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(11) EP 1 555 432 A1

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:  
20.07.2005 Bulletin 2005/29

(51) Int Cl.7: F04B 1/04

(21) Application number: 04250254.2

(22) Date of filing: 19.01.2004

(84) Designated Contracting States:  
AT BE BG CH CY CZ DE DK EE ES FI FR GB GR  
HU IE IT LI LU MC NL PT RO SE SI SK TR  
Designated Extension States:  
AL LT LV MK

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(54) Hydraulic pump

(57) An hydraulic pump (100) comprises a plurality of pumping bores (16a - 16d), each pumping bore (16a - 16d) including an inlet port (32a - 32d) for the supply of hydraulic fluid into said pumping bore (16a - 16d), a delivery port (30a - 30d) for the delivery of said hydraulic fluid from said pump (100) and a plurality of pump plungers (20a - 20d), each pump plunger (20a - 20d) being reciprocable within a respective one of said pumping bores (16a - 16d). Each pump plunger includes a head portion (22a - 22d) and a skirt portion (24a - 24d), and each pump plunger (20a - 20d) defines with said pumping bore (16a - 16d) a pumping chamber (23a - 23d) disposed between said head portion of said pump plunger and one end of said pumping bore and a transfer

chamber disposed between said head portion (22a - 22d) and said skirt portion (24a - 24d) of said pump plunger (20a - 20d). The pump also includes communication means connected between the pumping chamber of each pumping bore and the transfer chamber of an adjacent pumping bore, and drive means (140) for reciprocally driving each of the pump plungers (20a - 20d) within said pumping bores (16a - 16d) such that hydraulic fluid is drawn into said pumping chamber through the inlet port of an adjacent pumping bore and pumped from said pumping chamber through the delivery port of said adjacent pumping bore. The drive means (140) includes means for temporarily halting at least one of the pump plungers (20a - 20d) during a part of its stroke.

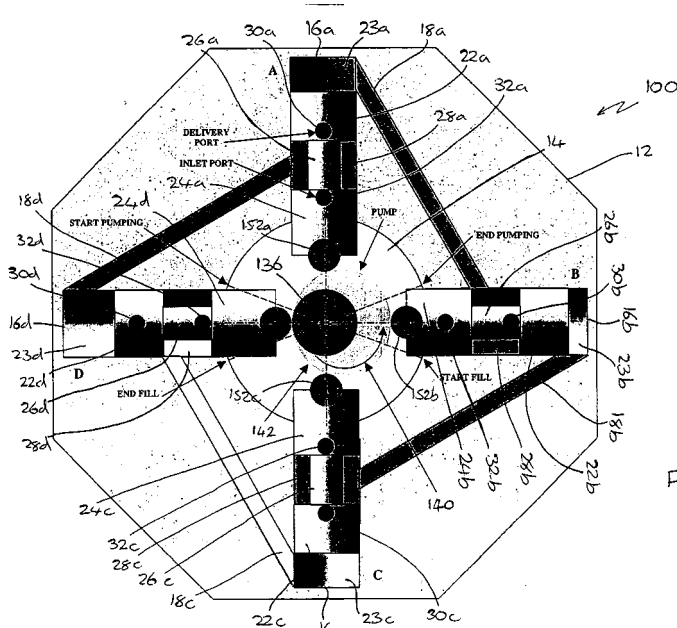


FIGURE 2

## Description

**[0001]** The present invention relates to an hydraulic pump for pressurising liquid and particularly, but not exclusively, to an hydraulic pump for pumping fuel. The pump may find application as a fuel pump in fuel injection systems for supplying high pressure fuel to an internal combustion engine or the like, and may be particularly suitable for use in common rail fuel injection systems.

**[0002]** Many current fuel injection systems for compression ignition engines are of the so-called "common rail" type in which low pressure fuel is pressurised to a high level by a pump for supplying fuel to an accumulator volume in the form of a common rail. The common rail supplies the high pressure fuel to injectors of the injection system for delivery to the combustion chambers of the associated engine.

**[0003]** One particular type of hydraulic pump is known as an adjacent plunger valve pump or APVP. An APVP consists of a plurality of cylinders, usually four, which are equi-angularly spaced around a driving member, such as a crankshaft, which is itself engine-driven. Each cylinder has a piston slidably mounted therein which is connected at one end to a single crankpin by a respective connecting rod. Rotation of the crankshaft causes each of the pistons to reciprocate within their respective cylinders in a phased, cyclical manner.

**[0004]** Two axially spaced ports are located in the wall of each cylinder, one representing an inlet port for the supply of low pressure fluid into the cylinder and the other representing a delivery port for the delivery of high pressure fluid from the cylinder. As a result of the reciprocating motion of each piston, fuel is drawn into an associated pump chamber through the inlet port and then pressurised to a high level for delivery through the delivery port. The ports are alternately opened and closed by the movement of the piston itself.

**[0005]** Although this form of pump has few components, is relatively simple to make and operates more efficiently than other forms of pump, it suffers from the disadvantage that, owing to the substantially sinusoidal motion of the pistons within the cylinder resulting from the rotation of the crank, the arrangement attempts to close one of the ports whilst simultaneously opening the other port. There is therefore an element of "overlap" of the ports whereby both the high pressure delivery port and the low pressure inlet port are open, or partially open, at the same time. This results in a certain amount of high pressure fluid leakage into the inlet port during the transition period immediately prior to opening and closing of the respective ports.

**[0006]** It is not generally possible simply to adjust the spacing of the inlet and delivery ports within the cylinder wall such that opening and closing of the ports is sequential (i.e. so that one port is fully closed before the other port is opened) since this can result in a condition known as "hydraulic lock". In this condition, closing of

both the inlet port and the delivery port traps residual fluid in the pump chamber, and the incompressibility of the fluid prevents the piston from moving within the cylinder.

5 **[0007]** The manufacture of such APVP pumps to ensure continuous, reliable operation, minimising leakage of hydraulic fluid from the low pressure inlet port whilst avoiding hydraulic lock, is therefore difficult.

10 **[0008]** It is an aim of the present invention to provide an hydraulic device which addresses this problem.

**[0009]** According to one aspect of the present invention, therefore, there is provided an hydraulic pump comprising a plurality of pumping bores, each pumping bore including an inlet port for the supply of hydraulic fluid into said pumping bore and a delivery port for the delivery of said hydraulic fluid from said pump, a plurality of pump plungers, each pump plunger being reciprocable within a respective one of said pumping bores and comprising a head portion and a skirt portion, wherein 15 each pump plunger defines with said pumping bore a pumping chamber disposed between said head portion of said pump plunger and one end of said pumping bore and a transfer chamber disposed between said head portion and said skirt portion of said pump plunger, communication means connected between the pumping chamber of each pumping bore and the transfer chamber of an adjacent pumping bore and drive means for reciprocally driving each of the pump plungers within said pumping bores such that hydraulic fluid is drawn 20 into said pumping chamber through the inlet port of an adjacent pumping bore and pumped from said pumping chamber through the delivery port of said adjacent pumping bore, characterised in that said drive means includes means for temporarily halting at least one of the pump plungers during a part of its stroke.

25 **[0010]** In one embodiment, the head portion and the skirt portion of each pump plunger is connected by a region of reduced diameter. The arrangement may be such that movement of a pump plunger within its pumping bore in a first direction opens the inlet port and closes the delivery port and movement of the pump plunger in a second, opposite direction opens the delivery port and closes the inlet port.

30 **[0011]** A first one of said pump plungers may be arranged to move in the first direction when or during which the inlet port of an adjacent pumping bore is open and in fluid communication with the transfer chamber of the adjacent pumping bore, the arrangement being such that the pumping chamber of the first pump plunger is caused to fill with hydraulic fluid from the inlet port.

35 **[0012]** The first pump plunger may be arranged to move in the second direction when (during which) the delivery port of the adjacent pump plunger is closed and in fluid communication with the transfer chamber of the adjacent pumping bore, the arrangement being such that the hydraulic fluid in the pumping chamber is caused to be pressurised and delivered from the pump through the delivery port.

**[0013]** The drive means may comprise cam means having a cam surface arranged to cooperate with each pump plunger thereby to cause the reciprocating movement thereof. The cam means may be arranged to rotate relative to the pumping bores, rotation of the cam means bringing the cam surface into cooperation with the pump plungers so as to generate reciprocal motion thereof in a substantially phased, cyclical manner.

**[0014]** In one embodiment, the cam surface comprises one or more cam lobes which are arranged to rotate eccentrically relative to the pumping bores. The means for temporarily halting at least one of the pump plungers may comprise at least one dwell region of the cam surface having a different profile from the remainder of the cam surface.

**[0015]** In one embodiment, the at least one dwell region comprises a region of the cam surface which is arranged to rotate concentrically relative to the pumping bores.

