guide member 316 is provided with an outwardly-extending flange 316b. As shown most clearly in Figure 6, the upper surface of the flange 316b is provided with a plurality of channels 316c that extend radially inwards from the periphery of the flange 316b. The channels 316c stop short of the bore 316a.

[0096] The retaining member 320 is of similar form to the retaining member 220 of the pumping head 200 of the first embodiment of the invention. The retaining member 320 is therefore of generally tubular form and includes a bore 320a for receiving the lowermost end 204a of the housing 204. The retaining member 320 and the lowermost end 204a of the housing 204 are provided with cooperating threaded regions (not shown). When assembled, an upper end 320c of the retaining member 320 abuts a shoulder 204c of the housing 204.

[0097] A lower end portion of the retaining member 320 is provided with an inwardly-extending flange 320b. The guide member 316 is a clearance fit within the flange 320b, and the outer diameter of the flange 316b of the guide member 316 is less than the inside diameter of the retaining member 320.

[0098] Furthermore, the flange 316a of the slide member has a thickness that is less than the gap between the lowermost end 204a of the housing 204 and the uppermost face of the flange 320b of the retaining member 320.

[0099] Accordingly, the guide member 316 can move in a direction parallel to the pumping axis Q within the gap between the lowermost end 204a of the housing 204 and the flange 320b of the retaining member. In use, the guide member 316 cooperates with the retaining member 320 and the housing 204 to act as an inlet disc valve for the pumping head 300, as will now be described.

[0100] When the pumping element 202 moves upwards, during the forward stroke of the pumping cycle, the decreasing pressure in the first pumping chamber 240 causes the guide member 316 to move upwards into a first position. In the first position, the upper surface of the flange 316b of the guide member 316 abuts the lowermost end 204a of the housing 204, leaving a gap between the lower surface of the flange 316b of the guide member 316 and the upper surface of the flange 320b of the retaining member 320. With the guide member 316 in this first position, fluid can flow into the first pumping chamber 240 via the clearances between the guide member 316 and the retaining member 320, and through the channels 316c in the upper surface of the flange 320b that provide a flow path for fluid past the lowermost end 204a of the housing 204.

[0101] When the pumping element 202 moves downwards, during the return stroke of the pumping cycle, the increasing pressure in the first pumping chamber 240 causes the guide member 316 to move downwards into a second position. In the second position, the flange 316b of the guide member 316 seats against the flange 320b of the retaining member 320, thereby preventing fluid flow out of the first pumping chamber 240 through the inlet arrangement 314.

[0102] The pumping head 300 shown in Figures 5 and 6 may be used where the fluid to be pumped is supplied to the pumping head 300 by way of an internal volume defined by a housing (not shown) that houses the drive mechanism for the pumping element 204. In such a case, the fluid to be pumped may comprise a lubricating fluid, such as diesel fuel, that lubricates the drive mechanism.

[0103] Several modifications and variations of the embodiments described above can be contemplated.

[0104] For example, any suitable inlet means may be provided for supplying fluid to the first pumping chamber. Instead of an inlet passage that is occluded by the port (as shown in Figure 4) or a disc-valve arrangement (as shown in Figures 5 and 6), an inlet passage that is always in communication with the first pumping chamber may be provided, and an external check valve may be used to prevent back-flow into the inlet passage during the return stroke of the pumping element. In any arrangement, an inlet metering valve may be provided to regulate the supply of fluid to the pumping head through the inlet means. Conceivably, the inlet means may include one or more passages in the pumping element.

[0105] Any suitable outlet valve arrangement could be provided in place of the ball-type outlet valve described above. The outlet valve arrangement may be integral with the pumping head, as described above, or may be

housed separately from the pumping head with a high-pressure line to convey fluid from the pumping head to the outlet valve arrangement.

[0106] Similarly, any suitable transfer passage valve arrangement could be provided. For example, a transfer passage arrangement having one or more ports that are occluded by the pumping element during part of the pumping cycle could be used to effect transfer of fluid from the first chamber to the second chamber.

[0107] Any suitable means may be used to transfer fluid from the first pumping chamber to the second pumping chamber, in use. For example, instead of or in addition to a transfer passage in the pumping element, one or more transfer passages that extend within a wall of the housing could be provided.

