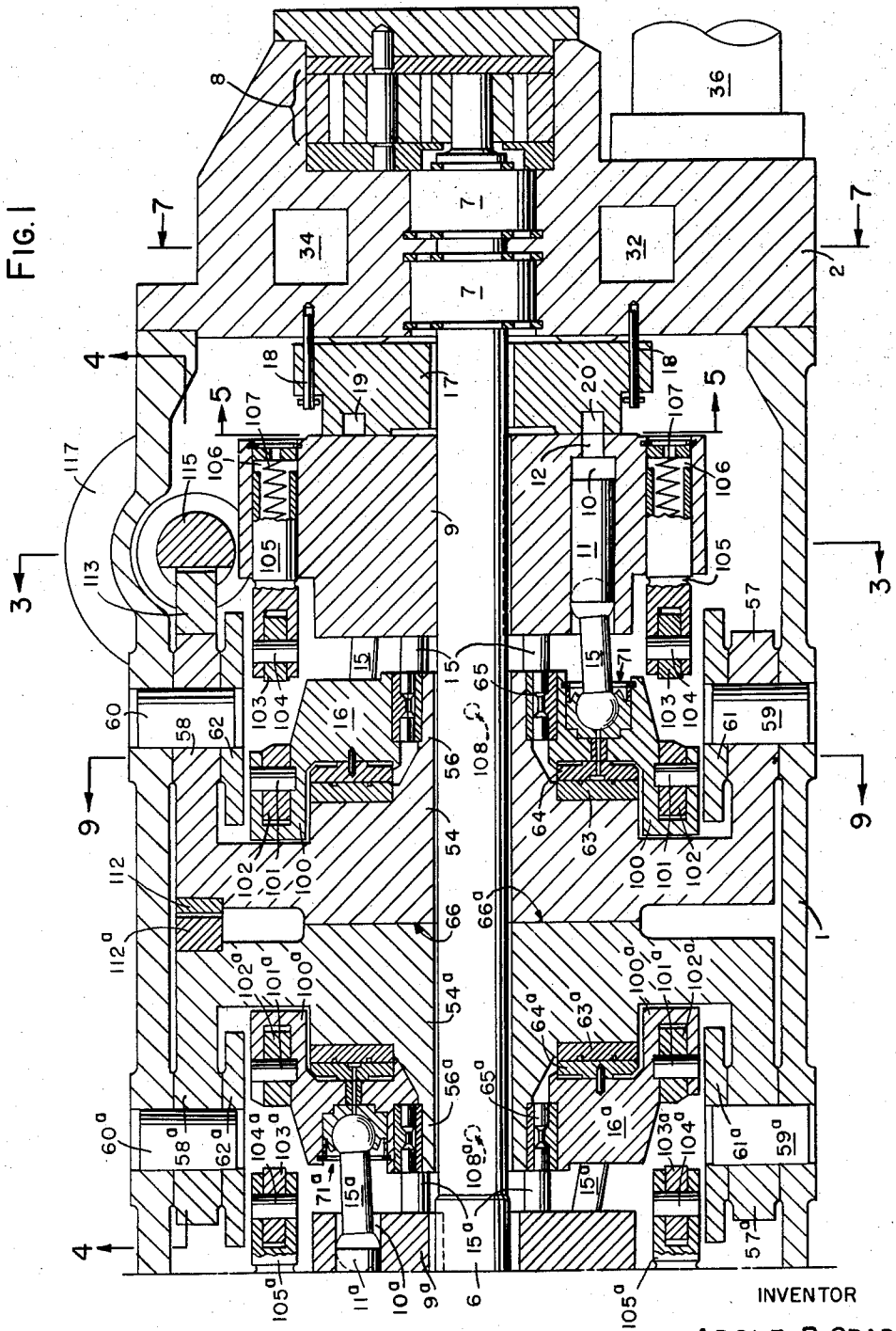
Sept. 9, 1958 A. R. GRAD 2,850,986

AXIAL HYDRO-DYNAMIC MACHINE HAVING OPPOSED PISTONS

Filed Nov. 7, 1955 8 Sheets-Sheet 1

FIG. 1



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AXIAL HYDRO-DYNAMIC MACHINE HAVING OPPOSED PISTONS

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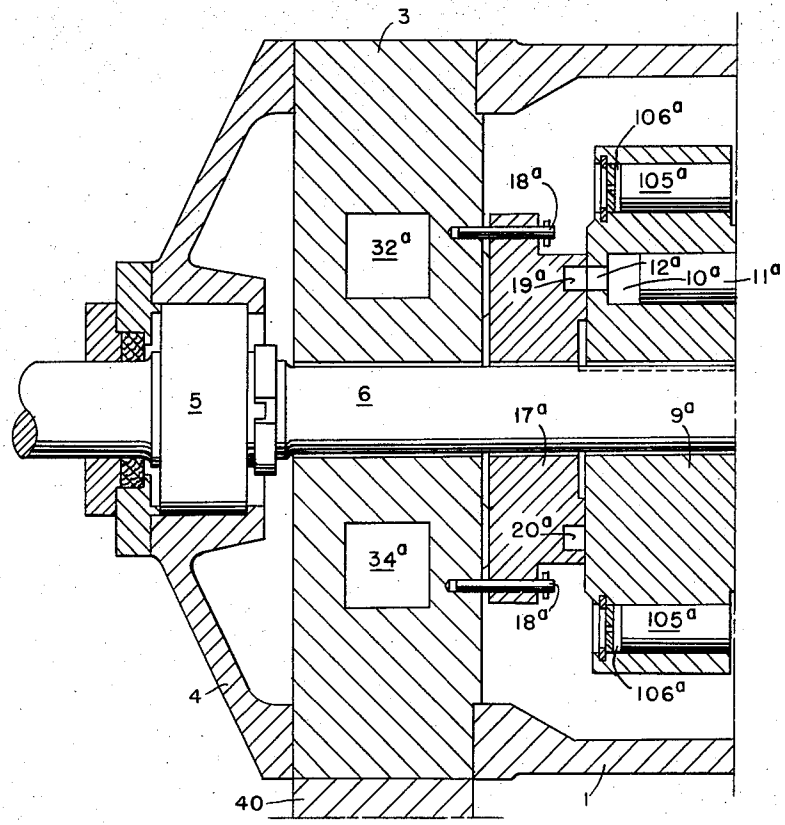
FIG. 1A