**[0016]** The first pump plunger may be arranged to halt at the top of its stroke thereby to permit the delivery port of the adjacent pumping bore to close prior to movement of the first pump plunger in the first direction. The dwell region of the cam surface with the pump plungers may be arranged to cause the first pump plunger to remain substantially stationary within the cylinder for a predetermined angle of rotation of the cam.

**[0017]** In one embodiment, the cam surface comprises two dwell regions, substantially diametrically opposed on the cam means and wherein a second one of the dwell regions is arranged to cause the first one of the plungers to halt at the bottom of its stroke, thereby to permit the inlet port of the adjacent pumping bore to close prior to movement of the first pump plunger in the second direction.

**[0018]** The pump may comprise four pumping bores, equi-angularly spaced around the drive means. Each pump plunger may be arranged to reciprocate at a phase difference of substantially  $\pm 90^\circ$  with respect to the pump plunger in an adjacent pumping bore.

**[0019]** The invention described in the preceding paragraphs may alleviate or remove the problems suffered by prior art hydraulic pumps by causing each piston in turn to halt at the top of its stroke, immediately after pumping fluid from its pumping chamber. This temporary halting of a piston allows both the inlet and the delivery ports in the adjacent pumping bore to be closed simultaneously, thereby reducing leakage of high pressure fluid into the inlet port, without resulting in hydraulic lock.

**[0020]** According to another aspect of the invention there is provided a method of operating an hydraulic pump having a plurality of pump plungers, each pump plunger being reciprocable within a respective pumping bore and drive means for reciprocally driving each of the pump plungers within the bores thereby to pump hydraulic fluid supplied to the bores, characterised in that the method includes temporarily halting at least one of

the pump plungers during a part of its stroke.

**[0021]** The present invention will now be described, by way of example only, with reference to the accompanying drawings in which:

Figure 1 illustrates a cross-section through a known form of hydraulic pump;

Figure 2 illustrates a cross-section through a form of pump according to the invention;

Figure 3 illustrates a preferred form of drive means for use with the pump of Figure 2;

Figures 4a and 4b illustrate respective positions of the pump plungers during a pumping cycle of the pump of Figure 2;

Figure 5 is a graph representing the stroke of each pump plunger during the pumping cycle of the pump of Figure 2;

Figure 6 is a graph illustrating the opening and closing of inlet and delivery ports during the pumping cycle of the pump of Figure 2; and

Figure 7 is a graph representing the volumetric flow rate of the pump of Figure 2 during the pumping cycle.

**[0022]** The following description is made with reference to a device for use as an hydraulic pump. This is not intended to be limiting, however, and the skilled person will appreciate that the device can, with only minor adjustment, equally be used as an hydraulic motor or a flow meter.

**[0023]** Referring firstly to Figure 1, a known form of hydraulic pump is shown generally at 10. The hydraulic pump 10 comprises an annular housing 12 having a generally cylindrical aperture 14 extending therethrough. Four cylinder arrangements, identified as arrangements A, B, C and D, are disposed within the housing 12 equi-angularly about the cylindrical bore 14. Cylinders that are spaced  $90^\circ$  from one another are referred to as "adjacent cylinders".

**[0024]** The following description of Figure 1 is made mainly with reference to the cylinder arrangement A, the elements of which are each denoted by reference numerals suffixed by the letter "a". The cylinder arrangements B - D are each substantially identical in construction and arrangement to the cylinder arrangement A and will not be described in detail separately. For clarity, however, throughout the specification elements of the cylinder arrangements B - D corresponding to those of the cylinder arrangement A, where described, are identified with the same reference numerals suffixed by the letters "b", "c" or "d", respectively.

**[0025]** The cylinder arrangement consists of a radially

directed pumping bore in the form of a cylinder 16a which extends into the aperture 14 such that it is open at one end. The other end of the cylinder 16a is closed. The open end of the cylinder 16a is referred to hereafter as the lower end of the cylinder. Correspondingly, the closed end of the cylinder 16a is referred to hereafter as the upper end of the cylinder.

**[0026]** A pump plunger, in the form of a plunger piston 20a, is located within the cylinder 16a and is arranged for reciprocating movement therein between the upper and lower ends thereof. The piston 20a comprises a head 22a and a skirt 24a, both of which are generally cylindrical and have a diameter which is sized to fit closely within the cylinder 16a. The space within the cylinder 16a between the upper end thereof and the head 22a of the piston 20a defines a pumping chamber 23a, the volume of which varies as the piston 20a reciprocates within the cylinder 16a.

**[0027]** The head 22a and skirt 24a of the piston 20a are separated by a region 26a of reduced diameter, hereafter referred to as a stem, which defines with the walls of the cylinder 16a a transfer chamber 28a. The arrangement is such that the volume of the transfer chamber 28a is fixed irrespective of the position of the piston 20a within the cylinder 16a. The position of the transfer chamber 28a within the cylinder 16a will, however, depend on the position of the piston 20a itself.

**[0028]** The cylinder 16a communicates with the cylinder 16b by means of a passage 18a extending therebetween. A first end of the passage 18a is in fluid communication with the pumping chamber 23a of the cylinder 16a whilst the opposite end is in fluid communication with its immediately adjacent cylinder (in a clockwise direction in the drawing, hereafter referred to as its "adjacent leading cylinder") at a region intermediate the upper and lower ends thereof. Specifically, the passage 18a opens into the cylinder 16b at a location which coincides with the transfer chamber 28b, irrespective of the position of the piston 20b.

**[0029]** Similarly, a second passage 18b connects the pumping chamber 23b of the cylinder 16b with the transfer chamber 28c of its adjacent leading cylinder 16c. Two further passages 18c, 18d connect the pumping chambers 23c, 23d of the cylinders 16c and 16d with the transfer chambers 28d, 28a of the cylinders 16d and 16a, respectively. The purpose of the passages 18a - 18d is described below.

**[0030]** The cylinder 16a is provided with first and second ports 30a, 32a disposed in the side walls thereof. In the illustrated embodiment, the ports 30a, 32a are spaced apart and are aligned in an axial direction along the cylinder wall. The spacing of the ports 30a, 32a is such that when the piston 20a is at the upper end of its stroke, the first port 30a is opened into the transfer chamber 28a, thereby communicating with the pump volume 23d of its adjacent lagging cylinder 16d via the transfer chamber 28a and the passage 18d, whilst the second port 32a is closed or sealed by the skirt 24a of

the piston 20a. In Figure 1, it is actually the cylinder arrangement B which shows the piston 20b in this situation. When the piston 20a is at the lower end of its stroke, the second port 32a is opened into the transfer chamber 28a, thereby communicating with the pump volume 23d of its lagging cylinder 16d via the transfer chamber 28a and the passage 18d while the first port 30a is closed or sealed by the head 22a of the piston 20a. In Figure 1, it is actually the cylinder arrangement D which illustrates the piston 20d in this situation.

**[0031]** The first port 30a - 30d of each cylinder arrangement is connected to a low pressure supply (not shown) of hydraulic fluid such as fuel. The second port 32a - 32d of each cylinder arrangement, on the other hand, represents a delivery port for the delivery of high pressure fluid, as described below, and may be connected to an accumulator volume (not shown) for storing pressurised fuel, which is itself connected to one or more injectors of a combustion engine.

**[0032]** The lower end of the piston skirt 24a is pivotally connected to one end of a connecting rod 34a, the other end of which is rotatably mounted to a crankpin 36 of an associated crankshaft. The arrangement is such that rotation of the crankshaft causes eccentric rotation of the crankpin 36 relative to the cylinder arrangement which, via the connecting rod, in turn causes the reciprocating movement of the piston 20a within the cylinder 16a, as described above.

**[0033]** Operation of the pump 10 will now be described.

**[0034]** The crankshaft and crankpin 36 is driven, for example by means of a combustion engine so that they rotate in the direction shown by the arrow X. As mentioned above, the crankpin 36 rotates in an eccentric manner relative to the cylinder arrangements A - D so that each piston 20a - 20d, to which the crankpin is connected via the respective connecting rod 34a - 34d, is caused to reciprocate within its respective cylinder 16a - 16d. Owing to the mutually orthogonal orientation of the cylinder arrangements, the pistons 20a - 20d reciprocate in a cyclical, phased manner whereby each piston is 90° ( $\pi/2$  radians) out of phase with the pistons in adjacent cylinders.

**[0035]** The following description assumes a starting point as illustrated in Figure 1, which represents the instantaneous positions of the crankpin 36 and pistons 20a - 20d at time  $t = 0$ . The crankpin is positioned at 90° and is rotating anticlockwise resulting in the piston 20b being at the top of its stroke (with the delivery port 30b fully open and the inlet port 32b fully closed) and the piston 20d being at the bottom of its stroke (with the inlet port 32d fully open and the delivery port 30d fully closed). The pistons 20a and 20c, on the other hand, are mid-stroke, the piston 20a moving towards the top of its stroke (i.e. towards the innermost position within the cylinder 16a) and the piston 20c towards the bottom of its stroke (i.e. towards the outermost position within the cylinder 16c). In the case of the cylinder arrange-

ment A, the piston 20a is in the transition period between closing of the inlet port 32a and opening of the delivery port 30a whilst in the case of the cylinder arrangement C, the piston 20c is in the transition period between closing of the delivery port 30c and opening of the inlet port 32c.