[0108] Pumping heads according to the invention with alternative configurations of the pumping element and pumping bore can be envisaged. For example, the upper portion of the pumping bore and the upper portion of the pumping element shaft could be omitted, and the first chamber could be provided in the space occupied by the third chamber in the above-described embodiments.

[0109] In the embodiments described above, the third chamber serves only to provide a path for leakage fluid to return to drain. However, the third chamber could instead be used as an additional pumping chamber of the pumping head.

[0110] In an arrangement with three pumping chambers and a suitable arrangement of transfer passages to transfer fluid between the pumping chambers, the fluid could be pressurised to a first intermediate pressure in a first pumping chamber during one stroke of the pumping element, then pressurised to a second, higher intermediate pressure in the second pumping chamber during the next stroke, and then pressurised to the outlet pressure in the third pumping chamber during the next stroke.

[0111] For example, in one embodiment (not illustrated), the third chamber comprises an inlet pumping chamber. Instead of being connected to the first chamber, the inlet passage is arranged to deliver fluid to the inlet pumping chamber. A second inlet passage is provided to transfer fluid from the inlet pumping chamber to the first pumping chamber. The second inlet passage may, for example, extend through the collar portion of the pumping element, and may include a non-return valve to prevent back flow from the first chamber into the inlet pumping chamber.

[0112] When the volume of the inlet pumping chamber increases during the return stroke of the pumping element, fluid flows into the inlet pumping chamber from the first inlet passage. Then, when the volume of the inlet pumping chamber decreases during the forward stroke of the pumping element, the fluid in the inlet pumping chamber is pressurised to a first intermediate pressure, and is transferred from the inlet pumping chamber to the first pumping chamber through the second inlet passage. A subsequent return stroke elevates the pressure of the fluid in the first pumping chamber further, to a second

intermediate pressure, while the fluid is transferred to the second pumping chamber. Finally, on the next forward stroke, the fluid pressure is increased from the second intermediate pressure to the outlet pressure in the second pumping chamber.

[0113] A known drive mechanism such as that described with reference to Figure 3 may be used to drive the reciprocal movement of the pumping element, in which case the force available to drive the return stroke of the plunger depends on the strength of the return spring of the drive mechanism. In an alternative embodiment, a drive mechanism capable of driving the return stroke of the plunger by means other than a return spring may be used.

[0114] It will be appreciated that the pumping head of the present invention is not limited to use in a fuel injection system, but would be suitable for any application in which a high-pressure pumping head with good reliability and a simple design is desirable.

[0115] Further modifications and variations could also be contemplated by a person skilled in the art, without departing from the scope of the invention as defined in the appended claims.

Claims

1. A pumping head (200; 300) for a high-pressure fuel pump, comprising:

a head housing (204) having a bore (206);
 a pumping element (202) slidably received in the bore (206) and arranged for reciprocal linear movement along a pumping axis (Q) in alternating forward and return strokes together defining a pumping cycle;
 a first pumping chamber (240) and a second pumping chamber (242), each pumping chamber (240, 242) being defined, in part, by the pumping element (202);
 inlet means (290; 314) for delivering fluid to the first pumping chamber (240) from a source of fluid;
 outlet means (246, 248) for conveying fluid from the second pumping chamber (242) to an outlet (244) of the pumping head; and
 transfer means (260, 262) for conveying fluid from the first pumping chamber (240) to the second pumping chamber (242);
 wherein each forward stroke of the pumping element (202) causes an increase in volume of the first pumping chamber (240) and a decrease in volume of the second pumping chamber (242), thereby to cause fluid to flow into the first pumping chamber (240) from the inlet means (290; 314) and to cause fluid to flow out of the second pumping chamber (242) to the outlet means (246, 248);