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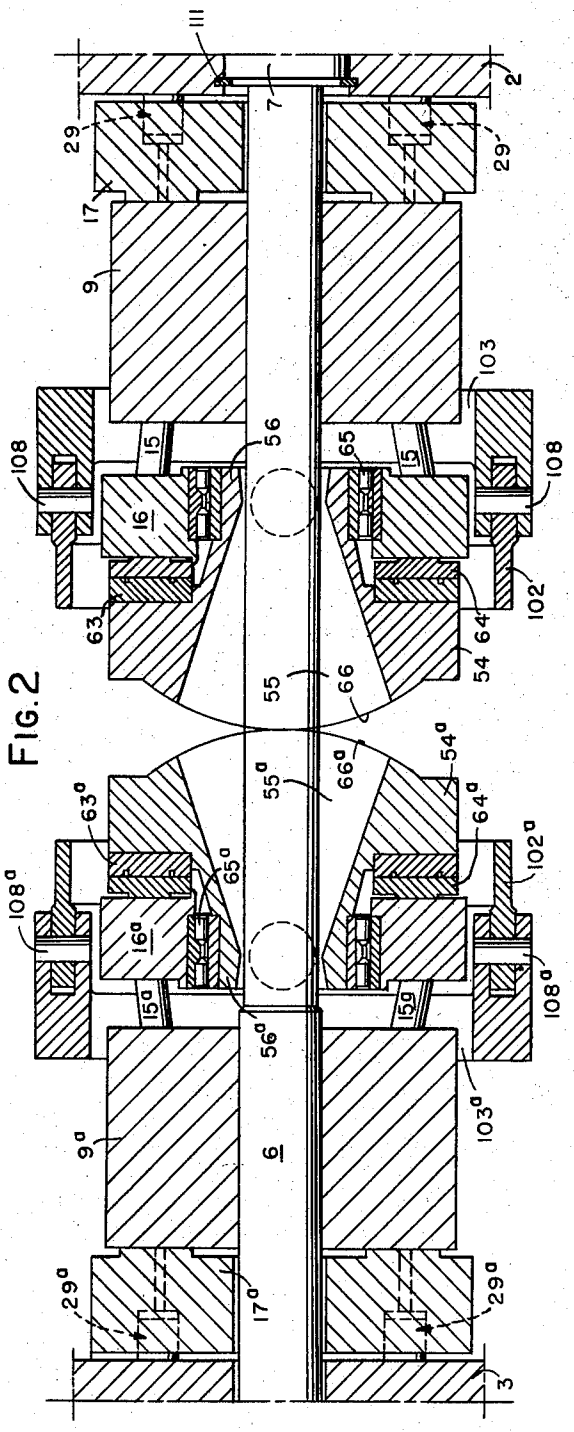