**[0036]** The downward movement of the piston 20c reduces the pressure within the pumping chamber 23c below that of the low pressure hydraulic fuel supply. Since the inlet port 32d is open and in communication with the pumping chamber 23c via the passage 18c and the transfer chamber 28d, the pumping chamber 23c therefore fills with fuel from the inlet port 32d. This downward movement of a piston between the top of its stroke and the bottom of its stroke, which occurs as the crankshaft rotates through 180° away from the respective cylinder arrangement, is termed the filling stroke.

**[0037]** It follows, therefore, that at time  $t = 0$  the pumping chamber 23d, the passage 18d and the transfer chamber 28d are already filled with fuel since the piston 20d is at the bottom of its stroke, having just completed its filling stroke.

**[0038]** The upward movement of the piston 20a pressurises the fuel within the pumping chamber 23a, the passage 18a and the transfer chamber 28b. Since the delivery port 30b is open and in fluid communication with the pumping chamber 23a via the passage 18a and the transfer chamber 28b, the fuel therein is forced out of the delivery port 30b in the form of a high pressure jet or wave. This upward movement of a piston between the bottom of its stroke and the top of its stroke, which occurs as the crankshaft rotates through 180° towards the respective cylinder arrangement, is termed the pumping stroke.

**[0039]** Finally, the pumping chamber 23b, the passage 18b and the transfer chamber 28c are, theoretically, substantially empty, the fuel having been delivered through the delivery port 30c (which in Figure 1 is now closed due to the downward movement of the piston 20c through its filling stroke) by the pumping stroke of the piston 20b during the previous 180° of rotation of the crankpin 36. In practice, however, because the swept volume of the piston 20b is significantly less than the total combined volume of the pumping chamber 23b, the passage 18b and the transfer chamber 28c, not all of the fluid contained therein prior to the pumping stroke will have been delivered through the delivery port 30c. A certain amount of residual fuel therefore remains in these spaces following completion of the pumping stroke. This residual fuel remains at a high pressure within the pumping chamber 23b, the passage 18b and the transfer chamber 28c until the filling stroke of the piston 20b commences.

**[0040]** Rotation of the crankpin 36 through a further 90° (in an anti-clockwise direction in the drawing) will result in the piston 20a reaching the top of its pumping stroke, the piston 20c reaching the bottom of its filling stroke and the pistons 20b and 20d reaching mid-stroke,

the piston 20d on its pumping stroke and the piston 20b on its filling stroke.

**[0041]** At this time, referred to as time  $t = 1$ , with the piston 20a at the top of its stroke, the passage 18a contains only residual fuel, the piston 20a having completed its pumping stroke and delivered much of its fuel through the delivery port 30b of the cylinder 16b. In addition, at time  $t = 1$ , the delivery port 30b has been closed by the downward movement of the piston 20b.

**[0042]** Since the piston 20b is midway through its filling cycle, the transfer chamber 28c, the passage 18b and the pumping chamber 23b are being filled with fuel through the inlet port 32c, now open owing to the position of the piston 20c at the bottom of its stroke.

**[0043]** With the piston 20c at the bottom of its stroke, the pumping chamber 23c, the passage 18c and the transfer chamber 28d contain "static" fuel which is being neither filled nor delivered. Finally, the fuel in the pumping chamber 23d, the passage 18d and the transfer chamber 28a is being delivered, at high pressure, through the delivery port 30a (this latter now being open due to the position of the piston 20a at the top of its stroke) by virtue of the pumping action of the piston 20d.

**[0044]** It will be clearly understood by the skilled person that further rotation of the crank through 90° will result in high pressure fluid delivery from the delivery port 30d by the pumping stroke of the piston 20c and then, after a further rotation of 90°, from the delivery port 30c by the pumping action of the piston 20b, following which the pump 10 will have returned to the instantaneous position shown in Figure 1.

**[0045]** It will be further understood that continuous rotation of the crankshaft causes the substantially continuous, cyclical reciprocation of each of the pistons 20a - 20d, in the manner described above, to generate a substantially continuous high pressure delivery of fuel from the pump.

**[0046]** This form of pump is relatively simple to construct and involves few components. Furthermore, the positively driven valve system is not subject to the detrimental effects of inertia and load that can cause conventional free-sprung poppet valves, ball valves or disc valves to suffer low efficiency.

**[0047]** A disadvantage of such devices, however, is that, owing to the substantially continuous sinusoidal motion of the pistons 20a - 20d generated by the rotation of the crank 36, there is a period between closing of the delivery port 30a - 30d and opening of the inlet port 32a - 32d on the filling stroke of the piston 20a - 20d in any given cylinder arrangement A - D during which high pressure fuel in the transfer chamber 28 of the piston 20 (being pressurised by the pumping action of the piston in the immediately lagging cylinder) can leak past the piston skirt 24a - 24d and into the inlet port 32a - 32d of the cylinder. This problem is particularly acute where the pressure difference between the delivery port 30a - 30d and the inlet port 32a - 32d is high, such as when the device is used as an hydraulic pump as described

above. This represents a considerable reduction in operational efficiency of the pump.

**[0048]** Previously, the solution to this problem has been to try to minimise any "overlap" of the inlet and delivery ports 32a- 32d, 30a - 30d, that is to say to minimise the amount by which both ports are open simultaneously. This can be achieved by spacing the ports 30a - 30d, 32a - 32d so that the delivery port is closed some time before the inlet port is opened. However, in doing this, the pump becomes prone to "hydraulic lock" whereby the simultaneous closure of both inlet and delivery ports of the cylinder arrangement leaves no outlet for the fluid in the pumping chamber 23a - 23d of the immediately lagging cylinder. The incompressibility of the fuel means that the upwardly moving piston in the lagging cylinder is halted, preventing further rotation of the crank 36 and creating a locked state within the pump.

**[0049]** Referring now to Figure 2, an improved form of hydraulic pump according to one aspect of the invention is shown generally at 100. In this Figure, and in subsequent Figures in this specification, like reference numerals are used, as far as possible, to indicate like parts.

**[0050]** It will be seen that the pump 100 is similar in form to that illustrated in, and described with reference to, Figure 1. In particular, the device 100 features an annular housing 12 with a central aperture 14, four radially directed and equi-angularly spaced cylinder arrangements A - D having respective cylinders or pumping bores 16a - 16d within which respective pistons 20a, 20d are disposed and fluid passages 18a - 18d extending between the pumping chamber 23a - 23d of one cylinder 16a - 16d and a midpoint of the immediately leading cylinder. Each cylinder has an inlet port 32a - 32d and a delivery port 30a - 30d disposed in the sidewalls thereof.

**[0051]** The piston 20a - 20d disposed in each cylinder 16a - 16d is again provided with a narrowed region or stem 26a - 26d between head 22a- 22d and skirt 24a - 24d portions thereof, defining with the walls of the cylinder 16a - 16d a transfer chamber 28a - 28d.

**[0052]** Drive means, in the form of a rotatable member axially disposed within the central aperture 14, rotates to drive the pistons 20a - 20d in a cyclical, phased manner so that the device operates on a similar principle to the prior art pump of Figure 1.

**[0053]** In the pump 100 of the present invention, however, the rotatable member takes the form of a shaft 136 having a cam 140 disposed thereon. The cam 140 includes a cam surface 142, the profile of which is more easily seen in Figure 3. The shaft rotates in the direction of arrow X.

**[0054]** Referring to Figure 3, the cam 140 generally takes the form of an oblate, circular disc mounted to the shaft 136 eccentrically, that is to say at a point offset from its geometrical centre. The cam surface 142 thus consists of two diametrically opposed lobes 144, 146, which are eccentrically located relative to the shaft 136 and which define, respectively, a pumping ramp and a

filling ramp. Orthogonally to the lobes 144, 146, the cam surface 142 also defines two diametrically opposed "flats" or "dwell platforms", the purpose of which is described below. In the illustrated embodiment, the dwell platforms consist of two circular surfaces 148, 150 which are concentric with the shaft.

**[0055]** The eccentricity of the lobes 144, 146 means that the radial distance between the cam surface 142 and any given cylinder 16a - 16d varies as the lobe rotates past the bottom end of the cylinder. For the dwell platforms 148, 150, however, their concentricity means that the cam surface 142 remains a constant distance from each cylinder as it rotates past the bottom end thereof.

