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(54) Fuel pump

(57) A fuel pump comprising a plurality of radially spaced pumping arrangements (10a, 10b, 10c), each of which includes a pumping plunger (20a, 20b, 20c) which is reciprocable within a plunger bore (19a, 19b, 19c) formed in a pump housing (18) under the influence of a respective driven tappet member (24a, 24b, 24c) which acts to transmit a force to the pumping plunger (20a, 20b, 20c) during a forward stroke thereof. The plunger bore (19a, 19b, 19c) defines a pumping chamber (22a, 22b, 22c) within which pressurisation of fuel to a relatively high level occurs upon reciprocal movement of the pumping plunger within the plunger bore. An end region of the tappet member (24a, 24b, 24c) is provided with a further bore (70a, 70b, 70c), a surface associated with the end region of the tappet member (24a, 24b, 24c) defining, in part, an annular auxiliary pumping chamber (40a, 40b, 40c) for fuel, the further bore (70a, 70b, 70c) defining a working chamber (51a, 51b, 51c) arranged to receive fuel to generate a force on the tappet member (24a, 24b, 24c) which acts in a return direction so as to increase the volume of the pumping chamber (22a, 22b, 22c) during a return stroke of the pumping plunger. The fuel pump further comprises a transfer pressure flow path (43) providing communication between the auxiliary pumping chamber (40a, 40b, 40c) of a first pumping arrangement (10a) and the pumping chamber (22b, 22c) of at least one of the other pumping arrangements (10a, 10b) such that fuel displaced from the auxiliary pumping chamber (40a, 40b, 40c), in use, can be supplied through the transfer pressure flow path (43) to said at least one of the other pumping chambers (22b, 22c). The auxiliary pumping chambers (40a, 40b, 40c) and the transfer pressure flow path (43) are constructed and adapted to ensure fuel flows through the transfer pressure flow path (43) at a substantially constant flow rate for a given speed of rotation of the pump.

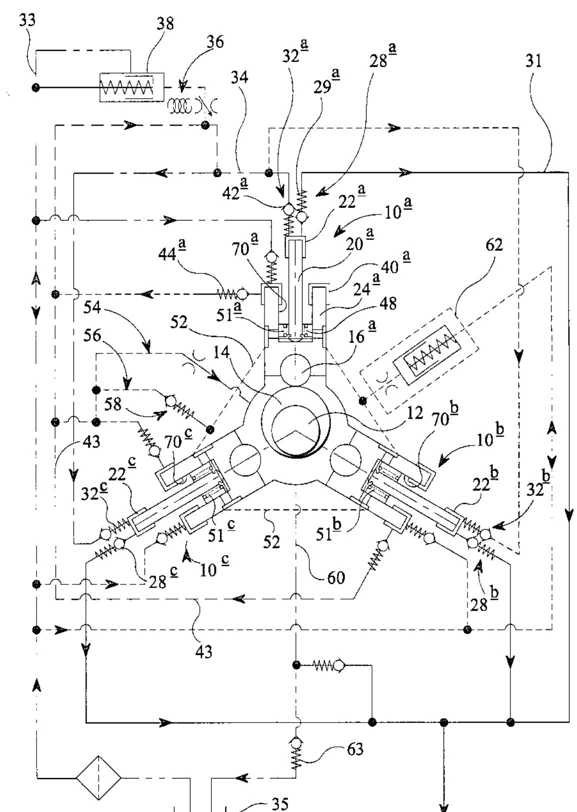

FIG 1

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Description

[0001] The invention relates to a fuel pump for use in supplying fuel to a compression ignition internal combustion engine.

[0002] A known high pressure fuel pump for use in supplying fuel to a compression ignition internal combustion engine comprises a pumping plunger reciprocable within a plunger bore under the influence of a cam drive arrangement so as to pressurise fuel within a pumping chamber. During a forward, delivery stroke of the plunger, the plunger moves inwardly within the plunger bore to reduce the volume of the pumping chamber, thereby causing the pressure of fuel therein to be increased. During the forward stroke of the pumping plunger, fluid is delivered from the pumping chamber through a suitable valve arrangement. Following each delivery stroke, the plunger performs a return stroke in which the plunger moves in an outward direction within the plunger bore to increase the volume of the pumping chamber. During the return stroke, fuel is delivered to the pumping chamber through an inlet valve arrangement ready for pressurisation during the next forward stroke.

[0003] It is known to provide the pumping plunger with a spring for the purpose of driving the pumping plunger during the return stroke. However, in certain circumstances the use of a spring can be undesirable.

[0004] EP 0 972 936 describes a fuel pump in which the return stroke of the pumping plunger is performed by supplying fluid to a working chamber defined, in part, by a tappet assembly which acts to transmit a force from the cam arrangement to the pumping plunger during the forward stroke of the plunger. A force due to fuel pressure within the working chamber acts on the tappet assembly and serves to drive the plunger to perform the return stroke, the pumping plunger moving outwardly from the plunger bore to increase the volume of pump chamber.

[0005] It is also known to provide the fuel pump with a low pressure pump to permit charging of the pumping chamber of the high pressure pump within the time available. However, the provision of such a separate low pressure pump results in the fuel system being relatively complex, bulky and expensive.

[0006] It is an object of the present invention to provide an improved fuel pump which is suitable for use in supplying fuel to a compression ignition internal combustion engine and in which the disadvantages of known pump arrangements are alleviated or removed.

[0007] According to the present invention, there is provided a fuel pump comprising a plurality of radially spaced pumping arrangements, each of which includes a pumping plunger which is reciprocable within a plunger bore formed in a pump housing under the influence of a driven tappet member which acts to transmit a force to the pumping plunger during a forward stroke thereof, the plunger bore defining a pumping chamber within which pressurisation of fuel to a relatively high level occurs upon reciprocal movement of the pumping plunger within the plunger bore, wherein an end region of the tappet member is provided with a further bore, a surface associated with the end region defining, in part, an annular auxiliary pumping chamber for fuel, the further bore defining a working chamber arranged to receive fuel to generate a force on the tappet member which acts in a return direction so as to increase the volume of the pumping chamber during a return stroke of the pumping plunger, the fuel pump further comprising a transfer pressure flow path providing communication between the auxiliary pumping chamber of a first pumping arrangement and the pumping chamber of at least one of the other pumping arrangements such that fuel displaced from the auxiliary pumping chamber, in use, can be supplied through the transfer pressure flow path to said at least one of the other pumping chambers, wherein the auxiliary pumping chambers and the transfer pressure flow path are constructed and adapted to ensure fuel flows through the transfer pressure flow path at a substantially constant flow rate for a given speed of rotation of the pump.

