July 13, 1965 H. SCHOTTLER 3,194,172

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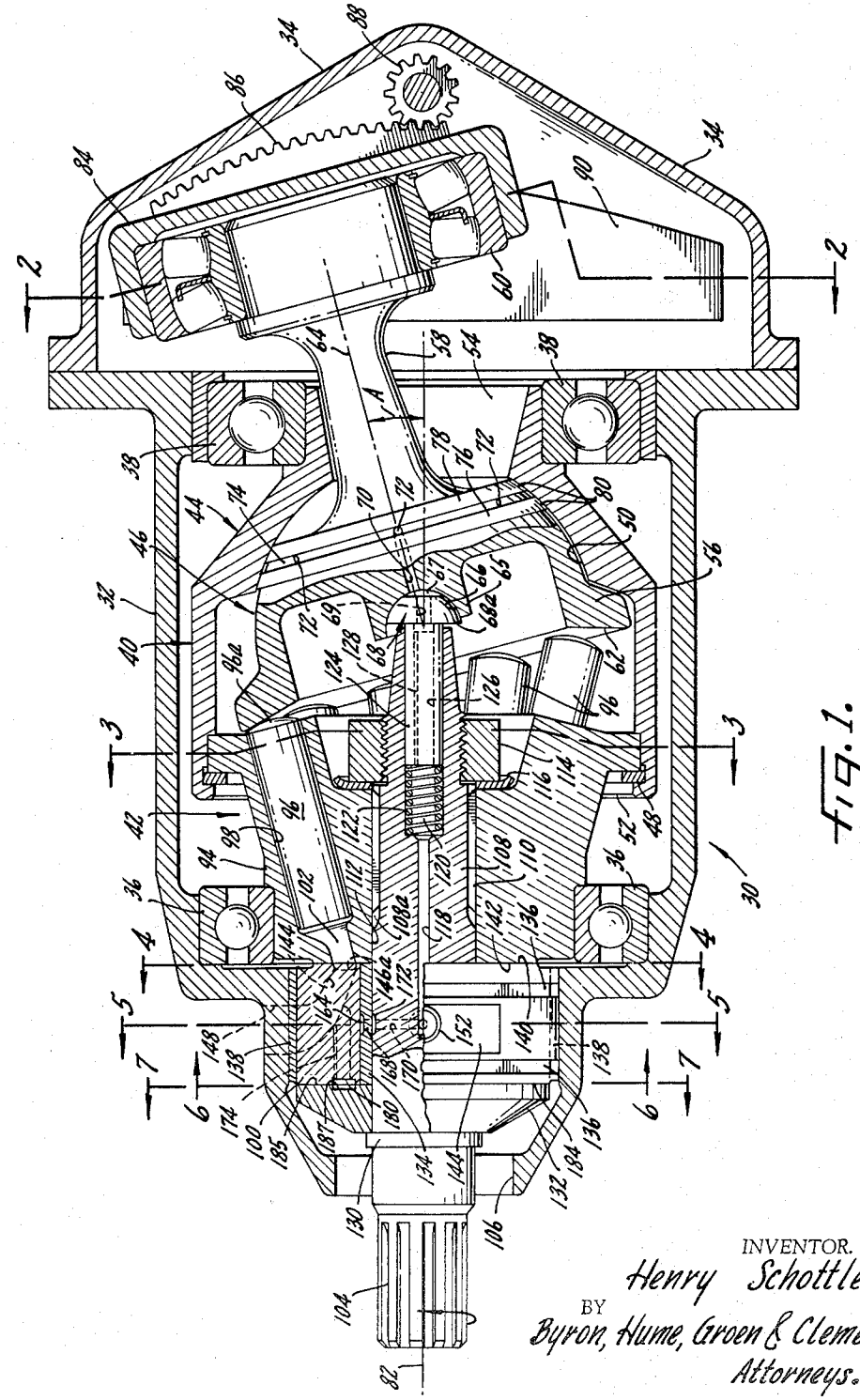


FIG. 1.

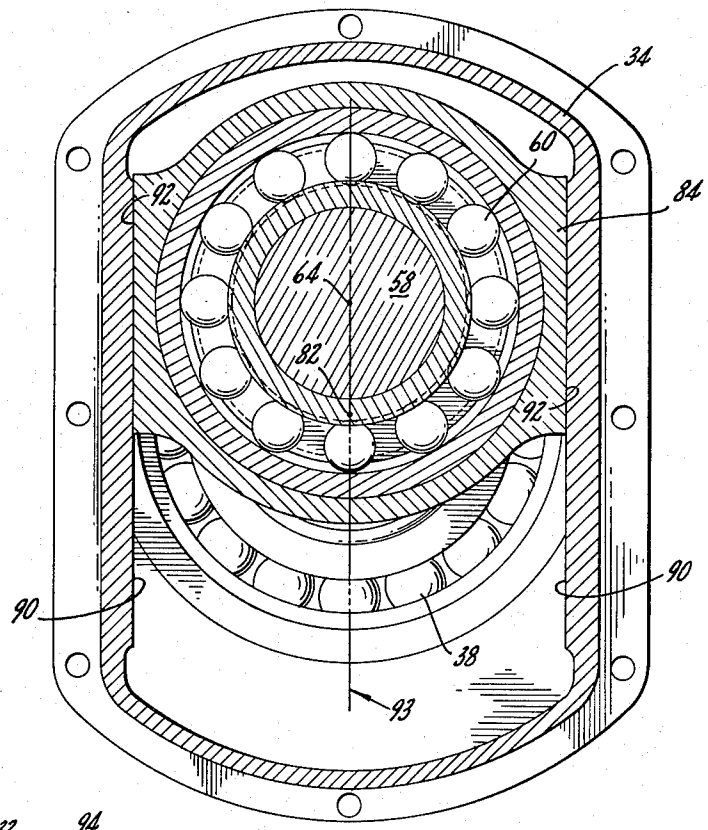
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Fig. 2.



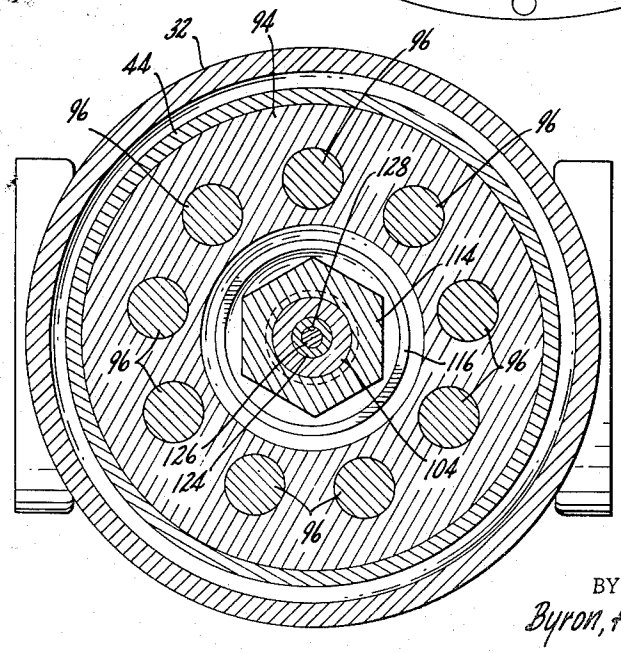


Fig. 3.

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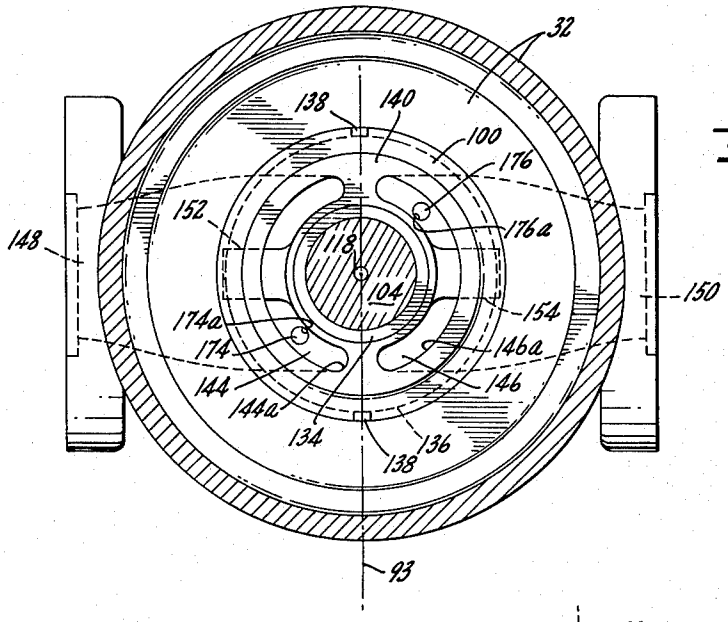


Fig. 4.

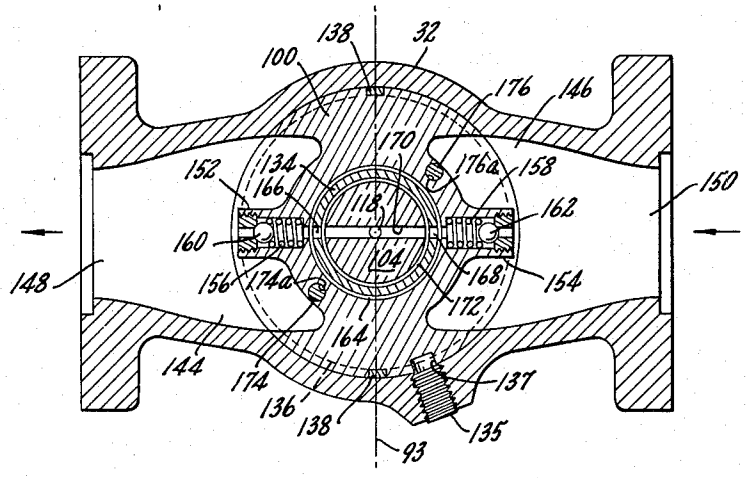


Fig. 5.

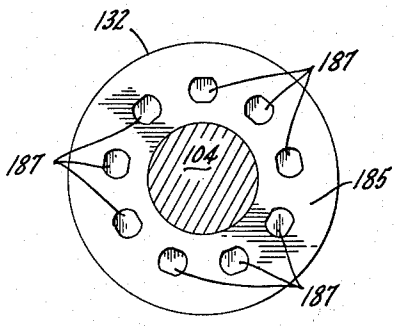


Fig. 7.

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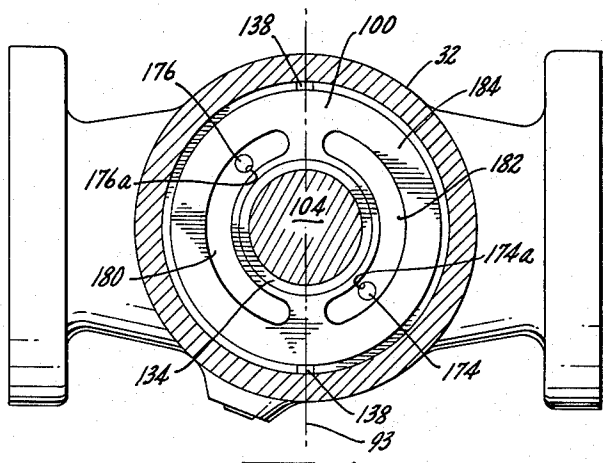


Fig. 6.

Fig. 8.