**[0056]** The skirt 24a - 24d of each piston 20a - 20d cooperates with the cam surface 142 by means of a respective spherical bearing or roller 152a - 152d located in a recess 154a - 154d in the bottom of the piston 20a - 20d. As the cam 140 rotates with the shaft 136 it bears against each piston 20a - 20d in such a way that, for one full rotation of the cam 140, each piston 20a - 20d reciprocates within its cylinder 16a - 16d, driven towards the top of its stroke by the pumping ramp 144 and falling to the bottom of its stroke over the filling ramp 146.

**[0057]** Unlike the pump of Figure 1, the cam 140 provides no force on the piston 20a - 20d to drive it downwards, towards the bottom of its stroke. Instead, each piston 20a - 20d may be biased towards the bottom dead centre position by the pressure of the fluid from the inlet port 32. This may require the provision of a feed pump or the like (not shown) for generating a sufficiently high fluid pressure at the inlet port 32. The use of such a feed pump may also reduce the occurrence of cavitation within the cylinder.

**[0058]** Alternatively, or in addition, each cylinder 16a - 16d may be biased towards the bottom dead centre position by means of a resilient member, such as a return spring or the like (not shown), which is connected or otherwise coupled to the piston 20a - 20d. The return spring biases the piston towards the bottom of its stroke thereby maintaining cooperation of the piston 20a - 20d with the filling ramp 146 as the cam 140 rotates.

**[0059]** However, owing to the dwell platforms 148, 150 defined on the cam surface 142, each piston 20a - 20d is subjected to a dwell period in its movement whereby the piston is made to halt at top and bottom dead centres (i.e. at the top and bottom of its stroke) for a predetermined angle of rotation of the cam, defined by the angle subtended by the dwell platform 148, 150. In an advantageous embodiment, this angle is between 30° and 50°.

**[0060]** During the dwell period of a piston (for example the piston 20a, which shall be referred to for convenience as the pumping piston), the pistons in the immediately adjacent cylinders 16b - 16d are moving between top and bottom dead centre positions at their greatest speed within their respective cylinders. Because the pumping piston 20a is halted at the top of its stroke, the

swept volume of the piston is substantially zero and it is possible to arrange for the delivery port 30b in the adjacent leading cylinder 16b to close well before the inlet port 32b is opened.

**[0061]** Specifically, the cam 140 is arranged such that the pumping piston 16a is made to halt at the top of its stroke a predetermined time before the delivery port 30b is closed. This is to ensure that 'wire drawing' of the pumped oil does not damage the edges of the delivery port 30b and the transfer chamber 28b. The inlet port 32b is then opened a predetermined time after the delivery port 30b is closed. There is therefore a period, of predetermined duration, during which both the inlet port 32 and the delivery port 30 of the adjacent leading cylinder (in this case the cylinder 16b) are closed simultaneously without the pump 100 suffering hydraulic lock. The cam 140 and the shaft 136 are able to continue to rotate so that the pumping cycle of the pump 100 is substantially uninterrupted.

**[0062]** As described above, the effect of closing the delivery port 30b well before the opening of the inlet port 32b is a significant reduction, or even substantial elimination, of high pressure fuel leakage into the inlet port 32b. In order to ensure that the delivery port 30b is indeed closed before the inlet port 32b is opened, the ports can be spaced further apart than in the case of the prior art device. Alternatively, or in addition, the length of the stem 26a - 26d of each piston 20a - 20d can be reduced. Either or both arrangements have the effect that the head portion 22a - 22d of each piston 20a - 20d fully closes the respective delivery port 30a - 30d before the skirt portion 24a - 24d opens the inlet port 32a - 32d.

**[0063]** Because the delivery port 30b of the adjacent leading cylinder 16b is closed well before the inlet port 32b is opened, and because the pumping piston 20a is no longer pressurising the fuel in the pumping chamber 23a, leakage of fuel past the skirt 24b of the piston 20b in the adjacent leading cylinder 16b and into the inlet port 32b is minimal.

**[0064]** The pump 100 thus works in a similar principle to the prior art pump of Figure 1 with the exception that each piston 20a - 20d is made to halt temporarily at the top and bottom of its stroke, by virtue of the dwell platform 148, 150 provided on the surface 142 of the cam. This temporary halting of each piston 20a - 20d allows the delivery port 30a - 30d in the respective adjacent leading cylinder to be fully closed before the inlet port 32a - 30d is opened, thereby significantly reducing high pressure fuel leakage, without the danger of hydraulic lock occurring.

**[0065]** Figures 4a and 4b illustrate, respectively, the instantaneous positions of the pistons 20a - 20d as they are shown in Figure 2 and their positions following a further rotation of the cam 140 through approximately 40°, together with the cooperation of each piston 20a - 20d with the cam surface 142. For clarity, only the elements of the cylinder arrangement A are labelled in Figures 4a and 4b.

**[0066]** In Figure 4a it can be seen that the piston 20a is cooperating with the pumping ramp 144 of the cam surface 142 and is thus moving upward, midway through its pumping stroke. At this point in its stroke, the inlet port 32a is still partly open but the delivery port 30a is fully closed. The piston 20b, on the other hand, is cooperating with the first dwell platform 148 having completed its pumping stroke and is thus halted at the top of its stroke with the delivery port 30b fully open and the inlet port 32b fully closed.

**[0067]** The piston 20c is cooperating with the filling ramp 146 of the cam surface 142 and is thus moving downward, midway through its filling stroke. At this point in its stroke, the delivery port 30c is still partly open but the inlet port 32c is fully closed. The piston 20d is cooperating with the second dwell platform 150, having completed its filling stroke and is thus halted at the bottom of its stroke with the inlet port 32d fully open and the delivery port 30d fully closed.

**[0068]** In Figure 4b which represents the positions of the pistons 20a - 20d after rotation of the cam 140 through approximately 40°, it can be seen that the piston 20a is almost at the top of its stroke while the piston 20b is still cooperating with the first dwell platform 148. On the other hand, the piston 20c is almost at the bottom of its stroke having closed the delivery port 30c and partly opened the inlet port 32c. Because the piston 20b is stationary, the piston 20c can be arranged to close the delivery port 30c fully before opening the inlet port 32c without the risk of hydraulic lock occurring. The simultaneous closure of both the delivery port 30c and the inlet port 32c for a short period of time does not compromise the pumping cycle of the pump 100 since there is no swept volume from the halted piston 20b.

**[0069]** Figure 5 illustrates graphically the simultaneous movement of the pistons 20a - 20d in the pump 100. Trace 200a represents the movement of the piston 20a whilst traces 200b, 200c and 200d represent the movement of the pistons 20b, 20c and 20d, respectively. Accordingly, the trace 200a is shown as lagging behind the trace 200b, since for anticlockwise rotation of the pump 100 shown in Figure 2, the piston 20b leads the piston 20a. Likewise, the trace 200c is shown as lagging the trace 200d since the piston 20d leads the piston 20a.

**[0070]** For clarity, it is mentioned that this order of piston lead/lag is relevant only for anticlockwise rotation of the pump 100 when viewed as in Figure 2. Clockwise rotation would result in the piston 20a leading the piston 20b and so on. Furthermore, it is mentioned that the position of the pump 100 shown in Figure 2 is inconsistent with the graph of Figure 5. Figure 2 illustrates the pump 100 at the 90° position at which the piston 20b is at the top of its stroke. Figure 5, however, shows the piston 20b to be at the top of its stroke at the 180° position. Although the lead/lag order of the graph of Figure 5 is correct, therefore, the graph itself is approximately 90° out of phase compared with the drawing of Figure 2. This will be fully understood by the skilled person and does

not compromise a discussion of Figure 5 *in vacuo*.

[0071] From Figure 5, it can be seen that the pistons 20a - 20d reciprocate  $90^\circ$  ( $\pi/2$  radians) out of phase of one another and exhibit the same substantially sinusoidal movement of the prior art pump pistons for a greater part of their respective strokes. At the top and bottom of its stroke, however, each piston is made to halt temporarily for a predetermined period, as described above. This period, during which the piston is stationary, is represented by the horizontal lines at stroke lengths of  $\pm 2.5\text{mm}$  in each trace 200a - 200d and continues for approximately  $30^\circ$ - $50^\circ$  of rotation of the cam 140, corresponding to the period of rotation of the cam 140 during which the dwell platforms 140, 150 cooperate with the rollers (152a - 152d) of the pistons (20a - 20d).

[0072] Figure 6 illustrates the opening and closing of the ports 30b, 32b relative to the stroke timing shown in the graph of Figure 5. It can be seen that the delivery port 30b (trace 230b) is opened as the piston 20b (illustrated by the trace 200b in Figure 5) approaches the top of its stroke and shortly before the commencement of the pumping stroke of the piston 20a (illustrated by the trace 200a in Figure 5). The delivery port 30b remains open during the entire pumping stroke of the piston 20a and closes shortly after the piston 20b begins its filling stroke.