FIG. 2

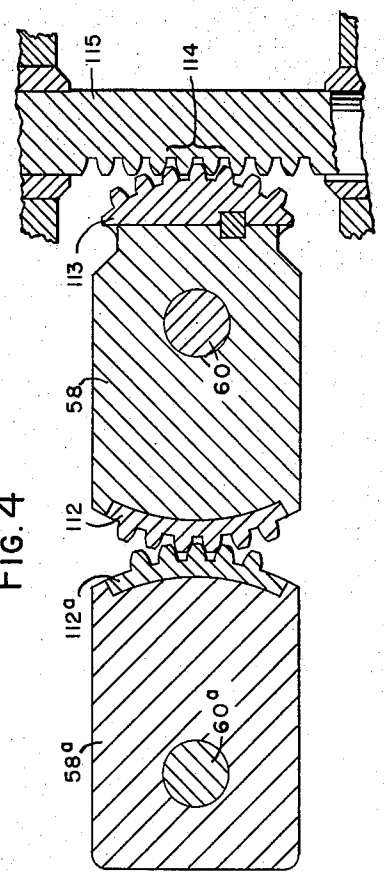

FIG. 4

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FIG. 3

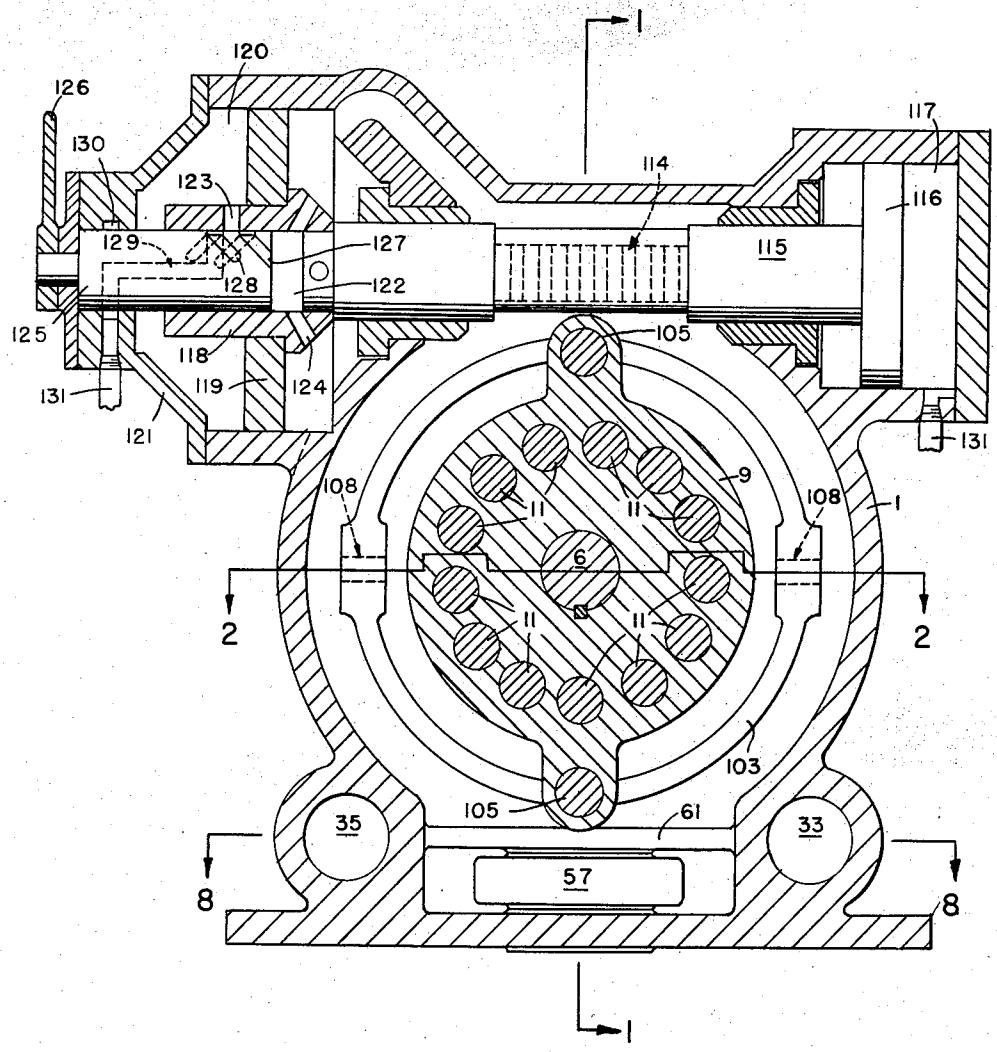

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FIG. 7

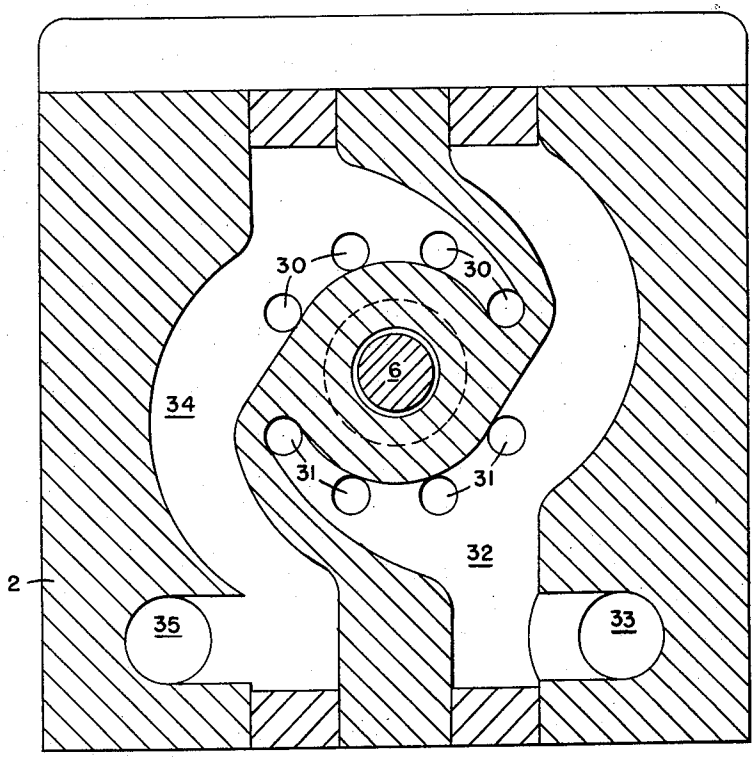

FIG. 6

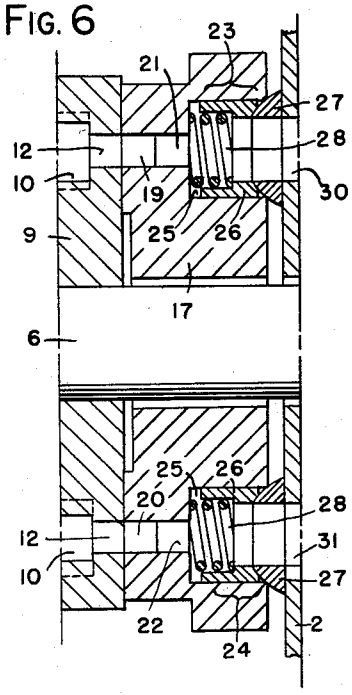

FIG. 5

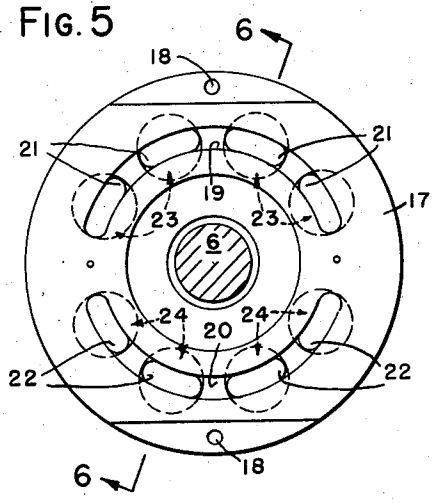

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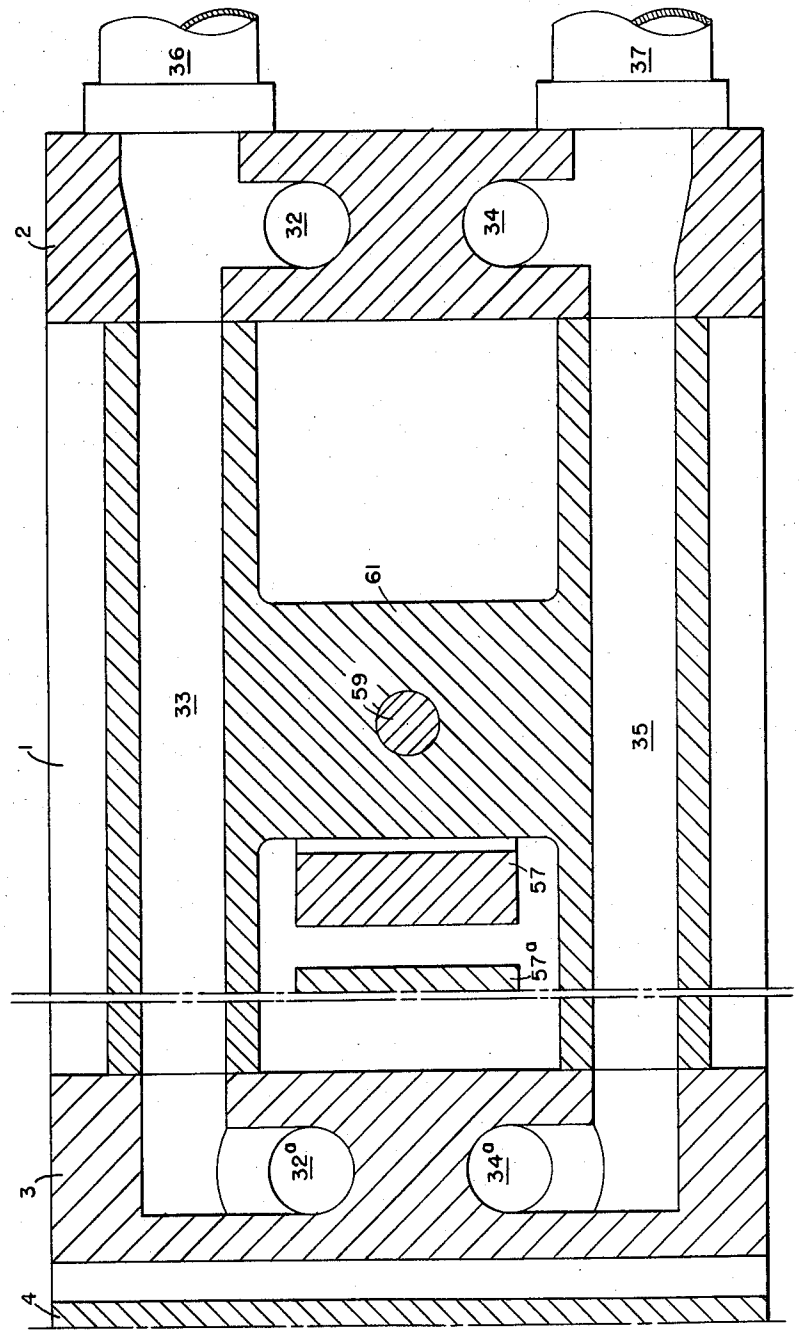
FIG. 8



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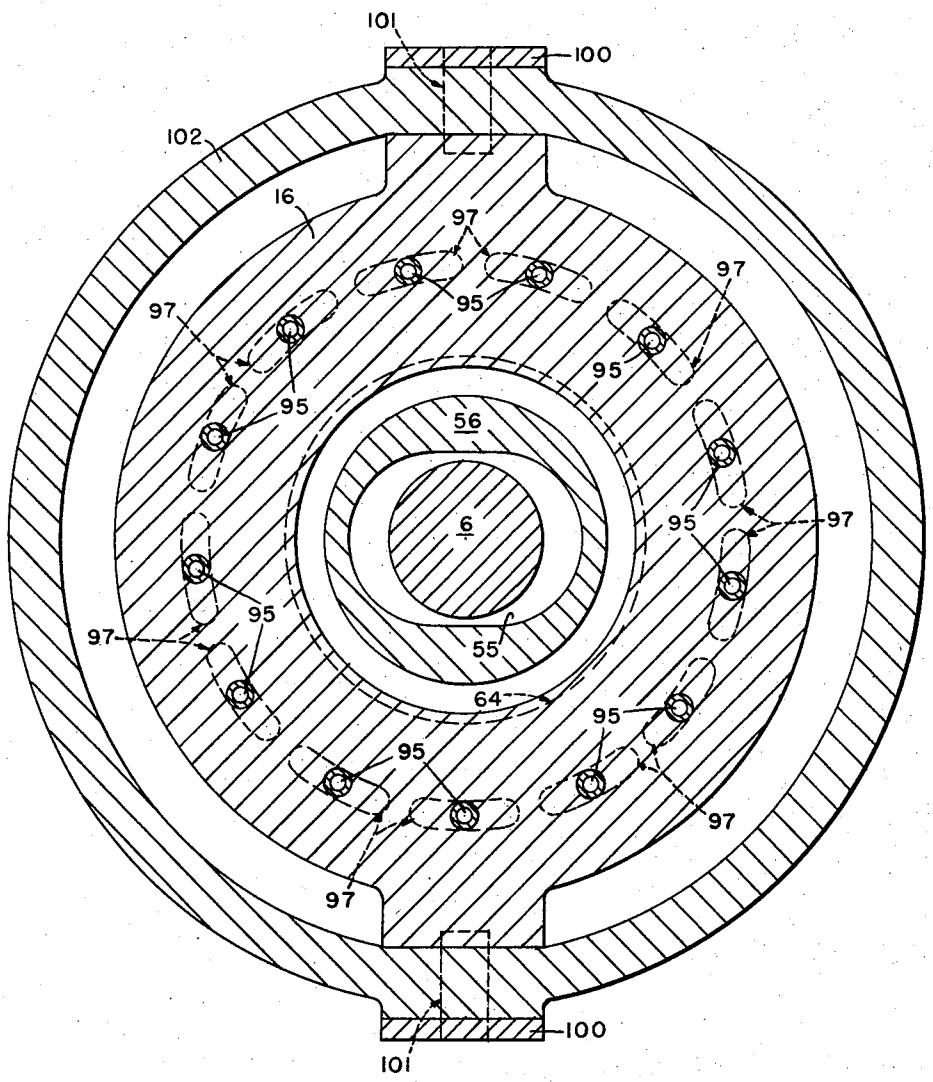
AXIAL HYDRO-DYNAMIC MACHINE HAVING OPPOSED PISTONS