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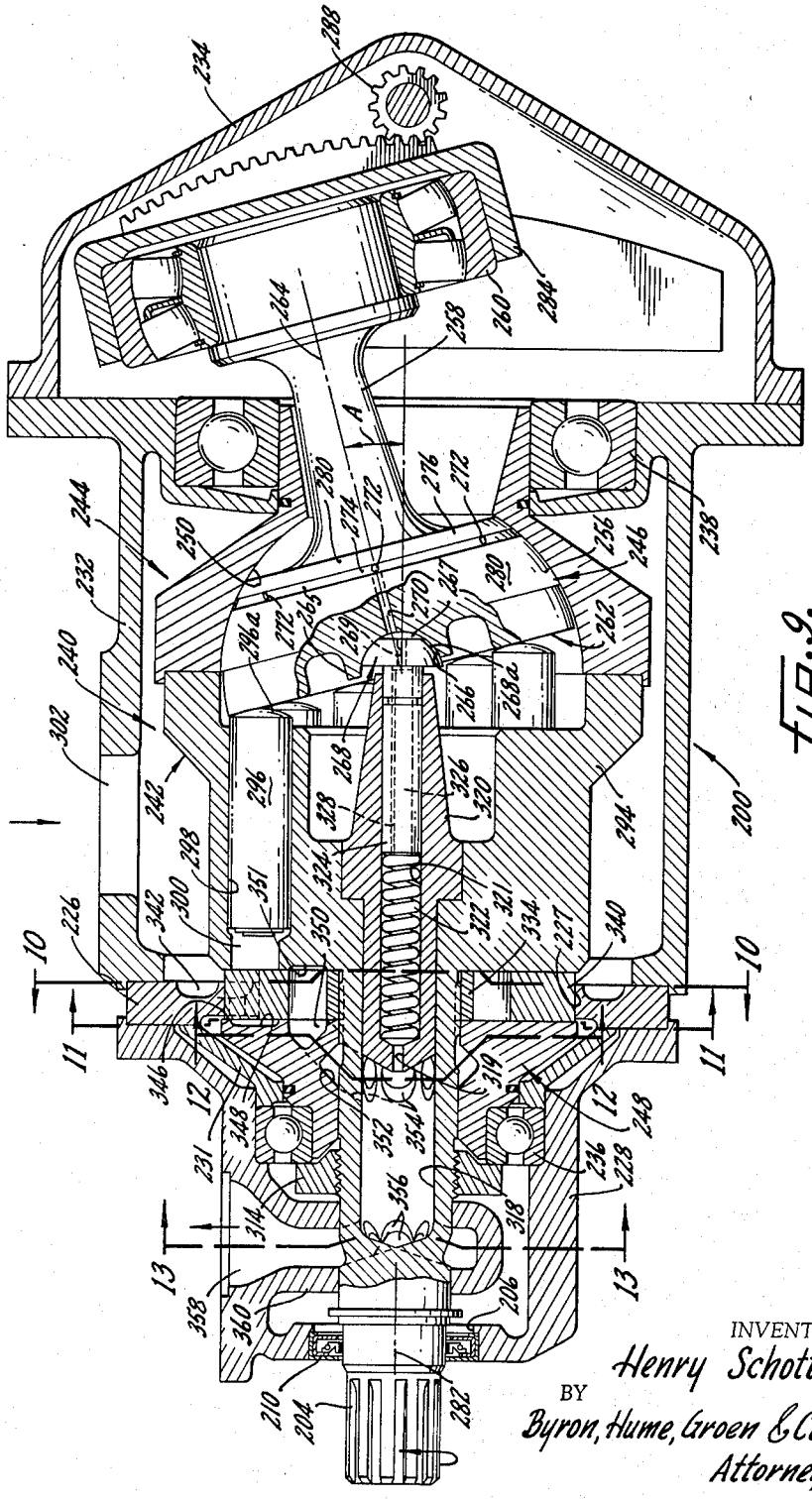


Fig. 9.

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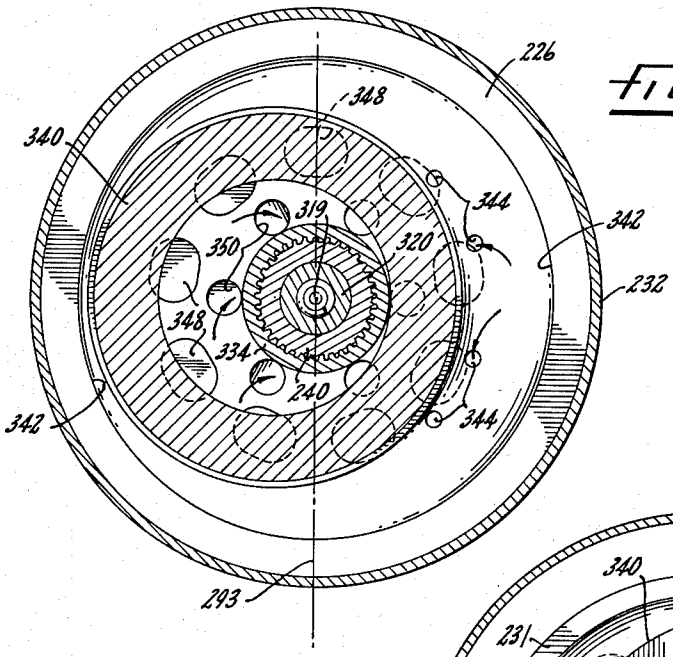


Fig. 10.

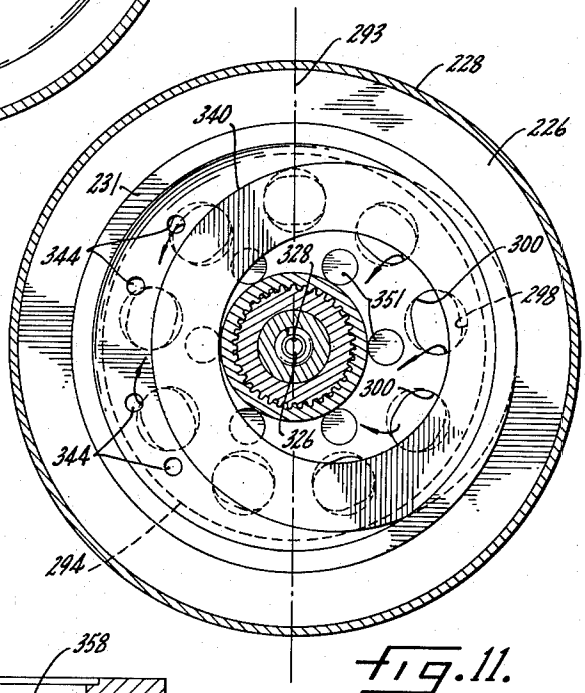


Fig. 11.

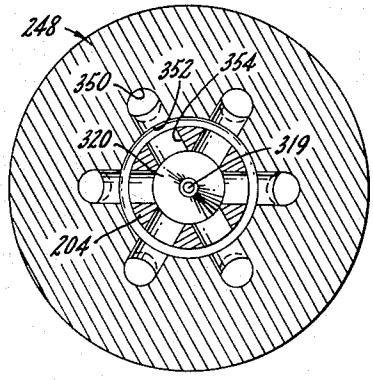


Fig. 12.

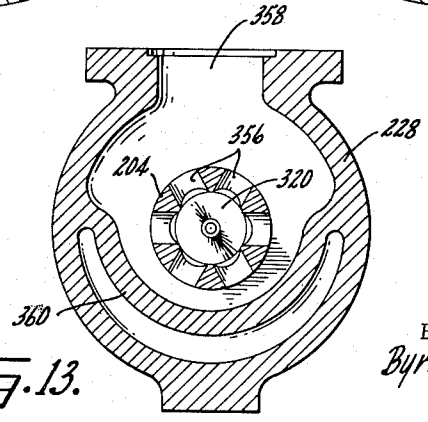


Fig. 13.

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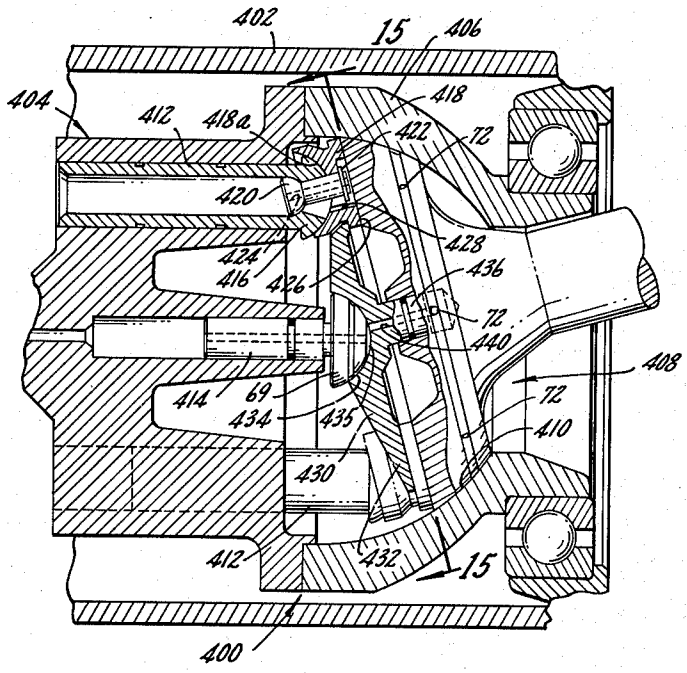


Fig. 14.

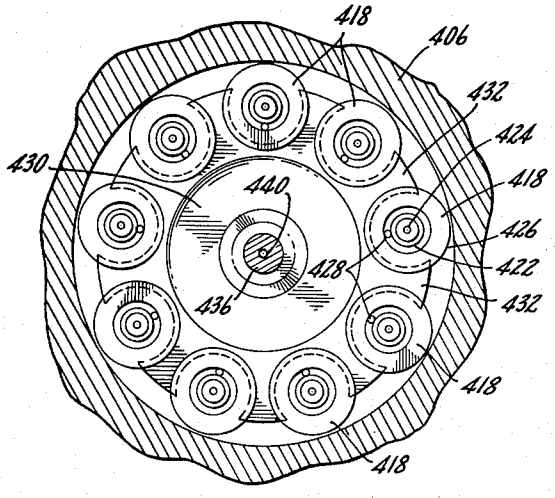


Fig. 15.

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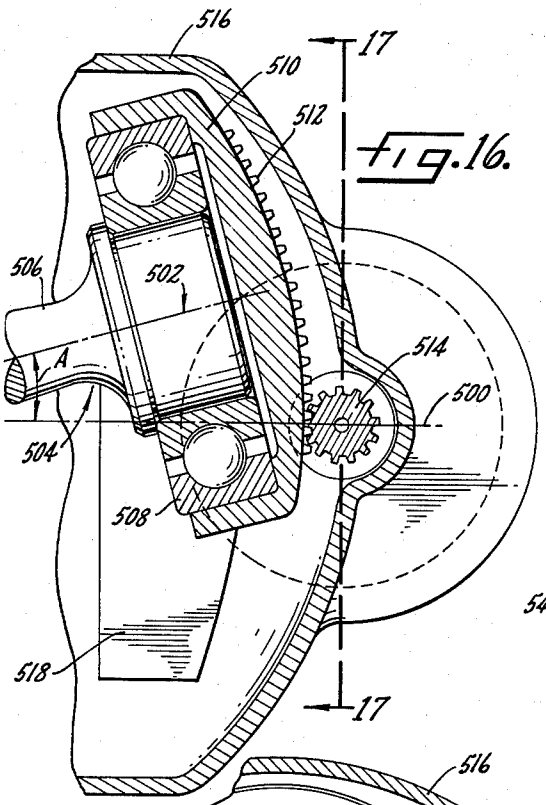


Fig. 16.