[0008] In use, reciprocal movement of the pumping plungers within their respective bores is phased such that pressurisation of fuel within the auxiliary pumping chamber of one pumping arrangement causes fuel, pressurised to a first, slightly pressurised level, to be delivered to the pumping chamber of at least one of the other pumping arrangement, wherein pressurisation to a relatively high level occurs, pressurised fuel being delivered from the pumping chamber(s) to a delivery passage. The delivery passage may, for example, deliver fuel to a common rail of a common rail fuel system or an accumulator.

[0009] For the purpose of this specification, inward movement of the pumping plunger within the plunger bore to cause pressurisation of fuel within the pumping chamber shall be referred to as "the forward stroke", and outward movement of the pumping plunger from the plunger bore to increase the volume of the pumping chamber shall be referred to as "the return stroke".

[0010] The invention provides the advantage that the auxiliary pumping chamber is defined within the pump housing, rather than being a separate pump attached to the main pump housing. The cost and weight of the pump is therefore reduced, as is the volume occupied by the pump. Additionally, the need for a return spring to effect the return stroke of the pumping plunger is also removed, as the return stroke of the pumping plunger is driven by means of fuel within the working chamber.

[0011] Preferably, the auxiliary pumping chamber of each pumping arrangement is defined by the end region of the tappet member and a tappet bore provided in the pump housing.

[0012] The tappet member of each pumping arrangement is preferably provided with an associated spring arrangement which serves to urge the pumping plunger outwardly from the plunger bore.

[0013] The provision of the spring arrangement provides the advantage that, upon engine start up, the pumping plunger and the tappet member are caused to reciprocate, thereby drawing fuel into the auxiliary pumping chamber. Only fuel displaced from the auxiliary pumping chamber is delivered to the pumping chamber.

[0014] In a preferred embodiment, the working chambers are in fluid communication with one another through a common tappet return flow path, wherein the common tappet return flow path is provided with a damping arrangement which serves to minimise pressure variations within the common tappet return flow path.

[0015] As the end region of the tappet member is used to provide the auxiliary pumping function, and a different region of the same moving component is used to provide the return force for the pumping plunger, the pump may be relatively compact. In addition, by using different regions of the same component to define the auxiliary pumping chamber and the working chamber respectively, any leakage flow from the tappet return flow path and the working chamber is recycled to the transfer pressure flow path, rather than being lost from the pump, subject to a relatively small amount of fuel leakage directly from the tappet return flow path as described in further detail hereinafter. Pump losses can therefore be limited to a relatively low level.

[0016] Preferably, the tappet member is shaped to ensure the working chamber communicates with the tappet return flow path throughout the full extent of the forward stroke and throughout the full extent of the return stroke.

[0017] Preferably, the transfer pressure flow path is provided with a metering valve arrangement which serves to regulate the rate of fuel flow into the pumping chambers.

[0018] Each of the auxiliary pumping chambers is preferably provided with a respective inlet valve arrangement for controlling the flow of fuel into the associated auxiliary pumping chamber and a respective outlet valve arrangement for controlling the flow of fuel between the associated auxiliary pumping chamber and the transfer pressure flow path.

[0019] In a preferred embodiment, each inlet valve arrangement is constructed and adapted to ensure the flow of fuel into the associated auxiliary pumping chamber is substantially unrestricted.

[0020] Additionally, each outlet valve arrangement is preferably constructed and adapted to ensure the flow of fuel from the associated auxiliary pumping chamber is substantially unrestricted. In this way, the flow of fuel within the transfer pressure flow path to the pumping chambers can be maintained at a substantially constant flow rate.

[0021] As fuel within the auxiliary pumping chamber is only pressurised to a relatively low level, the inlet and outlet valve arrangements associated with the auxiliary pumping chamber can be arranged to share a common flow passage through which fuel flows to and from the auxiliary pumping chamber.

[0022] Preferably, each plunger bore has, associated therewith, an additional inlet valve arrangement which serves to control the flow of fuel into the respective pumping chamber and an additional outlet valve arrangement which serves to control the flow of fuel from the respective pumping chamber to a delivery flow path.

[0023] In a preferred embodiment, the tappet member of each pumping arrangement is provided with a radially extending drilling which provides communication between the associated working chamber and an aperture provided on the surface of said tappet member, the aperture communicating the common tappet return flow path. Preferably, the aperture is of relatively small size compared to an outer diameter of the associated tappet member. For example, the aperture may take the form of a slot having an outer periphery which is small compared with the outer diameter dimension of the associated tappet member.

[0024] In one embodiment, the fuel pump comprises three radially spaced pumping plungers, each having an associated auxiliary pumping chamber defined by the tappet member. The provision of three or more pumping plungers, all driven through a common cam arrangement in cyclical phased motion, ensures a smooth flow enters the transfer pressure flow path to the pumping chambers.

[0025] The invention will further be described, by way of example only, with reference to the accompanying drawings, in which:

Figure 1 is a sectional view illustrating a fuel pump in accordance with an embodiment of the invention, and

Figure 2 is a sectional view of a part of the pump in Figure 1,

Figure 3 is a longitudinal view of the part of the pump in Figure 2, and

Figure 4 is a perspective view of a tappet member forming part of the fuel pump in Figures 1 to 3.

[0026] Referring to Figures 1 to 3, there is shown a high pressure fuel pump for use in a fuel injection system of an internal combustion engine. In particular, the high pressure fuel pump is suitable for use in delivering high pressure fuel to an accumulator or the common rail of a common rail fuel system.

[0027] The pump comprises three equi-angularly spaced pumping arrangements, 10a, 10b, 10c, which extend radially around a drive shaft 12 within a pump housing 18. The drive shaft 12 carries a cam arrangement 14 which defines a cam surface, the cam surface being cooperable with roller members 16a, 16b, 16c associated with the pumping arrangements 10a, 10b, 10c respectively. The pumping arrangements 10a, 10b, 10c are substantially the same as each other and therefore, for convenience, only one of the pumping arrangements 10a will be described in detail.

[0028] The pump housing 18 is provided with a first plunger bore 19a within which a pumping plunger 20a is reciprocable. The plunger bore 19a defines a pumping chamber 22a to which fuel is delivered, in use. The pumping plunger 20a engages a tappet member 24a forming part of a tappet assembly, referred to generally as 17a, the tappet member 24a being slidably mounted in a further tappet bore 26a provided in the pump housing 18. The region 18a of the pump housing 18 within which the plunger bore 19a is provided may be referred to as the 'plunger support cylinder'.