- and wherein each return stroke of the pumping element (202) causes a decrease in volume of the first pumping chamber (240) and an increase in volume of the second pumping chamber (242), thereby to cause fluid to flow from the first chamber (240) to the second chamber (242) through the transfer means (260, 262).
2. A pumping head according to Claim 1, wherein fluid is delivered to the first pumping chamber (240) at a relatively low inlet pressure, and wherein:
 - the decrease in volume of the first pumping chamber (240) during the return stroke causes an increase in fluid pressure to an intermediate pressure; and
 - the decrease in volume of the second pumping chamber (242) during the forward stroke causes a further increase in fluid pressure to a relatively high outlet pressure.
 3. A pumping head according to Claim 1 or Claim 2, wherein the first pumping chamber (240) is larger in cross-sectional area in a plane normal to the pumping axis than the second pumping chamber (242).
 4. A pumping head according to any preceding Claim, wherein the transfer means comprises a transfer passage (260) in the pumping element (202).
 5. A pumping head according to any preceding Claim, wherein the transfer means comprises a transfer valve (262) arranged to permit fluid flow from the first chamber (240) to the second chamber (242) during the return stroke, and to restrict fluid flow from the second chamber (242) to the first chamber (240) during the forward stroke.
 6. A pumping head according to any preceding Claim, further comprising relief means (274, 276, 278, 280) for providing communication between the bore (206) and a low-pressure drain, the relief means (274, 276, 278, 280) being remote from the first chamber (240) and the second chamber (242)
 7. A pumping head according to Claim 6, wherein the relief means comprises a non-return valve (280) to prevent the flow of fluid from the drain into the pumping bore (202).
 8. A pumping head according to Claim 6 or Claim 7, wherein the relief means comprises a relief chamber (274) defined, in part, by the pumping element (202).
 9. A pumping head according to Claim 8, wherein the pumping element (202) comprises a shaft (210) and a collar portion (212), and wherein the first chamber (240) is defined, in part, by a first surface of the collar portion (212) and the relief chamber (274) is defined, in part, by an oppositely-facing second surface of the collar portion (212).
 10. A pumping head according to any of Claims 1 to 8, wherein the pumping element (202) comprises a shaft (210) and a collar portion (212), and wherein the first chamber (240) is defined, in part, by a surface of the collar portion (212).
 11. A pumping head according to any preceding Claim, wherein the second pumping chamber (232) is defined, in part, by an end of the pumping element (202).
 12. A pumping head according to any preceding Claim, comprising a guide member (216; 316) for the pumping element (202) and a retaining member (220; 320) for retaining the guide member (216; 316), wherein the first pumping chamber (240) is defined, in part, by the guide member (216; 316).
 13. A pumping head according to Claim 12, wherein the inlet means comprises a fluid flow path between the guide member (316) and the retaining member (320), and wherein the guide member (316) is engageable with the retaining member (320) to restrict fluid flow through the fluid flow path during the return stroke.
 14. A pumping head according to any of Claims 1 to 12, wherein the inlet means comprises an inlet passage (290) that opens into the first chamber (240), and wherein the pumping element (202) is arranged to occlude the inlet passage (290) to limit flow between the first chamber (240) and the inlet passage (290) during a portion of the pumping cycle.
 15. A method for pressurising fluid to a relatively high outlet pressure in a pumping head (200; 300) of a fluid pump, the method comprising:
 - admitting fluid to the pumping head at a relatively low inlet pressure;
 - pressurising the fluid to an intermediate pressure during a first stage of a pumping cycle; and
 - pressurising the fluid to the relatively high outlet pressure during a second stage of the pumping cycle.

Amended claims in accordance with Rule 137(2) EPC.

1. A pumping head (200; 300) for a high-pressure fuel pump, comprising:
 - a head housing (204) having a bore (206);

a pumping element (202) slidably received in the bore (206) and arranged for reciprocal linear movement along a pumping axis (Q) in alternating forward and return strokes together defining a pumping cycle;

a first pumping chamber (240) and a second pumping chamber (242), each pumping chamber (240, 242) being defined, in part, by the pumping element (202);

inlet means (290; 314) for delivering fluid to the first pumping chamber (240) from a source of fluid;

outlet means (246, 248) for conveying fluid from the second pumping chamber (242) to an outlet (244) of the pumping head; and

transfer means (260, 262) for conveying fluid from the first pumping chamber (240) to the second pumping chamber (242);

wherein each forward stroke of the pumping element (202) causes an increase in volume of the first pumping chamber (240) and a decrease in volume of the second pumping chamber (242), thereby to cause fluid to flow into the first pumping chamber (240) from the inlet means (290; 314) and to cause fluid to flow out of the second pumping chamber (242) to the outlet means (246, 248);

and wherein each return stroke of the pumping element (202) causes a decrease in volume of the first pumping chamber (240) and an increase in volume of the second pumping chamber (242), thereby to cause fluid to flow from the first chamber (240) to the second chamber (242) through the transfer means (260, 262).