Filed Nov. 7, 1955 8 Sheets-Sheet 7

FIG. 9



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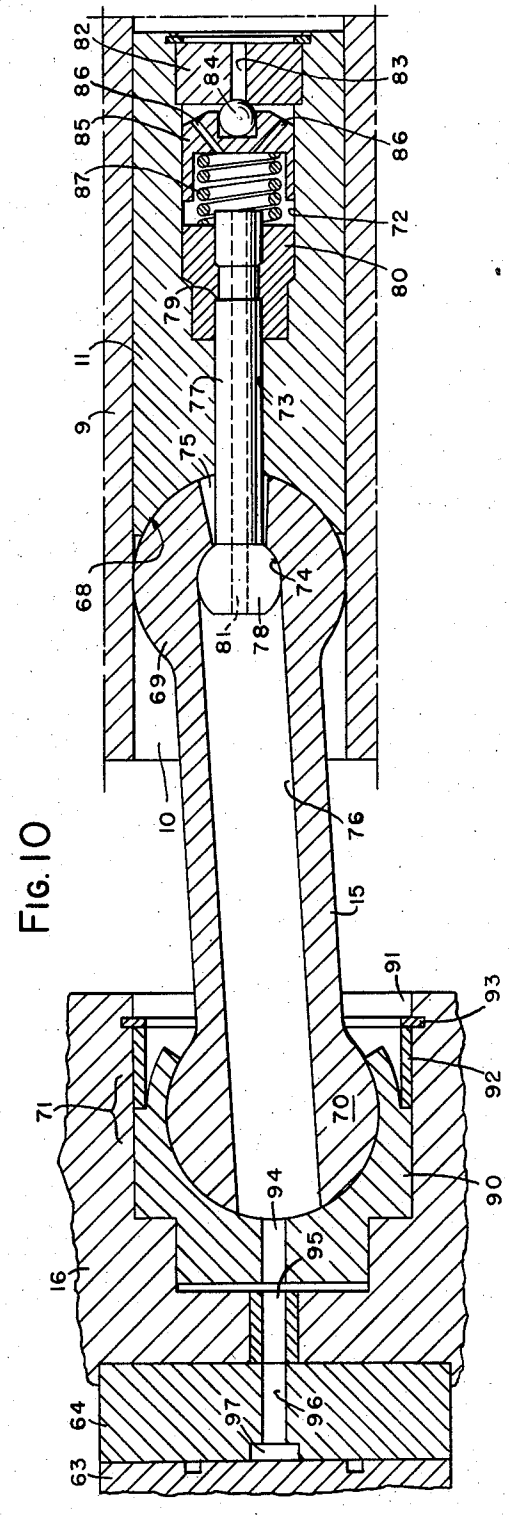

FIG. 10

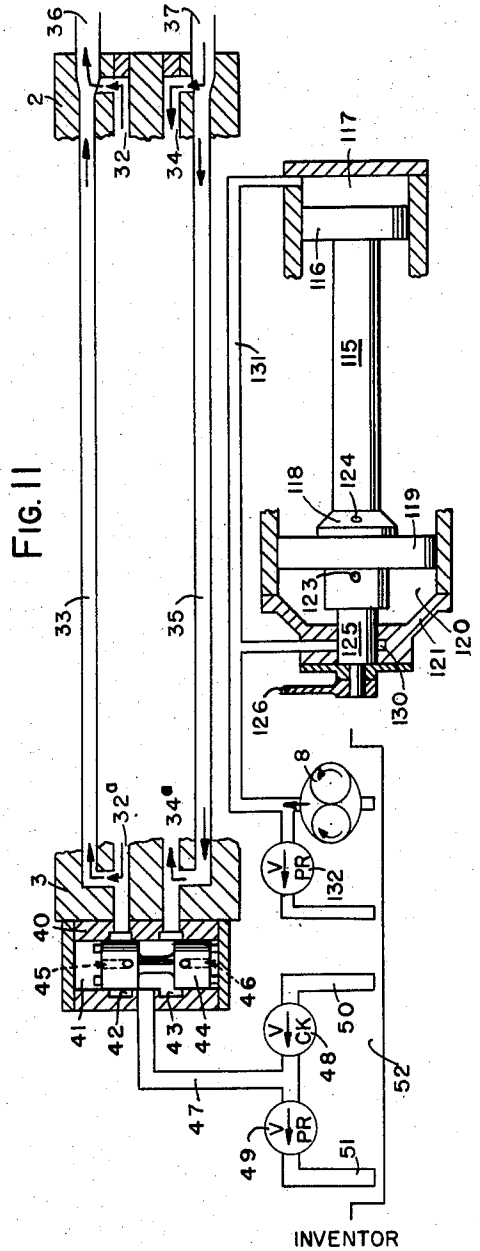

FIG. 11

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2,850,986

AXIAL HYDRO-DYNAMIC MACHINE HAVING OPPOSED PISTONS

Adolf R. Grad, Milwaukee, Wis., assignor to The Oilgear Company, Milwaukee, Wis., a corporation of Wisconsin

Application November 7, 1955, Serial No. 545,242

11 Claims. (Cl. 103—162)

This invention relates to hydrodynamic machines of the axial type which will function as pumps when driven mechanically and will function as motors when supplied with motive liquid. Since the function of a motor is substantially opposite to the function of a pump, a machine embodying the invention will be referred to herein as a pump in order to simplify the description, but it is to be understood that the invention is equally applicable to motors, and that the term "pump" as used herein is intended to mean either a pump or a motor.

The type of pump to which the invention relates in particular has its pistons and cylinders arranged in a rotatable cylinder barrel around and parallel to the axis thereof, rotation of the cylinder causes the pistons to be reciprocated by a swash plate when that plate is inclined to the cylinder barrel axis, and the swash plate is carried by a cradle which may be tilted to vary the displacement of the pump. Such a pump is disclosed in application Serial No. 388,163, filed October 26, 1953, now Patent No. 2,804,828, of which this application is a continuation in part.

The cradle is tiltable upon trunnions carried by the pump casing, and the swash plate is rotatably supported upon the cradle and is rotated with the cylinder barrel. The pumping reactions are transmitted through the swash plate and the cradle to the casing and, when the pump is of large capacity and is creating a high pressure, the resultant of the pumping reactions is tremendous and causes deflection of the cradle regardless of how heavy the cradle is made. The deflection of the cradle is slight, but it is sufficient to cause some wear between the swash plate and the cradle when the pump is creating very high pressures.