[0029] The tappet member 24a carries the roller member 16a associated with the pumping arrangement 10a such that, upon rotation of the drive shaft 12 about its axis, the roller member 16a and the tappet member 24a transmit reciprocating motion to the pumping plunger 20a. The reciprocating motion of the pumping plunger 20a is such that, during inward movement of the pumping plunger 20a within the plunger bore 19a (the forward stroke), the pumping plunger 20a is moved to reduce the volume of the pumping chamber 22a. The pumping chamber 22a has an associated outlet valve arrangement 28a (as shown in Figure 1) having an associated spring 29a which serves to urge an outlet valve member against a seating to prevent fuel flow from the pumping chamber 22a into a fuel delivery path 31. When fuel pressure within the pumping chamber 22a is increased beyond a predetermined amount, the outlet valve member is caused to lift away from the seating to permit pressurised fuel to flow into the delivery path 31 and to a common rail or accumulator 30 associated with the fuel system. It will be appreciated that high pressure fuel is also delivered from the pumping chambers 22b, 22c associated with the pumping arrangements 10b, 10c to the common rail 30 in a similar manner. Closure of the outlet valve arrangement 28a occurs under the action of the spring 29a when the pumping plunger 22a has reached top-dead-centre and starts the return stroke.

[0030] The pumping chamber 22a also has an associated inlet valve arrangement 32a, the inlet valve arrangement 32a having an open position in which fuel is delivered to the pumping chamber 22a through a primary, transfer pressure supply path 34. The primary supply path 34 receives fuel from a secondary fuel supply path 43 through a metering valve arrangement 36 which serves to regulate, by means of a variable restriction, the rate of flow of fuel to the pumping chamber 22a. The flow of fuel through the primary supply path 34 is therefore a metered flow of fuel. The secondary fuel supply path 43 receives fuel at transfer pressure, as will be described in further detail hereinafter, and may therefore be referred to as a "transfer pressure flow path". A pressure regulator 38 serves to regulate fuel pressure at the inlet of the metering valve arrangement 36, to permit excess fuel to return from the transfer pressure flow path 43 to a feed path 33 in communication with a fuel reservoir 35.

[0031] It will be appreciated that the pumping arrangements 10b, 10c also have associated inlet valve arrangements 32b, 32c respectively through which fuel is delivered to the respective pumping chamber 22b, 22c from the primary fuel supply path 34 in a similar manner, the primary fuel supply path 34 being common to all three pump arrangements 10a, 10b, 10c.

[0032] An end region of the tappet member 24a is provided with an additional bore 70a which extends a part of the way along the longitudinal axis of the tappet member 24a . The end region of the tappet member 24a forming part of the pumping arrangement 10a defines, together with the tappet bore 26a within which the tappet member 24a is reciprocable, an annular auxiliary pumping chamber 40a for fuel. The auxiliary chamber 40a has an associated inlet valve arrangement 42a which serves to control the supply of fuel to the auxiliary chamber 40a from the feed path 33, fuel being delivered from the feed path 33, through the inlet valve arrangement 42a, to the auxiliary chamber 40a via a flow passage 46 (as shown in Figure 3) provided in the pump housing 18. The auxiliary chamber 40a also has an associated outlet valve arrangement 44b which serves to control the flow of fuel from the auxiliary chamber 40a, through the flow passage 46, into the transfer pressure flow path 43.

[0033] The auxiliary pumping chambers 40b, 40c also have inlet and outlet valve arrangements 42b, 42c and 44b, 44c respectively associated therewith, fuel delivered through the outlet valve arrangements 44b, 44c from the associated auxiliary pumping chamber 40b, 40c also being delivered to the secondary supply path 43.

[0034] Referring to Figure 4, the additional bore 70a which extends a part of the way along the longitudinal axis of the tappet member 24a communicates, via radially extending drillings 72, with axial slots or apertures 74 provided on the surface of the tappet member 24a. The bore 70a provided in the tappet member 24a and a region of the housing 18 together define a working chamber 51a for fuel. The working chamber 51a communicates, via the drillings 72 and the apertures 74 provided in the tappet member 24a, with a further flow path 52 for fuel, the further flow path 52 also being in communication with corresponding working chambers associated with the other pumping arrangements 10b, 10c. The working chamber 51a is arranged such that the pressure of fuel within the working chamber 51a serves to urge the plunger member 20a and the tappet member 24a in a radially inward direction (i.e. outwardly from their respective bores) to perform a return stroke.

[0035] The tappet members 24b, 24c are also provided with corresponding apertures and drillings to provide communication between the respective working chamber 51b, 51c and the further flow path 52, the apertures in the tappet members 24a, 24b, 24c being arranged to ensure the working chambers 51a, 51b, 51c remain in communication with the further flow path 52 throughout the full range of movement of the tappet members 24a, 24b, 24c on both the forward and return strokes. Communication between the working chambers 51a, 51b, 51c through the further flow path 52 provides a means for returning each of the tappet members 24a, 24b, 24c to their starting positions (outermost position within their respective bores) for each pumping stroke. Conveniently, the further flow path 52 may therefore be referred to as 'tappet return flow path' through which fuel flows, in both directions between adjacent working chambers, depending on the phase of motion of the tappet members 24a, 24b, 24c and, hence, the pumping plungers 20a, 20b, 20c.

[0036] The tappet return flow path 52 receives fuel from the transfer pressure flow path 43 through an auxiliary flow path 56 provided with a top-up valve arrangement 58. Fuel leakage from the tappet return circuit 52, 51a, 51b, 51c through clearances between the tappet members 24a, 24b, 24c and their respective bores 26a, 26b, 26c is able to flow, via a backleak flow passage 60, to the fuel reservoir 35 through a backleak valve arrangement 63. Fuel is also able to flow, through a restricted flow path 54, from the transfer pressure flow path 43 into the central region of the housing 18 to provide lubrication and cooling of the cam surfaces, the rollers 16a, 16b, 16c and the tappet members 24a, 24b, 24c.

