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(54) Variable displacement high pressure pump.

(57) A variable displacement piston pump (10) including a plurality of axially aligned pumping cylinders - (24) with a driven drive shaft (16) extending there between having a tiltable swash plate (30) disposed on one end of the drive shaft (16) for operating the pumping cylinders, and a reaction thrust plate (38) on the other end of the drive shaft (16), for providing reaction force in the drive shaft (16) opposite that provided by the swash plate (30). The pumping cylinders (24) feed a common manifold (52). A check valve (50) is disposed between each cylinder (24) and the common manifold (52) to ensure one way flow. Check valve (50) between cylinders (24) and the common manifold (52) also reduces pressure pulsations during pumping. The thrust plate - (38) is formed with a centrifugal impeller opening - (62) formed therein through which incoming fluid flows and its pressure is increased. A dummy piston (28) is provided in each cylinder (24) opposite the active pumping piston (26). The active piston (26) and the dummy piston (34) each include an opening there through which is exposed during an intake stroke so that fluid is admitted into both ends of the cylinder (24). After the intake stroke, the openings in both pistons (26, 28) are sealed and pumping action occurs.

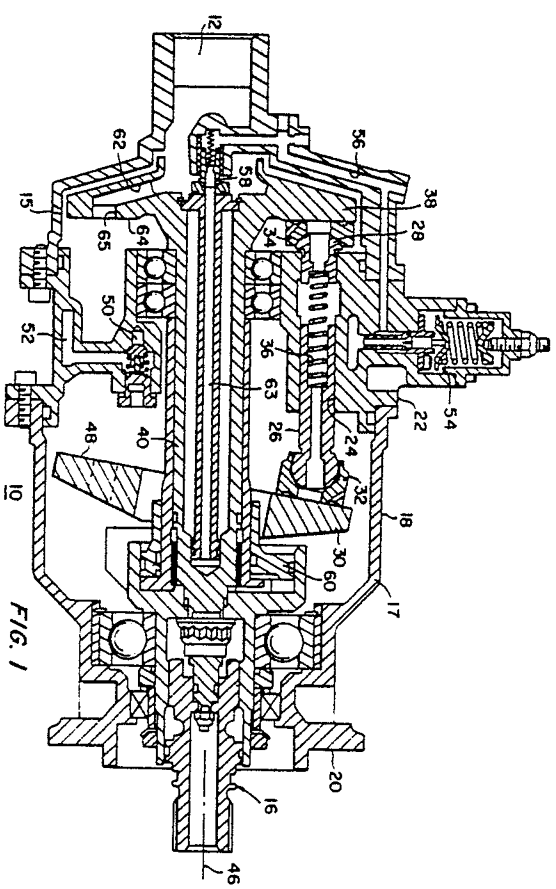

FIG. 1

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VARIABLE DISPLACEMENT HIGH PRESSURE PUMP

BACKGROUND OF THE INVENTION

Field of the Invention

This invention relates to variable displacement piston pumps and particularly to pumps of the type described which are compensated to maintain constant pressure with variable flow. More particularly, this invention relates to means for force balancing of the piston thrust loads to provide a relatively lightweight, high pressure pump.

Description of the Prior Art

A type of variable displacement piston pump known in the prior art, includes a shaft having a driven end and an opposite end arranged for supporting a swash plate. The swash plate is caused to pivot about an axis displaced from and generally perpendicular to the center line of the driven shaft. A plurality of cylinders having pistons disposed therein are arranged with associated check valves in a fixed pump block. During the delivery stroke of the pistons, pressure in the cylinders becomes high enough to open the check valves and deliver fluid to a common discharge manifold. When the manifold pressure approaches a predetermined set value, a force is created which is transmitted to the swash plate and pivots the swash plate away from a maximum flow position. The pistons are arranged with respect to the swash plate so that when the swash plate pivots away from the maximum flow position, the stroke of the pistons is decreased to reduce fluid flow and pressure. Equilibrium is thus established and a reduced fluid flow at a predetermined substantially constant pressure is maintained.