The present invention has as an object to provide a pump of the above type in which deflection of the cradle is avoided.

Another object is to provide a pump having a longer stroke than is possible in the prior pumps because of deflections of the cradles thereof.

Another object is to split the phase of an axial pump in order to provide better delivery characteristics and to reduce the noise level.

Another object is to provide a pump which may be driven at a speed considerably higher than the speed at which a conventional pump of the same capacity must be driven, thereby enabling the user to employ a high speed electric motor for driving the pump.

Another object is to provide a pump which may be made in very large capacities and operated at very high pressures.

A pump constructed according to the invention has the advantage that it may be fully tested on a test stand having a capacity only one-half that of the pump.

Another advantage is that the majority of the parts of a large pump embodying the invention and the majority of the parts of a pump having one-half the capacity of the large pump are identical, thereby reducing tooling and inventory costs.

Other objects and advantages will appear from the following description of the embodiment of the invention shown somewhat schematically in the accompanying drawings in which the views are as follows:

Figs. 1 and 1A taken together constitute a central, vertical, longitudinal section through a pump in which the invention is embodied, the plane of the view being indicated by the line 1—1 of Fig. 3.

Fig. 2 is a central sectional plan view taken on the irregular line 2—2 of Fig. 3, but with the pump casing and the end portions of the pump omitted.

Fig. 3 is a vertical transverse section taken on the line 3—3 of Fig. 1.

Fig. 4 is a section taken on the line 4—4 of Fig. 1, but with the pump casing omitted.

Fig. 5 is a face view of one of the valves which control the flow of liquid to and from the pumping cylinders, the plane of the view being indicated by the line 5—5 of Fig. 1.

Fig. 6 is a section taken through the valve of Fig. 5 and portions of the adjacent parts, the view being taken on the line 6—6 of Fig. 5, but drawn to a larger scale.

Fig. 7 is a transverse section taken on the line 7—7 of Fig. 1.

Fig. 8 is a sectional plan view showing the connections between the main fluid passages of the pump, the view being taken on the line 8—8 of Fig. 3, but with certain portions omitted.

Fig. 9 is a sectional view taken through a swash plate and through one ring of the universal joint which transmits rotary motion from a cylinder barrel to the swash plate, the view being taken in the plane indicated by the line 9—9 of Fig. 1, but drawn to a larger scale.

Fig. 10 is an enlarged longitudinal section through one of the piston and piston rod assemblies shown in Fig. 1.

Fig. 11 is a diagram illustrating the hydraulic circuits of the pump.

The pump has its mechanism arranged within and supported by a suitable casing shown as including a body 1, a block 2 which is fixed to and closes the right or rear end of body 1, a block 3 which is fixed to and closes the front or left end of body 1, and an end head 4 which is fixed to block 3 and carries a bearing 5 for a drive shaft 6 which extends through body 1 and is journaled in a pair of bearings 7 carried by block 2. The right end of the shaft 6 is reduced in diameter and has fixed thereon the driven gear of a gear pump 8 which supplies liquid for control purposes as will presently be explained.

Shaft 6 has fixed for rotation therewith two cylinder barrels 9 and 9^a which are arranged opposite hand to each other. Cylinder barrel 9 has a plurality of cylinders 10 formed therein parallel to shaft 6 and equally spaced in a circular row concentric with shaft 6. Each cylinder 10 has a piston 11 fitted therein and an elongated cylinder port 12 extending therefrom through the end of the cylinder barrel.

Cylinder barrel 9^a is identical to cylinder barrel 9 and is similarly provided with identical cylinders 10^a, pistons 11^a and ports 12^a. However, cylinder barrel 9^a is rotated one-fourth of a cylinder space in respect to cylinder barrel 9 in order to split the phase of the pump. That is, there are an odd number of cylinders in each cylinder barrel and one cylinder barrel is angularly displaced far enough from the other to prevent any two cylinders from opening to the valve ports at the same instant. In order to simplify the drawings, Figs. 1 and 1A show a cylinder 10 and a cylinder 10^a in the plane indicated by the line 1—1 of Fig. 2 but actually that plane passes through only a small portion of cylinder 10^a.

Each piston 11 is connected by a piston rod 15 to a swash plate 16, and each piston 11^a is connected by a piston rod 15^a to a swash plate 16^a. The swash plates

are caused to rotate with the cylinder barrels and will effect reciprocation of the pistons when shaft **6** is rotated and the swash plates are inclined to the axis of shaft **6** as will presently be explained.

Reciprocation of the pistons causes liquid to be alternately drawn into and discharged from the cylinders. The valve for controlling the flow of liquid to and from the cylinders in each of the two cylinder barrels and the passages for such flow are substantially the same as in the pump shown in application Serial No. 388,163 to which reference may be had for details of construction.

As shown, flow of liquid into and out of the several cylinders **10** is controlled by an annular flat valve **17** which engages the end of cylinder barrel **9** and extends around shaft **6**. The contacting surfaces are made flat and smooth to provide a substantially liquid tight joint between valve **17** and cylinder barrel **9**. Rotation of valve **17** is prevented such as by means of the one or more pins **18** which extend through valve **17** and into block **2**.

Valve **17** has two arcuate ports **19** and **20** (Fig. 5) formed in the face thereof upon the same radius as cylinder ports **12** each of which registers with ports **19** and **20** alternately as cylinder barrel **9** rotates. The adjacent ends of ports **19** and **20** are spaced apart a distance equal to or slightly greater than the length of a cylinder port **12**. The portions of the valve face between the ends of port **19** and **20** constitute seals or bridges which prevent a cylinder port **12** from establishing communication between the two valve ports as the cylinder port moves from one valve port to the other.

Valve port **19** communicates with a plurality of oblong holes **21**, four being shown, and valve port **20** communicates with an equal number of oblong holes **22**. Each hole **21** communicates with a hold-up motor **23** and each hole **22** communicates with a hold-up motor **24** all of which are arranged within valve **17**.

The hold-up motors are all alike and, as shown in Fig. 6, each includes a cylinder **25** which is formed in valve **17**, a tubular piston **26** which is fitted in cylinder **25**, an annular sealing member **27** which is arranged between piston **26** and block **2**, and a spring **28** arranged between piston **26** and the end wall of cylinder **25** to initially urge valve **17** against cylinder barrel **9**, piston **26** against member **27** and member **27** against block **2**. The contacting surfaces of member **27** and block **2** are made flat and smooth and the contacting surfaces of member **27** and piston **26** are made spherical and smooth to provide substantially liquid tight joints therebetween while permitting valve **17** to adjust itself to the end of cylinder barrel **9**.

Valve **17** is adapted to be intermittently urged against cylinder barrel **9** by a plurality of balancing motors **29** one of which is shown in Fig. 2 behind each of the bridges between the adjacent ends of valve ports **19** and **20**. The hold-up motors and the balancing motors hold valve **17** in contact with cylinder barrel **9** and compensate for variations in the force which tends to move valve **17** away from cylinder barrel **9** as is well known and fully explained in application Serial No. 388,163.

Each hold-up motor **23** and each hold-up motor **24** register respectively with a hole **30** and a hole **31** found in block **2**. As shown in Fig. 7, the four holes **31** communicate with a passage **32** which is found in block **2** and communicates with a passage **33**. Likewise, the four holes **30** communicate with a passage **34** which is found in block **2** and communicate with a passage **35**.

