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(54) **Pump assembly**

(57) A pump assembly suitable for use in a fuel injection system is disclosed. The pump assembly comprises at least one high-pressure pumping head having an associated pumping element; a housing (124), a chamber (130) for lubricating fluid, a drive shaft bearing (126) received in the housing; and a drive shaft (120) received in the bearing (126), the drive shaft (120) being rotatable to cause reciprocal pumping movement of the or each pumping element. The drive shaft (120) is arranged to move in reciprocal linear movement in a first direction and in a second, opposite direction along a drive shaft axis (A) during rotation of the drive shaft (120) in use, and the pump assembly further comprises an auxiliary pumping chamber (160) arranged to draw lubricating fluid from the lubricating fluid chamber (130) during axial movement of the drive shaft (120) in the first direction, and to deliver lubricating fluid towards the bearing (126) during linear movement of the drive shaft (120) in the second direction.

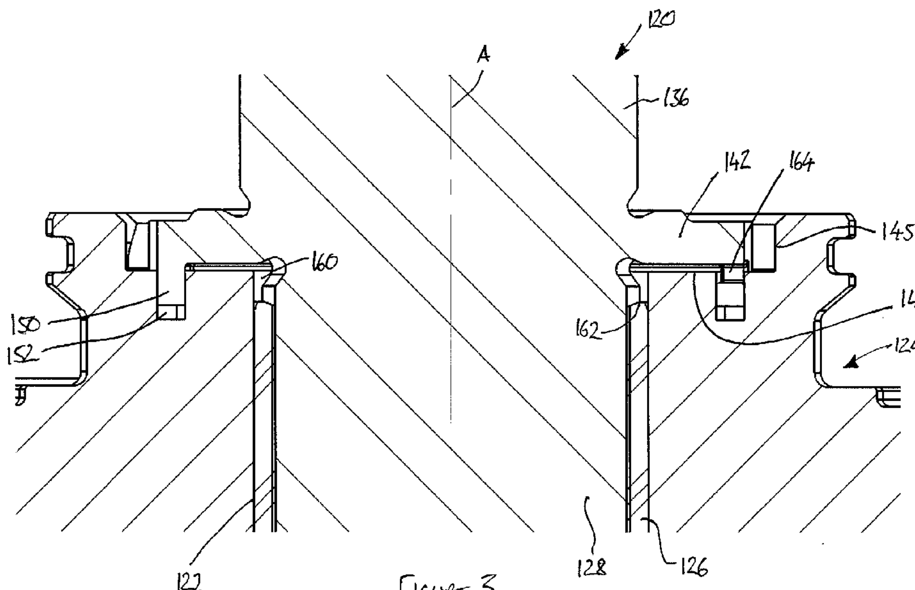


FIGURE 3



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## Description

### Field of the invention

**[0001]** The present invention relates to a pump assembly. In particular, but not exclusively, the invention relates to a high-pressure fuel pump assembly having auxiliary pumping means for supplying lubricating fluid to a bearing of the pump assembly.

### Background to the invention

**[0002]** Fuel injection systems for modern internal combustion engines, particularly compression ignition engines, comprise a plurality of fuel injectors arranged to deliver an atomised spray of high-pressure fuel to a respective combustion chamber of the engine. The injectors receive fuel at high pressure from an accumulator volume or rail.

**[0003]** The rail comprises a reservoir for high-pressure fuel. Fuel is pumped to the rail from a storage tank by a fuel pump assembly. In a typical example, the fuel pump assembly includes a low-pressure transfer pump, which serves to convey fuel from the tank to the pump assembly, and a high-pressure pump which elevates the pressure of the fuel to the injection pressure, typically of the order of 2000 bar.

**[0004]** The high-pressure pump comprises one or more pumping heads which are arranged to receive a reciprocable pumping plunger or pumping element. The pump further comprises a drive assembly for driving reciprocal movement of the pumping element. The drive assembly is received within a housing, also known as a cam box, which houses a cylindrical cam. The cam is driven in eccentric rotational movement by a drive shaft that extends through the housing. The eccentric rotational movement of the drive shaft is converted into reciprocal linear movement of the pumping element by way of a cam rider and follower arrangement.

**[0005]** Fuel is supplied from the transfer pump to a pumping chamber of the pumping head through an inlet check valve or non-return valve. The pumping chamber is defined, in part, by the pumping element, so that reciprocal linear movement of the pumping element causes cyclical changes in the volume of the pumping chamber. When the pumping element moves to decrease the volume of the pumping chamber (known as a forward stroke or pumping stroke), fuel in the pumping chamber is pressurised and then released from the pumping chamber through an outlet valve configured to open at a predetermined pressure. When the pumping element moves to increase the volume of the pumping chamber (known as a return stroke or filling stroke), fuel is drawn through the inlet valve to replenish the pumping chamber.

**[0006]** Figure 1 of the accompanying drawings is a schematic illustration of some of the components of a fuel pump assembly of this type. The pump assembly includes an elongate drive shaft 20 arranged for rotation about a drive shaft axis A. The drive shaft 20 extends through a housing or cam box of the pump assembly. Only one part of the housing is shown in Figure 1, namely a front plate 24 of the housing. The drive shaft 20 extends through an aperture 22 in the front plate 24.

**[0007]** The aperture 22 houses a tubular plain bearing 26, which serves to support the drive shaft 20 and to constrain its lateral movement whilst allowing rotation of the shaft 20. A front journal portion 28 of the shaft 20 is received in the bearing 26.

**[0008]** The front plate 24 is attached to a housing body (not shown) to define an internal volume 30 of the pump. Part of the drive shaft 20 extends from the front plate 24 into the internal volume 30, and then through an aperture in a rear face (not shown) of the housing body. A rear journal portion 32 of the shaft 20 is received in a tubular plain bearing (not shown) housed in the aperture of the rear face of the housing body.

**[0009]** Beyond the rear journal portion 32, the drive shaft 30 extends out of the housing, and the end of the drive shaft 30 adjacent to the rear journal portion 32 is formed into a drive gear 34 for driving a transfer pump (not shown) attached to the housing.

**[0010]** Between the front and rear journal portions 28, 32, the drive shaft 20 is formed into an eccentric cylindrical cam portion 36. The cam portion 36 is arranged to drive linear reciprocal movement of one or more pumping elements (not shown) of the pump, in use, for example by means of a cam rider and follower arrangement. The or each pumping element is arranged for linear movement along or parallel to an axis that lies perpendicular to the drive axis A.

**[0011]** The part of the drive shaft 20 that extends out of the housing through the front plate 24 (i.e. the lowermost part of the drive shaft 20 in the orientation shown in Figure 1) includes a conically tapered portion 38 that carries a helical drive gear 40. In use, the drive gear 40 is engaged with and driven by a corresponding helical input gear (not shown) that is, in turn, driven by an engine-driven input shaft (not shown).

**[0012]** As will be appreciated, the torque that acts on the shaft 20 through the cam portion 36 during pumping varies cyclically as the or each pumping element undergoes its forward and return strokes. Because helical gears are used to drive the shaft 20, the varying torque results in linear movement of the shaft 20 along the axis A as it rotates.

**[0013]** To constrain this linear movement of the shaft 20, the drive shaft 20 includes a flange 42 positioned between the front journal portion 28 and the cam portion 36. The flange 42 is arranged to bear against a thrust face 44 of the front plate 24. In this way, cooperation of the flange 42 and the thrust face 44 constrains linear movement of the shaft 20 in a first axial direction (downwards in Figure 1).

**[0014]** The rear face of the housing body is similarly provided with a thrust face that cooperates with a shoulder 46 of the drive shaft 30, formed where the cam portion

36 meets the rear journal portion 32. Cooperation of the shoulder 46 and the thrust face of the rear face of the housing body constrains linear movement of the shaft 30 in a second axial direction (upwards in Figure 1), opposite the first axial direction.

**[0015]** During operation of the pump, the journal portion 28 of the drive shaft 20 therefore both rotates and moves axially relative to the bearing 22. Accordingly, it is important that the bearing 22 is designed not to overheat or otherwise fail at high pump speeds and high outlet pressures.