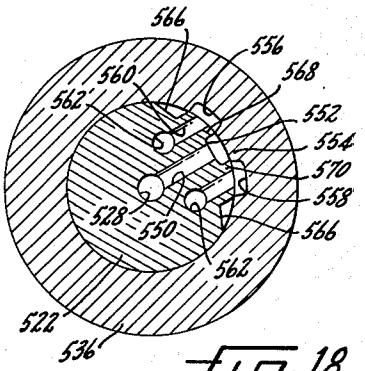


Fig. 18.

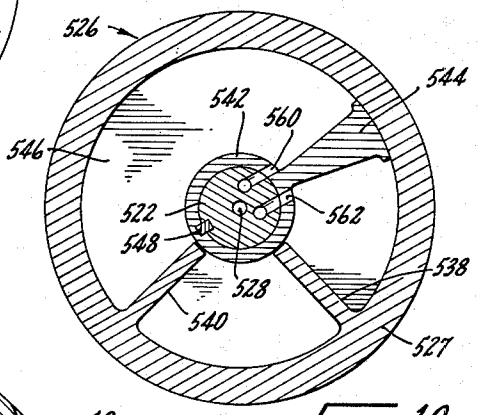


Fig. 19.

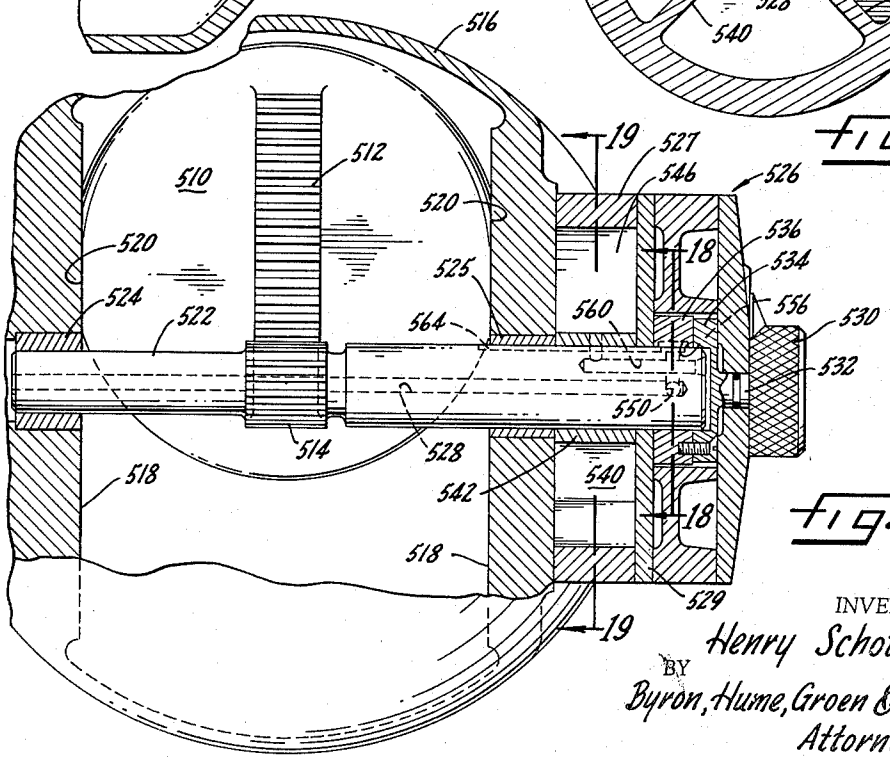


Fig. 17.

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United States Patent Office 3,194,172 Patented July 13, 1965

3,194,172

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Filed Apr. 19, 1962, Ser. No. 188,777
16 Claims. (Cl. 103—162)

This invention relates to a fluid device and more particularly to a swash plate type fluid pump or motor. The invention further relates to an improved control for the fluid device.

In swash plate type fluid pumps and motors large thrust forces are created between the swash plate assembly and the cylinder block assembly as a result of the reciprocation of the pistons. Heretofore these thrust forces have ordinarily been transferred from the rotating parts to the casing through thrust bearings. It is well known, however, that thrust bearings involve considerably higher friction losses than are encountered in ordinary radial type anti-friction bearings, particularly at relatively high speeds of rotation. Furthermore, thrust bearings are somewhat more expensive to manufacture and are subject to a higher rate of wear. Prior to the present invention, however, there has been no practical way of avoiding their use.

To avoid all of these problems the swash plate hydraulic devices of the present invention embody an entirely new concept in which thrust forces are self-contained in the rotating parts so that ordinary radial bearings may be utilized to rotatably mount the swash plate assembly and the cylinder block assembly.

Swash plate devices in the past have also ordinarily utilized universal joints in order to synchronize the speed of rotation of the swash plate and the cylinder block while rotating with their axes at an angle. Earlier devices utilized standard universal joints of the Hookes or Cardan type which did not transmit uniform or constant velocity drive between the swash plate assembly and the cylinder block assembly, and such non-constant velocity universal joints are still utilized in some swash plate devices employing relatively low speeds. However, in swash plate devices operating at relatively high speeds it has been imperative to utilize so-called "constant velocity" universal joints which transmit true constant velocity between the rotating members, or at least a velocity approaching true constant velocity. Otherwise the periodic fluctuations in speed result in high frequency vibrations causing early failure. Furthermore, as the angularity between the shafts is increased the speed fluctuations increase with the square of the change in angle, resulting in much more serious problems at higher angles. Constant velocity universal joints which solve the vibrational problems are expensive and far from foolproof. Furthermore, they introduce a serious installation problem and ordinarily increase the space requirements. By reason of the novel construction of the swash plate devices of the present invention, no universal joint at all is required between the swash plate assembly and the cylinder block assembly, thus completely eliminating all of these problems.

It is an object of the present invention to provide an improved fluid device of the swash plate type.

An important object is to provide an improved swash plate fluid device without a universal joint between the swash plate assembly and the cylinder block assembly.

An additional important object is to provide a swash plate fluid device utilizing radial bearings only.

Another object of the invention is to provide a swash plate pump or motor which does not require either a universal joint or thrust bearings.

A further object of the present invention is to provide

a swash plate device wherein the thrust load between the swash plate assembly and the cylinder block assembly is self-contained.

Still another object is to provide a swash plate device having a thrust member rotating with the swash plate assembly and the cylinder block assembly to directly transmit the thrust load therebetween.

A still further object of the invention is to provide a swash plate type pump or motor having a thrust member which cooperates with the swash plate assembly to transmit the thrust load on said swash plate assembly back to the cylinder block assembly, wherein said swash plate and said thrust member are separated from one another by an oil film automatically maintained at a predetermined thickness.

It is an additional object of the present invention to provide a swash plate device having a self-centering port plate which minimizes shear and leakage losses within said pump.

Another object is to provide a swash plate type pump or motor wherein the pistons are positively actuated by the relative movement between the cylinder block assembly and the swash plate assembly.

A further object of the present invention is to provide an improved control device wherein a control member may be rotated automatically through a predetermined arc.

Still another object of the invention is to provide a fluid actuated control system wherein a shaft, pinion or the like may be automatically rotated through an arc determinded by the rotation of a control knob.

Other objects, features and advantages of the present invention will be apparent from the following detailed description taken in conjunction with the accompanying drawings, in which:

FIGURE 1 is a longitudinal sectional view with parts in elevation, of a swash plate pump embodying the features of the present invention;

FIGURE 2 is a sectional view of the pump of FIGURE 1 taken along line 2—2 of FIGURE 1;

FIGURE 3 is a sectional view taken along line 3—3 of FIGURE 1;

FIGURE 4 is a sectional view taken along line 4—4 of FIGURE 1;

FIGURE 5 is a sectional view taken along line 5—5 of FIGURE 1;

FIGURE 6 is a sectional view taken along line 6—6 of FIGURE 1;

FIGURE 7 is a sectional view taken along line 7—7 of FIGURE 1;

FIGURE 8 is a graphical illustration showing the effect upon shear and leakage losses when the port plate of the pump of FIG. 1 is out of center;

FIGURE 9 is a longitudinal sectional view of a modified swash plate pump embodying the features of the present invention;

FIGURE 10 is a sectional view taken along line 10—10 of FIGURE 9;

FIGURE 11 is a sectional view taken along line 11—11 of FIGURE 9;

FIGURE 12 is a sectional view taken along line 12—12 of FIGURE 9;

FIGURE 13 is a sectional view taken along line 13—13 of FIGURE 9;

FIGURE 14 is a fragmentary sectional view of a swash plate pump embodying a modified construction wherein the swash plate assembly is coupled to the pistons in the pump;

FIGURE 15 is a sectional view taken along line 15—15 of FIGURE 14;

FIGURE 16 is a fragmentary sectional view of the

control system of the present invention adapted in this instance to change the position of this axis of the swash plate assembly;

FIGURE 17 is a sectional view of the control system of FIGURE 16 taken along line 17—17 of FIGURE 16;

FIGURE 18 is an enlarged fragmentary sectional view taken along line 18—18 of FIGURE 17; and,

FIGURE 19 is a sectional view taken along line 19—19 of FIGURE 17.

I. The FIGURE 1–8 pump

Referring now to FIGURES 1–8, a swash plate pump embodying features of the present invention is indicated generally by reference numeral 30. The pump 30 may be employed as a motor but herein will be described in connection with its pump function.

As seen in FIGURE 1, the pump 30 includes a stationary housing or casing 32 having open ends, one of which is closed by a cover 34 suitably secured to the casing 32 by nuts and bolts or the like (not shown).

Rotatably supported within the housing 32 on anti-friction radial type ball bearings 36 and 38 is a swash plate type pump mechanism, indicated generally by reference numeral 40. The pump mechanism 40 includes a cylinder block assembly 42, a thrust member 44 and a swash plate assembly 46. The cylinder block assembly 42 is rotatably mounted in the casing through the anti-friction bearing 36, and the thrust member is rotatably mounted through the anti-friction bearing 38. The axis of rotation of the pump mechanism 40 is the axis of the cylinder block assembly 42 and the thrust member 44 and is indicated generally by reference numeral 82.

The thrust member 44 is generally bell-shaped with open ends 52 and 54. The cylinder block assembly 42 extends into the open end 52 and is secured to the thrust member 44 by a snap ring 48 or the like. In this manner the thrust member 44 and the cylinder block assembly 42 rotate together. The thrust member 44 has a concave segmental spherical surface 50 which cooperates with the swash plate assembly 46 in a manner discussed in more detail hereinafter.

The swash plate assembly 46 includes a swash portion or plate 56 with an integral, axially aligned shaft 58. The shaft 58 extends through the open end 54 of the thrust member 44, and has its free end rotatably supported in an anti-friction roller bearing assembly 60. The swash plate 56 has an annular, conically shaped swash face 62 concentrically positioned about an axis 64 of the swash plate assembly 46 and facing toward the cylinder block assembly 42. Also extending toward the cylinder block assembly 42 is a cylindrical projection 65 coaxial with the axis 64 and integral with the swash plate 56. A free end of the projection 65 has a segmental spherical socket 66, coaxial with the axis 64 of the swash plate assembly 46, which opens toward the cylinder block assembly 42. A segmental spherical ball end surface 68*a* of a fluid dispenser 68 fits within the socket 66 in substantially fluid-tight engagement therewith to form a chamber 67. Extending axially through the dispenser 68 is a passageway 69 which communicates with the chamber 67.