2. A pumping head according to Claim 1, wherein fluid is delivered to the first pumping chamber (240) at a relatively low inlet pressure, and wherein:

the decrease in volume of the first pumping chamber (240) during the return stroke causes an increase in fluid pressure to an intermediate pressure; and

the decrease in volume of the second pumping chamber (242) during the forward stroke causes a further increase in fluid pressure to a relatively high outlet pressure.

3. A pumping head according to Claim 1 or Claim 2, wherein the first pumping chamber (240) is larger in cross-sectional area in a plane normal to the pumping axis than the second pumping chamber (242).

4. A pumping head according to any preceding Claim, wherein the transfer means comprises a transfer passage (260) in the pumping element (202).

5. A pumping head according to any preceding Claim, wherein the transfer means comprises a transfer valve (262) arranged to permit fluid flow from the first chamber (240) to the second chamber (242) during the return stroke, and to restrict fluid flow from the second chamber (242) to the first chamber (240) during the forward stroke.

6. A pumping head according to any preceding Claim, further comprising relief means (274, 276, 278, 280) for providing communication between the bore (206) and a low-pressure drain, the relief means (274, 276, 278, 280) being remote from the first chamber (240) and the second chamber (242)

7. A pumping head according to Claim 6, wherein the relief means comprises a non-return valve (280) to prevent the flow of fluid from the drain into the pumping bore (202).

8. A pumping head according to Claim 6 or Claim 7, wherein the relief means comprises a relief chamber (274) defined, in part, by the pumping element (202).

9. A pumping head according to Claim 8, wherein the pumping element (202) comprises a shaft (210) and a collar portion (212), and wherein the first chamber (240) is defined, in part, by a first surface of the collar portion (212) and the relief chamber (274) is defined, in part, by an oppositely-facing second surface of the collar portion (212).

10. A pumping head according to any of Claims 1 to 8, wherein the pumping element (202) comprises a shaft (210) and a collar portion (212), and wherein the first chamber (240) is defined, in part, by a surface of the collar portion (212).

11. A pumping head according to any preceding Claim, wherein the second pumping chamber (232) is defined, in part, by an end of the pumping element (202).

12. A pumping head according to any preceding Claim, comprising a guide member (216; 316) for the pumping element (202) and a retaining member (220; 320) for retaining the guide member (216; 316), wherein the first pumping chamber (240) is defined, in part, by the guide member (216; 316).

13. A pumping head according to Claim 12, wherein the inlet means comprises a fluid flow path between the guide member (316) and the retaining member (320), and wherein the guide member (316) is engageable with the retaining member (320) to restrict fluid flow through the fluid flow path during the return stroke.

14. A pumping head according to any of Claims 1 to 12, wherein the inlet means comprises an inlet passage (290) that opens into the first chamber (240), and wherein the pumping element (202) is arranged to occlude the inlet passage (290) to limit flow between the first chamber (240) and the inlet passage (290) during a portion of the pumping cycle. 5

15. A method for pressurising fluid to a relatively high outlet pressure in a pumping head (200; 300) according to any of Claims 1 to 14, the method comprising: 10

- admitting fluid to the first pumping chamber (240) of the pumping head at a relatively low inlet pressure, by way of the inlet means (290, 314); 15
- pressurising the fluid to an intermediate pressure in the first pumping chamber (240) during a return stroke of the pumping element (202); 20
- and
- pressurising the fluid to the relatively high outlet pressure in the second pumping chamber (242) during a forward stroke of the pumping element (202). 25