[0073] The inlet port, on the other hand (illustrated by trace 232b) opens as the piston 20b approaches the bottom of its stroke and shortly before the commencement of the filling stroke of the piston 20a. The inlet port 32b remains open during the entire filling stroke of the piston 20a and closes shortly after the piston 20b begins its pumping stroke.

[0074] The period during which both the delivery port 30b and the inlet port 32b are closed can be clearly seen in Figure 6 at and about angles of rotation of the cam 140 of  $90^\circ$  and  $270^\circ$ . It should be mentioned that the graph of Figure 6 shows the ports opening and closing substantially instantaneously. It will be appreciated, however, that this is not strictly accurate and that a more gradual, possibly nonlinear transition between open and closed states would be achieved by the movement of the pistons 20a - 20d.

[0075] Figure 7 illustrates the pumping rate of the device 100 in terms of pumped fluid volume per degree of rotation of the cam 140. The traces 300a - 300d represent the individual pumping rates of the pistons 20a - 20d respectively and show that a positive pumping rate exists for each piston 20a - 20d only during the pumping stroke of that piston, as shown in Figure 5. Thus, rotation of the cam 140 between the positions of approximately  $120^\circ$  and  $245^\circ$ , for example, shows a positive pumping rate for the piston 20a, corresponding to the pumping stroke of piston 20a shown by the trace 200a in Figure 5.

[0076] Figure 7 also illustrates the total pumping rate of the device 100 by the bold trace 310. At the rotational position of  $180^\circ$ , for example, the pumping rate (shown by the trace 300) is generated virtually exclusively by

the piston 20a which is midway through its pumping stroke and moving at its greatest speed within the cylinder 16a (trace 200a in Figure 5). At the rotational position of  $225^\circ$ , however, the pumping rate is generated by both the piston 20a nearing the end of its pumping stroke and the piston 20d having just commenced its pumping stroke. The trace 310 therefore represents the sum of the instantaneous pumping rates of each piston 20a - 20d and shows that there is a substantially continuous flow of fluid from the pump 100, which varies by only a small percentage in dependence on the positions of the respective pistons 20a - 20d.

[0077] It will be appreciated that the imposing of a dwell period on the pistons' movement must be achieved, for a given angular velocity of the cam 140, by shortening the stroke of the pistons 20a - 20d compared with the prior art pump of Figure 1 and/or by adjusting the profile of the cam lobes 144, 146 to increase the rate of movement of the pistons 20a - 20d within their respective cylinders 16a - 16d during the transition between the top and bottom of their strokes. Shortening the stroke of the pistons 20a - 20d, by effectively "clipping" the top and bottom of the piston's sinusoidal motion, reduces the swept volume of the piston and thus reduces the overall pumping rate of the pump 100. On the other hand, increasing piston speed within the cylinder maintains the stroke length but increases the pumping rate of the pump. Which arrangement is selected is one of choice although an increase in pumping rate may be considered preferable.

[0078] While the above described embodiment represents an advantageous form of hydraulic pump, it will be appreciated that a number of modifications can be made to the device without departing from the scope of the invention.

[0079] For example, the cam 140 can be mounted on the shaft 136 or can be integral therewith and may be formed from any suitable material. The engagement of the cam surface 142 with the pistons 20a - 20d need not be achieved through the use of spherical bearings 152 and any suitable means, such as conventional followers or tappets, may be employed.

[0080] The angle subtended by the dwell platform may be selected as desired but in the preferred embodiment is between  $30^\circ$  and  $50^\circ$  and, more preferably, between  $40^\circ$  and  $45^\circ$ .

[0081] Furthermore, it is not essential that a cam 140 of the form described be used. The function of the cam 140, as opposed to the crankshaft 36 of the prior art, is to allow the provision of a dwell period, the forming of which by the appropriate profiling of a cam is relatively straightforward. However, any other suitable means can be employed to provide this functionality.

[0082] It is envisaged, for example, that connecting the pistons 20a - 20d to a crankpin by way of a coil spring or other resilient member could provide a similar effect. Increasing the radius of rotation of the crankpin allows each piston 20a - 20d to reach the top or bottom of its

stroke before the crank is aligned with the piston. Further rotation of the crank is permitted, without further movement of the piston, through compression or extension of the spring. Each piston 20a - 20d is thus forced to remain temporarily stationary at the top and bottom of its stroke for a period of time determined by the characteristics of the spring.

**[0083]** Furthermore, it is possible to provide the improved performance over prior art devices using only one dwell platform, arranged to temporarily halt the piston at the top of its stroke. It is not essential to provide two dwell platforms on the cam 140. For the coil spring arrangement mentioned above, the provision of a single dwell period could be achieved by means of a non-extensible compression spring.

**[0084]** It will be appreciated that the present invention provides a simple yet highly effective hydraulic device, which can be used as a pump, a motor or a fluid flow meter, and which is far less susceptible to hydraulic lock than prior art devices. The invention may find particular application as the basis for a Common Rail Pump.

## Claims

### 1. An hydraulic pump (100) comprising:

a plurality of pumping bores (16a - 16d), each pumping bore (16a - 16d) including an inlet port (32a - 32d) for the supply of hydraulic fluid into said pumping bore (16a - 16d) and a delivery port (30a - 30d) for the delivery of said hydraulic fluid from said pump (100);

a plurality of pump plungers (20a - 20d), each pump plunger (20a - 20d) being reciprocable within a respective one of said pumping bores (16a - 16d) and comprising a head portion (22a - 22d) and a skirt portion (24a - 24d), wherein each pump plunger (20a - 20d) defines with said pumping bore (16a - 16d) a pumping chamber (23a - 23d) disposed between said head portion of said pump plunger and one end of said pumping bore and a transfer chamber disposed between said head portion (22a - 22d) and said skirt portion (24a - 24d) of said pump plunger (20a - 20d);

communication means connected between the pumping chamber of each pumping bore and the transfer chamber of an adjacent pumping bore; and

drive means (140) for reciprocally driving each of the pump plungers (20a - 20d) within said pumping bores (16a - 16d) such that hydraulic fluid is drawn into said pumping chamber through the inlet port of an adjacent pumping bore and pumped from said pumping chamber through the delivery port of said adjacent pumping bore;

**characterised in that** said drive means (140) includes means for temporarily halting at least one of the pump plungers (20a - 20d) during a part of its stroke.

2. An hydraulic pump as claimed in claim 1 wherein movement of said pump plunger (16a - 16d) within said pumping bore (16a - 16d) in a first direction opens said inlet port (32a - 32d) and closes said delivery port (30a - 30d) and movement of said pump plunger in a second, opposite direction opens said delivery port (30a - 30d) and closes said inlet port (32a - 32d);

3. An hydraulic pump as claimed in claim 1 or claim 2 **characterised in that** the drive means (140) comprises cam means having a cam surface (142) arranged to cooperate with each pump plunger (20a - 20d) thereby to cause reciprocal movement thereof.

4. An hydraulic pump as claimed in claim 3 wherein the cam means (140) is arranged to rotate relative to said pumping bores (16a - 16d), rotation of the cam means (140) bringing the cam surface (142) into cooperation with the pump plungers (20a - 20d) so as to generate reciprocal motion thereof in a substantially phased, cyclical manner.

5. An hydraulic pump as claimed in claim 3 or claim 4 wherein the cam surface (142) comprises one or more cam lobes (144, 146) which are arranged to rotate eccentrically relative to the pumping bores (16a - 16d).

6. An hydraulic pump as claimed in claim 5 wherein the means for temporarily halting at least one of the pump plungers comprises at least one dwell region (148, 150) of the cam surface (142) having a different profile from the remainder of the cam surface.

7. An hydraulic pump as claimed in claim 6 wherein the at least one dwell region (148, 150) comprises a region of the cam surface which is arranged to rotate concentrically relative to said pumping bores (16a - 16d).

8. An hydraulic pump as claimed in claim 7 wherein at least one of said pump plungers (20a - 20d) is arranged to halt at the top of its stroke thereby to permit the delivery port (30a - 30d) of an adjacent pumping bore (16a - 16d) to close prior to movement of said pump plunger (20a - 20d) in said first direction.

9. An hydraulic pump as claimed in any one of claims 6 to 8 wherein the at least one dwell region (148, 150) of the cam surface (142) is arranged to cause

a first one of said pump plungers (20a - 20d) to remain substantially stationary within the pumping bore (16a - 16d) for a predetermined angle of rotation of the cam (140).