Also communicating with the chamber 67 is an axially extending passageway 70 in the swash plate 56 which branches out into radially extending passageways 72 communicating with an annular groove 74 formed between annular lands 76 and 78 on the exterior surface of the swash plate 56. Segmental spherical surfaces 80 of the lands 76 and 78 define a segmental sphere having a diameter substantially equal to the diameter of the concave segmental spherical surface 50 of the thrust member 44. Accordingly, the swash plate assembly 46 is universally tiltably associated with the thrust member 44.

The swash plate assembly 46 is tiltable by moving its axis 64 in a tilt or swash plane 93 (see FIGURE 2). The axis of rotation 82 lies in this plane 93. The tilting is effected by moving the free end of the shaft 58 which is supported in the radial roller bearing 60. The angle between the axis 64 of the swash plate assembly 46 and the axis of rotation 82 is referred to as the "swash angle" and is designated by A. It will be seen that when the swash angle A is zero the axis 64 of the swash plate assembly and the axis of rotation 82 coincide.

As seen in FIGURES 1 and 2, the roller bearing assembly 60 is secured by a press fit or other suitable means within a non-rotatable guide member 84 having an external rack 86 thereon which meshes with a rotatable pinion 88. The cover 34 has two opposing parallel internal guide flats 90, which are parallel to the tilt plane 93. These cooperate with two complementary flats 92 on the guide member 84 whereby rotation of the pinion 88 moves the guide member 84 parallel to the guide flats 90 to increase or decrease the swash angle A on either side of the axis of rotation 82. In this manner, the swash plate assembly 46 may be tilted to control the capacity and flow direction of the pump 30.

As seen in FIGURES 1 and 3, the cylinder block assembly 42 includes a cylinder block 94 having a plurality of cylinders 98 therein, each cylinder 98 containing a reciprocable piston 96. The pistons 96 have convex, spherical heads 96*a* which cooperate with the swash face 62 of the swash plate 56. The face 62 normally contacts the heads 96*a* off the axes of the pistons 96. Accordingly, relative movement between the swash plate 56 and the cylinder block 94 causes the pistons 96 to rotate within the cylinders 98. This minimizes uneven wear on the pistons 96 and the cylinders 98.

The cylinders 98 communicate with a port plate 100 through cylinder ports 102. The pistons 96 reciprocate during rotation of the pump mechanism 40 at other than zero swash angle, the amount of reciprocation and, accordingly, the pump displacement, increasing with increased swash angle. Oil to be pumped enters each cylinder 98 as its associated piston 96 moves away from the port 102, and the oil is discharged under pressure from the cylinder 98 as its associated piston 96 moves toward the port 102.

It is preferred, as shown in FIGURE 1, to have the axes of the pistons 96 and cylinders 98 lie in a conical plane, since this configuration allows the largest pump capacity with the smallest cylinder block 94. However, it will be understood that the axes of the pistons 96 and the cylinders 98 may be parallel to the axis of rotation 82 or in any other suitable configuration without departing from the spirit of this invention.

Though the pump 30 of the present invention has been illustrated with nine pistons 96, it will be understood that any number of pistons may be employed. It is preferable, however, to employ an odd number of equally spaced pistons 96.

For rotating the cylinder block assembly 42, the thrust member 44 and the swash plate assembly 46, an externally splined drive shaft 104 extends through an axial aperture 106 in the housing 32. The axially inward end portion 108 of the drive shaft is secured to the cylinder block 94 through external splines 108*a* of the shaft which mate with internal splines 110 formed in an axial hole 112 of the block 94. Axial movement of the block 94 is prevented by a spring washer 116 and a nut 114, the latter threadedly engaging the inner end portion 108 of the shaft 104.

The drive shaft 104 has an axial passageway 118 extending from the inner end portion 108. The axial passageway 118 has an axially inward bore section 120 of enlarged diameter. In fluid-tight engagement with the bore section 120 and axially movable therein is a cylindrical positioning member 124. A spring 122 in the bore section 120 acts upon one end of the positioning member 124 to urge its other end into abutting relationship with the fluid dispenser 68.

An axially extending passageway through the position-

ing member 124 has secured therein by a press fit or the like a fluid transfer member 126 having a narrow longitudinally extending groove thereon which forms with the positioning member 124 a capillary passageway 128 through which a controlled amount of fluid may flow from the port plate 100 to the annular groove 74 between the surface 50 and the surfaces 80 in a manner more apparent hereinafter. As shown in FIGURE 1, the outer end of the fluid transfer member 126 is spaced sufficiently inwardly from the outer end of the positioning member 124 to assure that the capillary passageway 128 will communicate with the passageway 69 in the fluid dispenser 68 despite transverse movement of the fluid dispenser 68.

Also splined or keyed to the drive shaft 104, between an annular ridge 130 on the drive shaft 104 and the nut 114, is a rotating plate 132. An annular spacer 134 is positioned between the plate 132 and the block 94. The plate 132, the spacer 134, and the block 94 are always retained in this abutting relationship by the spring washer 116 and the nut 114 and rotate at the same speed as the shaft 104. The spacer 134 has a slightly larger longitudinal dimension, in the order of about .001 inch, than the non-rotatable port plate 100 to effect the self-centering feature of the port plate 100 to be discussed in more detail hereinafter.

The port plate 100 is non-rotatably secured to the housing 32 by a set screw 135 (see FIG. 5) which cooperates with a longitudinal slot 137 in the periphery of the port plate 100. In this manner, the port plate 100 is free to move axially substantially the length of the slot 137. Two annular grooves 136 on opposite ends of the slot 137 extend around the periphery of the port plate 100 and form passageways with the housing 32 (see FIGS. 1 and 4–6). Longitudinally extending, diametrically opposing seals 138 in the tilt plane 93 prevent oil from flowing through the grooves 136 across the seals 138. The plane 93 is the division between the high pressure side and the low pressure side of the port plate 100, and the seals 138 minimize circumferential oil flow around the port plate 100 from the high pressure side to the low pressure side.

The port plate 100 has an annular land 140 at one end which is slidably associated with a complementary annular land 142 of the cylinder block 94. Two kidney-shaped ports 144*a* and 146*a* in the land 140 communicate with channels 144 and 146, respectively, in the port plate 100. These channels 144 and 146 communicate with openings 148 and 150, respectively, in the housing 32. The tilt plane 93 in which the axis 64 of the swash plate assembly 46 is tilted bisects the port plate 100 and divides it into two semi-circular sections, with the kidney ports 144*a* and 146*a* symmetrically disposed in these two half-sections of the port plate 100. The adjacent ends of the kidney ports 144*a* and 146*a* are spaced sufficiently far apart that one cylinder port 102 may not communicate with both the kidney ports 144*a* and 146*a* at the same time.

The oil to be pumped by the pump 30 enters either the opening 150 or the opening 148, depending on the direction of rotation. It then flows through the channel 146 or 144 and the kidney port 146*a* or 144*a* into the cylinder block assembly 42 and is discharged therefrom under pressure through the other kidney port and the other channel to the other opening.

Extending radially into the channels 144 and 146 are cylindrical projections 152 and 154, respectively, (see FIGS. 1, 4 and 5) which do not extend past the outer periphery of the port plate 100. Radially extending passageways 156 and 158 extend through the projections 152 and 154, respectively, and communicate with the channel 144 and the kidney port 144*a* and the channel 146 and the kidney port 146*a*, respectively. Each passageway 156 and 158 has therein a one-way check valve 160 and 162, respectively, which permits oil to flow through its respective passageway in only one direction.

As illustrated in FIGURE 5, the one-way check valves 160 and 162 are spring-biased ball valves, but it will be understood that any suitable type of one-way check valve may be employed. The check valves 160 and 162 are set in opposing relationship, that is, in such a manner that oil may flow to the right (when viewing FIG. 5) through the passageway 156 but may not flow to the left through the passageway 156. By contrast, the valve 162 allows fluid to flow through the passageway 158 from right to left (when viewing FIG. 5) but not from left to right.

The spacer 134 has two coaxial radially extending holes 166 and 168 (see FIGS. 1 and 5) extending therethrough which communicate with an annular groove 164 in the outer periphery of the spacer. The groove 164 communicates with the passageways 156 and 158. Similarly, the drive shaft 104 has a radially extending passageway 170 extending therethrough which communicates with the axially extending passageway 118 and an annular groove 172 in the periphery of the shaft 104. The groove 172 communicates with the passageways 166 and 168 in the spacer 134.

Two cylindrical members 174 and 176 having narrow grooves 174*a* and 176*a*, respectively, are press fitted into bores in the port plate 100. These grooves form capillary passageways which communicate with the channels 144 and 146, repsectively, and with kidney-shaped relief ports 180 and 182, respectively, formed in a land 184 at the opposite end of the port plate 100. As seen in FIGURE 6, these relief ports 180 and 182 are axially aligned with and have the same cross-sectional dimensions as the kidney ports 146*a* and 144*a*, respectively.

A face 185 of the plate 132, which is slidably associated with the land 184 of the port plate 100, has relief ports 187 therein (see FIG. 7). There are the same number of relief ports 187 as there are cylinder ports 102. The ports 187 and 102 have the same transverse cross-sectional dimensions and each cylinder port 102 has an opposed, axially aligned port 187. The alignment between the plate 132, the port plate 100 and the cylinder block 94 is maintained during operation inasmuch as they are mounted for concurrent rotation with the drive shaft 104 in the manner discussed hereinbefore.

II. Operation of the FIGURE 1–8 pump

In discussing the operation of the pump 30, it will be assumed that the drive shaft 104 rotates in the direction indicated by the arrow in FIGURE 1 and that the swash angle A between the axis 64 of the swash plate assembly 46 and the axis of rotation 82 is greater than 0° in the direction shown in FIGURE 1. When the pump 30 is actuated by rotation of the drive shaft 104, the plate 132, the spacer 134, the cylinder block assembly 42 and the thrust member 44 rotate in the same direction and at the same speed as the drive shaft 104. Through the contact of the swash face 62 of the swash plate 56 upon the pistons 96 and through the force exerted by the positioning member 124 upon the fluid dispenser 68, the swash plate assembly 46 will also rotate in the same direction as the other members and at substantially the same speed. However, it is not imperative that the swash plate assembly 46 rotate at the same speed as the cylinder block assembly 42 or the thrust member 44.

During the rotation of the cylinder block assembly 42, half of the pistons 96 will be moving toward their respective cylinder ports 102, i.e., in their compression strokes, while the other pistons 96 will be moving away from their respective channel 102, i.e., in their intake strokes, except when individual pistons are bottom dead center position (when the piston has completed its intake stroke and before it has begun its compression stroke) or at top dead center position (when the piston has completed its compression stroke and before it has begun its intake stroke).

The piston chambers 98 of those pistons 96 going through their intake strokes communicate through cylinder ports 102 with the kidney port 146*a*. Oil under

sufficient charging pressure to force the pistons 96 into contact with the swash face 62 of the swash plate 56 enters the opening 150 of the housing 32 and passes through the channel 146 and the kidney port 146*a* into the piston chambers 98 via the cylinder ports 102 communicating with the kidney port 146*a*. As the piston 96 reaches bottom dead center position its port 102 is blocked by the land 140 and will no longer communicate with the kidney port 146*a*.