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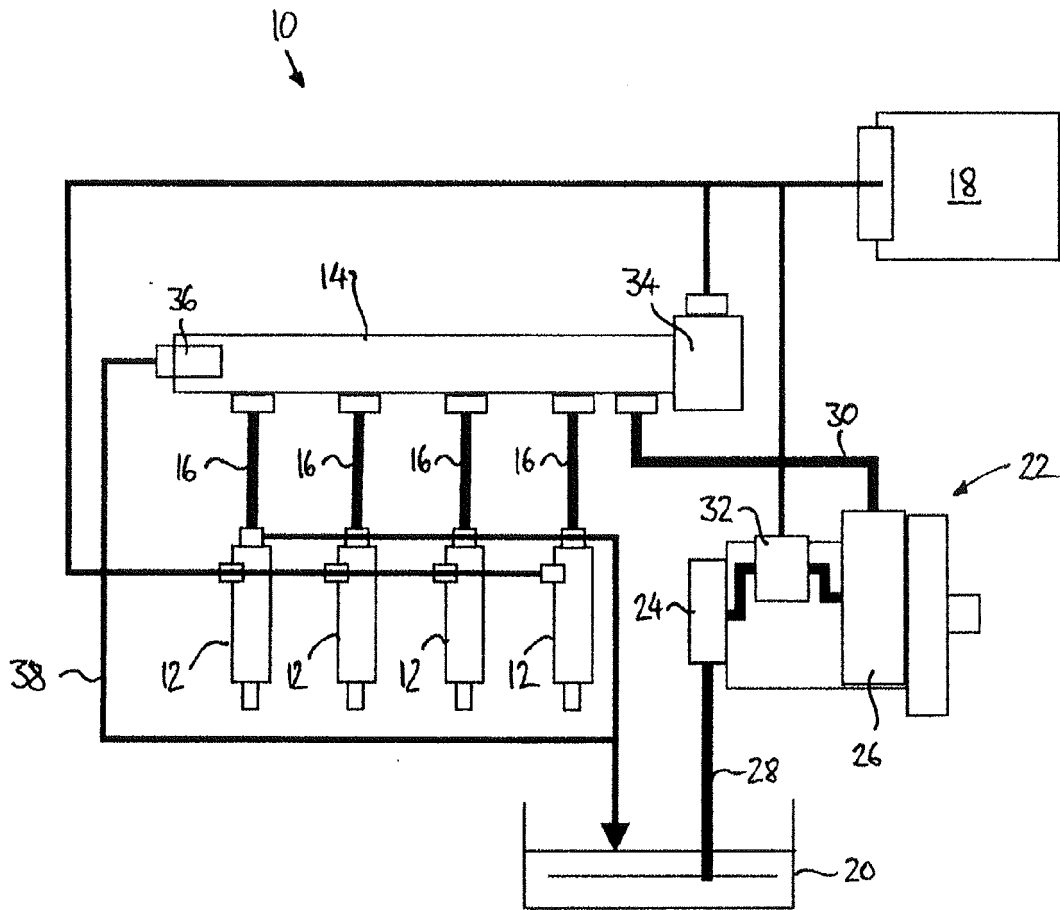