[0037] The pumping plunger 20a is retained in position within the tappet assembly 17a by means of a spring arrangement 48 arranged within the working chamber 51a, the spring arrangement 48 acting on the pumping plunger 20a in a radially inward direction to ensure that the pumping plunger 20a, tappet member 24a, roller member 16a and the surface of the cam arrangement 14 remain properly in contact during an initial brief period of rotation, during which the tappet return flow path 52 may be incompletely filled. It will be understood that the tappet return flow path 52 must be completely filled for normal reciprocation to take place, and therefore for the auxiliary pumping action to supply correctly the flow of fuel at transfer pressure. This flow is necessary to fill the pumping chambers 22a, 22b, 22c, as well as the return flow path 52. However, at very slow speeds, just after engine start-up, relatively light springs are sufficient to cause reciprocation.

[0038] The load imparted to the pumping plunger 20a by the spring arrangement 48a counteracts the tendency of fuel pressure within the working chamber 51a to force the pumping plunger 20a into the pumping chamber 22a, and thereby ensures the pumping plunger 20a and the tappet member 24a move radially inward together. Additionally, or alternatively, the pumping plunger 20a may be mechanically trapped in position in the tappet member 24a. The pumping arrangements 10b, 10c are also provided with corresponding spring arrangements for the purpose described previously in relation to pumping arrangement 10a.

[0039] In use, starting from a position in which the tappet member 24a and the pumping plunger 20a occupy their retracted, outermost positions within the bores 26a, 19a respectively (i.e. at the end of a return stroke, prior to a subsequent forward, pumping stroke), the auxiliary chamber 40a and the pumping chamber 22a are charged with fuel at relatively low pressure. Rotation of the drive shaft 12 and the cam arrangement 14 causes movement of the roller member 16a and, hence, inward movement of the tappet member 24a and the pumping plunger 20a within their respective bores 26a, 19a, thereby causing fuel within the pumping chamber 22a to be compressed. The provision of the outlet valve arrangement 28a prevents fuel from flowing from the pumping chamber 22a to the delivery passage 31 until such time as fuel pressure within the pumping chamber 22a is increased to an amount which is sufficient to overcome the force due to the spring arrangement 29a, thereby causing the outlet valve arrangement 28a to open and permitting fuel to flow from the pumping chamber 22a into the delivery passage 31.

[0040] As the tappet member 24a reciprocates within the bore 26a, fuel within the auxiliary chamber 40a is pressurised, fuel being delivered through the outlet valve arrangement 44a into the transfer pressure flow path 43 when the pressure of fuel within the auxiliary chamber 40a is sufficient to cause the outlet valve arrangement 44a to open. Fuel within the transfer pressure flow path 43 is delivered through the metering valve arrangement 36 to the primary supply path 34 and through the inlet valve arrangement 32a associated within the pumping arrangement 10a to the pumping chamber, 22b or 22c, associated with one of the other pumping arrangements 10b or 10c depending on the phase of motion and which of the pumping chambers 22b or 22c is increasing in volume. It will therefore be understood that the flow of fuel to the pumping chambers 22a, 22b, 22c is regulated (or metered) by the metering valve arrangement 36. In addition, fuel is delivered from the secondary supply path 43 to the tappet return flow path 52 through the top-up valve arrangement 58, as described previously.

[0041] Reciprocal movement of the tappet member 24a within the bore 26a causes fuel within the auxiliary pumping chamber 40a to be pressurised to a first, relatively low level, referred to as "transfer pressure". Thus, fuel flowing through the outlet valve arrangement 44a into the transfer pressure flow path 43 is pressurised to transfer pressure prior to being delivered to the primary fuel supply path 34, and hence to whichever of the pumping chambers 22b, 22c is being filled. Further pressurisation of fuel to a relatively high pressure occurs within the pumping chambers 22b, 22c as the respective plungers 20b, 20c reciprocate.

[0042] The complete pump assembly includes three pumping circuits; a transfer pressure circuit (based on auxiliary pumping chambers 40a, 40b, 40c), a high pressure circuit (based on pumping chambers 22a, 22b, 22c) and a tappet return circuit (based on working chambers 51a, 51b, 51c). The actions of each of the circuits are interdependent, co-ordinated and in phased relationship as motion of the three pumping plungers 20a, 20b, 20c and the respective tappet members 24a, 24b, 24c is phased in a manner dependent upon the profile of the cam surface.

[0043] By appropriate shaping of the cam surface of the cam arrangement, reciprocal movement of the pumping plungers and the tappet members within their respective bores is phased in a cyclical manner such that, when a particular pumping plunger, for example 20a, is driven from its bottom-dead-centre position to its top-dead-centre position, the volume of the associated auxiliary chamber 40a will decrease, whereas the volume of the auxiliary chamber 40b, 40c associated with at least one of the other pumping arrangements 10b, 10c will increase. Accordingly, fuel will tend to be drawn into any auxiliary chamber, the volume of which is increasing, from the feed path 33, through the respective inlet valve arrangement 42a, 42b, 42c. Conveniently, the cam arrangement may be of generally cylindrical form, the surface of the cam arrangement including a single lobe.

[0044] It will be appreciated that fuel is delivered to the primary fuel supply path 34 from all three of the auxiliary pumping chambers 40a, 40b, 40c, and is delivered, from the primary fuel supply path 34, to all three pumping chambers 22a, 22b, 22c, the pressurisation of fuel within each of the pumping chambers 22a, 22b, 22c occurring in the manner described previously such that fuel is delivered through the outlet valve arrangements 28a, 28b, 28c to the common delivery passage 31 for delivery to the common rail 30.

[0045] Due to the phased reciprocal motion of the pumping plungers 20a, 20b, 20c, the rate of flow of fuel to the common rail 30 will be substantially constant throughout the pumping cycle for a given speed of rotation of the pump drive shaft 12. This is only true, however, if each of the pumping chambers 22a, 22b, 22c is filled completely during its respective filling or return stroke. Often, complete filling of the pumping chambers 22a, 22b, 22c, does not occur as the average rate of flow of fuel to the common rail 30 is controlled by operation of the metering valve 36, which serves to restrict the rate of flow of fuel into the primary fuel supply path 34, and hence into the pumping chambers 22a, 22b, 22c, when it is desired to reduce the output of the pump. In such circumstances, each pumping chamber 22a, 22b, 22c is only partly filled at the start of the forward, pumping stroke of the associated pumping plunger. Thus, the pumping plunger will contact fuel within the respective pumping chamber some time after the start of the forward stroke when the plunger is already moving relatively quickly.