**[0016]** A known type of bearing used in common-rail fuel pumps includes a tubular three-layer bush (also known as a bushing), received in a tubular bore or aperture in a concentric arrangement. The bush comprises an outermost backing layer made from steel, an intermediate metallic layer made from sintered bronze, and an innermost layer made from a relatively thin coating of poly(tetrafluoroethylene)-based material (PTFE). Alternatively, a poly (ether ether ketone)-based material (PEEK) can be used as the bearing running layer. In use, the bush is retained in the bore.

**[0017]** In use, the internal volume 30 of the housing contains a liquid lubricant. Conveniently, in a combustion-ignition engine, diesel fuel can be used as the lubricant. The lubricant serves to lubricate the cam and rider/follower mechanism that drives the or each pumping element, and also serves to lubricate the bearing 22.

**[0018]** To improve engine efficiency and emissions control, it is desirable to increase the output pressure of high-pressure fuel pumps of the type shown in Figure 1. In this context, it would be desirable to provide a fuel pump in which the reliability and performance of the front plate bearing is improved compared to known arrangements, so that the pump can operate reliably at higher speeds and outlet pressures. Furthermore, it would be desirable to provide a fuel pump having an improved durability or service life.

## Summary of the invention

**[0019]** Against this background, from a first aspect, the present invention resides in a pump assembly comprising at least one high-pressure pumping head having an associated pumping element, a housing, a chamber for lubricating fluid, a drive shaft bearing received in the housing, and a drive shaft received in the bearing. The drive shaft is rotatable to cause reciprocal pumping movement of the or each pumping element, and is arranged to move in reciprocal linear movement in a first direction along a drive shaft axis and in a second, opposite direction along the drive shaft axis during rotation of the drive shaft in use.

**[0020]** The pump assembly further comprises auxiliary pumping means including an auxiliary pumping chamber arranged to draw lubricating fluid from the lubricating fluid chamber during axial movement of the drive shaft in the first direction, and to deliver lubricating fluid towards the bearing during linear movement of the drive shaft in the second direction. Preferably, the volume of the auxiliary pumping chamber increases during axial movement of the drive shaft in the first direction, and decreases during axial movement of the drive shaft in the second direction.

**[0021]** In this way, the auxiliary pumping chamber provides an auxiliary pumping means that delivers a flow of lubricating fluid to the bearing. The lubricant flow ensures that the bearing is always supplied with lubricating fluid. Furthermore, providing a directed flow of lubricating fluid to the bearing significantly improves cooling of the bearing compared to known pumps without auxiliary pumping means.

**[0022]** Preferably, the lubricating fluid chamber comprises an internal volume defined by the housing, and the drive shaft extends into the internal volume.

**[0023]** In one embodiment, the auxiliary pumping chamber is defined, in part, by the drive shaft. For example, the auxiliary pumping chamber may be defined, in part, by a flange of the drive shaft. In this case, the auxiliary pumping chamber may also be defined, in part, by a thrust face of the housing, for example a thrust face on a front plate component of the housing. In use, the flange moves away from the thrust face during linear movement of the drive shaft in the first direction and towards the thrust face during linear movement of the drive shaft in the second direction.

**[0024]** The drive shaft may comprise an annular projection disposed on the flange. The housing may comprise an annular recess in the thrust face for receiving the annular projection, and the auxiliary pumping chamber may be defined, in part, by the annular projection. In this way, the annular projection may cooperate with the annular recess so as to close or seal the auxiliary pumping chamber, or at least to restrict fluid flow between the auxiliary pumping chamber and the lubricating fluid chamber.

**[0025]** The pump assembly preferably comprises inlet means for allowing fluid into the auxiliary pumping chamber from the lubricating fluid chamber during movement of the drive shaft in the first direction, and for restricting fluid flow between the lubricating fluid chamber and the auxiliary pumping chamber during movement of the drive shaft in the second direction. By providing such inlet means, fluid can be pumped efficiently from the auxiliary pumping chamber to lubricate and cool the bearing during movement of the drive shaft in the second direction.

**[0026]** The inlet means may comprise an inlet port member having at least one inlet port. The inlet port member is preferably rotatable with the drive shaft, and is preferably cooperable with the housing to restrict fluid flow between the auxiliary pumping chamber and the lubricating fluid chamber. The housing may include inlet flow means, and the inlet port member is preferably rotatable to bring the or each of the inlet ports into fluid communication with the inlet flow means, thereby to allow fluid flow into the auxiliary pumping chamber from the lubricating fluid chamber by way of the inlet flow means. Said another way, the inlet port member may be rotatable to cause the inlet ports to overlap with the inlet flow means.

**[0027]** When the inlet ports do not overlap with or are not in fluid communication with the inlet flow means, no flow is possible through the inlet flow means and the inlet port member restricts fluid flow between the auxiliary pumping chamber and the lubricating fluid chamber. By linking rotation of the inlet port member to rotation of the drive shaft, opening of the inlet means can be synchronised with axial movement of the drive shaft in the first direction.

**[0028]** When an annular projection that cooperates with an annular recess in a thrust face of the housing is provided, the inlet port member may conveniently comprise the annular projection. In this case, the at least one inlet port is provided in the annular projection. The inlet flow means may comprise one or more radial channels in the thrust face that intersect the annular recess.

**[0029]** The auxiliary pumping chamber may open into a clearance between the bearing and the drive shaft. The bearing may be received in an aperture of the housing, in which case the auxiliary pumping chamber may be in fluid communication with the aperture by way of a flow passage in the housing, alternatively or in addition to the auxiliary pumping chamber opening into a clearance between the bearing and the drive shaft. The bearing may, for example, comprise a tubular bush received directly in the aperture, or in a bearing housing that is, in turn, received in the aperture.

**[0030]** The pump assembly may comprise a helical gear for transmitting drive to the drive shaft. In such an arrangement, axial movement of the drive shaft arises as a consequence of having a helical gear drive arrangement when the drive shaft is subject to varying torque during operation, as is the case when the drive shaft drives a pumping element of a high-pressure pumping head. In particular, reciprocal movement of the drive shaft occurs when the torque acting on the drive shaft reverses direction in use due to the re-expansion of compressed fluid in the pumping head at the start of a return or filling stroke, following a pumping or forward stroke of the pumping element.

**[0031]** In this way, or otherwise, the pump assembly may be arranged such that the drive shaft moves in the second direction during a pumping stroke of the or each high-pressure pumping element. Similarly, the pump assembly may be arranged such that the drive shaft moves in the first direction at the start of a return stroke of the or each high-pressure pumping element.

**[0032]** From a second aspect, the present invention resides in a pump assembly comprising a housing defining an internal volume of the pump assembly and comprising a drive shaft bearing, and a pump drive shaft received rotatably in the bearing and extending into the internal volume. In use, the internal volume contains a lubricating fluid. The pump assembly further comprises auxiliary pumping means for pumping the lubricating fluid from the internal volume towards the bearing, thereby to lubricate the bearing.

**[0033]** Preferred and/or optional features of each aspect and embodiment of the invention may be used, alone or in appropriate combination, in the other aspects and embodiments of the invention also.

**Brief description of the drawings**

**[0034]**

Figure 1 of the accompanying drawings, which has already been referred to above, is a schematic cross-sectional view of selected components of a known pump assembly.

**[0035]** Embodiments of 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 parts, and in which:

Figure 2 is a schematic cross-sectional view of selected components of a pump assembly according to an embodiment of the present invention;

Figure 3 is an enlarged and more detailed cross-sectional view of the pump assembly of Figure 2;

Figure 4 is a perspective view of a drive shaft of the pump assembly of Figure 2;

Figure 5 is an enlarged view of part of the drive shaft of Figure 4;

Figure 6 is a perspective view of part of a housing component of the pump assembly of Figure 2; and

Figures 7(a) and 7(b) are cutaway perspective views of part of the pump assembly of Figure 2, illustrating a filling step and a pumping step of auxiliary pumping means of the pump assembly, respectively.