FIGURE 1

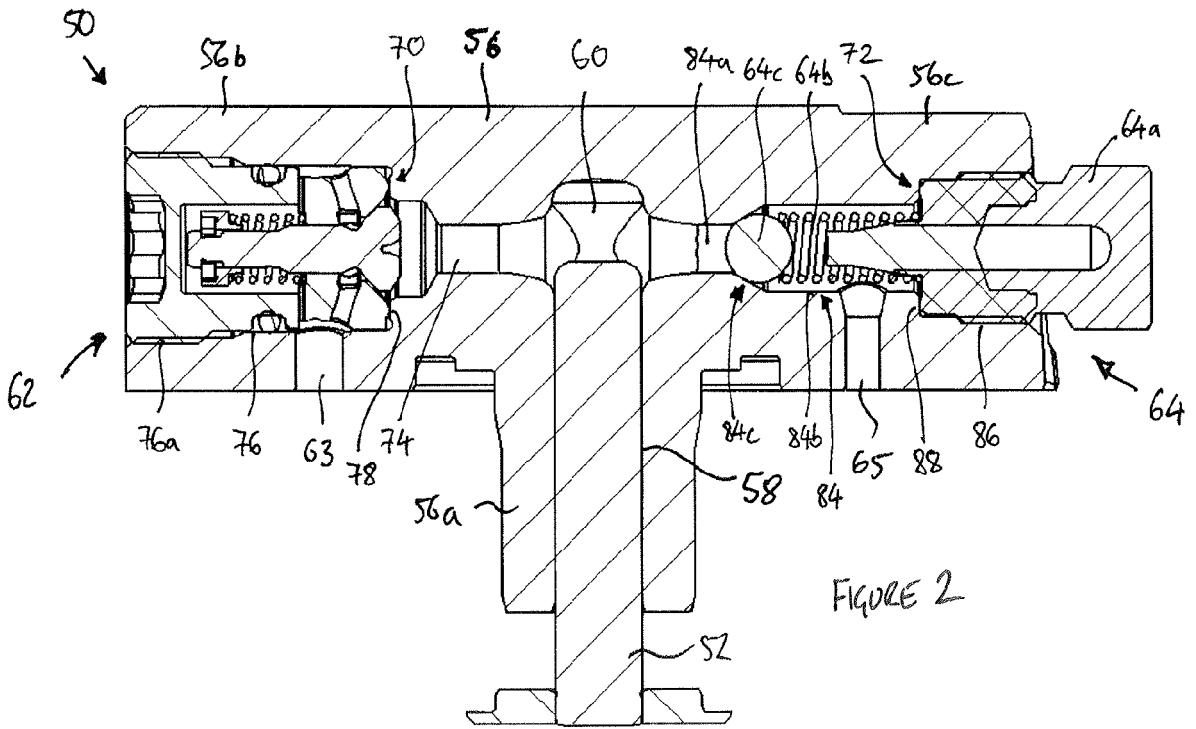


FIGURE 2

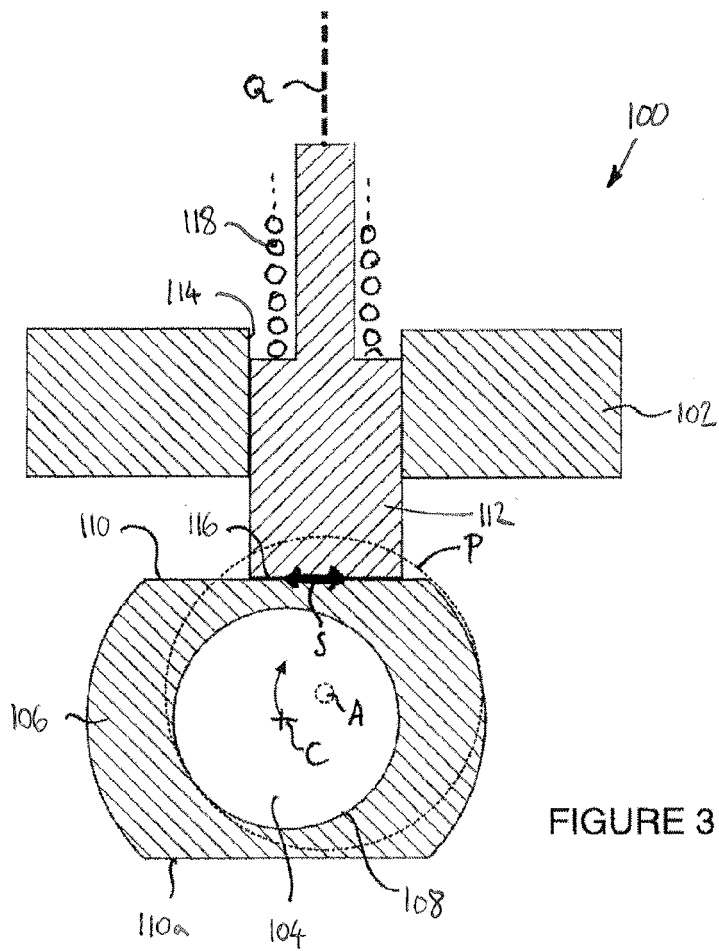


FIGURE 3

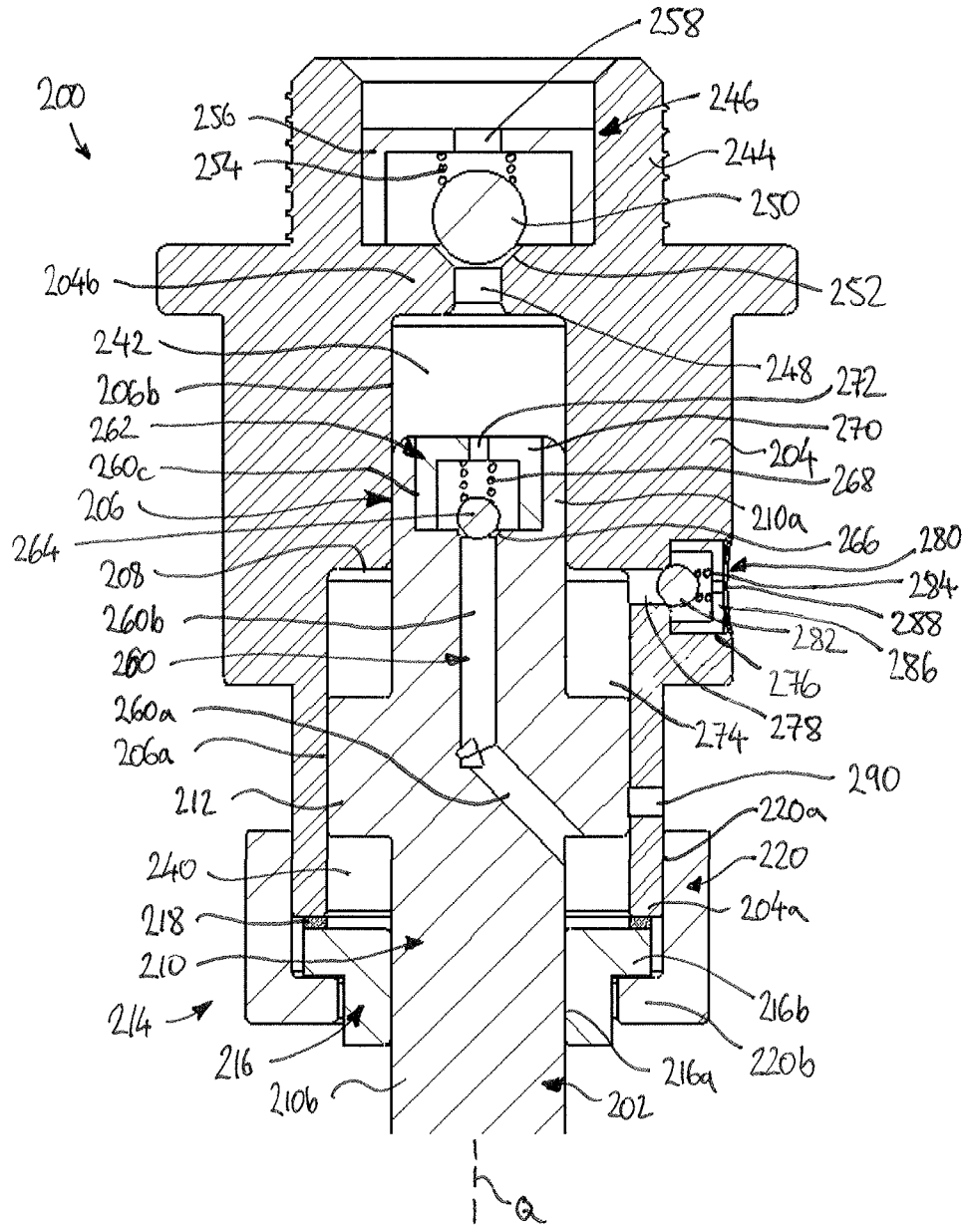


FIGURE 4

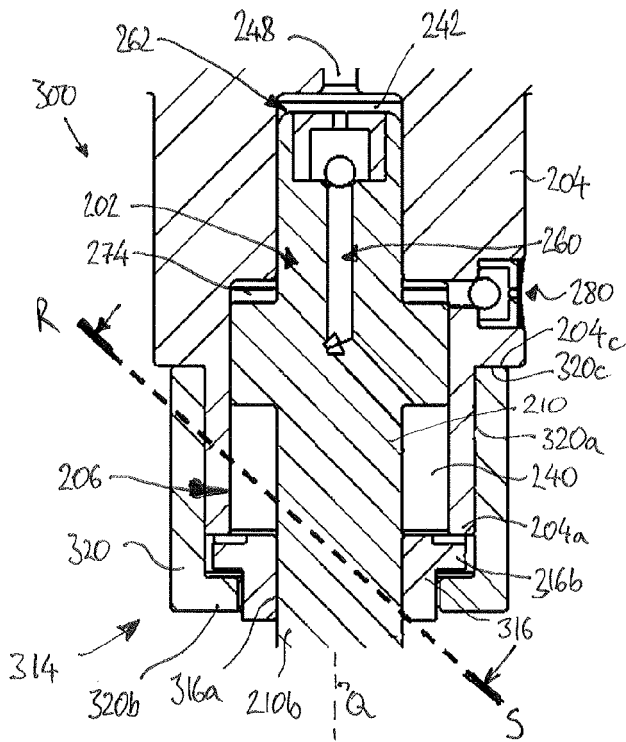


FIGURE 5

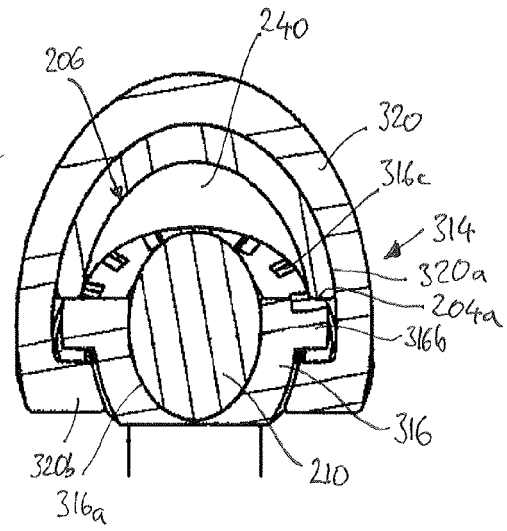


FIGURE 6
(SECTION ON R-S)



EUROPEAN SEARCH REPORT

Application Number
EP 11 15 6280

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
8 A	US 1 545 475 A (ADAMS EDWARD T) 14 July 1925 (1925-07-14) * page 1, line 80 - page 2, line 99; figure 1 *	1,2,4,5, 11,12	INV. F04B1/04 F04B53/16 F04B53/12 F02M37/04
3 A	----- US 2006/188380 A1 (STRONG CHRISTOPHER L [US]) 24 August 2006 (2006-08-24) * paragraph [0030] - paragraph [0032]; figure 4 *	1,2,4,5, 11,12	
8 A	----- US 2009/007861 A1 (MAJOR JEAN-LOUIS [CA]) 8 January 2009 (2009-01-08) * abstract; figure 1 * * paragraphs [0037], [0038] *	1	
The present search report has been drawn up for all claims			TECHNICAL FIELDS SEARCHED (IPC)
			F04B F02M
12	Place of search Munich	Date of completion of the search 7 March 2012	Examiner Richmond, Robin
CATEGORY OF CITED DOCUMENTS		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document	