[0046] The expansion or filling stroke of each auxiliary chamber 40a, 40b, 40c, (i.e. outward movement of the tappet members 24a, 24b, 24c within their respective bores 26a, 26b, 26c) is simultaneous with that of the respective pumping chamber 22a, 22b, 22c, as the pumping plunger and tappet member of each pump arrangement 10a, 10b, 10c travel over the same distance, and with the same speed, for any period of time. The inlet valve arrangement 42a, 42b, 42c to each auxiliary pumping chamber 40a, 40b, 40c is configured such that the flow of fuel into each auxiliary pumping chamber is substantially unrestricted, thereby minimising any pressure drop due to suction. Thus, each auxiliary pumping chamber 40a, 40b, 40c always fills fully during the return stroke, and the flow of fuel at transfer pressure from the three auxiliary pumping chambers 40a, 40b, 40c, through the transfer pressure flow path 43, is maintained at a substantially constant rate at any given pump speed (i.e. for a given speed of rotation of the pump drive shaft 12). Any excess flow entering the transfer pressure flow path 43 which is not required for filling the pumping chambers 22a, 22b, 22c, is diverted back to the pump inlet by the regulator 38 and is recycled to fill the auxiliary pumping chambers 40a, 40b, 40c. It will be understood, however, that the flow of fuel through the primary supply path 34 is not constant, but will vary according to the position of the metering valve arrangement 36 which serves to regulate the flow of fuel to the pumping chambers 22a, 22b, 22c.

[0047] As fuel pressure within the working chamber 51a is increased during inward movement of the tappet member 24a and the pumping plunger 20a within their respective bores, the force acting on the other tappet members 24b, 24c in a radially inward direction is also increased. Once the pumping plunger 20a has reached its top-dead-centre position, the force acting on the tappet member 24a due to fuel pressure within the working chamber 51a serves to urge the pumping plunger 20a in a radially inward direction, outwardly from the bore 19a, to increase the volume of the pumping chamber 20a and the volume of the auxiliary chamber 40a. Furthermore, the pressure of fuel acting on the tappet member 24a ensures the roller member 16a maintains contact with the cam surface of the cam arrangement 14 during the return stroke. The total volume of fuel within the working chamber 51a associated with the pumping arrangement 10a, the corresponding working chambers 51b, 51c associated with the pumping arrangements 10b, 10c, and the common tappet return path 52 is therefore substantially constant, allowing for a small amount of fuel leakage through clearances within the pump arrangement which is able to escape through the back leak passage 60, as will be described in further detail below. As the total volume of the working chamber 51a and the volumes of the associated working chambers 51b, 51c of the pumping arrangements 10b, 10c are relatively small, the magnitude of the flow between the working chambers is relatively low and parasitic pumping losses are therefore reduced.

[0048] Each working chamber 51a, 51b, 51c is exposed to three fuel leakage paths due to the construction and arrangement of various radial clearances. The first leakage path is between the outer diameter of the tappet member 24a, 24b, 24c and the respective tappet bore 26a, 26b, 26c, extending radially inwards from the apertures 74 of the tappet members, to the tappet return path 52 and to the cambox or pump housing interior at relatively low pressure. Leakage flow along this first leakage path eventually exits the pump via the backleak valve 63. The second leakage path is due to the same clearance (i.e. between the outer diameter of the tappet member 24a, 24b, 24c and the respective tappet bore 26a, 26b, 26c), but in the direction of the associated auxiliary pumping chamber 40a, 40b, 40c. Leakage flow along this second leakage path is recycled by the auxiliary pumping chamber 40a, 40b, 40c. The third leakage path is due to the radial clearance between the inner diameter of the tappet bore 70a, 70b, 70c and the outer diameter of the adjacent region 18a of the pump housing (referred to as the plunger support cylinder). The third fuel leakage path accesses the associated working chamber 51a, 51b, 51c directly, rather than via the apertures 74 and drilling 72, and so leakage through this third path is also collected by the associated auxiliary pumping chamber 40a, 40b, 40c and recycled. Thus, only fuel leakage through the first leakage path is lost from the pump.

[0049] The relatively small size of each aperture 74 (i. e. the outer periphery of each aperture 74) compared with the outer diameter of the tappet members 24a, 24b, 24c (i.e. the outer circumference of the aperture 74 compared with the outer diameter of the tappet member) serves to minimise the leakage flow area of the first leakage path through which pressurised fuel in the tappet return flow path 52 can flow. The direction of fuel flow along any clearance will depend on the direction in which the pressure gradient, if any, acts. When the working chamber 51a, 51b, 51c is pumping, and therefore reducing in volume, the volume of the associated auxiliary chamber 40a, 40b, 40c is also reducing, and unwanted exchange of fuel between the two is therefore minimised. The pressure within the tappet return circuit tends to increase with pump rotational speed as the inertial resistance of the tappet member increases, but the time available for leakage during any stroke decreases and, as a result, leakage losses from the tappet return circuit 52, 51a, 51b, 51c are low.

[0050] In order to avoid any unwanted increases in fuel pressure within the return passage 52 (i.e. pressure "spikes") it may be preferable to include a damping arrangement or damper circuit 62 within the fuel pump (as shown in Figure 1) to provide some volumetric resilience.

[0051] As pressurisation of fuel to transfer pressure occurs within the auxiliary pumping chambers 40a, 40b, 40c within the pump housing 18, the need for a separate auxiliary or transfer pump is removed. Hence, the complexity, weight, size and cost of the fuel pump are reduced. Additionally, as fuel within the auxiliary chamber 40a is only pressurised to a relatively low level, and therefore is negligibly affected by loss of volume due to compressibility so that minimising the volume of the pressurised chambers is unimportant, both the flow of fuel to the auxiliary chamber 40a and from the auxiliary chamber 40a can pass through a common flow passage 46, thereby providing a further benefit in terms of pump size and complexity.

[0052] The present invention provides the further advantage that the plunger return stroke is driven by means of fuel pressure within the working chambers defined, in part, by the bores 70a, 70b, 70c provided in the tappet members, thereby removing the need for a relatively large spring. Additionally, the arrangement of flow paths required to provide communication between the auxiliary pumping chambers 40a, 40b, 40c and the pumping chambers 22a, 22b, 22c is relatively simple.

[0053] The fuel pump of the present invention is particularly suitable for use in delivering high pressure fuel to the fuel injection system of an internal combustion engine. However, it will be appreciated that the pump may also be used in other applications. It will further be appreciated that the drive arrangement for the pump need not take the form of the cam arrangement illustrated, but may take an alternative form.