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10. An hydraulic pump as claimed in claim 8 or claim 9 wherein said cam surface (142) comprises two dwell regions (148, 150), substantially diametrically opposed on said cam means and wherein a second one of said dwell regions is arranged to cause said first one of said plungers to halt at the bottom of its stroke, thereby to permit the inlet port of said adjacent pumping bore to close prior to movement of the first pump plunger in said second direction.
11. An hydraulic pump as claimed in any one of claims 6 to 10 wherein the or each dwell region (148, 150) subtends an angle of between 30° and 50°.
12. An hydraulic pump as claimed in claim 11 wherein the or each dwell region (148, 150) subtends an angle of approximately 40°.
13. An hydraulic pump as claimed in any one of claims 3 to 12 wherein each of said pump plungers (20a - 20d) cooperates with said cam means (140) via a respective roller or spherical bearing (152a - 152d).
14. An hydraulic pump as claimed in any one of the preceding claims having four pumping bores (16a - 16d), equi-angularly spaced around said drive means (140).
15. An hydraulic pump as claimed in any one of the preceding claims wherein each pump plunger (20a - 20d) is arranged to reciprocate at a phase difference of  $\pm 90^\circ$  with respect to the pump plunger in an adjacent pumping bore (16a - 16d).

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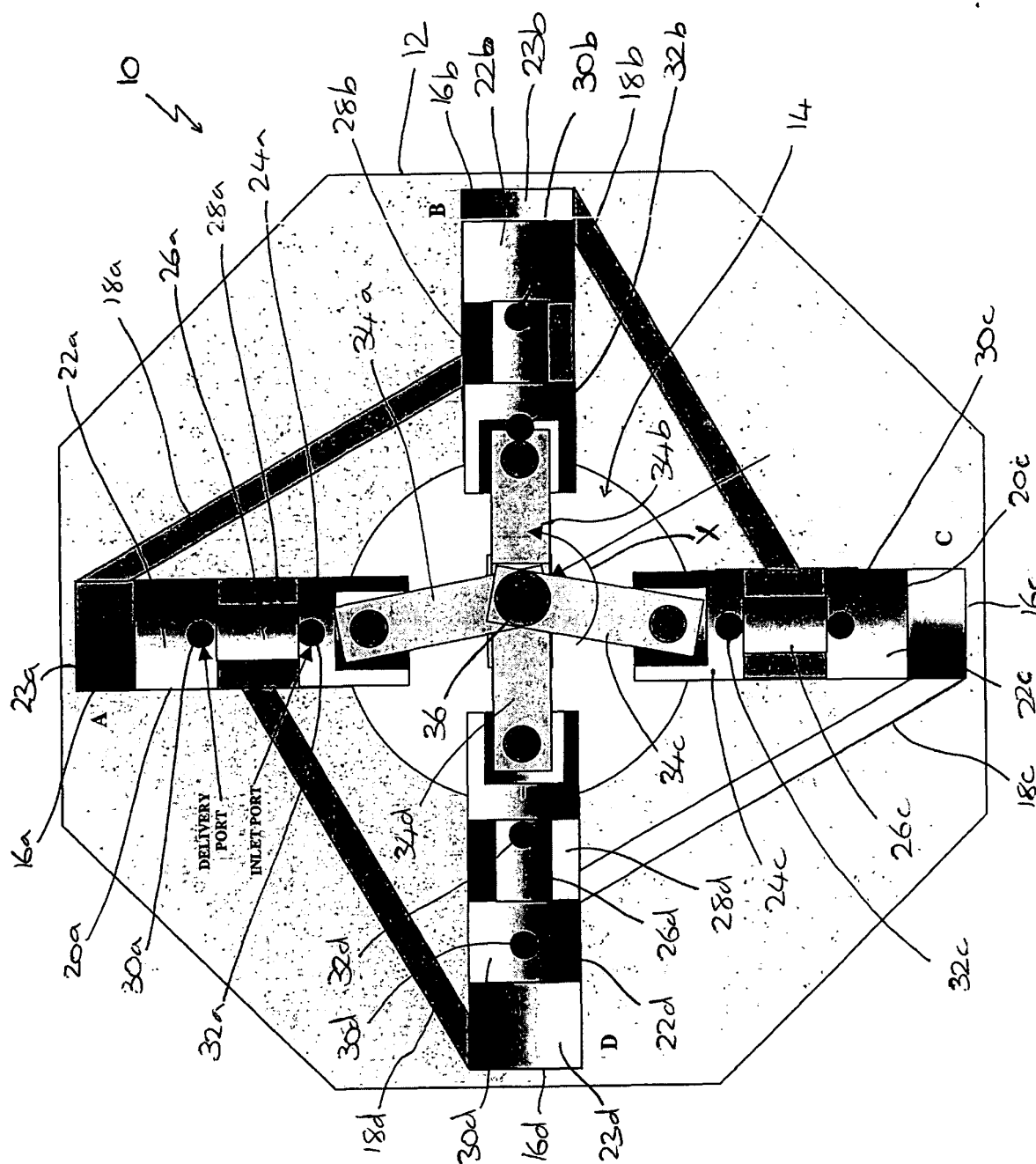