**Detailed description of embodiments of the invention**

**[0036]** Referring first to Figure 2, a pump assembly 100 according to one embodiment of the present invention comprises an elongate drive shaft 120 arranged for rotation about a drive shaft axis A. The drive shaft 120 extends through a front plate 124 of a housing or cam box of the pump assembly 100.

**[0037]** The housing also comprises housing body (not shown) to which the front plate 124 is attached. In this embodiment, the housing body includes an integral rear face, although a separate rear plate or back plate of the housing could be provided. The front plate 124 and the housing body together define an internal volume 130 of the housing. For clarity, only the front plate 124 of the housing is shown in Figure 2.

**[0038]** The drive shaft 120 extends through a bore or aperture 122 in the front plate 124. The aperture 122 houses a tubular plain bearing 126, which serves to support the drive shaft 120 and to constrain its lateral movement whilst allowing rotation of the shaft 120. A front journal portion 128 of the shaft 120 is received in the bearing 126. The bearing 126 may be of a known type. For example, the bearing 126 may include a three-layer PTFE, bronze and steel bush press-fitted directly into the aperture 122. In another example, a PEEK layer is provided instead of a PTFE layer.

**[0039]** Part of the drive shaft 120 extends from the front plate 124 into the internal volume 130, and then through an aperture in the rear face (not shown) of the housing body. A rear journal portion 132 of the shaft 120 is received in a tubular plain bearing (not shown) housed in the aperture of the rear face.

**[0040]** Beyond the rear journal portion 132, the drive shaft 120 extends out of the housing, and the end of the drive shaft 120 adjacent to the rear journal portion 132 is formed into a drive gear 134 for driving a transfer pump (not shown) attached to the housing. As is known in the art, the transfer pump serves to supply fluid to high-pressure pumping heads of the pump assembly.

**[0041]** Between the front and rear journal portions 128, 132, the drive shaft 120 is formed into an eccentric cylindrical cam portion 136. The cam portion 136 is arranged to drive linear reciprocal movement of opposed first and second pumping elements (not shown) of the pump, in use, by means of a cam rider and follower arrangement.

**[0042]** Each pumping element is arranged for linear movement along or parallel to an axis that lies perpendicular to the drive axis A, and the first and second pumping elements are received within corresponding first and second high-pressure pumping heads (not shown). The pumping heads may be of a known type, as will be familiar to those skilled in the art. The pumping elements define, in part, pumping chambers in the respective pumping heads, and each pumping element is configured to reduce the volume of the corresponding pumping chamber during a forward or pumping stroke and to increase the volume of the pumping chamber during a return or filling stroke. Each pumping head has an associated inlet valve that permits fluid to flow into the pumping chamber during the filling stroke, and an associated outlet valve that allows fluid to flow from the pumping chamber to a high-pressure supply line and prevents the back-flow of fluid into the pumping chamber.

**[0043]** The pumping heads are mounted on opposite sides of the housing body. The configuration of the cam portion 136 of the drive shaft 120, the pumping elements and the pumping heads may, for example, be as described in the Applicant's European Patent Application Publication No. 2 050 952.

**[0044]** As in the known pump assembly of Figure 1, in the pump assembly 100 of this embodiment of the invention shown in Figure 2, the part of the drive shaft 120 that extends out of the housing through the front plate 124 (i.e. the lowermost part of the drive shaft 120 in the orientation shown in Figure 2) includes a conically tapered portion 138 that carries a helical drive gear 140. In use, the drive gear 140 is engaged with and driven by a corresponding helical input gear (not shown) that is, in turn, driven by an engine-driven input shaft (not shown).

**[0045]** The torque that acts on the shaft 120 through the cam portion 136 during pumping varies cyclically as the pumping elements undergo their forward and return strokes. Because helical gears are used to drive the shaft 120, the varying torque results in forces on the shaft 120 that act along the axis A as the shaft 120 rotates. These axial forces give rise to linear movement of the shaft 120.

**[0046]** In particular, when one of the pumping elements is driven by the cam portion 136 in a forward (pumping) stroke, compression of the fluid in the associated pumping chamber results in a torque that acts on the shaft 120 in a first direction. Then, at the start of the return (filling) stroke, the remaining compressed fluid in the pumping chamber expands, causing a torque that acts on the shaft 120 in a second direction opposite to the first direction. In other words, a torque reversal occurs during operation, and the resulting axial forces on the drive shaft 120 result in reciprocal linear movement of the shaft 120 along the axis A.

**[0047]** The torque acts in the second direction only during an initial phase of the return stroke of the pumping element (i.e. for a short period of the rotation cycle of the drive shaft 120 starting when the cam portion 136 is positioned at top dead centre with respect to the pumping element in question). Once the compressed fluid has expanded, the torque acting on the drive shaft 120 reverses and begins to act instead in the first direction. Accordingly, the drive shaft 120 moves axially in the second direction only for a minor fraction of each revolution of the drive shaft 120.

**[0048]** To constrain the linear movement of the shaft 120, the drive shaft 120 is provided with a flange 142 positioned between the front journal portion 128 and the cam portion 136. The flange 142 is arranged to bear against a thrust face 144 of the front plate 124. In this way, cooperation of the flange 142 and the thrust face 144 constrains linear movement of the shaft 120 in a first axial direction (downwards in Figure 2). The thrust face 144 is provided at the base of a recess 145 in which the flange 142 is received.

**[0049]** The rear face of the housing body is similarly provided with a thrust face (not shown) that cooperates with a shoulder 146 of the drive shaft 120, formed where the cam portion 136 meets the rear journal portion 132. Cooperation of the shoulder 146 and the thrust face of the rear face constrains linear movement of the shaft 120 in a second axial direction (upwards in Figure 1), opposite the first axial direction. The two opposed thrust faces, of the front plate 124 and the rear face of the housing body respectively, are sufficiently spaced apart to allow a small amount of linear movement of the shaft 120 along the axis, in use, to allow for manufacturing tolerances and to avoid frictional drag on the rotational movement of the drive shaft 120.

**[0050]** In use, the internal volume 130 of the housing contains a lubricating fluid or lubricant. The internal volume 130 therefore provides a chamber for lubricating fluid. In a compression-ignition engine application, the internal volume 130 contains diesel fuel, which has lubricating properties, and in the following description, the term 'fuel' will be used to describe the lubricating fluid. It will however be appreciated that in other applications the lubricant may differ from the fluid that is pumped by the high-pressure pumping elements of the pump assembly.

**[0051]** As will now be described, in the present invention, an auxiliary pumping means is provided to generate a flow of fuel from the internal volume 130 towards the front plate bearing 126, to assist in lubrication and cooling of the bearing 126. Operation of the auxiliary pumping means is effected by an interaction between the drive shaft 120 and the housing front plate 124 in the region of the drive shaft flange 142.

**[0052]** Referring additionally to Figures 3, 4 and 5, the drive shaft flange 142 is provided with a peripheral annular projection or lip 150 that extends towards the front journal portion 128 of the shaft. As shown in Figure 2 and 3 and also in Figure 6, the lip 150 is slidably received in an annular recess or slot 152 in the housing front plate 124, which runs adjacent to or around the periphery of the thrust surface 144.

**[0053]** As seen most clearly in Figure 3, an annular auxiliary pumping chamber 160 is defined in part by each of the flange 142, the lip 150, the journal portion 128 of the shaft 120, the upper end 162 of the bearing 126 and the wall of the aperture 122.

**[0054]** It will be appreciated that, as the drive shaft 120 undergoes reciprocal linear movement along its axis A, the volume of the pumping chamber 160 increases and decreases in a cyclical manner. In particular, as the flange 142 moves away from the front plate 124, the volume of the pumping chamber 160 increases, and as the flange 142 moves towards the front plate 124, the volume of the pumping chamber 160 decreases.

**[0055]** To admit fluid into the auxiliary pumping chamber 160, the lip 150 on the drive shaft flange 142 is provided with inlet ports or slots 164 that extend radially through the lip 150. In this way, the lip 150 provides an inlet port member of the drive shaft 120. In this embodiment, two diametrically-opposed inlet slots 164, aligned along a diameter of the lip 150, are provided. One edge of each slot 164 is coplanar with the surface of the flange 142. The inlet slots 164 rotate with the drive shaft 120.