The flow of liquid into and out of the several cylinders **10**[a] is controlled by a flat valve **17**[a] which is identical to valve **17** and has identical hold-up and balancing motors. The hold-up motors in valve **17**[a] communicate with passages **32**[a] and **34**[a] which are found in block **3**. Valve **17**[a] and the passages in block **3** have not been shown in detail because views showing the same would be substantially duplicates of Figs. 5, 6, and 7. Therefore, corresponding parts and passages which appear in the drawings have been indicated by corresponding reference numerals with the exponent "*a*" added to the numerals applied to valve **17**[a] and the passages in block **3**. As best shown in Fig. **8**, passages **33** and **35** extend from passages **32**[a] and **34**[a], respectively, through casing body **1** and block **2** for connection to opposite sides of an external circuit which has been represented by portions of two pipes **36** and **37**.

Passages **32** and **34** have been shown in Figs. 7 and 11 as having the lower ends thereof closed and passages **32**[a] and **34**[a] have been shown in Fig. 11 as having the lower ends thereof controlled by an automatic suction valve, but a suction valve may be arranged at either or both ends of the pump. Such valves are well known and in extensive use.

As indicated in Fig. 11, a valve body **40** is attached to the bottom of block **3** and provided with an axial bore **41** having formed in the wall thereof two annular grooves or ports **42** and **43** with which passages **32**[a] and **34**[a] communicate respectively. Communication between ports **42** and **43** is controlled by a valve **44** which is fitted into bore **41** and has two ducts **45** and **46** extending axially into it from its opposite ends and then extending radially outward into communication with ports **42** and **43** respectively.

Bore **41** communicates at a point between ports **42** and **43** with one end of a channel **47** the other end of which is connected to the outlet of a check valve **48** and the inlet of a low pressure resistance valve **49**. A channel **50** connected to the inlet of the check valve **48** and a channel **51** connected to outlet of resistance valve **49** extend into a supply liquid contained in a reservoir **52** upon which the pump ordinarily is mounted.

The arrangement is such that, when valve **44** is in the position shown and the pump discharges into passages **34** and **34**[a], the discharged liquid will tend to flow through body **40**, channel **47** and resistance valve **49** into reservoir **52**, but the resistance of valve **49** will cause pressure to rise and liquid to flow through duct **46** into the end of bore **41** and move valve **44** against the other end of bore **41** in which position valve **44** blocks port **43** and prevents the pump from discharging into reservoir **52**. Then when the pump is reversed, valve **49** will cause pressure to rise and liquid to flow through duct **45** into the end of bore **41** and move valve **44** to the position shown, in which position it blocks discharge from the pump into reservoir **52**. When the liquid returned to the pump from the external circuit is in excess of the volume required to supply the pump, the excess is exhausted through valve body **40** and resistance valve **49** into reservoir **52** and, when the pump requires more liquid than is returned to it from the external circuit, it will draw liquid through body **40**, channel **47**, check valve **48** and channel **50** from reservoir **52** regardless of the position of valve **44**.

As shown in Figs. 1 and 2, swash plates **16** and **16**[a] are rotatably supported, respectively, by two reaction members or cradles **54** and **54**[a] which are swingable in a horizontal plane to vary the angle between the swash plates and the cylinder barrels and thereby vary the displacement of the pump, swinging of the cradles being permitted by tapered openings **55** and **55**[a] which extend through cradles **54** and **54**[a] respectively and through which shaft **6** passes.

Cradle **54** has an integral central horn **56** and two integral arms **57** and **58** which are arranged diametrically opposite each other and are pivotally supported by two trunnions **59** and **60** respectively. Trunnion **59** is carried by the lower wall of casing **1** and by a web **61** which is formed integral with casing **1**. Trunnion **60** is carried by the upper wall of casing **1** and by a web **62** which is formed integral with casing **1**. Trunnions **59** and **60** are ordinarily provided with anti-friction bearings which

have been omitted from the drawings in order to simplify the views.

Cradle 54 also includes a flat annular wear plate 63 which extends around the base of horn 56 and is engaged by an annular thrust bearing 64 which is fixed for rotation with swash plate 16. Horn 56 has fixed thereon a bearing 65 on which swash plate 16 is journaled.

Except for the means for swinging the cradles upon their trunnions, cradle 54a and the means for mounting it are the same as, but are arranged opposite hand to cradle 54 and its mounting means. Therefore, further description thereof is deemed unnecessary since corresponding parts have been indicated by corresponding reference numerals the exponent "a" added to the numerals applied to cradle 54a and its mounting means.

The adjacent ends of cradles 54 and 54a are provided, respectively, with rolling contact faces 66 and 66a which firmly engage each other so that pumping reactions transmitted through swash plate 16 to cradle 54 are opposed by equal and opposite pumping reactions transmitted through swash plate 16a to cradle 54a, thereby preventing the cradles from being deflected by the pumping reactions. Contact faces 66 and 66a have equal radii and are concentric with the trunnions of the respective cradles so that they remain in firm contact with each other throughout the swinging movements of the cradles.

The piston and piston rod assemblies comprise pumping piston 11 or 11a piston rods 15 or 15a and the associated parts are all alike and a description of one will suffice for all. As shown in Fig. 10, each piston 11 has formed in its outer end a spherical seat 68 which is complementary to and engaged by a spherical head 69 forming one end of piston rod 15 the other end of which is formed into a spherical head 70 which forms a part of a ball and socket joint 71 as will presently be explained. Head 69 is nearly as large in diameter as cylinder 10 to provide between it and piston 11 bearing surfaces which are of maximum area to thereby permit very high pumping forces to be transmitted therethrough and thereby enable piston 11 to create very high pressures in cylinder 10.

Piston 11 has a recess 72 of varying diameters extending into it from its inner end and a bore 73 extending from recess 72 through seat 68. Piston rod 15 has a spherical seat 74 formed within head 69 concentric with seat 68, an opening 75 extending from seat 74 through head 69 and a bore 76 extending from seat 74 through head 70.

Head 69 is held in contact with seat 68 by a pin 77 having a spherical head 78 the surface of which is complementary to and in contact with seat 74. Pin 77 extends through opening 75 and bore 73 into recess 72 and has a cannelure 79 formed in the portion which extends into recess 72. When connecting piston 11 and piston rod 15 to each other, head 78 is urged against seat 74, head 69 is urged against seat 68 and then a plug 80 of suitable metal is upset or swaged into the inner end portion of recess 72 and into cannelure 79 thereby preventing any relative axial movement between piston 11 and rod 15 while permitting rod 15 to gyrate relatively to piston 11 as cylinder barrel 9 rotates. Also, the end of pin 77 has no tendency to move radially relatively to the piston as is the case in the prior piston and rod assemblies of this type.

In order to provide liquid for lubrication and hold-up purposes, pin 77 has a passage 81 extending axially therethrough and controlled by a check valve shown as comprising a plug 82 which is fixed in recess 72 and has a passage 83 extending therethrough, a ball 84 which normally closes the end of passage 83, a piston 85 which is fitted in recess 72 and has one or more passages 86 extending through its head end, and a spring 87 which urges piston 85 against ball 84 and ball 84 against plug 82. The arrangement is such that, when pressure is created in cylinder 10, it will raise ball 84 away from its seat, and then liquid can flow from cylinder 10 through passages 83, 86 and 81 into bore 76 and create pressure therein and, when cylinder 10 opens to the low pressure valve port, spring 87 will urge ball 84 to its seat and prevent escape of liquid from bore 76 into cylinder 10 Also, if the pump case is not filled with liquid, check valve 84—87 will prevent piston 11 during its suction stroke from drawing any air into cylinder 10 through the above described passages and through the fit between wear plate 63 and thrust bearing 64.