As the cylinder block assembly 42 continues rotation, the piston 96 then begins its compression stroke because of its cooperation with the swash face 62 of the swash plate 56. Simultaneously therewith the cylinder port 102 communicates with the kidney port 144*a*. In this manner, as the piston 96 moves toward top dead center position, fluid is being compressed in the piston chamber 98 and forced out through the cylinder port 102 into the kidney port 144*a* and the channel 144 and out of the housing 32 through the opening 148.

As the piston 96 completes its compression stroke, i.e., it reaches top dead center position, the land 140 again blocks off channel 102. The cycle is repeated as the piston 96 begins its intake stroke and simultaneously its piston chamber 98 communicates with the kidney port 146*a*.

It will be understood that if the swash angle A is decreased, the capacity of the pump 30 is decreased as the piston 96 goes through a shorter intake and compression stroke. Therefore, it will be understood that when the swash angle A is 0°, no pumping action is effected by the pump 30. The pump 30 is then in its neutral position.

If the shaft 104 is rotated in the opposite direction, then the opening 148 becomes the inlet for the oil and the opening 150 becomes the pump outlet. The operation of the pump 30 is identical to that described hereinbefore with the exception that the intake and pressure sides of the pump 30 have therefore been reversed.

Likewise the pump 30 may be reversed by actuation of the pinion 88 to change the swash angle A such that it is on the other side of the axis of rotation 82.

Thrust, of course, is created during the operation of the pump 30. According to this invention, the thrust is transmitted from the pistons 96 to the swash plate assembly 46, but instead of being transmitted from the swash plate to the casing through a thrust bearing, the thrust force exerted against the thrust member 44 is carried back to the cylinder block 94. Furthermore, by this arrangement the need for a universal joint has been eliminated. In particular, the thrust force is transferred from the swash plate assembly 46 to the thrust member 44 through the cooperation of the convex surfaces 80 of the lands 76 and 78 with the concave surface 50 of the thrust member. To prevent the surfaces 80 and the surface 50 from binding, the pump 30 is adapted to provide a lubricating film of oil of predetermined thickness between the surfaces 80 and the surface 50. The film of oil is thick enough to provide adequate lubrication between the surfaces 80 and 50 and yet is thin enough to prevent excessive leakage loss of pressurized oil.

During operation of the pump 30 high pressure oil in the channel 144 will flow through the check valve 160 into the passageway 156. The oil flows through the annular groove 164, the radial passageways 166, the annular groove 172 and the passageway 170 into the axially extending passageway 118 of the shaft 104. Flowing into the bore action 120 the oil then passes through the capillary passageway 128, the axial hole 69 in the fluid dispenser 68 and the passageway 70 in the swash plate 56. The oil is distributed by the radially extending passageway 72 to the groove 74 between the lands 76 and 78 and lubricates the cooperating surfaces 80 and the surface 50 of the thrust member 44.

The thrust force exerted by the swash plate assembly 46 upon the thrust member 44 will be substantially equal to the force exerted by the pistons 96 on the swash face 62. This force is equal to the sum of the forces exerted by each piston 96. Each piston 96 will exert a force equal to its cross-sectional area times the pressure of the oil in its respective piston chamber 98. This thrust force must be balanced by the force of the oil film between the convex surfaces 80 and the concave surface 50, which is equal to the mean pressure of the oil film between the surface 50 and the surfaces 80 times the area of the surfaces 80.

The thrust force of the pistons 96 on the swash face 62 may readily be calculated for a given pump pressure output. Likewise, the desired oil thickness between the surfaces 80 and the surface 50 may be calculated. Once these have been determined, the desired mean pressure of the oil film between the surface 50 and the surfaces 80 and the pressure of the oil in the groove 74 may be calculated. Since the pressure of the oil in the passageway 118 and bore section 120 is known, the desired pressure drop across the capillary passageway 128 may be calculated. The size and length of the capillary passageway 128 is constructed accordingly. Thus, during operation of the pump 30 oil is supplied at a sufficient pressure to maintain an oil film of predetermined thickness between the surfaces 80 and the surface 50.

Should the thrust force increase sufficiently to move the surfaces 80 closer to the surface 50 of the thrust member 44 than desired, the flow of oil between the surfaces 80 and the surface 50 will, of course, be decreased. The resultant reduced flow of oil in the capillary passageways 128 will decrease the pressure drop through the passageway 128, whereby the pressure of the oil between the surfaces 80 and the face 50 increases and moves the swash plate assembly 46 and the thrust member 44 back to their predetermined distance apart. Likewise, should the thrust force decrease and the surfaces 80 move away from the surface 50, the flow of oil therebetween will increase. This increase in oil flow will also occur in the passageway 128, which will increase the pressure drop through the passageway 128, thereby decreasing the pressure of the oil between the surfaces 80 and the surface 50. This causes the surfaces 80 to move closer to the surface 50 and therefore back to their predetermined spaced relationship. In this manner a predetermined spaced relationship between the surfaces 80 and the surface 50 is automatically maintained.

It will be understood that this self-positioning aspect of the pump 30 operates at any pressure output of the pump 30, as the pressure drop across the capillary passageway 128 will be a predetermined percentage of the pressure output which is in the passageway 128. Furthermore, it will be understood that oil from the channel 144 will enter the passageway 158, but will be prevented from entering the channel 146 by the check valve 162.

If the flow of the pump 30 is reversed by the methods described hereinbefore whereby channel 144 will be carrying the high pressure oil, the operation of the pump 30 is basically the same. However, in such an instance the oil to be supplied to the surfaces 80 and the surface 50 comes from the channel 146 and the passageway 158 through the check valve 162. The check valve 160 prevents the oil, in this instance, from flowing through to the channel 144.

To reduce shear losses and leakage between the port plate 100 and the plate 132 and the cylinder block 94, the port plate 100 is adapted to automatically center itself between the plate 132 and the cylinder block 94. A small amount of oil will tend to leak between the face 142 of the cylinder block 94 and the face of the land 140 of the port plate 100 and exert a force upon the port plate 100 toward the left when viewing FIGURE 1. Basically, the self-centering feature of the port plate 100 is achieved by allowing a controlled amount of oil to flow between the port plate 100 and the rotating plate 132 to create a sufficient force on the port plate 100 toward the right

to counterbalance these forces acting upon it toward the left.

To these ends, the face 185 of the port plate 100 has a greater surface area than the surface area of the face of the land 140. The kidney ports 144*a*, 146*a*, 180 and 182 are, however, the same size and aligned in the manner described hereinbefore. The counterbalancing oil flows from the channels 144 and 146 through the grooves 174*a* and 176*a*, respectively, to the kidney ports 182 and 180, respectively. The grooves 174*a* and 176*a*, provide predetermined pressure drops for the oil passing between the plate 132 and the port plate 100. Since the area of the face 184 is larger than the area of the face of the land 140, the pressure of the oil on the left side of the port plate 100 need not be as large as the pressure on the right side of the port plate 100 to exert the same force toward the right as is being exerted toward the left on the port plate 100. In this manner the forces on either side of the port plate 100 are balanced and it is thereby centered between the plate 132 and the cylinder block 94.

If the port plate 100 should move off center toward the right, the land 140 and the face 142 will move together and the faces 185 ond 184 will move apart. As a result, the flow of oil betwen the faces 184 and 185 will increase and likewise the flow of oil through the capillary grooves 174*a* and 176*a*. Increased flow through the capillary grooves 176*a* and 174*a* causes the oil flowing therethrough to experience an increased pressure drop. This reduces the pressure of the oil between the faces 185 and 184 and decreases the rightward force exerted by the oil upon the port plate 100. The leftward force exerted by the oil between the land 140 and the face 142 thereby becomes greater than the rightward force on the port plate 100 and the plate 100 moves axially to the left until it is centered between the plate 132 and the block 94 and the forces on either side are balanced.

The reverse occurs if the port plate 100 moves off-center to the left. In this instance, the flow of oil between the faces 184 and 185 is reduced. This causes the flow of fluid through the capillary grooves 174*a* and 176*a* to likewise decrease whereby the pressure drop across these grooves is also reduced. As a result, the pressure of the oil between the faces 184 and 185 increases, thereby increasing the rightward force upon the port plate 100 and causing it to move to the right until it is centered and the forces on both sides of the plate 100 are balanced.

FIGURE 8 is a graph illustrating the effect upon shear and oil leakage losses when the port plate 100 is not centered. It will be understood that this is an empirical analysis in which X represents the maximum distance the port plate 100 may be off center, i.e., when one face of the port plate 100 is in contact with the cylinder block 94 or the plate 132, and 0 represents the centered position of the port plate 100, i.e., when it is equidistant between the plate 132 and the cylinder block 94.

The graph of FIGURE 8 is prepared for those instances in which the port plate 100 moves to the right, i.e,, the left side of the port plate 100 moves away from the plate 132 and the right side of the port plate 100 moves toward the face 184 of the cylinder block 94. The solid lines R_1 and L_1 represent the shear loss between the faces 140 and 142 and the faces 185 and 184, respectively, while the dotted lines L_2 and R_2 represent the leakage losses between the faces 185 and 184 and the faces 140 and 142, respectively. The total losses curve is the sum of the leakage and shear losses for both sides of the port plate 100 at any condition.

An example will suffice to explain the manner in which the graph illustrates the importance of the port plate 100 being centered. For an example assume that the port plate 100 is 0.6X off center toward the right. In this position the leakage losses between the port plate 100 and the cylinder block 94 is about 0.04% as indicated by the R_2 line. From the L_2 line the leakage between the faces 185 and 184 is seen to be about 1% when the port plate 100 is in this position. On the other hand, the L_1 line shows that the shear losses between the plate 100 and the plate 132 are about 0.14% and the R_1 line indicates that the shear losses between the plate 100 and the cylinder block 94 are about 0.62%. The sum of these losses is about 1.84% as indicated on the total losses curve. Therefore, when the port plate 100 is .6X off center the shear and leakage losses are about 80% greater than when it is centered and the desirability of the self-centering port plate 100 in the pump 30 is apparent.

III. The FIGURES 9–13 pump

Referring now to FIGURES 9–13, a modified swash plate pump is indicated generally by reference numeral 200. The pump 200 may be employed as a motor, but herein will be described in connection with its pump function.

As seen in FIGURE 9, the pump 200 includes a stationary housing or casing 232 having open ends, one of which is closed by a cover 234 suitably secured to the casing 232 by nuts and bolts or the like (not shown). Secured to the other end of the casing 232 is an outlet section 228 which cooperates with the housing 232 to hold an eccentric ring 226 in proper fixed position. Suitable means, not shown, such as nuts and bolts may be employed to secure the outlet section 228, the eccentric ring 226 and the housing 232 together.

Rotatably supported within the section 228 and the housing 232 on anti-friction radial type ball bearings 236 and 238 is a swash plate type pump mechanism, indicated generally by reference numeral 240. An annular bearing spacer 231 prevents movement of the ball bearing assembly 236. The pump mechanism 240 includes a cylinder block assembly 242, a thrust member 244, a swash plate assembly 246 and a port plate 248. The port plate 248 is rotatably supported by the bearing 236, and the thrust member 244 is rotatably supported by the bearing 238. The axis of rotation of the swash plate mechanism 240 is indicated generally by reference numeral 282.