**[0056]** In addition, as seen most clearly in Figure 6, inlet flow means in the form of radial channels 166 are provided in the base of the recess 145 in the housing front plate 124. In this embodiment, two diametrically-opposed channels 166, aligned along a diameter of the recess 145, are provided. Each channel 166 extends from the outer edge of the base of the recess 145 towards the aperture 122, but does not intersect the aperture 122 in this example.

**[0057]** As the drive shaft 120 rotates in use, the slots 164 periodically come into alignment with the channels 166 in the recess 145. As will be described in more detail below, when the slots 164 in the lip 150 are aligned with the channels 166 in the recess 145, fuel can flow from the internal volume 130 of the housing into the auxiliary pumping volume 160.

**[0058]** Operation of the present invention will now be described with reference to Figures 7(a) and 7(b), which show the relative position of the pump assembly components at successive stages of operation, with the drive shaft 120 both rotating and also undergoing reciprocal linear movement along the axis A, as described above.

**[0059]** The slots 164 in the flange lip 150 and the channels 166 in the recess 145 are positioned with respect to one another so that, when the slots 164 and channels 166 overlap as shown in Figure 7(a), the drive shaft 120 is undergoing axial movement in a first direction, to move the flange 142 away from the front plate 124 (in the direction labelled P in Figure 7(a)). The resulting increase in the volume of the auxiliary pumping chamber 160 causes fuel to be drawn into the auxiliary pumping chamber 160, in the direction indicated by arrow Q. In other words, the auxiliary pumping means undergoes a filling phase of operation while the slots 164 overlap with the channels 166.

**[0060]** As the drive shaft 120 rotates, the slots 164 in the lip 150 move out of alignment with the channels 166, as shown in Figure 7(b). In this condition, fluid communication between the auxiliary pumping chamber 160 and the internal volume 130 of the housing is substantially reduced or prevented by cooperation of the lip 150 and the walls of the annular slot 152.

**[0061]** While the slots 164 are out of alignment with the channels 166, the drive shaft 120 undergoes axial movement in a second direction, opposite to the first direction, to move the flange 142 towards the front plate 124. The direction of drive shaft axial movement is labelled R in Figure 7(b). The resulting decrease in volume of the auxiliary pumping chamber 160 causes an increase in pressure of the fuel therewithin.

**[0062]** In this way, fuel is urged under elevated pressure towards the bearing 126, and is forced into the clearance between the bearing 126 and the journal portion 128 of the drive shaft 120. The direction of fuel flow during this pumping phase of operation is labelled S in Figure 7(b).

**[0063]** As the drive shaft 120 continues to rotate, the slots 164 in the lip 150 again come into alignment with the channels 166, as shown in Figure 7(a). The pumping cycle thus repeats, so that a flow of fuel is established in the clearance between the bearing 126 and the journal portion 128 of the drive shaft 120.

**[0064]** Referring back to Figure 2, the fuel that is pumped through the clearance between the bearing 126 and the journal portion 128 of the drive shaft 120 drains into a cavity 170 between the journal portion 128 of the drive shaft 120 and an annular seal 172 provided in a recess 173 in the front plate 124. The seal 172 is retained by a circlip or similar retaining means located in an annular groove 174 in the wall of the recess 173.

**[0065]** The front plate 124 includes return passage means (not shown) to provide fluid communication between the internal volume 130 and the cavity 170 between the journal portion 128 of the drive shaft 120 and the seal 172. In this way, lubricating fuel pumped between the bearing 126 and the drive shaft 120 can be returned to the internal volume 130 through the return passage means, thereby to enable a continuous flow of fuel past the bearing 126 during operation of the pump.

**[0066]** Advantageously, by providing a flow of lubricating fuel between the bearing 126 and the drive shaft 120, friction between the sliding surfaces of the components is greatly reduced. Furthermore, because the lubricating fuel between the bearing 126 and the shaft 120 is continually replenished, in use, cooling of the bearing 126 is improved. These factors help to increase the service life of the bearing 126, compared to previously-known arrangements.

**[0067]** The fuel pressure in the auxiliary pumping chamber 160 peaks when the maximum pumping load is applied to the fuel in the pumping heads. Conveniently, therefore, the flow of fuel to lubricate the front plate bearing 126 is at its maximum when the drive shaft 120 is under maximum load from the high-pressure pumping operation. In other words, the present invention automatically provides maximum lubrication to the front plate bearing 126 at the time when the friction between the shaft 120 and the bearing 126 is at its highest.

**[0068]** It will also be appreciated that the rate of flow of fuel from the auxiliary pumping chamber 160 increases as the rotational speed of the drive shaft 120 increases. This means that lubrication of the front plate bearing 126 increases automatically to compensate for a higher drive shaft speed.

**[0069]** An additional benefit of the present invention is that compression of the fuel in the auxiliary pumping chamber 160 during movement of the flange 142 towards the thrust face 144 helps to guard against wear of the thrust face 144 and the flange 142, and therefore the thrust carrying capacity of the drive shaft 150 is improved compared to previously-known pump assemblies.

**[0070]** For correct operation of the auxiliary pumping means, the drive shaft 120 must move axially in the direction labelled P in Figure 7(a), to cause movement of the flange 142 away from the front plate 124, while the slots 164 in the lip 150 overlap with the channels 166 in the front plate 124. This allows the auxiliary pumping chamber 160 to fill with fuel.

**[0071]** Also, during the at least some of the remainder of the rotational cycle of the drive shaft 120, when the slots 164 do not overlap with the channels 166, the drive shaft 120 must move axially in the direction labelled S in Figure 7(b), to cause movement of the flange 142 towards the front plate 124. This forces fuel to flow out of the auxiliary pumping chamber 160 towards the bearing 126.

**[0072]** It will be appreciated, therefore, that it is important in this embodiment that the slots 164 in the lip 150 are provided at a suitable angular orientation with respect to the channels 166 such that overlap between the slots 164 and the channels 166 occurs at the appropriate phase during the rotational cycle of the drive shaft 120, when the flange 142 is moving away from the front plate 124.

**[0073]** The amount of fuel that is pumped from the auxiliary pumping chamber 160 towards the bearing 126 for a given drive shaft speed can be optimised by selecting appropriate widths for the slots 164 and the channels 166 such that the slots 164 overlap with the channels 166 over an appropriate fraction of a revolution of the drive shaft 120.

**[0074]** For example, if a relatively low fuel flow to the bearing 126 is required, the slots 164 and channels 166 can be relatively narrow in the circumferential direction. In this way, fuel can flow into the auxiliary pumping chamber 160 only during a relatively small fraction of the period during which the drive shaft 120 moves to increase the volume of the auxiliary pumping chamber 160, thereby allowing only a small volume of fuel into the chamber. If a higher flow of fuel to the bearing 126 is desired, the slots 164 and channels 166 can be wider in the circumferential direction to allow overlap of the slots 164 and channels 166 over a relatively larger fraction of the period during which the drive shaft 120 moves to increase the volume of the auxiliary pumping chamber 160, thereby allowing more fuel to fill the auxiliary pumping chamber 160.

**[0075]** In the above-described embodiment, which has opposed first and second pumping heads, the drive shaft 120 moves axially back and forth twice per revolution. In other words, during the first half-revolution of the drive shaft 120, the drive shaft 120 is subjected to a torque in a first direction as the pumping element in the first pumping head undergoes its forward stroke, and is then subjected to a torque in a second, opposite direction at the start of the return stroke of the pumping element in the first pumping head due to re-expansion of the compressed fuel in the pumping chamber of the first pumping head. Then, during the second half-revolution of the drive shaft 120, the drive shaft 120 is subjected to a torque in the first direction as the pumping element in the second pumping head undergoes its forward stroke and then to a torque in the second direction as the pumping element in the second pumping head starts its return stroke. As explained above, the direction of axial movement of the drive shaft 120 reverses as the direction of the torque reverses.