Ball and socket joint 71 includes a socket 90 which is closely fitted upon the spherical head 70 of piston rod 15 and is arranged within a pocket 91 formed in swash plate 16. Socket 90 is retained in pocket 91 in any suitable manner such as by means of a retainer ring 92 which has one end in contact with a shoulder formed upon socket 90 and its other end in contact with a snap ring 93 fitted in a suitable groove formed in the wall of pocket 91.

Socket 90 has a central hole 94 extending therethrough to provide communication between the bore 76 in rod 15 and a hole 95 which extends through swash plate 16 and communicates with a hole 96 which extends through thrust bearing 64 into communication with an elongated recess or pressure chamber 97 formed therein.

When pressure is first created in cylinder 10, it will cause liquid to flow therefrom through the previously described passages into bore 76 in rod 15 and from bore 76 through holes 94, 95 and 96 into pressure chamber 97. The pressure in chamber 97 will cause liquid to seep therefrom and spread over the contacting faces of thrust member 64 and wear plate 63 to form a lubricating film therebetween and the pressure will extend into that film. It has previously been stated that all of the pistons and piston rod assemblies are alike and it is to be understood that a pressure chamber is arranged in the same radial plane with each assembly. As indicated in Fig. 9, the pressure chambers in each thrust bearing are arranged in a circular row and spaced from each other.

As fully explained in application Serial No. 388,163, the area of each chamber 97 and the area of the surrounding film into which pressure can extend form a "balancing area" which is so proportioned that the force exerted by the liquid therein is just slightly less than the force exerted by the liquid upon the piston in the same radial plane.

When the pump is performing useful work, each cylinder will communicate with a high pressure valve port and the piston in that cylinder will be advanced and will eject liquid from the cylinder during one-half of each revolution of the cylinder barrels, and it will communicate with a low pressure port and the piston in that cylinder will be retracted and will draw liquid into the cylinder during the other half of each revolution of the cylinder barrels. The instant that a cylinder opens to the high pressure port, the pressure therein will act upon the end of the piston in that cylinder and also act upon the balancing area for that piston. The instant a cylinder opens to a low pressure port, pressure acting upon the piston in that cylinder and upon the balancing area for that piston will drop. The swash plates and the piston and piston rod assemblies are thus substantially hydrostatically balanced.

If it were not for this several check valves 82—87, each time a piston was retracted it would suck liquid out of the interior of that piston and piston rod assembly, thereby reducing the total volume of liquid delivered by the pump and causing momentary delays in establishing hydrostatic balance of the piston and piston rod assemblies.

Rotary motion is transmitted to swash plates 16 and 16a from cylinder barrels 9 and 9a through universal joints which are radially outward from the connections between the swash plates and the piston rods instead of being radially inward therefrom as is the common

practice in the prior pumps of the same general type. Since the two universal joints are identical and are connected to the swash plates and to the cylinder barrels by identical means, a description of one will suffice for both as like parts have been indicated by like reference numerals with the exponent "a" added to the reference numerals applied to the universal joint and the connecting means through which rotary motion is transmitted from cylinder barrel 9a to swash plate 16a.

As shown in Figs. 1, 2, and 9, swash plate 16 has two U shaped arms 100 formed integral with its outer peripheral portion at diametrically opposite points and connected by two pins 101 to a ring 102 at diametrically opposite points. A second ring 103 is connected to cylinder barrel 9 in the same radial plane in which ring 102 is connected to swash plate 16. As shown in Fig. 1, ring 103 is connected at diametrically opposite points by two pins 104 to the bifurcated outer ends of two plungers 105 which are slideable in bores 106 formed in cylinder barrel 9. Plungers 105 are urged outward by light springs 107. As shown in Fig. 2, rings 102 and 103 are pivotally connected to each other by two pins 108 which are spaced 90° from pins 101 and 104 and are arranged in the same transverse plane as trunnions 59 and 60.

The arrangement is such that cylinder barrel 9 when rotated will rotate ring 103 through plunger 105 and pins 104, ring 103 will rotate ring 102 through pins 108, ring 102 will rotate swash plate 16 through pins 101 and thrust bearing 64 will rotate with swash plate 16. If cradle 54 and swash plate 16 are inclined to the axis of cylinder barrel 9, ring 103 will pivot upon pins 104 and ring 102 will pivot upon pins 101 and 108 to compensate for the angle between the axes of rotation of cylinder barrel 9 and swash plate 16.

The pump has been shown with swash plates 16 and 16a in their neutral positions, that is, normal to shaft 6 in which position of the swash plates, pump displacement is zero. When the pump is driven and the swash plates are inclined to shaft 6, the pump will deliver liquid in a direction and at a rate determined by the direction and distance that the swash plates are inclined from their neutral positions. Swash plates 16 and 16a may be tilted by swinging cradles 54 and 54a upon their trunnions either manually or mechanically in any suitable manner.

As shown in Figs. 1 and 4, two intermeshing segmental gears 112 and 112a are fixed to cradles 54 and 54a, respectively, and a segmental gear 113 is fixed upon the arm 58 of cradle 54 and meshes with a rack 114 which is formed upon a piston rod 115 having a piston 116 (Fig. 3) fixed upon one of its ends. Piston 116 is fitted in a cylinder 117 which is carried by casing 1. The other end of piston rod 115 is fixed to the hub 118 of a piston 119 fitted in a cylinder 120 which is carried by casing 1 and has its outer end closed by a head 121. The inner ends of cylinders 117 and 120 communicate with the interior of casing 1 so that the inner faces of pistons 116 and 119 are never subjected to pressure.

Hub 118 has an axial bore 122 extending therethrough, a port 123 leading from bore 122 into communication with the outer end of cylinder 120 and at least one drain duct 124 leading from bore 122 into communication with the inner end of cylinder 120. Flow of liquid into and out of the outer end of cylinder 120 is controlled by a rotary valve 125 which is fitted into bore 122 and in end head 121 and has its outer end portion reduced in diameter and provided with a lever 126 for rotating it.

Valve 125 has a diagonal drain groove 127 and a diagonal pressure groove 128 formed in its peripheral surface. Grooves 127 and 128 are arranged upon opposite sides of port 123 and are spaced apart a distance equal to the width of port 123 so that a slight rotary movement of valve 125 in one direction or the other will cause port 123 to communicate with one or the other of grooves 127 and 128. Groove 127 extends to the inner end of valve 125 so that it is always connected to the exhaust. Groove 128 communicates with a passage 129 which is formed within valve 125 and communicates with an annular groove or port 130 which is formed in end head 121. The servo-motor mechanism including the follow-up valve just described is of a well known type and is similar to that illustrated and described in Patent No. 2,499,633.

Liquid for operating the above described servo-motor mechanism is supplied by gear pump 8 which, as indicated in Fig. 11, draws liquid from reservoir 52 and discharges it into a branched supply channel 131 which is connected to cylinder 117 and to port 130. Liquid discharged by gear pump 8 in excess of requirements is exhausted through a relief valve 132 which enables pump 8 to maintain a constant low pressure in channel 131.

The arrangement is such that when valve 125 is rotated in a direction to open groove 127 to port 123, the liquid continuously supplied to cylinder 117 will cause piston 116 to move rod 115 and piston 119 toward the left in respect to Fig. 3 and piston 119 to eject liquid from cylinder 120 through port 123, groove 127, bore 122 and duct 124 to exhaust. Piston 119 will move a linear distance proportional to the angular distance through which valve 125 was rotated and then port 123 will move out of communication with groove 127 and further movement will cease. Conversely, when valve 125 is rotated in a direction to open groove 128 to port 123, liquid will flow from channel 131 through port 130, passage 129, groove 128 and port 123 into cylinder 120 and cause piston 119 to move rod 115 and piston 116 toward the right in respect to Fig. 3 and piston 116 to eject liquid from cylinder 117 into channel 131 because the effective area of piston 119 is approximately twice that of piston 116. Movement will continue until port 123 moves out of communication with groove 128 at which time piston 119 will have moved a linear distance proportional to the angular distance through which valve 125 was rotated.