A prior art embodiment of such a pump is described in U.S. Patent 4,149,830 having Frank Woodruff as the named inventor. In the pump disclosed in U.S. Patent 4,149,830, a plurality of piston assemblies are permitted to reciprocate in a cylinder block which is fixed to the pump casing. The swash plate, in addition to pivoting to achieve equilibrium is caused to rotate. The rotation of the swash plate forces the pistons to reciprocate, thus achieving the desired pump action. The drive shaft and the attached swash plate form a rotating assembly. This rotating assembly must supply sufficient axial force against the piston assemblies to cause pumping.

A problem sometimes experienced with piston type pumps is for the pump output pressure to pulsate as each piston is sequentially reciprocated. U.S. Patent 4,149,830 describes a system in which individual check valves are associated with each cylinder assembly. Since the check valve is in a fixed, not rotating, cylinder block, pulsations are limited because high pressure communication with the individual cylinders is not effected until pressure within the cylinder exceeds that of the pump manifold or outlet. In these prior art systems, large bearings are utilized to handle the severe thrust loading. In prior art pumps, as the high pressures increase the required bearings become so large and cumbersome that they dictate the size and weight of the pump.

In aircraft systems using variable displacement piston pumps, it is desireable to provide increased pressure. Operating pressures exceeding 8,000 psi are anticipated in aircraft stabilization systems presently being designed. The use of high pressures reduces system weight and in some instances simplifies equipment design.

It is desireable in aircraft applications to provide a high pressure variable output pump which is light in weight and has a smooth output. It is also important that the pump contain as few parts as possible, have a reliable output and be of a rugged design.

SUMMARY OF THE INVENTION

In the disclosed variable displacement high pressure piston pump, the forces involved in actuating the pumping pistons are balanced by using dummy pistons to create a force equal and opposite to the force developed by the working pistons. The dummy pistons work against a non-tilting plate attached integrally to a shaft which supports the tiltable swash plate. The majority of the axial thrust forces are thus contained within rotating elements and not transmitted to the pump housing. The non-tiltable thrust plate is formed into a centrifugal pump impeller, integral with the drive shaft, to boost inlet fluid pressure. Boosting inlet fluid pressure prevents cavitation in supplying fluid to the pumping piston assemblies. The dummy piston and the working piston in each cylinder have openings formed there through so that hydraulic fluid flows from both ends into the pump cylinder chamber.

The tilt swash plate tilts in response to a control fluid pressure. The control fluid is supplied through an intermediate transfer tube within a hollow drive shaft to decrease the control fluid volume and speed response. The drive shaft assembly employs arcuate cutouts which both cradle and drive the tiltable swash plate. Moving the tiltable swash plate in the cradle is facilitated by using a permanently lubricated bearing material.

BRIEF DESCRIPTION OF THE DRAWINGS

For a better understanding of the invention, reference may be had to the preferred embodiment exemplary thereof shown in the accompanying drawings in which:

Figure 1 is a section view taken in Figure 2 along the lines I-I of a pump according to the invention;

Figure 2 is an inlet end view of a piston pump utilizing the present invention;

Figure 3 is a top view of the swash tilt block utilized in the present invention;

Figure 4 is a bottom view of the cradle which supports swash plate;

Figure 5 is a detailed view of a portion of the drive assembly; and

Figure 6 and Figure 7 are detailed views of the tilt piston.

DETAILED DESCRIPTION OF THE INVENTION

Referring now to the drawings, there is shown a variable displacement high pressure piston pump constructed according to the teaching of the present invention. Pump 10 is capable of working at high pressures, 8000 psi and above, and is relatively lightweight and suitable for aircraft hydraulic systems. Hydraulic fluid is fed at low pressure to pump 10 through an inlet port 12 and is discharged at the desired pressure from an outlet port 14. Pump 10 includes a rotating assembly 16 which rotates within a housing 18. Housing 18 includes a mounting flange 20 by which pump 10 is mounted to a suitable power source such as a gear casing of a gas turbine engine (not shown). The rotating assembly 16 includes a splined input shaft having spline teeth or other suitable means for engaging a power take off output of the power source.

A fixed steel cylinder block 22 having a plurality of cylinder bores 24 formed therein is disposed between aluminum end members 15 and 17 to form part of a housing 18. While cylinder block 22 includes a plurality of cylinder bores 24 only one is shown in the section view of Figure 1 and operation of only one will be described. Cylinder block 22 is fixed between members 15, 17 and its outer surface is exposed as part of a housing or shell 18. Each cylinder 24 in block 22 houses an active pumping piston 26 and a dummy piston 28. Active pistons 26 receive their motion from rotation of the inclined swash plate 30. The outer end of active piston 26 engages a shoe 32 and the outer end of dummy piston 28 engages a shoe 34. A spring 36 is disposed in cylinder 24 to bias apart pistons 26 and 28.