The thrust member 244 is substantially the same as the thrust member 44 described hereinbefore. The cylinder block assembly 242 is secured to the thrust member 244 by suitable means not shown. In this manner, the thrust member 244 and the cylinder block assembly 242 rotate together. The thrust member 244 has a thrust bearing, concave segmental spherical surface 250 which cooperates with the swash plate assembly 246 in the same manner that the concave spherical surface 50 of the thrust member 44 cooperates with the swash plate assembly 46 of the pump 30 described hereinbefore.

The swash plate assembly 246 is similar to the swash plate assembly 46 described hereinbefore. It includes a swash plate 256 having an integral, axially aligned shaft 258. The free end of the shaft 258 is rotatably supported in an anti-friction roller bearing assembly 260, which may be identical to the anti-fraction roller bearing assembly 60 described hereinbefore. The swash plate 256 has an annular swash face 262 concentrically positioned about an axis 264 of the swash plate assembly 246. The swash face 262 lies in a plane perpendicular to the axis 264 and faces toward the cylinder block assembly 242. Also extending toward the cylinder block assembly 242 is a cylindrical projection 265 coaxial with the axis 264 and integral with the swash plate 256. This cylindrical projection 265 is identical to the cylindrical projection 65 discussed hereinbefore and has a segmental spherical socket 266, coaxial with the axis 264 of the swash plate assembly 246, which opens toward the cylinder block assembly 242. As in the pump 30 described hereinbefore, a segmental spherical ball end surface 268*a* of a fluid dispenser 268 fits within the socket 266, its outer periphery being in substantially fluid-tight engagement therewith to form a chamber 267. Extending axially through the dispenser 268 is

a passageway 269 which communicates with the chamber 267.

Also communicating with the chamber 267 is an axially extending passageway 270 in the swash plate 256 which branches out into radially extending passageways 272 communicating with an annular groove 274 formed between annular lands 276 and 278 on the exterior surface of the swash plate 256. Segmental spherical surfaces 280 of the lands 276 and 278 define a segmental sphere having a diameter substantially equal to the diameter of the concave, segmental spherical surface 250 of the thrust member 244. Accordingly, the swash plate assembly 246 is universally tiltably associated with the thrust member 244.

The swash plate assembly 246 is tiltable by moving its axis 264 in a swash or tilt plane 293 (see FIGURES 10 and 11). The axis of rotation 282 lies in this plane 293. The tilting is effected by moving the free end of the shaft 258 which is supported in the radial roller bearing 260. The swash angle between the axis 264 of the swash plate assembly 246 and the axis of rotation 282 is referred to generally by A. It will be understood that when the swash angle A is 0° that the axis 264 of the swash plate assembly and the axis of rotation 282 coincide.

The pump 200 is provided with a guide member 284 which is similar in all respects to the guide member 84 described hereinbefore. It cooperates with a pinion 288 which likewise is in all respects similar to the pinion 88 described hereinbefore. The cover 234 is identical to the cover 34 of the pump 30 in that it has the opposing internal parallel guide flats which are parallel to the tilt plane 293 in which the swash plate assembly 246 is tilted. These cooperate with the two flats (not shown) on the guide member 284 whereby rotation of the pinion 288 moves the guide member 284 along the flats of the cover 234 to increase or decrease the swash angle A on either side of the axis of rotation 282. In this manner, the swash plate assembly 246 may be tilted to control the capacity and direction of flow of the pump 200.

The cylinder block assembly 242 includes a cylinder block 294 having a plurality of cylinders 298 therein, each cylinder 298 containing a reciprocable piston 296. The pistons 296 have convex, spherical heads 296*a* which cooperate with the swash face 262 of the swash plate 256. The swash face 262 normally contacts the heads 296*a* off the axes of the pistons 296 so that relative movement between the swash plate 256 and the cylinder block 294 will cause the pistons 296 to rotate within the cylinders 298. This minimizes uneven wear on the pistons 296 and the cylinders 298.

The cylinders 298 have cylinder ports 300. The pistons 296 reciprocate during the rotation of the pump mechanism 240 at other than zero swash angle, the amount of reciprocation and, accordingly, the pump displacement, increasing with increased swash angle. Oil to be pumped enters each cylinder 298 through its respective port 300 as its associated piston 296 moves away from the port 300 and the oil is discharged under pressure from the cylinder 298 as its associated piston 296 moves toward the port 300. The oil is supplied to the piston cylinders 298 through an opening 302 in the housing 232 and discharged from the cylinders 298 through the cylinder ports 300 to the port plate 248.

In the pump 200 the axis of the piston 296 and the cylinders 298 are parallel to the axis of rotation 282. It will be understood, however, that the axes of the pistons 296 and the cylinders 298 may be in any configuration so long as their ports 300 have a generally circular configuration.

Likewise, though the pump 200 of the present invention has been illustrated with nine pistons 296, it will be understood that any number of pistons may be employed. It is preferable to employ an odd number of pistons.

For rotating the cylinder block assembly 242, the thrust member 244, the swash plate assembly 246 and the port plate 248, the cylinder block 294 has integral therewith a drive shaft 204 which extends through an axial aperture 206 in the outlet section 228. A seal 210 prevents oil from leaking through the aperture 206 around the shaft 204.

An axial passageway 318 extends into the drive shaft 204. In fluid-tight engagement with the passageway 318 is a holding member 320 which has an axial passageway 321 therein. Supported within the passageway 321 is a spring 322 which acts upon a cylindrical positioning member 324. The cylindrical positioning member 324 is axially movable within and in fluid-tight engagement with the passageway 321. The spring 322 acts upon the inner end of the positioning member 324 to urge its other end into abutting relationship with the fluid dispenser 268. The force of the spring 322 upon the holding member 320 and the positioning member 324 will keep the holding member 320 in fluid-tight engagement with the cylinder block 294 and passageway 318. It will be understood however that the holding member 320 may be press-fitted into the passageway 318.

The holding member 320 has at its inner end a passageway 319 connecting the passageways 318 and 321. An axially extending passageway through the positioning member 324 has secured therein by a press fit or the like a fluid transfer member 326 have a longitudinally extending groove thereon which forms with the positioning member 324 a capillary passageway 328. In this manner fluid may flow from the passageway 318 through the passageways 319, 321, 328, 269, 270 and 272 to between the surface 250 and the surfaces 280.

As shown in FIGURE 9, the outer end of the fluid transfer member 326 is spaced sufficiently inwardly from the outer end of the positioning member 324 to assure that the capillary passageway 328 will communicate with the passageway 269 in the fluid dispenser 268, despite small transverse movement of the fluid dispenser 268. It will be understood from the above discussion that the positioning member 324 and the fluid transfer member 328 are identical to the positioning member 124 and fluid transfer member 128, respectively, of the pump 30.

Splined or keyed to the drive shaft 204 are the port plate 248 and an annular spacer 334. The spacer 334 is positioned between the port plate 248 and the cylinder block 294 and held in this abutting relationship by a nut 314 threadedly engaging the shaft 204. The port plate 248, the spacer 334 and the cylinder block 294 rotate at the same speed as the shaft 204. The spacer 334 has a slightly larger longitudinal dimension, in the order of about .0005 inch, than a rotatable annular follower ring 340 which cooperates with the eccentric ring 226 and is positioned between the port plate 248 and the cylinder block 294. The larger longitudinal dimension of the spacer 334 promotes the self-centering feature of the follower ring 340 to be discussed in more detail hereinafter.

The eccentric ring 226 has a longitudinally extending, circular opening 227 therethrough, the axis of which is eccentric to the axis of rotation 282. Within the circular opening 227 is the annular follower ring 340 having concentric inner and outer peripheries. The outer periphery of the follower ring 340 cooperates with the periphery of the opening 227 through the ring 226 whereby the follower ring 340 may rotate and move axially therein.

On one side of the eccentric ring 226 there is a groove 342 facing the cylinder block 294. The groove 342 has varying dimensions depending upon the width of the eccentric ring 226 at that point. A plurality of holes 344 extend longitudinally through the eccentric ring 226 and communicate with the groove 342.

The port plate 248 has an annular face 346 which cooperates with the follower ring 340 and the eccentric ring 226. In the face 346 of the port plate 248 are nine relief ports 348 which have identical cross-sections

to the cylinder ports 300 of the piston cylinders 298. The relief ports 348 are aligned with the cylinder ports 300.

In addition, the port plate 248 has a plurality of passageways 350 which communicate with the passageway 318 through an annular groove 352 in the port plate 248 and radially extending holes 354 through the drive shaft 204 (see FIGURES 9 and 12). In this manner fluid may flow from the piston cylinder 298 through the passageways 350, the annular groove 352 and the passageways 354 into the passageway 318 of the drive shaft 204. Also communicating with the passageway 318 are radially extending holes 356 which communicate with an outlet zone 358 in the outlet section 228 (see FIGURES 9 and 13). A wall 360 of the outlet zone 358 has holes through which the drive shaft 204 extends. The wall 360 and the drive shaft 204 are in fluid-tight engagement by means of seals (not shown) or the like well known in the art.

IV. Operation of the FIGURE 9-13 pump

In discussing the operation of the pump 200, it will be assumed that the drive shaft 204 rotates in the direction indicated by the arrow in FIGURE 9 and that the swash angle A between the axis 264 of the swash plate assembly 246 and the axis of rotation 282 is greater than 0° in the direction shown in FIGURE 9. When the pump 200 is actuated by rotation of the drive shaft 204, the port plate 248, the spacer 334, the cylinder block assembly 242 and the thrust member 244 rotate in the same direction and at the same speed as the drive shaft 204. The contact of the swash face 262 of the swash plate 256 upon the pistons 296 and the force exerted by the positioning member 326 upon the fluid dispensers 68 cause the swash plate assembly 246 to rotate in the same direction as these other members and at substantially the same speed. However, it is not essential that the swash plate assembly 246 rotate at the same speed as the cylinder block assembly 242 or the thrust bearing member 244. Also, the follower ring 340 will rotate in the same direction because the shear friction it has with the port plate 248 and the cylinder block 294 is greater than the force of frictional engagement with the eccentric ring 226.

It will thus be understood that during the rotation of the cylinder block assembly 242 that the pistons 296 will be reciprocated in the same manner as the pistons 96 were reciprocated in the pump 30. The piston cylinders 298 of those pistons 296 going through their intake stroke communicate through cylinder ports 300 with the inlet opening 302 in the housing 232 whereby oil under sufficient charging pressure to force the pistons 296 into contact with the swash face 262 of the swash plate 256 enters the inlet opening 302 of the housing 232 and passes between the eccentric ring 226 and the end of the cylinder block 294 into the piston chambers 298 via the cylinder ports 300. As the piston 296 reaches bottom dead center position, its respective port 300 is blocked off by the follower ring 340 and will no longer communicate with the inlet 302.

As the cylinder block 242 continues to rotate the piston 296 begins its compression stroke due to its cooperation with the swash face 262 of the swash plate 256. Simultaneously therewith the cylinder port 300 communicates with the passageways 350 in the port plate 248. In this manner, as the piston 296 moves toward top dead center, oil is being compressed in the piston chamber 298 and forced out through the cylinder port 300 between the annular ring 340 and the spacer 334 into the passageways 350 of the port plate 248. This compressed oil will then flow through the annular groove 352, the passageways 354, the passageway 318, and the passageways 356 into the outlet zone 358 where it is delivered to any desired source. As the piston 296 completes its compression stroke, i.e., it reaches top dead center position, the annular ring 340 again blocks off cylinder port 300. The cycle is repeated as the piston 296 begins its intake stroke and simultaneously its piston chamber 298 communicates with the inlet opening 302 in the housing 232.