Figure 1

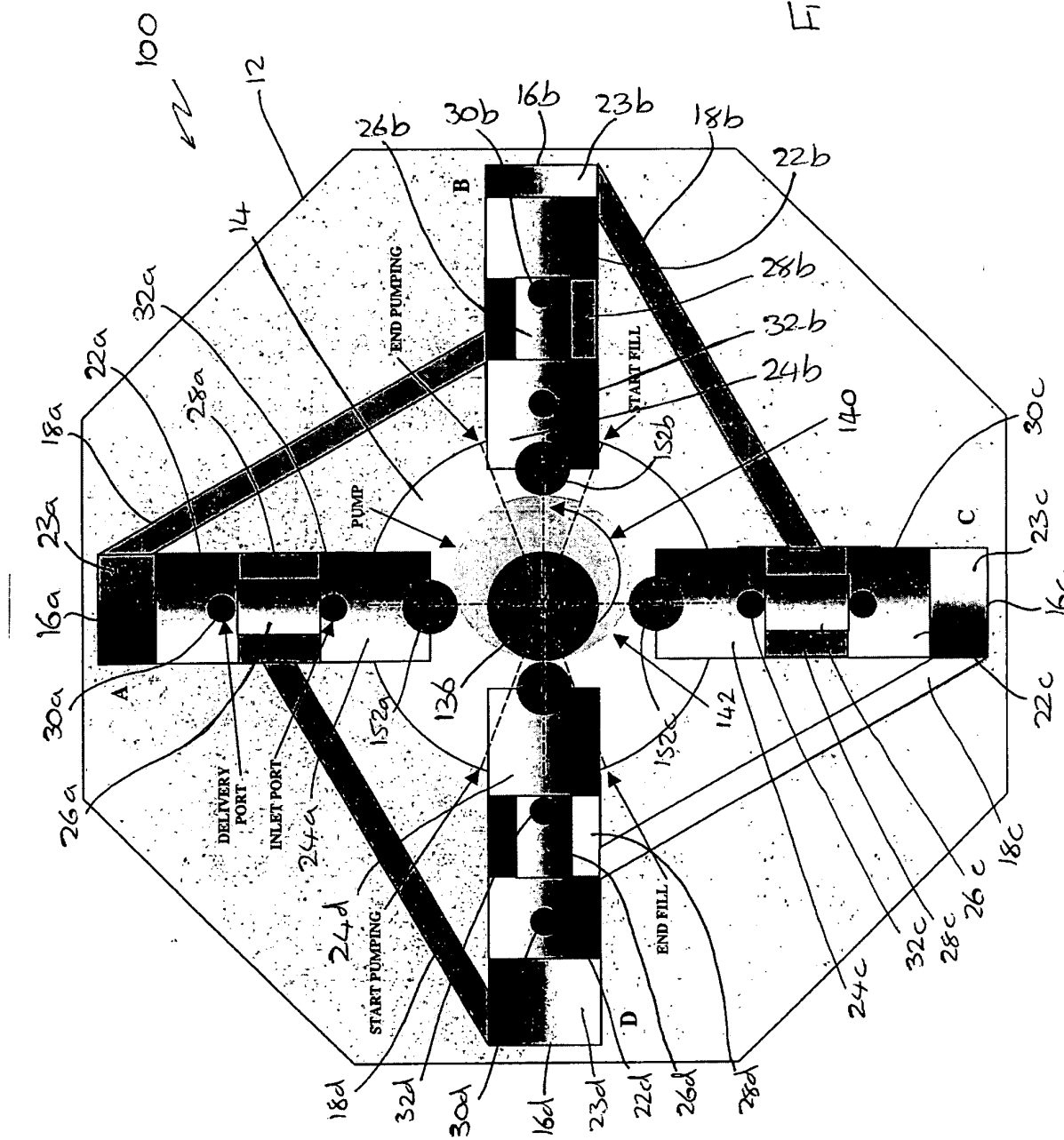


FIGURE 2

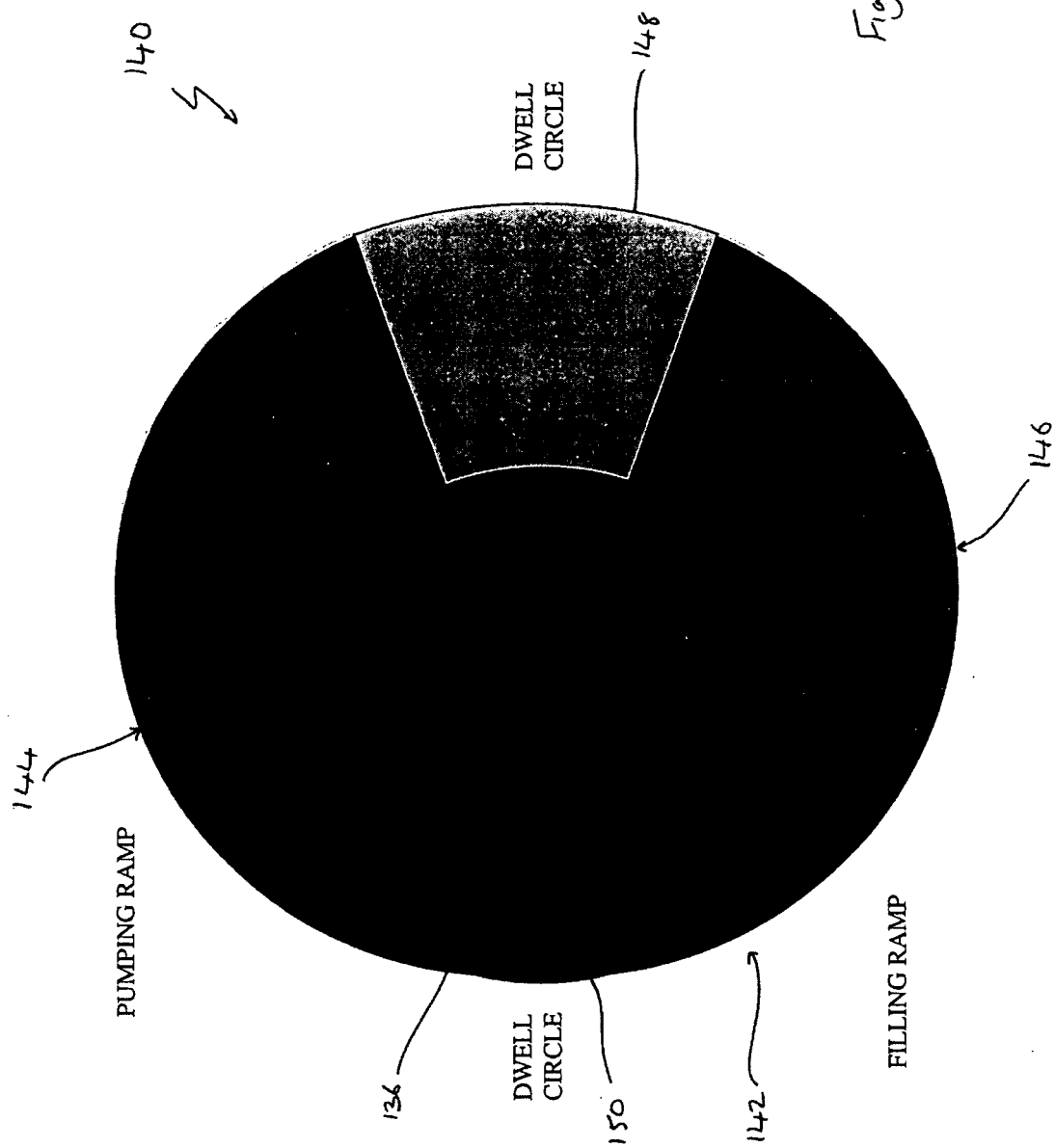


Figure 3

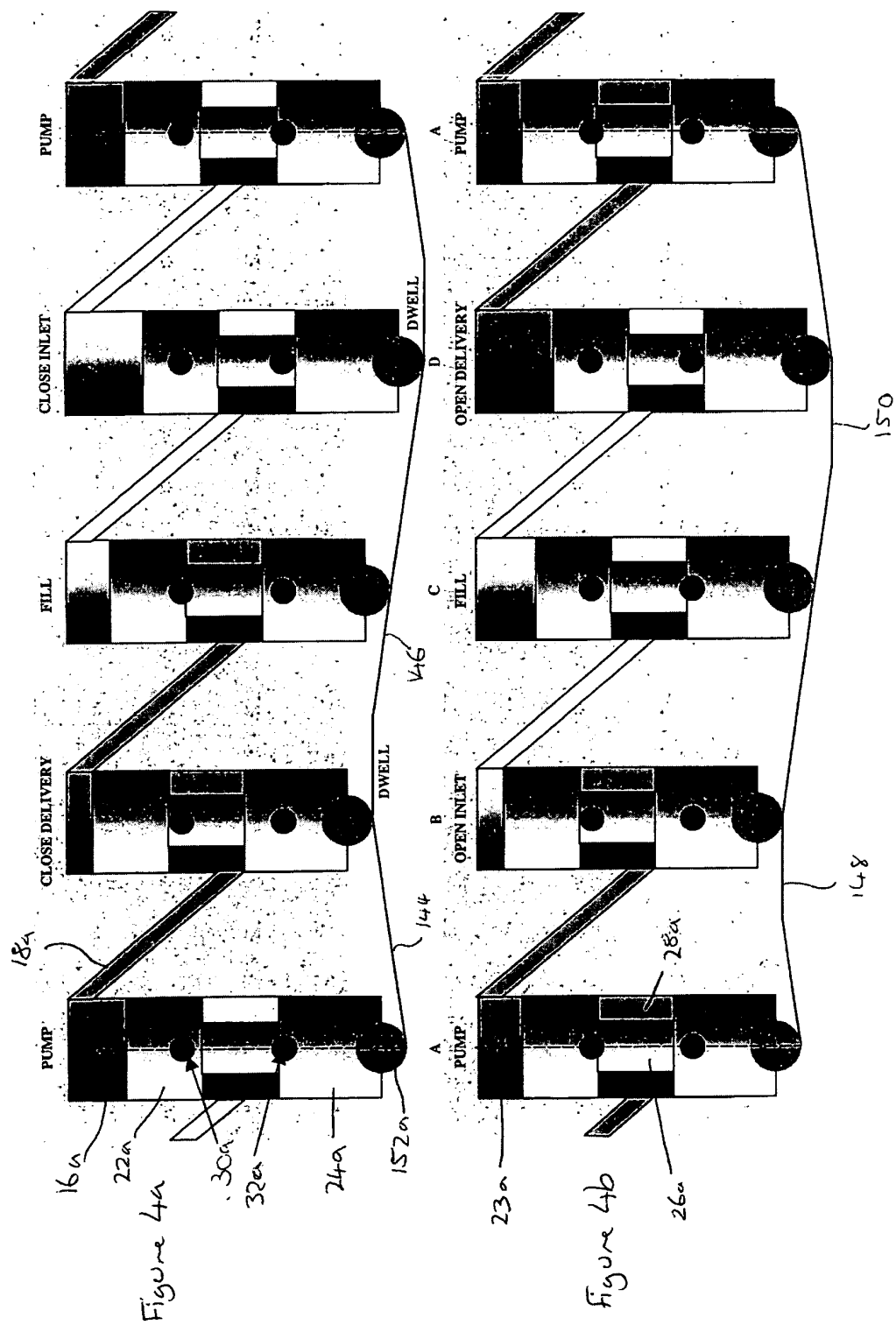


Figure 4

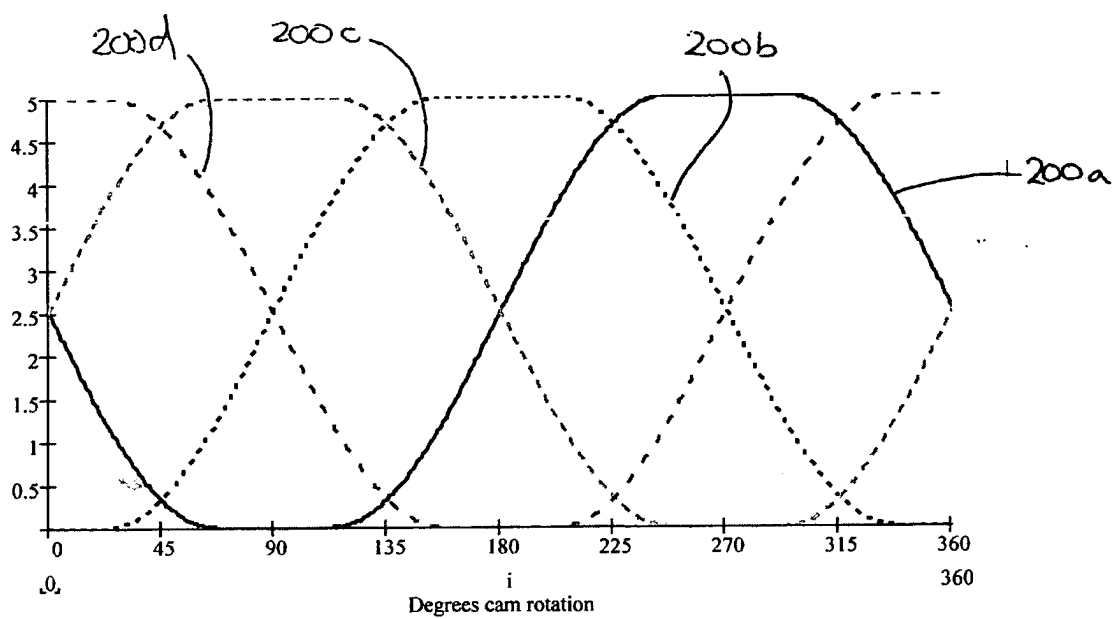


Figure 5

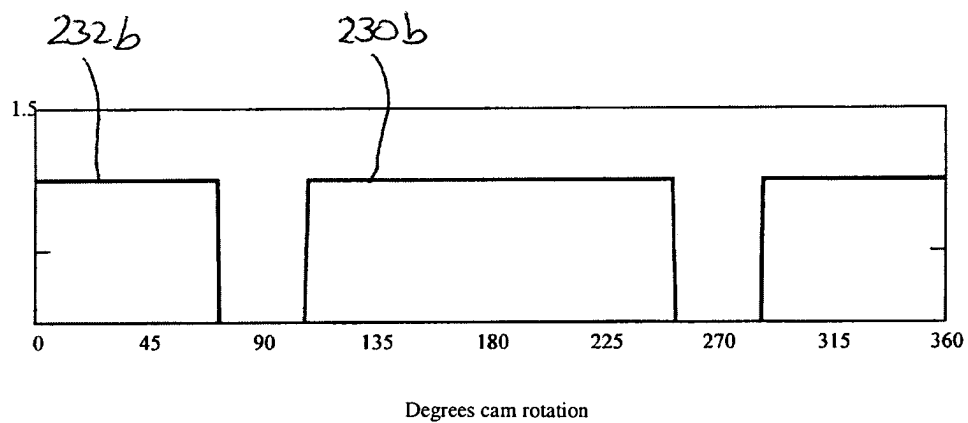


Figure 6

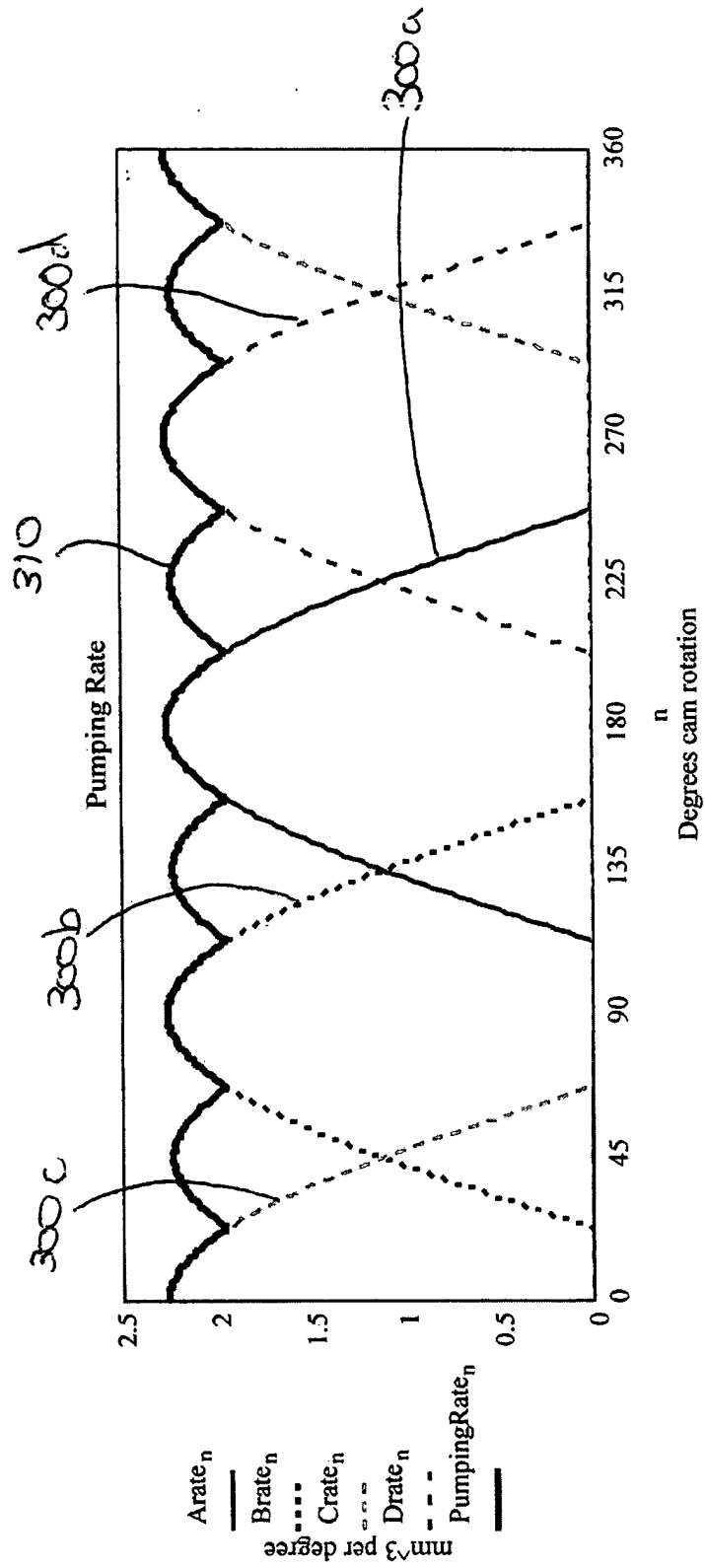


Figure 7



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| DOCUMENTS CONSIDERED TO BE RELEVANT                                                                                                                                                                                                                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                                                                                                                                                                                                                                                       |                                              |
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| Category                                                                                                                                                                                                                                               | Citation of document with indication, where appropriate, of relevant passages                                                                                                                                                                                                                                                                                                                                                                       | Relevant to claim                                                                                                                                                                                                                                                                     | CLASSIFICATION OF THE APPLICATION (Int.Cl.7) |
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| Y                                                                                                                                                                                                                                                      | * column 7, line 42 - column 8, line 21;<br>figures 2-4 *                                                                                                                                                                                                                                                                                                                                                                                           | 7-12                                                                                                                                                                                                                                                                                  |                                              |
| Y                                                                                                                                                                                                                                                      | ---<br>GB 592 386 A (TECALEMIT LTD; CAMILLE CLARE<br>SPRANKLING LE CL)<br>16 September 1947 (1947-09-16)<br>* page 1, column 1, line 30 - page 1,<br>column 1, line 38; figures *<br>* page 1, column 2, line 105 - page 2,<br>column 1, line 2 *<br>* page 5, column 1, line 78 - page 5,<br>column 2, line 96 *<br>* page 6, column 1, line 51 - page 6,<br>column 2, line 66 *<br>* page 11, column 2, line 66 - page 11,<br>column 2, line 71 * | 7-12                                                                                                                                                                                                                                                                                  |                                              |