Shoe 32 on active piston 26 engages swash plate 30 while shoe34 at the free end of dummy piston 28 engages a thrust plate centrifugal impeller 38. Rotatable drive assembly 16 includes a center shaft 40 extending to form integral thrust plate 38. The axial forces, generated during pumping, on swash plate 30 also react on shaft 40 and the axial forces are contained within the rotating drive assembly 16 and not transmitted to housing 18.

As can be seen, active piston 26 moves with respect to cylinder 24 as swash plate 30 rotates to effect pumping action. The dummy piston 28 remains substantially in the same position with respect to cylinder 24 while pumping; although, it is free to float in order to adjust for discrepancies in the relative distances between parts of the rotating assembly 16 and in order to transfer axial forces from the pumping action of the active piston 26 outside of cylinder 24 to the thrust plate 38.

Swash plate 30 is mounted around center shaft 40. Swash plate 30 is pivotally mounted to the rotating shaft assembly 16. Circular projections 31 on swash plate 30 fit into arcuate openings 43 formed on cradle 44. The operation of swash plate 30 is conventional and is described in detail in U. S. Patent 4,149,830. Briefly, swash plate 30 pivots relative to cradle 44 around an axis 42. The drive shaft assembly 16 thus employs arcuate cutouts 43 which both cradle and drive the swash plate 30. Easy movement of swash plate 30 in cradle 44 is made possible by utilizing a permanently lubricated bearing material on the mating surface or by hydrostatic bearings. Swash plate 30 is not pinned to cradle 44. Force vectors are such as to ensure swash plate 30 is securely seated in the arcuate bearing pockets 43 under all conditions. Swash plate 30 pivots about center 42 in the arcuate pockets 43 which rotate with shaft 44.

Swash plate 30 pivots in the arcuate cutouts 43 and cradle 44 in response to outlet pressure. Swash plate 30 may be positioned at varying angles to the center axis 46 of pump 10. Swash plate 30 is rotationally fixed to center shaft 40 and therefore, whenever its working face 48 is displaced from the perpendicular with respect to axis 46, active pistons 26 are reciprocated as drive assembly 16 rotates. In order to reduce pumping action, swash plate 30 is pivoted to bring the working surface 48 towards perpendicular alignment with axis 46. To increase pumping action, swash plate 30 is tilted at a greater angle with respect to perpendicular alignment with axis 46. Tilting of swash plate 30 is accomplished through pressurized fluid, at the outlet pressure, within passage 63.

Shoes 32 are hydraulically balanced at both the piston 26 and swash plate 30 interface. Likewise, shoes 34 are hydraulically balanced at both piston 28 and thrust impeller plate 38. The shoes 32, 34 are similar to shoes described in U.S. Patent 4,149,830. Pressure balancing of shoes 34, 32 is accomplished by the through hole and the vented annulus cut in the end of the shoe away from its associated piston 26, 28. The through hole pressure plus pressure distribution across the ends balance any forces developed by the pistons. The vented annulus helps to provide a constant fluid film and prevent overpressurization.

Each cylinder pump has associated therewith a check valve assembly 50, one of which is shown in Figure 1. Minimizing discharge pulsations in a high pressure pumping unit is an important criteria towards accurate system performance. An effective way of achieving a smooth pulse trace is through the use of individual check valves 50 with each pumping cylinder 24. During discharge, fluid from each check valve piston assembly will be expelled just after system pressure plus valve spring force return is met. There is no possibility of exposing the system to a lesser discharge pressure than desired; therefore, the possibility of increased pulsation is reduced. The discharge from pumping cylinders 24 during operation is through the associated check valve 50 into a common manifold 52.

To maintain a constant discharge pressure, a compensating valve 54, which communicates with manifold 52 is utilized. Compensating valve 54 is described in detail in U.S. Patent 4,182,365. Compensating value 54 modulates discharge pressure. Pressurized fluid for controlling the inclination of swash plate 30 is provided by compensating valve 54 through passage 56 and a balanced piston seal 58 through passage 63 to a chamber behind piston 60. When flow fluid from pump 10 is greater than conditions require, discharge pressure increases. The resulting intermediate pressure in passages 56, 63 is increased allowing tilt piston 60 pressure to increase. This pressure increase will move piston 60 to the left in Figure 1, lessen the swash plate angle, thereby decreasing flow. The converse of the above description applies when conditions require an increase in flow.