Viewing FIGURES 10 and 11, the manner in which the fluid flows into the piston cylinders 298 during the intake stroke of the piston 296 and flows through the port plate 248, the passageway 318 and the outlet zone 358 during the compression stroke of the piston 296 will be apparent. The arrows in FIGURES 10 and 11 indicate the flow paths of the oil. Since the annula follower ring 340 is eccentrically mounted in the ring 226, the ports 300 of the piston chambers 298 will be either blocked by the ring 340, communicate with the interior of the ring 340 or communicate with the exterior of the ring 340 as the cylinder block 294 rotates. The ports 300 are blocked by the ring 340 when their respective pistons 296 are at top dead center position or bottom dead center position. As seen in FIGURE 11, one of the ports 300 is blocked by the follower ring 340 as its associated piston 296 is at top dead center position. On the other hand, the cylinder ports 300 communicate with the exterior of the follower ring 340 as their respective pistons 296 are going through their intake stroke and oil from the inlet 302 flows between the cylinder block 294 and the eccentric ring 226 through the ports 300 into the piston chambers 298. The cylinder ports 300 communicate with the interior of the annular ring 340 as their respective pistons 296 are going through their compression stroke. In this manner the compressed oil flows from the cylinder 298 through the cylinder port 300 into the interior of the ring 340 where it travels through the passageways 350, the annular groove 352 and the passageways 354 into the passageway 318. From the passageway 318 the pressurized oil flows through the passageways 356 into the outlet zone 358 where it is delivered to any desired destination.

It will be understood that if the swash angle A is decreased, the capacity of the pump 200 is decreased as the pistons 296 go through a shorter intake and compression stroke. Therefore, it will be understood that when the swash angle A is zero degrees, no pumping action is effected by the pump 200.

If the shaft 204 is rotated in the opposite direction, the flow of fluid in the pump 200 is reversed. That is, the oil enters the zone 358 and is discharged under pressure through the opening 302.

Likewise, as in the pump 30, the oil flow of the pump 200 may be reversed by actuation of the pinion 288 to change the swash angle A so that it is on the opposite side of the axis of rotation 282.

Thrust, of course, is created during the operation of the pump 200. As in the pump 30, and in accordance with this invention, the thrust is transmitted from the pistons 296 to the swash plate assembly 246, but instead of being transmitted from the swash plate assembly 246 to the casing through a thrust bearing, the thrust force exerted against the thrust member 244 is carried back to the cylinder block 294. Furthermore, by this arrangement the need for a universal joint has been eliminated. In the pump 200 the surfaces 280 of the lands 276 and 278 cooperate with the concave surface 250 of the thrust member 244 in exactly the same manner that the surfaces 80 of the lands 76 and 78 cooperate with the concave surface 50 of the thrust member 44 in the pump 30. The only difference is that the pressurized oil is supplied between these cooperating surfaces from the passageway 318. The fluid flows through the passageway 319 of the holding member 320 into the chamber 321 from which it flows through the capillary passageway 328 and the passageways 269, 270 and 272 to the annular groove 274 on the periphery of the swash plate 256. Thus, the swash plate 256 is automatically separated from the thrust member 244 by an oil film of predetermined thickness in the

same manner described hereinbefore in detail with respect to the pump 30.

To reduce shear losses between the follower ring 340 and the port pate 248 and the cylinder block 294, the port plate 248 has relief ports 348 which are the same size as the cylinder ports 300 and are aligned therewith. Likewise the cylinder block 294 has a relief port 351 opposite each passageway 350 and axially aligned therewith. The relief ports 351 have the same cross-sectional area as the passageways 350 in the port plate 248. In this manner, where the follower ring 340 extends between the passageway 350 and the relief port 351 both sides of the follower ring 340 have the same area exposed to the pressure of the oil in the passageway 350. Likewise, the pressure exerted through the ports 300 upon one side, the follower ring 340 will be counterbalanced by the oil under the same pressure which flows through the holes 344 and the eccentric ring 226 to the relief ports 348. Where the ring 340 prevents communication between the port 300 and the inlet 302, there is direct communication between the port 300 and the relief port 348. Thus, any pressure exerted through oil at the port 300 will be counterbalanced on the other side of the ring 340 by oil in the relief port 348 at the same pressure and acting upon the same cross-sectional area on the other side of the ring 340. In this manner the ring 340 is maintained in a substantially balanced position between the port plate 248 and the cylinder block 294, thus reducing shear losses between these parts.

V. The embodiment of FIGURES 14 and 15

Referring now to FIGURES 14 and 15, there is illustrated a modified form of the present invention which may be employed in the pump or motor 30 or 200. In this embodiment the pistons are cooperatively secured to the swash plate assembly whereby the relative movement between the cylinder block assembly and the swash plate assembly causes the pistons to move through their intake stroke. This is contrasted with the pumps 30 and 200 wherein the pistons are maintained in contact with the swash plate assembly during their intake stroke by the charging pressure of the inlet oil.

As seen in FIGURE 14, the pump 400 includes a stationary housing or casing 402 rotatably supporting therein a cylinder block assembly 404, a thrust member 406 and a swash plate assembly 408. The thrust member 406 is secured to the cylinder block assembly 404, the thrust member 406 being substantially identical to the thrust member 44 of the pump 30 and the thrust member 244 of the pump 200. The swash plate assembly 408 is substantially identical to the swash plate assembly 46 of the pump 30 and the swash plate assembly 246 of the pump 200 and cooperates with a concave surface 410 of the thrust member 406 in the same manner described hereinbefore with respect to the pumps 30 and 200.

The cylinder block assembly 404 is similar to the cylinder block assemblies described hereinbefore, with the exception that its pistons 412 have a modified construction. Furthermore, a positioning member 414 is housed directly within the cylinder block 404 to cooperate with the fluid dispenser 68.

The pistons 412 are hollow and have convex segmental spherical heads 416. Guide members 418 having concave segmental spherical sockets 418*a* are connected to the pistons 412 by internal ball joints 420 secured in place by a snap ring 422. Each ball joint 420 has an axially extending hole 424 which connects the interior of the piston 412 with a flat surface 426 of the spherical guide member 418, which surface 426 cooperates with the face of the swash plate assembly 408. A passageway 428 in the spherical guide member 418 allows oil to pass back to the point where the ball joint 420 cooperates with the piston 412.

A disc 430 having radially extending arms 432 holds the sperical guide members 418 in position. The fluid dispenser 68 cooperates with a segmental spherical socket 434 in the disc 430. The disc 430 has a cylindrical projection 436 which is in fluid-tight engagement with an axial passageway 438 in the swash plate assembly 408. A passageway 440 extends from a cavity 435 formed by the fluid dispenser 68 and the socket 434 to the end of the projection 436. In this manner fluid flowing through the positioning member 414 and the fluid dispenser 68 may flow through the passageway 440 into the radial passageways 72 between the surface 410 of the thrust member 406 and the exterior surfaces of the swash plate assembly 408. It will be understood that the balance between the thrust force exerted by the pump 400 will be effected between the swash plate assembly 408 and the thrust member 406 in the same manner described hereinbefore with respect to the pump or motor 30 and 200.

During operation of the pump 400 the relative movement of the swash plate assembly 408 away from the cylinder block 404 will cause the spherical guide members 418 to move away from the cylinder block 404 and, through the ball joints 420, move the pistons 416 for their intake stroke. As the pistons 412 go through their pressure stroke, oil will flow through the passageway 424 in the ball joint 420 and flow between the face 426 of the guide member 418 and the cooperating face of the swash plate assembly 408. In this manner a predetermined oil film between the guide member 418 and the swash plate assembly 408 will be assured. Thus, if there is any relative rotation between the disc 432, and therefore the guide members 418, and the swash plate assembly 408, the shear losses between the guide members 418 and the swash plate assembly 408 will be minimized. Likewise oil may flow through the passageway 428 between the piston head 416 and the guide member 418 to prevent any shear losses which may occur between these members.

It will be understood that with respect to the other operational features of the pump 400 that they are identical to the pump 30 or the pump 200, depending upon the particular type of porting arrangement provided.

VI. Control system

Referring now to FIGURES 16–19, there is illustrated a control system adapted to change the swash angle A between an axis of rotation 500 of a pump like the pumps 30, 200 and 400 and an axis 502 of a swash plate assembly 504 employed in such a pump. It will be understood that the swash plate assembly 504 may be identical to any one of the swash plate assemblies described hereinbefore. This control system is fluid pressure actuated.

As seen in FIGURES 16 and 17 a free end of a shaft 506 of the swash plate assembly 504 is supported in an anti-friction radial ball bearing 508. The ball bearing assembly 508 is suitably secured, by means of a press fit or the like, within a non-rotatable guide member 510 having an external rack 512 thereon which cooperates with a pinion 514. The cover 516 of the pump has two opposing parallel internal guide flats 518 which are parallel to the tilt or swash plane. These cooperate with two complementary flats 520 on the guide member 510 whereby rotation of the pinion 514 moves the guide member 510 parallel to the guide flats 520 to increase or decrease the swash angle A on either side of the axis of rotation 500. To this point the arrangement is identical with that described hereinbefore with respect to the pump 30 and the pump 200.

The pinion 514 is mounted upon a rotatable shaft 522 supported by bushings 524 and 525 secured to the cover 516. One end of the shaft 522 extends into a servo control assembly indicated generally by reference numeral 526. The shaft 522 has a passageway 528 through which fluid under pressure from a suitable source (not shown) is directed to the servo control assembly 526 to regulate the movement of the pinion 514 in a manner more apparent hereinafter.

The servo control assembly 526 includes a stationary

housing 527 secured to the cover 516. A knob 530 having a shaft 532 with an annular flange 534 is rotatably mounted upon the housing 527. Secured to the flange 534 is an annular ring 536. As will be more apparent hereinafter, rotation of the knob 530 and the ring 536 causes the shaft 522 and the pinion 514 to rotate the same number of degrees in the same direction, thereby tilting the swash plate assembly 504 as desired.

The housing 527 has two radially, inwardly extending walls 538 and 540 (see FIGURE 19) which are in fluid-tight engagement with an annular section 542 of a pressure responsive means, such as rotary piston member 544, keyed to the shaft 522. Together with the cover 516 and a wall 529, the walls 538 and 540 form a fluid-tight chamber 546 within the housing 527. The rotary piston member 544 is in fluid-tight engagement with the walls of the chamber 546, but is movable therein in a manner more apparent hereinafter.

Extending radially from the passageway 528 in the shaft 522 is a passageway 550 which communicates with a short groove 552 on the periphery of the shaft 522. The ring 536 has a land 554 which has the same cross-sectional configuration as the groove 552, but has slightly larger dimensions. On opposite sides of the land 554 are grooves 556 and 558 in the ring 536. Communicating with the grooves 556 and 558 are passageways 560 and 562, respectively, in the shaft 522. These passageways 560 and 562 also communicate with the chamber 546 on opposite sides of the rotary piston member 544. Grooves 564 and 566 on the sides of the passageways 560 and 562 extend along the periphery of the shaft 522 to carry displaced fluid from the chamber 546 to any desired destination, e.g., to the area in the cover 516. The groove 556 has substantially the same dimensions as the land 568 between the grooves 564 and 552. Likewise the groove 558 has substantially the same dimensions as the land 570 between the grooves 552 and 566.