Claims

1. A fuel pump comprising a plurality of radially spaced pumping arrangements (10a, 10b, 10c), each of which includes a pumping plunger (20a, 20b, 20c) which is reciprocable within a plunger bore (19a, 19b, 19c) formed in a pump housing (18) under the influence of a respective driven tappet member (24a, 24b, 24c) which acts to transmit a force to the pumping plunger (20a, 20b, 20c) during a forward stroke thereof, the plunger bore (19a, 19b, 19c) defining a pumping chamber (22a, 22b, 22c) within which pressurisation of fuel to a relatively high level occurs upon reciprocal movement of the pumping plunger within the plunger bore, wherein an end region of the tappet member (24a, 24b, 24c) is provided with a further bore (70a, 70b, 70c), a surface associated with the end region of the tappet member (24a, 24b, 24c) defining, in part, an annular auxiliary pumping chamber (40a, 40b, 40c) for fuel, the further bore (70a, 70b, 70c) defining a working chamber (51a, 51b, 51c) arranged to receive fuel to generate a force on the tappet member (24a, 24b, 24c) which acts in a return direction so as to increase the volume of the pumping chamber (22a, 22b, 22c) during a return stroke of the pumping plunger, the fuel pump further comprising a transfer pressure flow path (34) providing communication between the auxiliary pumping chamber (40a, 40b,

40c) of a first pumping arrangement (10a) and the pumping chamber (22b, 22c) of at least one of the other pumping arrangements (10a, 10b) such that fuel displaced from the auxiliary pumping chamber (40a, 40b, 40c), in use, can be supplied through the transfer pressure flow path (34) to said at least one of the other pumping chambers (22b, 22c), wherein the auxiliary pumping chambers (40a, 40b, 40c) and the transfer pressure flow path (34) are constructed and adapted to ensure fuel flows through the transfer pressure flow path (43) at a substantially constant flow rate for a given speed of rotation of the pump.

2. The fuel pump as claimed in Claim 1, wherein the auxiliary pumping chamber (40a, 40b, 40c) is defined by the end region of the tappet member and a tappet bore (26a, 26b, 26c) provided in the pump housing (18).

3. The fuel pump as claimed in Claim 1 or Claim 2, wherein the tappet member (24a, 24b, 24c) is provided with an associated spring arrangement (48) which serves to urge the pumping plunger (20a, 20b, 20c) outwardly from the plunger bore (19a, 19b, 19c).

4. The fuel pump as claimed in any of Claims 1 to 3, wherein the working chambers (51a, 51b, 51c) communicate with one another through a common tappet return flow path (52), and wherein the common tappet return flow path (52) is provided with a damping arrangement (62) which serves to minimise pressure variations within the common tappet return flow path (52).

5. The fuel pump as claimed in Claim 4, wherein the tappet member (24a, 24b, 24c) is shaped to ensure the working chamber (51a, 51b, 51c) communicates with the tappet return flow path (52) throughout the full extent of the forward stroke and throughout the full extent of the return stroke.

6. The fuel pump as claimed in any of Claims 1 to 5, wherein the transfer pressure flow path (43) is provided with a metering valve arrangement (36) which serves to regulate the rate of fuel flow into the pumping chambers (22a, 22b, 22c).

7. The fuel pump as claimed in any of Claims 1 to 6, wherein each of the auxiliary pumping chambers (40a, 40b, 40c) is provided with a respective inlet valve arrangement (42a, 42b, 42c) for controlling the flow of fuel into the associated auxiliary pumping chamber (42a, 42b, 42c) and a respective outlet valve arrangement (44a, 44b, 44c) for controlling the flow of fuel between the associated auxiliary pumping chamber (40a, 40b, 40c) and the transfer pressure flow path (43).

8. The fuel pump as claimed in Claim 7, wherein each inlet valve arrangement (42a, 42b, 42c) is constructed and adapted to ensure the flow of fuel into the associated auxiliary pumping chamber (40a, 40b, 40c) is substantially unrestricted.

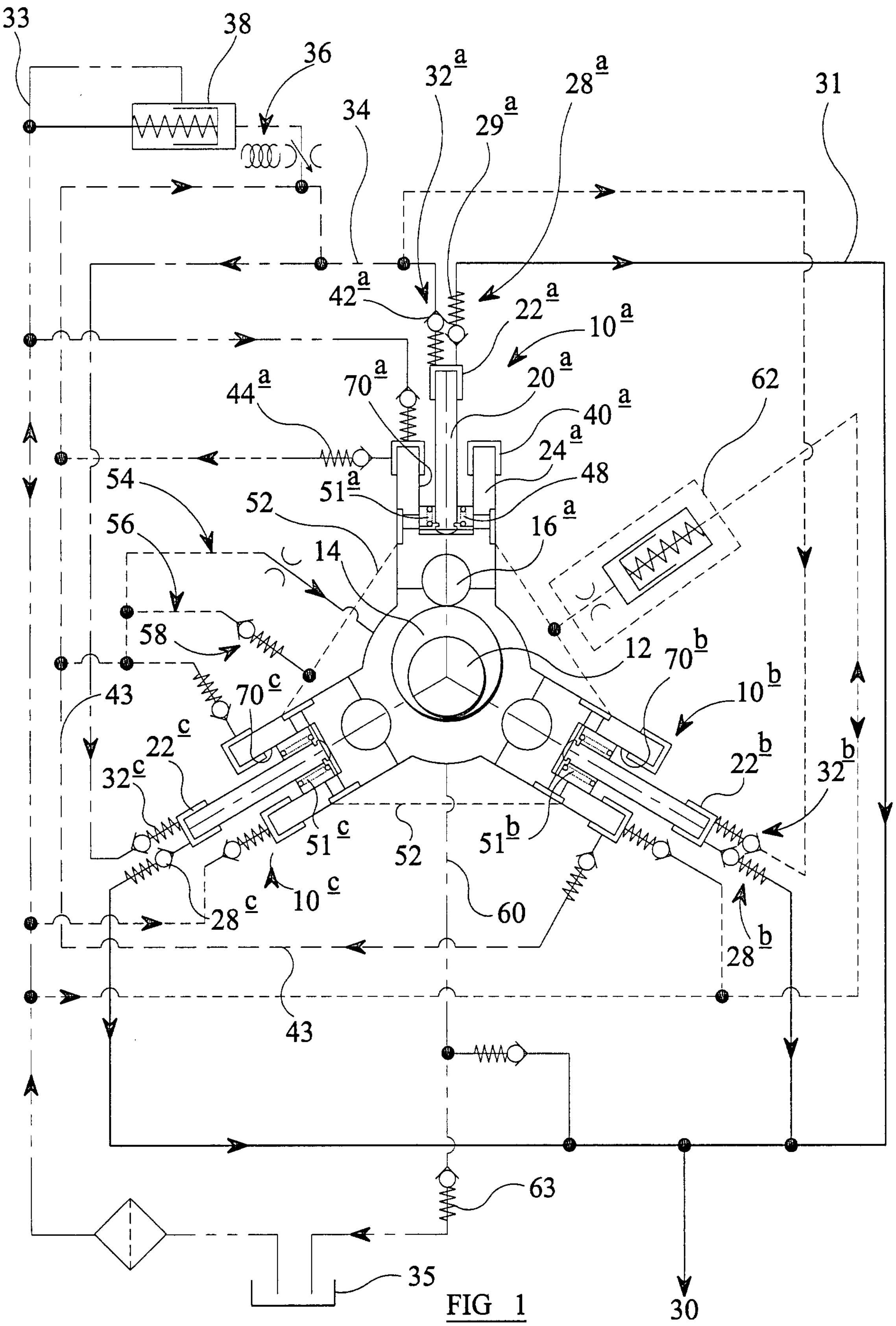
9. The fuel pump as claimed in Claim 8, wherein each outlet valve arrangement (44a, 44b, 44c) is constructed and adapted to ensure the flow of fuel from the associated auxiliary pumping chamber (40a, 40b, 40c) is substantially unrestricted.