**[0076]** It will be appreciated that, in other embodiments of the invention, the shaft may experience a different number of cycles of axial movement per revolution. For example, if only one pumping head were provided, the drive shaft would move back and forth only once per revolution. The shape of the cam and the configuration of the pump drive mechanism can also influence the number of cycles of axial movement. In all cases, the number of slots in the lip, and the number of corresponding channels in the front plate, would preferably match the number of cycles of axial movement per revolution of the drive shaft.

**[0077]** As will be noted, the present invention is suitable for pump arrangements in which the drive shaft undergoes reciprocal axial movement, in use. In some pump arrangements, such as those having three or more pumping heads driven by a single cam on the drive, the pumping cycles of the pumping heads may overlap such that there is no net reversal in torque during a pumping cycle to cause reciprocal axial movement of the drive shaft. Furthermore, in pump arrangements that are driven otherwise than by helical drive gears, even if the torque acting on the drive shaft reverses during a rotation, reciprocal axial movement of the drive shaft may not ordinarily result. If it were desirable to use the present invention in such cases, reciprocal axial movement of the drive shaft could be induced by the use of a suitable drive mechanism or additional mechanism, as would be understood by a person skilled in the art.

**[0078]** It will be appreciated that many variations and modifications of the present invention are possible.

**[0079]** For example, in the embodiment described above, fuel is pumped from the auxiliary pumping chamber 160 to the sliding interface at the front plate bearing 126 by way of the clearance between the bearing 126 and the journal portion 128 of the drive shaft 120. In an alternative embodiment, one or more drillings could be provided to permit communication between the auxiliary pumping chamber 160 and the aperture 122, so as to effect a directed delivery of fuel to one or more specific locations in the region of the bearing 126. The bearing 126 may include one or more radial holes to allow fuel to flow from the drillings to the sliding interface between the bearing 126 and the journal portion 128 of the drive shaft 120.

**[0080]** The front plate bearing may be of any suitable type. For example, the bearing may comprise a bush received within a separate bearing housing, with the bearing housing being retained in the aperture in the front plate, for example by a press-fit. The bush may be fixed within the bearing housing, or may be floating. In another arrangement, the bearing bush may be received directly within the aperture, with no separate bearing housing.

**[0081]** In the above-described embodiment, the auxiliary pumping means provides a flow of lubricating fuel only to the front plate bearing, which bears the majority of the load acting on the drive shaft in the illustrated embodiment. It is however conceivable that the auxiliary pumping means could instead be arranged to deliver the flow of lubricating fuel to the bearing in the rear face of the housing body. In another embodiment, the pump assembly includes a second auxiliary pumping means to provide a flow of lubricating fluid to the bearing in the rear face in addition to the front plate bearing.

**[0082]** In the illustrated embodiment of the invention, the inlet ports in the flange lip cooperate with the channels in the front plate to provide an inlet means to allow fuel into the auxiliary pumping chamber at the appropriate time. Alternative inlet means could also be used. For example, cooperating drillings in the flange lip and the front plate could be provided. In another example, the lip is uninterrupted by inlet ports, and instead an inlet check valve is provided to deliver fuel to the auxiliary pumping chamber through flow passages in the housing or, conceivably, in the drive shaft.

**[0083]** In the illustrated embodiment of the invention, the auxiliary pumping means pumps lubricating fluid to the bearing from a lubricating fluid chamber comprising an internal volume of the pump housing. It is however conceivable that the auxiliary pumping means could be arranged to pump lubricating fluid from a separate lubricating fluid chamber, for example a chamber external to the pump housing.

**[0084]** It will be appreciated that further modifications and variations not explicitly described above are also possible without departing from the scope of the invention as defined in the appended claims.

## Claims

1. A pump assembly comprising:

    at least one high-pressure pumping head having an associated pumping element;
    a housing (124);
    a chamber (130) for lubricating fluid;
    a drive shaft bearing (126) received in the housing; and
    a drive shaft (120) received in the bearing (126), the drive shaft (120) being rotatable to cause reciprocal pumping movement of the or each pumping element;

    wherein the drive shaft (120) is arranged to move in reciprocal linear movement in a first direction along a drive shaft axis (A) and in a second, opposite direction along the drive shaft axis (A) during rotation of the drive shaft (120) in use;
    and wherein the pump assembly further comprises auxiliary pumping means including an auxiliary pumping chamber (160) arranged to draw lubricating fluid from the lubricating fluid chamber (130) during axial movement of the drive shaft (120) in the first direction, and to deliver lubricating fluid towards the bearing (126) during linear movement of the drive shaft (120) in the second direction.

2. A pump assembly according to Claim 1, wherein the auxiliary pumping chamber (160) is defined, in part, by the drive shaft (120).

**3.** A pump assembly according to Claim 2, wherein the auxiliary pumping chamber (160) is defined, in part, by a flange (142) of the drive shaft (120).

**4.** A pump assembly according to any preceding Claim, wherein the auxiliary pumping chamber (160) is defined, in part, by a thrust face (144) of the housing (124).

**5.** A pump assembly according to Claim 3, wherein the auxiliary pumping chamber (160) is defined, in part, by a thrust face (144) of the housing (124) and wherein, in use, the flange (142) moves away from the thrust face (144) during linear movement of the drive shaft (120) in the first direction and towards the thrust face (144) during linear movement of the drive shaft (120) in the second direction.

**6.** A pump assembly according to Claim 5, wherein the drive shaft (120) comprises an annular projection (150) disposed on the flange (142), and the housing (124) comprises an annular recess (152) in the thrust face (144) for receiving the annular projection (150), and wherein the auxiliary pumping chamber (160) is defined, in part, by the annular projection (150).

**7.** A pump assembly according to any preceding Claim, comprising inlet means for allowing fluid into the auxiliary pumping chamber (160) from the lubricating fluid chamber (130) during movement of the drive shaft (120) in the first direction and for restricting fluid flow between the lubricating fluid chamber (130) and the auxiliary pumping chamber (160) during movement of the drive shaft (120) in the second direction.

**8.** A pump assembly according to Claim 7, wherein the inlet means comprises an inlet port member (150) having at least one inlet port (164), the inlet port member (150) being rotatable with the drive shaft (120) and cooperable with the housing (124) to restrict fluid flow between the auxiliary pumping chamber (160) and the lubricating fluid chamber (130).

**9.** A pump assembly according to Claim 8, wherein the housing includes inlet flow means (166), and wherein the inlet port member (150) is rotatable to bring the or each of the inlet ports (164) into communication with the inlet flow means (166), thereby to allow fluid flow into the auxiliary pumping chamber (160) from the lubricating fluid chamber (130) by way of the inlet flow means (166).

**10.** A pump assembly according to Claim 9 when dependent on Claim 6, wherein the inlet port member comprises the annular projection (150) and wherein the at least one inlet port (164) is provided in the annular projection (150).

**11.** A pump assembly according to Claim 10, wherein the inlet flow means comprises one or more radial channels (166) in the thrust face (144) that intersect the annular recess (152).

**12.** A pump assembly according to any preceding Claim, wherein the auxiliary pumping chamber (160) opens into a clearance between the bearing (126) and the drive shaft (120).

**13.** A pump assembly according to any preceding Claim, wherein the lubricating fluid chamber comprises an internal volume (130) defined by the housing (124), and wherein the drive shaft (120) extends into the internal volume (130).

**14.** A pump assembly according to any preceding Claim, comprising a helical gear (140) for transmitting drive to the drive shaft (120).

**15.** A pump assembly according to any preceding Claim, arranged such that the drive shaft (120) moves in the second direction during a pumping stroke of the or each pumping element.