Rack 114 being formed upon or fixed to piston rod 115, it will move with rod 115 and will cause gear 113 (Fig. 4) to rock cradle 54 on trunnions 59 and 60 and gears 112 and 112a will rock cradle 54a upon trunnions 59a and 60a to change the angle between swash plates 16 and 16a and the axis of the cylinder barrels and thereby change the displacement of the pump.

The pump illustrated and described herein may be modified various ways without departing from the scope of the invention which is hereby claimed as follows:

1. A pump, comprising a casing, two axially aligned cylinder barrels rotatably supported in said casing with each having a plurality of cylinders arranged therein around and parallel to the axis of rotation, means for rotating said cylinder barrels in unison, two swash plates arranged between the adjacent ends of said cylinder barrels, two pairs of trunnions carried by said casing and arranged between the adjacent ends of said cylinder barrels, a reaction member rotatably supporting each of said swash plates and journaled upon said trunnions, said members being swingable in opposite directions upon said trunnions to vary the angle between said swash plates and the axis of said cylinder barrels, means for rotating said swash plates in unison with said cylinder barrels, pistons fitted in said cylinders, piston rods connecting said pistons to said swash plates and effecting reciprocation of said pistons in response to said cylinder barrels and said swash plates being rotated and said swash plates being inclined to the axis of said cylinder barrels, valve means engaging said cylinder barrels to control the flow of liquid to and from said cylinders, and an arcuate contact face arranged upon each of said reaction members and engaging the contact face on the other member to thereby cause the pumping reactions from the pistons in one cylinder barrel to be counterbalanced by the pump-

ing reactions from the pistons in the other cylinder barrel.

2. A pump according to claim 1 and including displacement varying means carried by said casing, means connecting said displacement varying means to one of said reaction members to enable it to swing said member upon its trunnions, and gears connecting said reaction members to each other.

3. A pump, comprising a casing, two axially aligned cylinder barrels rotatably supported in said casing with each having a plurality of cylinders arranged therein around and parallel to the axis of rotation, means for rotating said cylinder barrels in unison, two swash plates arranged between the adjacent ends of said cylinder barrels, two pairs of trunnions carried by said casing and arranged between the adjacent ends of said cylinder barrels, a reaction member rotatably supporting each of said swash plates and journaled upon said trunnions, said members being swingable in opposite directions upon said trunnions to vary the angle between said swash plates and the axis of said cylinder barrels, two annular universal joints extending around said swash plates with each connecting a swash plate to the adjacent cylinder barrel to rotate it therewith, pistons fitted in said cylinders, piston rods connecting said pistons to said swash plates and effecting reciprocating of said pistons in response to said cylinder barrels and said swash plates being rotated and said swash plates being inclined to the axis of said cylinder barrels, flat valves engaging the far ends of said cylinder barrels to control the flow of liquid to and from said cylinders, and an arcuate contact face arranged upon each of said reaction members and engaging the contact face on the other member to thereby cause the pumping reactions from the pistons in one cylinder barrel to be counterbalanced by the pumping reactions from the pistons in the other cylinder barrel.

4. A pump according to claim 1 and including means for swinging said reaction members in unison upon said trunnions to thereby vary the displacement of said pump, said means comprising a pair of intermeshing gears connecting said members to each other, a third gear carried by one of said members, hydraulic servo-motor means carried by said casing, a rack carried by said servo-motor means and meshing with said third gear, and means for supplying motive liquid to said servo-motor means including a valve for controlling the flow of liquid thereto and therefrom.

5. A pump, comprising a casing, a drive shaft journaled in said casing, two cylinder barrels spaced from each other and fixed upon said shaft to rotate therewith, each of said cylinder barrels having a plurality of cylinders arranged therein around and parallel to said shaft, two swash plates arranged between the adjacent ends of said cylinder barrels, two pairs of trunnions carried by said casing and arranged between the adjacent ends of said cylinder barrels, a reaction member rotatably supporting each of said swash plates and journaled upon said trunnions, means for swinging said members in opposite directions upon said trunnions to vary the angle between said swash plates ad said shaft and thereby vary the displacement of said pump, means for rotating said swash plates in unison with said cylinder barrels, pistons fitted in said cylinders, piston rods connecting said pistons to said swash plates and effecting reciprocation of said pistons in response to said cylinder barrels and said swash plates being rotated and said swash plates being inclined to the axis of said cylinder barrels, flat valves engaging the far ends of said cylinder barrels to control the flow of liquid to and from said cylinders, and in arcuate contact face arranged upon each of said reaction members and engaging the contact face on the other member to thereby cause the pumping reactions from the pistons in one cylinder barrel to be counterbalanced by the pumping reactions from the pistons in the other cylinder barrel.

6. A pump according to claim 5 in which said casing includes a body portion and two blocks which are fixed to the opposite ends of said body portion and contain high and low pressure passages, said valves are supported by said blocks and control communication between said cylinders and said passages, and said body portion has formed therein two passages which connect the passages in one block with the corresponding passages in the other block.

7. In a pump of the class described having a casing, a cylinder barrel arranged within said casing and rotatable upon a stationary axis, a reaction member restrained from axial movement by said casing and inclined to said axis when the pump is functioning, a swash plate carried by said member and rotated in unison with said cylinder barrel, a socket carried by said swash plate and having an internal spherical surface, a hydraulic thrust bearing arranged between said swash plate and said member and having a pressure chamber formed therein and communicating with the interior of said socket, the combination of a piston fitted in said cylinder and having a spherical seat formed in its outer end, a piston rod having a first spherical head formed upon one end thereof and fitted in said seat, a second spherical head formed upon the other end of said piston rod and fitted in said socket to form therewith a ball and socket joint, said piston rod having an internal spherical seat formed therein concentric with the outer spherical surface of said first head and a bore extending therethrough from said internal seat into communication with the interior of said socket, said piston having a recess extending into it from its inner end and a bore extending from said recess through its outer end and said first piston rod head having an opening extending therethrough from said internal seat, a pin extending from said internal seat into said recess and having an axial passage extending therethrough to permit pressure in said cylinder to extend through said passage and the bore in said rod into said socket and from said socket into said pressure chamber, a spherical head formed upon said pin and engaging said internal seat, and means arranged in said recess and engaging said pin for holding the head of said pin in contact with said internal seat and said first piston rod head in contact with the spherical seat in said piston.

8. A combination as set forth in claim 7 including a check valve arranged in said recess to prevent escape of liquid from the interiors of said piston and said piston rod into said cylinder and to prevent air being sucked when case is empty of oil.

9. A combination as set forth in claim 8 in which said check valve includes a valve seat fixed in said recess to close the end thereof and having a duct extending therethrough, a valve normally engaging said seat and closing the inner end of said duct, a piston fitted in said recess and having a passage extending therethrough, and a spring engaging said piston to urge it against said valve and said valve against said seat.

10. A combination as set forth in claim 7 in which said pin has a cannelure formed in its peripheral surface and arranged within said recess and a metal plug is swaged into said cannelure and against the end of said recess to hold the head of said pin in contact with the spherical seat in said piston.

11. A combination as set forth in claim 10 including a check valve arranged in said recess to prevent escape of liquid from the interior of said piston and said piston rod into said cylinder and to prevent air being sucked when case is empty.

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