10. The fuel pump as claimed in any of Claims 1 to 9, wherein each plunger bore (19a, 19b, 19c) has, associated therewith, an additional inlet valve arrangement (32a, 32b, 32c) which serves to control the flow of fuel into the respective pumping chamber (22a, 22b, 22c) and an additional outlet valve arrangement (28a, 28b, 28c) which serves to control the flow of fuel from the respective pumping chamber (22a, 22b, 22c) to a delivery flow path (31, 30).

11. The fuel pump as claimed in any of Claims 1 to 10, wherein the tappet member (24a, 24b, 24c) of each pumping arrangement is provided with a radially extending drilling (72) which provides communication between the associated working chamber (51a, 51b, 51c) and an aperture (74) provided on the surface of said tappet member (24a, 24b, 24c), the aperture (74) communicating the common tappet return flow path (52).

12. The fuel pump as claimed in Claim 11, wherein the aperture (74) is shaped to have an outer periphery which is of relatively small dimension compared to an outer diameter of the associated tappet member (24a, 24b, 24c).

13. The fuel pump as claimed in any of Claims 1 to 12, wherein the fuel pump comprises three radially spaced pumping plungers (20a, 20b, 20c).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48
52
51a
16a
56
14
58
12
70b
10b
43
70c
22c
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32b
51c
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10c
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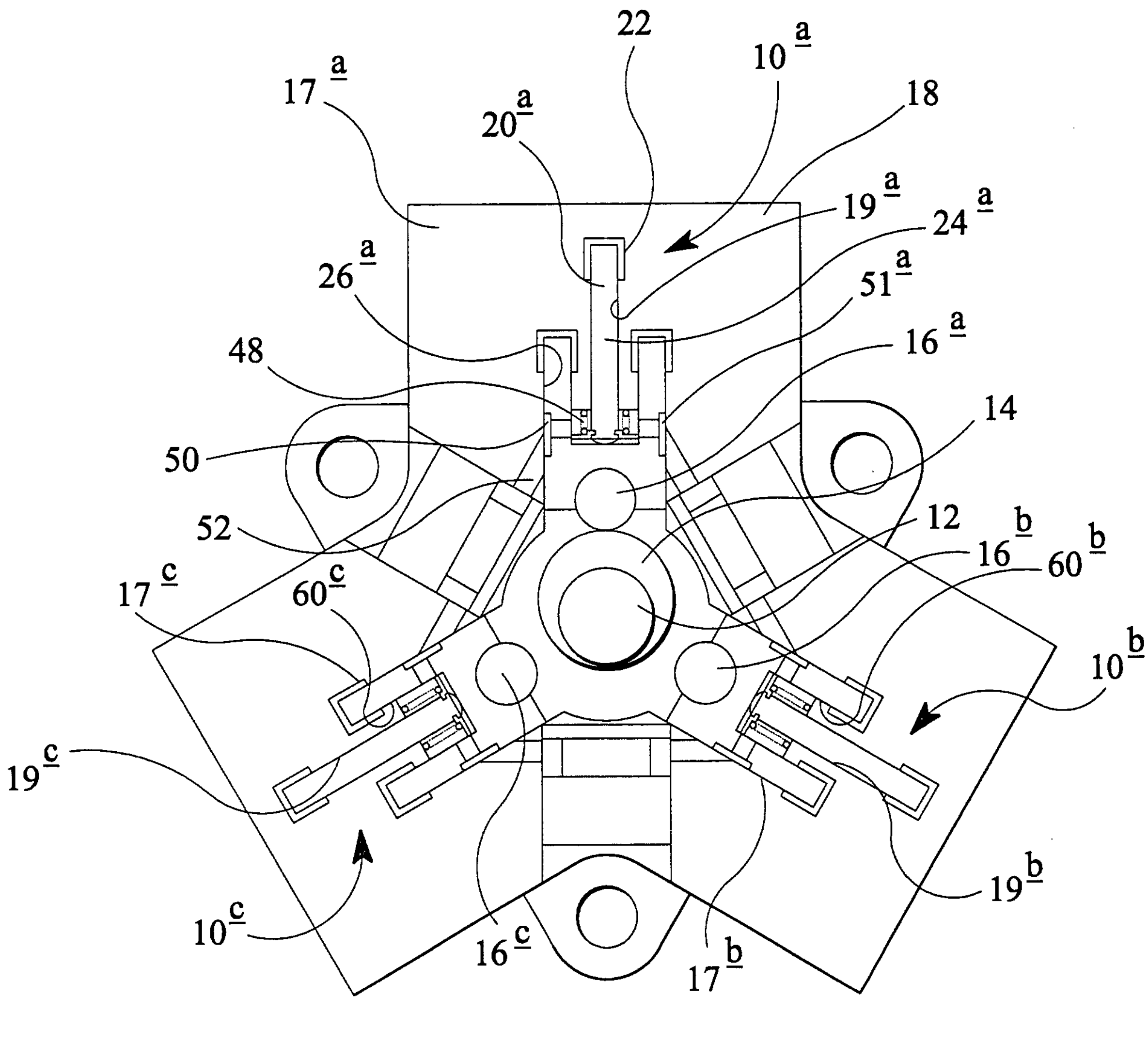
43
63
35
30