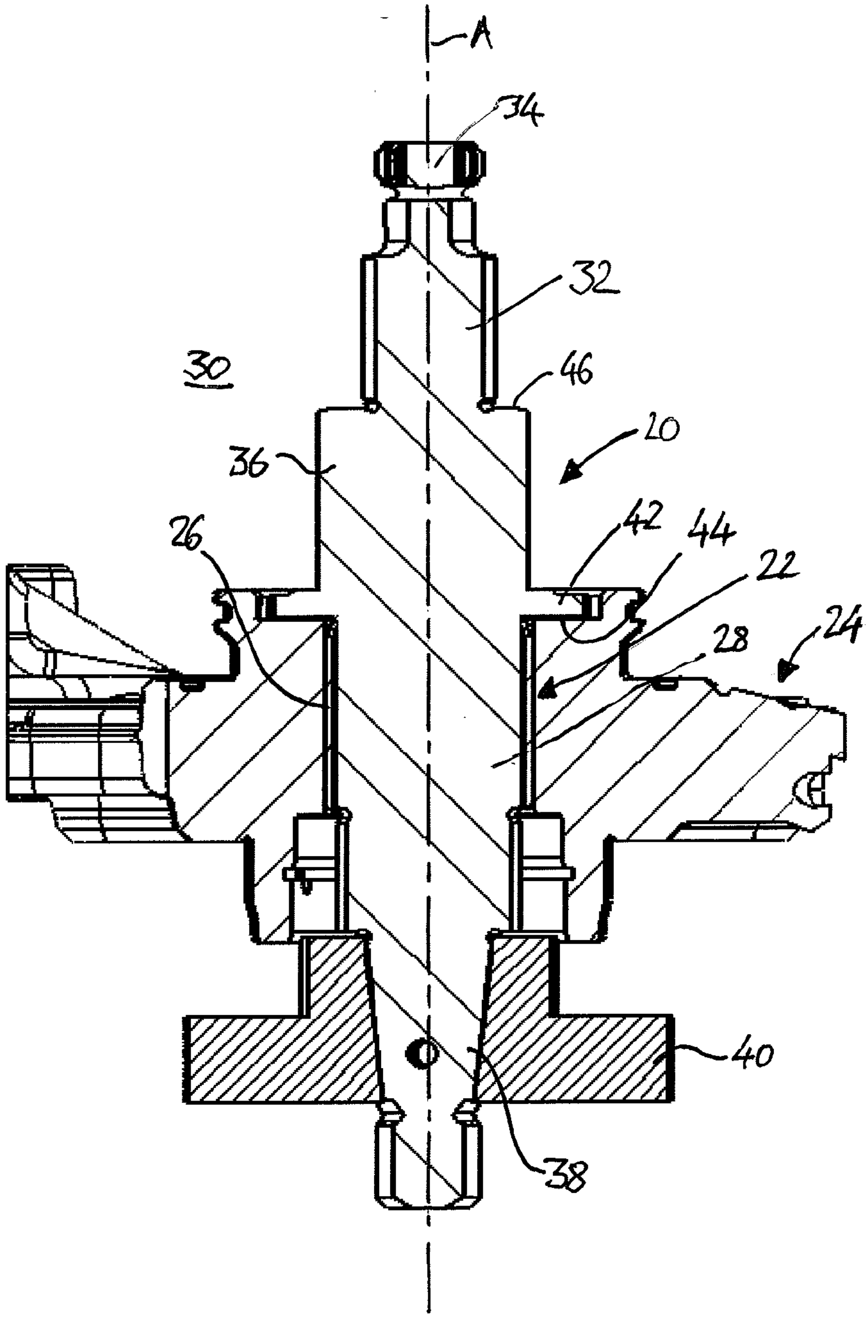
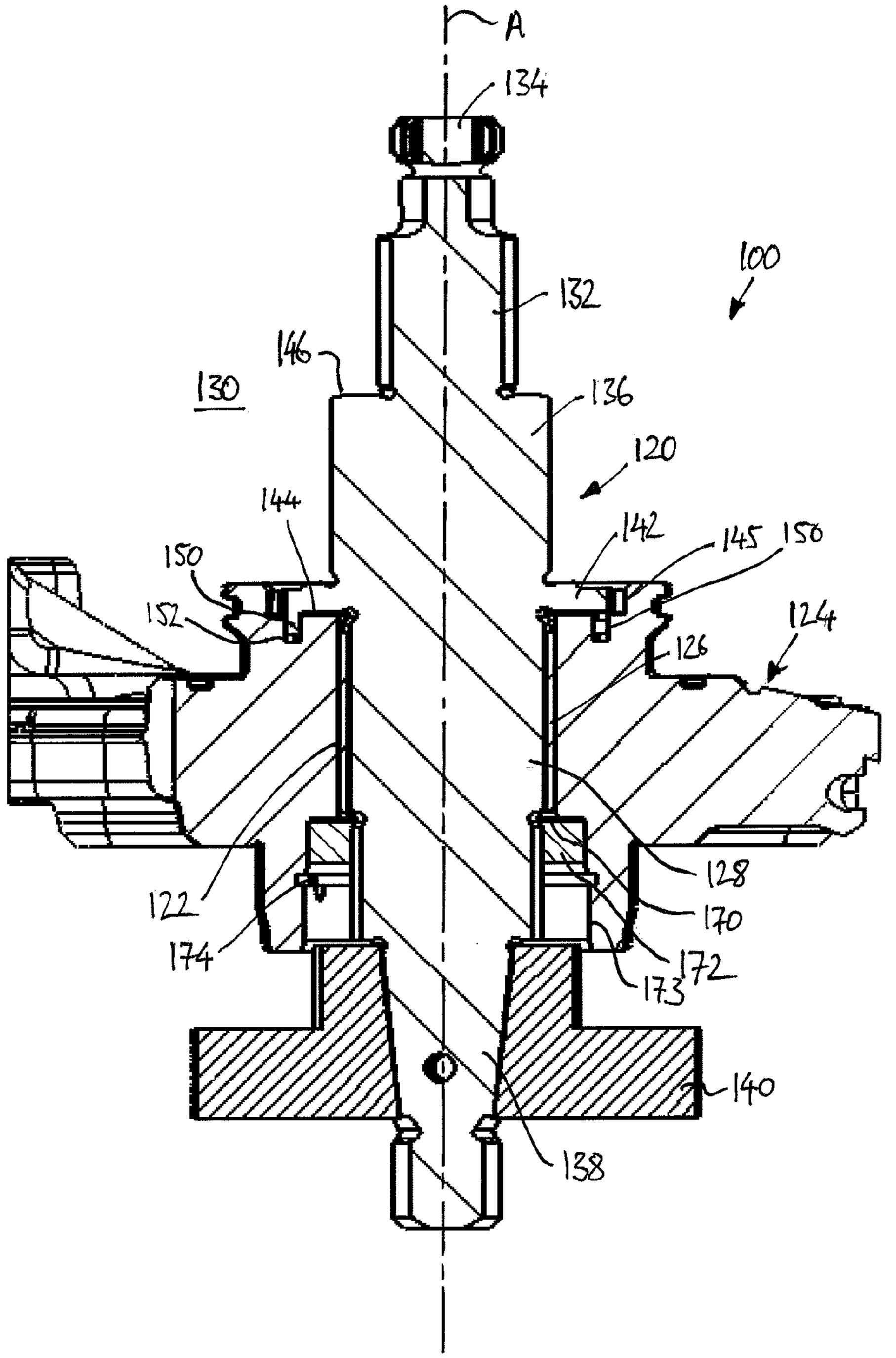



FIGURE 1
(PRIOR ART)


A
134
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100
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FIGURE 2