| Y                                                                                                                                                                                                                                                      | ---<br>US 6 412 454 B1 (GREEN EDWARD)<br>2 July 2002 (2002-07-02)<br>* column 3, line 20 - column 3, line 43;<br>figures 1-3 *<br>* column 7, line 32 - column 7, line 33 *<br>* claims 3-6 *                                                                                                                                                                                                                                                       | 7-12                                                                                                                                                                                                                                                                                  | TECHNICAL FIELDS<br>SEARCHED (Int.Cl.7)      |
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| The present search report has been drawn up for all claims                                                                                                                                                                                             |                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                                                                                                                                                                                                                                                       |                                              |
| Place of search<br><b>MUNICH</b>                                                                                                                                                                                                                       |                                                                                                                                                                                                                                                                                                                                                                                                                                                     | Date of completion of the search<br><b>22 June 2004</b>                                                                                                                                                                                                                               | Examiner<br><b>Pinna, S</b>                  |
| CATEGORY OF CITED DOCUMENTS<br>X : particularly relevant if taken alone<br>Y : particularly relevant if combined with another document of the same category<br>A : technological background<br>O : non-written disclosure<br>P : intermediate document |                                                                                                                                                                                                                                                                                                                                                                                                                                                     | T : theory or principle underlying the invention<br>E : earlier patent document, but published on, or after the filing date<br>D : document cited in the application<br>L : document cited for other reasons<br>.....<br>& : member of the same patent family, corresponding document |                                              |

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22-06-2004

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