FIG 1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17 b

FIG 2

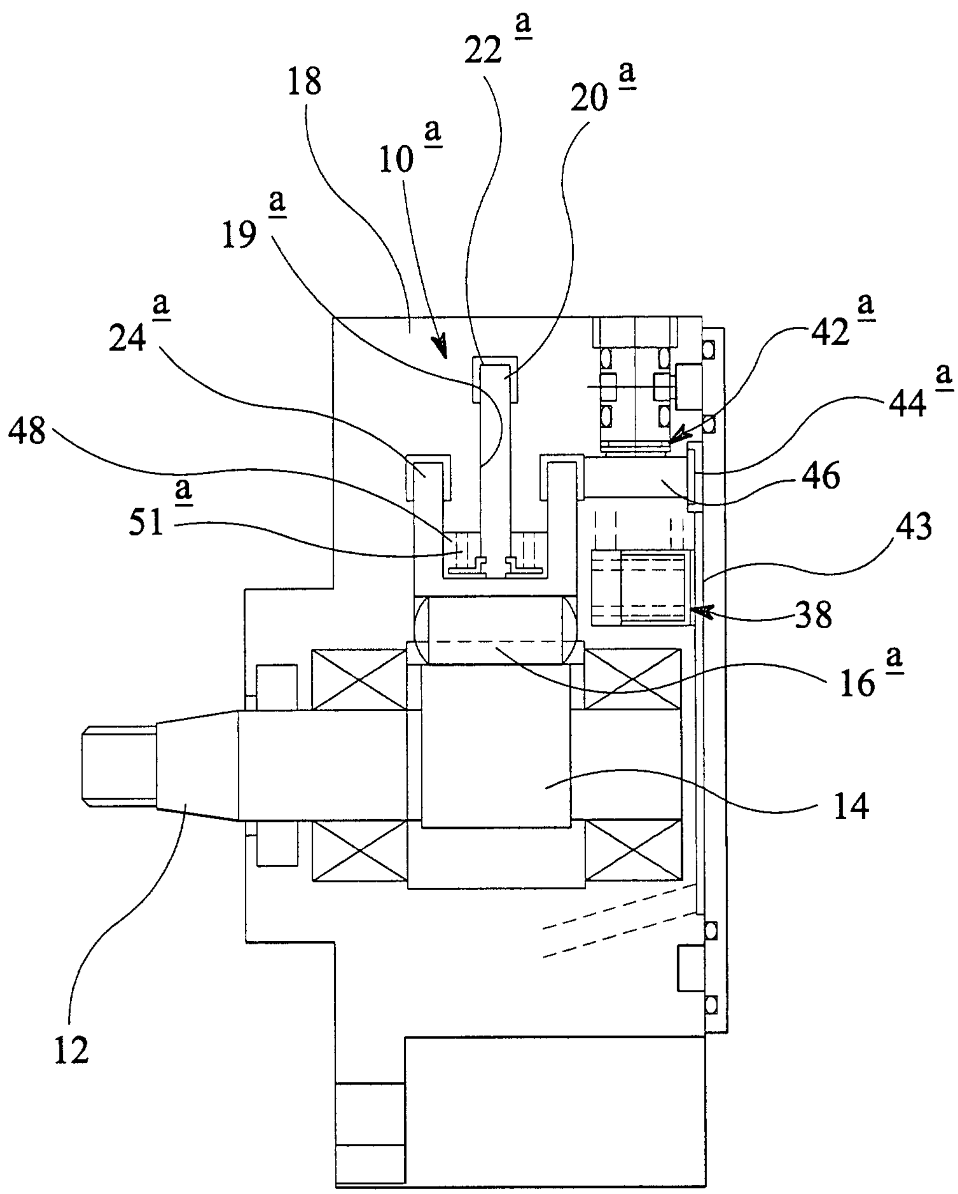

FIG 3

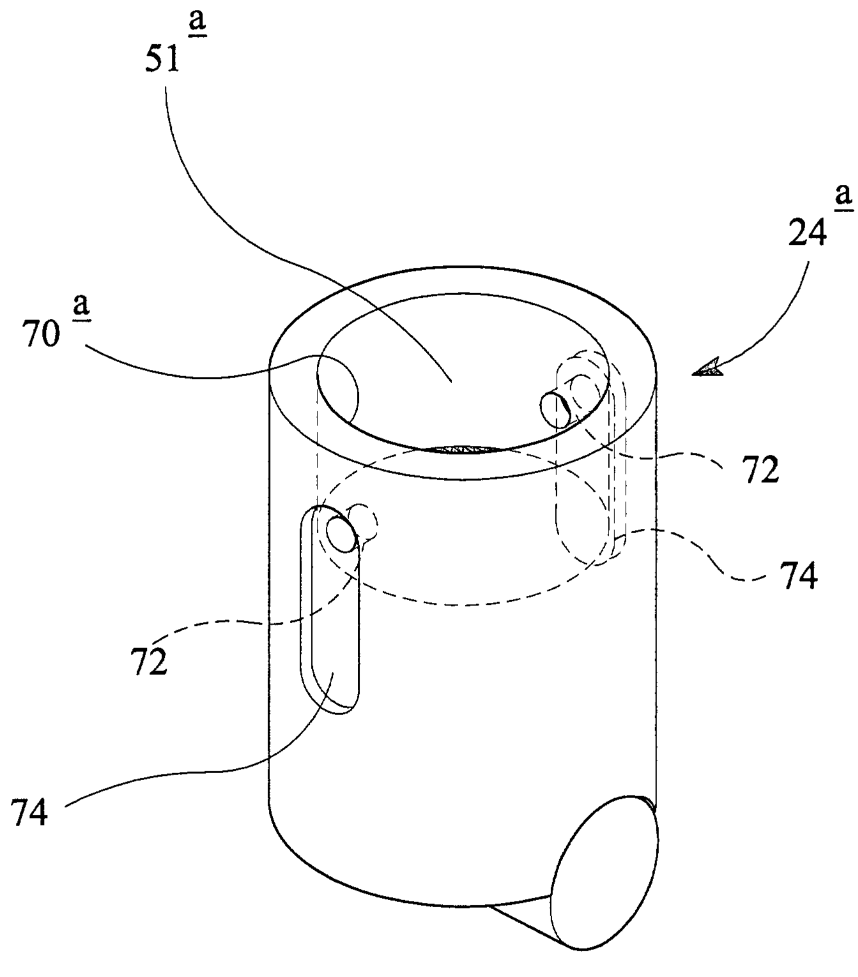

FIG 4