X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document			

EPO FORM 1503 03.02 (P04C01)



Application Number

EP 11 15 6280

CLAIMS INCURRING FEES

The present European patent application comprised at the time of filing claims for which payment was due.

- Only part of the claims have been paid within the prescribed time limit. The present European search report has been drawn up for those claims for which no payment was due and for those claims for which claims fees have been paid, namely claim(s):
- No claims fees have been paid within the prescribed time limit. The present European search report has been drawn up for those claims for which no payment was due.

LACK OF UNITY OF INVENTION

The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

see sheet B

- All further search fees have been paid within the fixed time limit. The present European search report has been drawn up for all claims.
- As all searchable claims could be searched without effort justifying an additional fee, the Search Division did not invite payment of any additional fee.
- Only part of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the inventions in respect of which search fees have been paid, namely claims:
- None of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the invention first mentioned in the claims, namely claims:
see additional sheet(s)
- The present supplementary European search report has been drawn up for those parts of the European patent application which relate to the invention first mentioned in the claims (Rule 164 (1) EPC).



**LACK OF UNITY OF INVENTION
SHEET B**

Application Number
EP 11 15 6280

The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

1. claims: 1-14

A pumping head having a reciprocating pump element, a first and second pump chamber and a transfer means in the pump element in order to enable flow from the first to second chamber during reciprocation of the pump element.

2. claim: 15

A method for pressurising fluid in a fluid pump by pressurising the fluid to an intermediate pressure at a first stage then pressurising the fluid to a high pressure at a second stage.

**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

EP 11 15 6280

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

07-03-2012

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EPO FORM P0459

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