To change the swash angle A between the axis 502 of the swash plate assembly 504 and the axis 500, the knob 530 is rotated through an arc corresponding to the number of degrees in which the pinion 514 is desired to be rotated. The ring 536 will likewise be rotated the same number of degrees causing the land 554 to be disaligned from the groove 552. If, for instance, the knob 530 is rotated in a clockwise direction when viewing FIGURES 18 and 19 this will cause the passageway 550 to communicate with the groove 556 whereby fluid under pressure passes through the groove 556 and the passageway 560 to the pressure chamber 546. The pressure of the fluid entering the pressure chamber 546 from the passageway 560 causes the rotary piston member 544 to move in a clockwise direction in the chamber 546. Fluid is displaced from the chamber 546 by such movement of the member 544 and it flows through the passageway 562, the groove 558 and the groove 566 to the cover 516 or any other suitable source. As the rotary piston member 544 rotates in a clockwise direction, the shaft 522 will also be rotated in a clockwise direction until the groove 552 again becomes aligned with the land 554. When this occurs the flow of fluid to the pressure chamber 546 will be cut off or terminated. This occurs when the shaft 522 has been rotated through exactly the same number of degrees as the knob 530.

Likewise, if it is desired to rotate the shaft 522 in a counterclockwise direction, the knob 530 is rotated in a counterclockwise direction. This causes the passageway 550 to pass pressurized fluid through the groove 558 and the passageway 562 to the fluid pressure chamber 546. The fluid under pressure entering the pressure chamber 546 pushes the rotary piston member 544 in a counterclockwise direction, the displaced fluid flowing through the passageway 560 into the groove 556 and out through the groove 564 to any suitable predetermined destination. This continues until the rotary piston member 544 has been rotated in a counterclockwise direction sufficiently that the shaft 522, which rotates with the member 544, has moved in a counterclockwise direction sufficiently that the groove 552 is again aligned with the land 554 thereby cutting off the flow of fluid to and from the pressure chamber 546.

It will thus be understood that by rotation of the knob 530 through a predetermined number of degrees that the pinion 514 on the shaft 522 will simultaneously and automatically be rotated in the same direction in the same number of degrees.

It will be understood that the section headings in this application are merely a matter of convenience and are not limitations upon the present invention.

While several embodiments described herein are at present considered to be preferred, it is understood that various modifications and improvements may be made therein, and it is intended to cover in the appended claims all such modifications and improvements as fall within the true spirit and scope of the invention.

What is desired to be claimed and secured by Letters Patent of the United States is:

1. A swash plate fluid device comprising a casing having rotatably mounted therein a cylinder block assembly, a rotatable swash plate assembly and a rotatable thrust member, said cylinder block assembly having a plurality of pistons reciprocably mounted therein, said swash plate assembly cooperating with said pistons for reciprocating said pistons, said thrust member having a concave, segmental spherical surface which cooperates with a convex spherical surface of said swash plate assembly, the thrust load of said piston against said swash plate assembly being transmitted from said surface of said swash plate assembly to said surface of said thrust member, means connecting said thrust member and said cylinder block assembly whereby said thrust load is transmitted directly from said thrust member to said cylinder block assembly.

2. In a swash plate fluid device including a casing having rotatably mounted therein a cylinder block assembly and a swash plate assembly, said cylinder block assembly having a plurality of pistons reciprocally mounted therein and said swash plate assembly cooperating with said pistons for reciprocating said pistons, a port plate mounted within said casing and axially movable therein, said port plate positioned between an end of said cylinder block assembly and a plate rotating with said cylinder block assembly, said port plate allowing oil to enter said cylinder block assembly and receiving oil discharged from said cylinder block assembly and automatically centering itself between said plate and said cylinder block assembly.

3. In a swash plate fluid device comprising a casing having rotatably mounted therein a cylinder block assembly and a swash plate assembly, said cylinder block assembly having a plurality of piston chambers, each having a cylinder port and a reciprocal piston, said cylinder port communicating with an end of said cylinder block assembly remote from said swash plate assembly, said swash plate assembly cooperating with said pistons for reciprocating said pistons in said piston chambers, a port plate adjacent said end of said cylinder block assembly remote from said swash plate assembly, said port plate distributing oil to said piston chambers and receiving oil discharged from said piston chambers, said port plate being mounted within said casing and axially movable therein between said end of said cylinder block assembly and a plate rotatable with said cylinder block assembly, said plate having relief ports therein adjacent said port plate, said relief ports having cross-sectional areas substantially the same as the cross-sectional areas of said cylinder ports, means for transmitting oil from said port plate to said relief ports whereby said port palte is automatically centered between said rotating plate and said cylinder block assembly.

4. In the fluid device of claim 3 wherein said port plate

has symmetrically disposed kidney ports in opposite half sections of said port plate, each of said kidney ports communicating with a channel which communicates with the exterior of said casing, whereby oil enters said device through one of said channels and is discharged from said device through said other channel, each of said channels having a capillary-type passageway leading therefrom communicating with a face of said port plate remote from said cylinder block assembly and adjacent said rotating plate.

5. In the fluid device of claim 3 wherein a spacer means maintains said plate and said cylinder block assembly apart a distance slightly larger than the longitudinal dimension of said port plate.

6. A swash plate fluid device comprising a casing having rotatably mounted therein a cylinder block assembly, a swash plate means and a thrust member, said cylinder block assembly being non-rotatably mounted upon a rotatable shaft extending into said casing, said cylinder block assembly having a plurality of piston chambers therein, each of said piston chambers having a reciprocal piston therein, said swash plate means cooperating with said pistons for reciprocating said pistons, each of said piston chambers having a cylinder port communicating with an end of said cylinder block assembly remote from said swash plate assembly, a rotating plate fixedly mounted on said shaft, a non-rotatable port plate mounted within said casing between said remote end of said cylinder block assembly and said rotating plate, said non-rotatable port plate being free to move axially between said cylinder block assembly and said rotating plate, said port plate having two channels therein both of which communicate with the exterior of said casing whereby oil enters said piston chambers through one of said channels and is discharged from said piston chambers through said other channel.

7. The fluid device of claim 6 wherein said port plate has a first and second side, each channel in said port plate having a kidney port opening in said first side toward said cylinder ports, said kidney ports being symmetrically disposed in opposite half-sections of said first side of said port plate, each channel having a capillary-type passageway extending therefrom which communicates with said second side of said port plate which is adjacent said rotating plate whereby said port plate automatically is centered between said cylinder block assembly and said rotating plate.

8. The fluid device of claim 7 wherein a face of said port plate adjacent said second side of said port plate has relief ports therein being axially aligned with and having substantially the same cross-sectional dimensions as said cylinder ports, said second side of said port plate having two kidney-shaped relief ports therein axially aligned with and having substantially the same cross-sectional dimensions as said kidney ports, said capillary-type passageways from said channels communicating with said kidney-shaped relief ports.

9. The fluid device of claim 6 wherein said thrust member has a concave, segmental spherical surface which cooperates with a convex, segmental spherical surface of said swash plate assembly, means connecting said thrust member and said cylinder block assembly whereby a thrust load against said swash plate assembly is transmitted to said thrust bearing member and back to said cylinder block assembly and means for providing a film of predetermined thickness of oil between said surface of said swash plate assembly and said surface of said thrust member.

10. The fluid device of claim 9 wherein said means for providing a film of pre-determined thickness of oil includes a passageway communicating with the channel in said port plate receiving the oil discharged from said piston chambers, said passageway delivering oil from said channel to between said surface of said swash plate assembly and said surface of said thrust member and having

therein a capillary passage which causes a pressure drop on the oil flowing from said channel to between said surface of said swash plate assembly and said surface of said thrust member.

11. A swash plate fluid device comprising a casing having rotatably mounted therein a cylinder block assembly, a swash plate assembly and a thrust member, said cylinder block assembly having a plurality of pistons reciprocally mounted therein, said swash plate assembly cooperating with said pistons for reciprocating said pistons, said thrust member having a concave, segmental spherical surface which cooperates with a convex segmental spherical surface of said swash plate assembly, the thrust load of said piston against said swash plate assembly being transmitted from said surface of said swash plate assembly to said surface of said thrust member, means connecting said thrust member and said cylinder block assembly whereby a thrust load against said swash plate assembly is transmitted to said thrust member and back to said cylinder block, and means to provide an oil film of predetermined thickness between said surface of said swash plate assembly and said surface of said thrust member.

12. A swash plate pump comprising a casing having rotatably mounted therein a cylinder block assembly, a swash plate assembly and a thrust bearing member, said cylinder block assembly having a plurality of pistons reciprocally mounted therein, said swash plate assembly cooperating with said pistons for reciprocating said pistons, said thrust bearing member having a concave, partially spherical surface which cooperates with a convex, partially spherical face of said swash plate assembly, means connecting said thrust bearing member and said cylinder block assembly whereby a thrust load against said swash plate assembly is transmitted through said thrust bearing member to said cylinder block assembly, means for providing an oil film of pre-determined thickness between said faces of said swash plate assembly and said surface of said thrust bearing member, said means including a passageway communicating with a port plate which receives oil discharged from said cylinder block assembly, said passageway delivering oil from said port plate between said face of said swash plate assembly and said surface of said thrust bearing member, said oil flowing through a restricted passage whereby the pressure of said oil is reduced as it flows therethrough.

13. In the fluid device of claim 12 said means for providing an oil film including a fluid dispenser cooperatively engaging said swash plate assembly and a spring-biased positioning member in said passageway abutting said fluid dispenser and holding it in cooperative engagement with said swash plate assembly, said positioning member having said restricted passage therein whereby said oil travels through said restricted passage and said fluid dispenser as it travels to between said surfaces of said thrust member and said swash plate assembly.

14. In the fluid device of claim 13 wherein said swash plate assembly has a segmental spherical socket opening toward said cylinder block assembly, said fluid dispenser being a segmental, spherical member extending into said socket and being held therein by said positioning member, said fluid dispenser having a passageway therein through which said oil passes.

15. A swash plate fluid device comprising a casing having rotatably mounted therein a cylinder block assembly and a swash plate assembly, said cylinder block assembly having a plurality of piston chambers each having a piston reciprocally mounted therein, said piston chambers communicating through cylinder ports with an end of said cylinder block assembly remote from said swash plate assembly, said swash plate assembly cooperating with said pistons for reciprocating said pistons, an eccentric ring fixedly mounted within said casing and supporting a rotatable annular follower ring positioned adjacent said cylinder ports, said annular follower ring being supported in said eccentric ring whereby its axis is eccentric to a

longitudinal axis of said cylinder block assembly, a port plate mounted within said casing and rotating with said cylinder block assembly, whereby fluid enters said cylinder port and its piston chamber when said cylinder port is on one side of said follower ring and fluid is discharged from said piston chamber when said cylinder port is on the other side of said follower ring, said eccentric ring having a plurality of holes therethrough by which oil may flow between said annular follower ring and said port plate, said port having a face adjacent said follower ring with relief ports, each relief port being axially aligned with a port in said cylinder block assembly and having substantially the same cross-sectional dimensions as the ports with which it is aligned whereby said follower ring is maintained substantially equidistant between said port plate and said cylinder block assembly.

16. The swash plate fluid device of claim 15 wherein said cylinder block assembly has a shaft connected thereto which extends axially from said casing, said port plate being non-rotatably secured to said shaft, said casing having an outlet section therein, said outlet section communicating with an oil passageway in said shaft, said port plate having a passageway therein whereby oil is discharged from said piston chamber through said ports, passes through said passageway in said port plate and said oil passageway in said shaft to said outlet section in said casing.

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