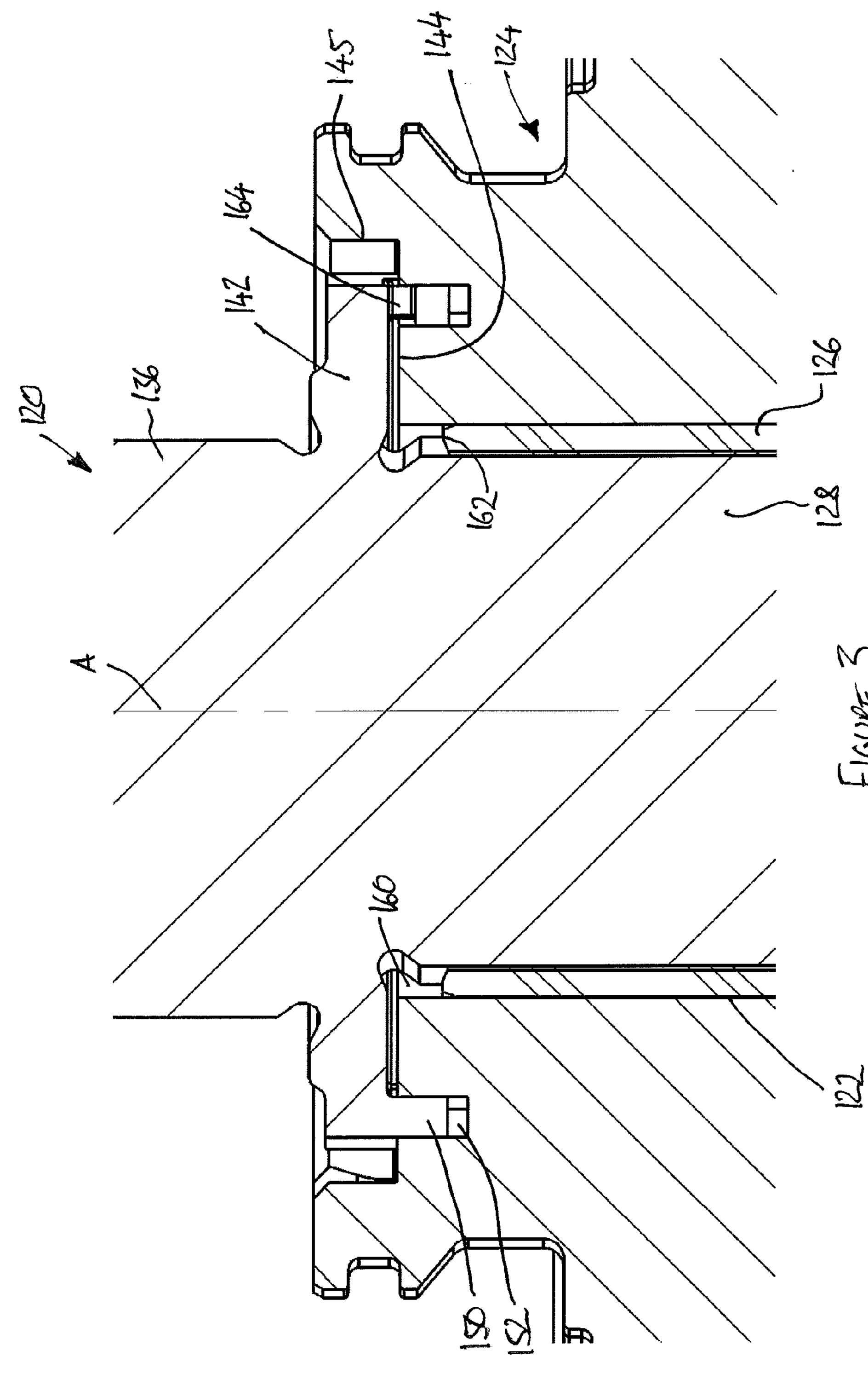


FIGURE 3

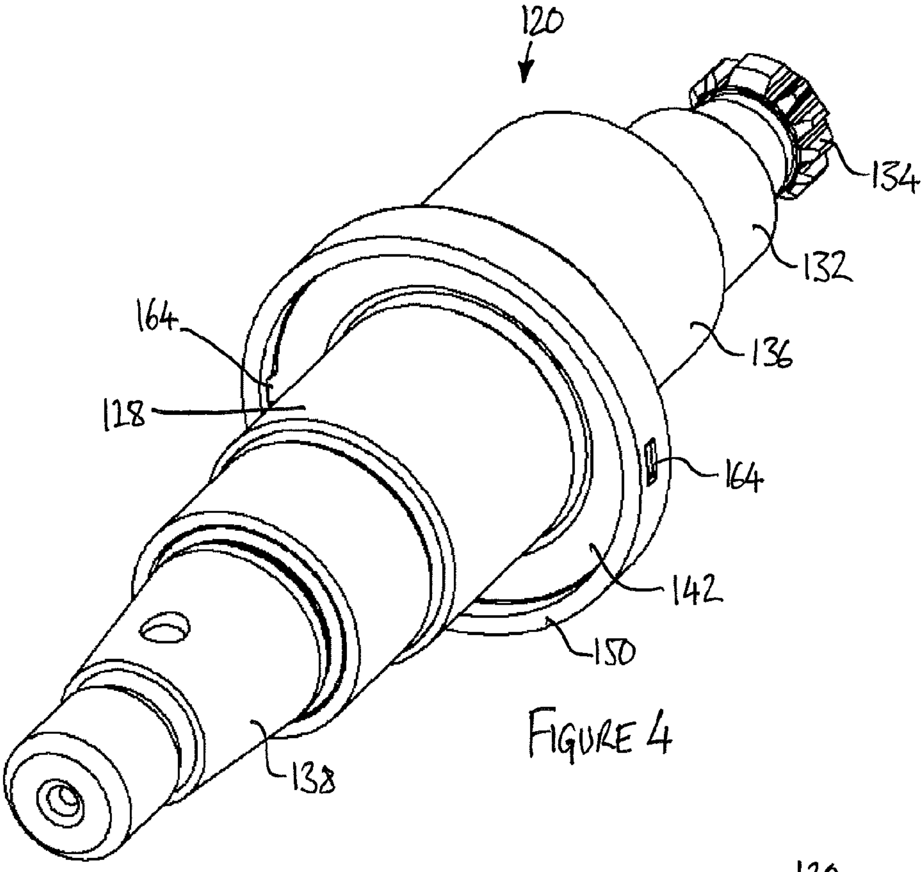


FIGURE 4

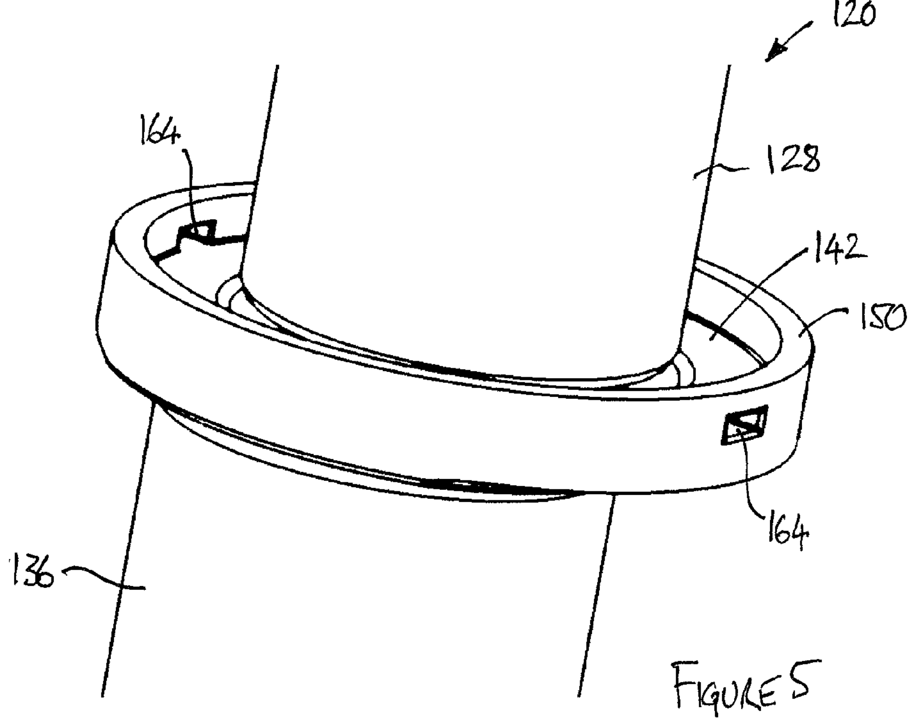


FIGURE 5

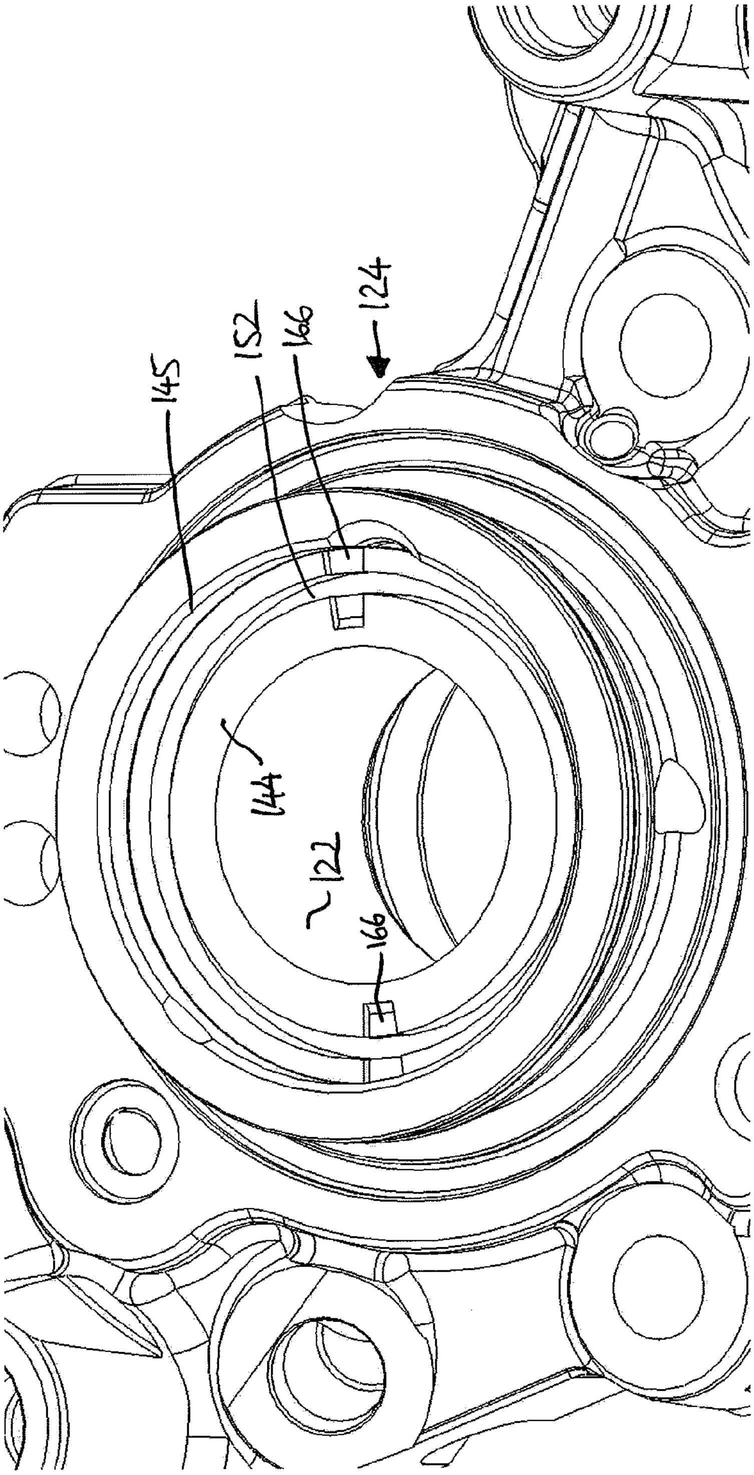


FIGURE 6

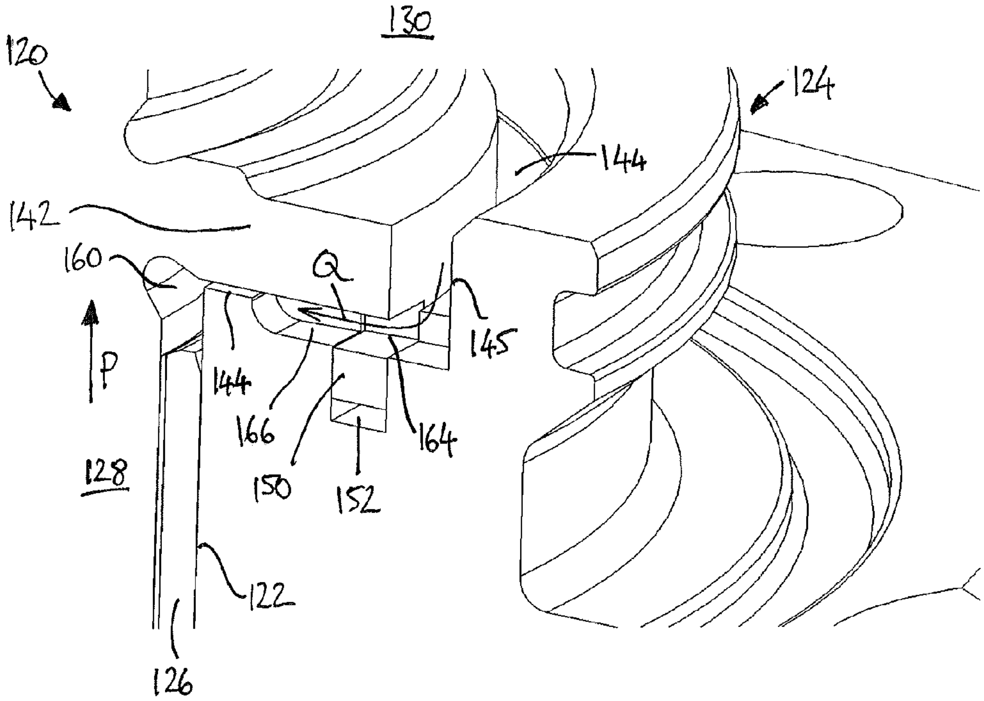


FIGURE 7(a)

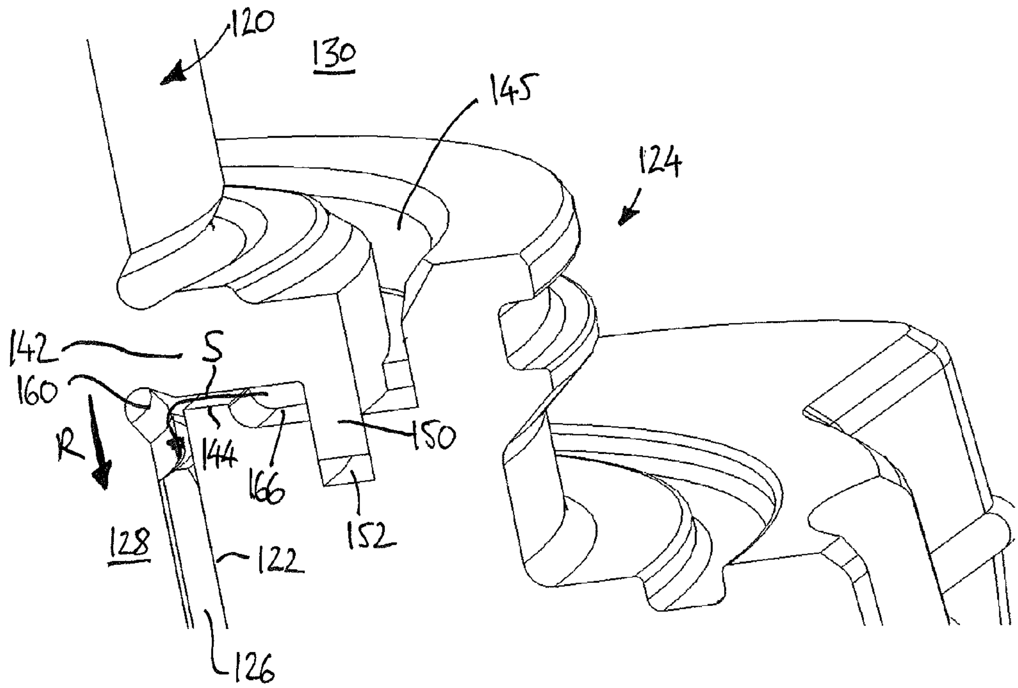


FIGURE 7(b)

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# EUROPEAN SEARCH REPORT

Application Number
EP 11 16 9953

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| Category | Citation of document with indication, where appropriate, of relevant passages | Relevant to claim | CLASSIFICATION OF THE APPLICATION (IPC) |
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The present search report has been drawn up for all claims

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|---|---|---|
| Munich | 20 October 2011 | Fistas, Nikolaos |

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20-10-2011

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