Piston 60 includes arcuate portions 57 which engage and tilt swash plate 30 around axis 42. When piston 60 is forced to the left as shown in Figure 1, swash plate 30 is moved towards vertical alignment and thereby decreases the stroke of working piston 26. Inlet to pump housing 18 is through port 12. A thrust plate 38 extends from the center shaft 40. Passage 62 is formed in thrust plate 38. Thrust plate 38 during operation acts as a centrifugal pump, boosting the pressure of the hydraulic fluids supplied into port 12. Thrust plate 38 includes a working surface 64 on which shoes 34 ride as plate 38 rotates. Passage 62 connects to an opening 65 in the working face 64 of thrust plate 38. As thrust plate 38 rotates, when the opening 65 in the working surface 64 aligns with the opening in shoe 34, fluid passes through dummy piston 28 into cylinder 24. Swash plate 30 includes an opening 66 formed therein. When the opening 66 in swash plate 60 aligns with the opening in show 32, fluid passes through opening 66, shoe 32 and hollow piston 26 into cylinder 24. When opening 66 passes beyond shoe 32, then shoe 32 seals against working surface 48. Likewise, when opening 36 passes beyond shoe 34, then shoe 34 seals against working surface 64 of thrust plater 38. Force balancing of the working piston 26 thrust load is accomplished by dummy piston 28, which is placed opposite the working piston 36. Dummy piston 28 rides through shoe 34, on thrust plate 38 and transmits negative forces required to balance the positive forces of working piston 26. The working surface 34 of thrust plate 38 is used as the dummy piston 28 bearing surface. The dummy pistons 28 are used to create an equal force opposite to the force developed by the working pistons 26. This approach saves weight and decreases the envelope size. The large bearings as required in prior art high pressure similar type piston pumps are not required.

The disclosed high pressure variable displacement piston pump will boost an inlet pressure of 103KPa (15 psi) to 55,160KPa (8000 psi) or greater and hold it there under a variety of flow and speed conditions. By providing a centrifugal pump impeller plate 38 integral with the drive shaft 40, the inlet fluid pressure can be raised as a function of rotational speed by an amount such as 138KPa (20 psi). This avoids cavitation in the pump. Each piston pump is fed pressurized fluid through the slot 66 cut in the swash plate 30 and also by the port channel 62 and opening 65 formed in thrust plate 38. The rotating swash plate 30 provides the reciprocating action for the working piston 26 assembly. Once system pressure has been developed by a piston, its associated check valve 50 will open thereby releasing fluid to the pump manifold 52 and discharge port 16. In a pump having several working pistons, the pulse magnitude is a small percent of the discharge pressure. Return springs 36, which assist in the suction stroke, in the piston pump assembly are required only for cold start up. Once system pressure has been established, the spring force when pumping becomes insignificant. Control valve 54 through piston 60 and tilting of swash plate 30 controls the output pressure. Control valve 54 operates until an equilibrium has been achieved and pressure will hold constant. Following changes in the load, control valve 54 causes corresponding corrections of the swash plate 30 angle.

Claims

1. A variable displacement multiple piston pump having an inlet and an outlet disposed on a housing which includes a cylinder block with a plurality of cylinders each having a pumping piston which is caused to reciprocate by a swash plate, tiltable in response to outlet pressure to vary the stroke of the pumping piston to maintain the output pressure relatively constant, the improvement comprises:
a longitudinally extending drive shaft extending through an opening in the swash plate and the cylinder block;
swash plate connecting means for connecting the swash plate to one end of the drive shaft and transferring axially generated pumping forces to the drive shaft;
a thrust plate attached to the other end of said drive shaft; and
transfer means disposed between said thrust plate and said cylinder block for transferring forces to the thrust plate and the attached drive shaft which are opposite the forces transferred to the drive shaft from the swash plate.

2. A pump as claimed in claim 1 wherein: said thrust plate is a centrifugal impeller which boosts the pressure of fluid entering the pump inlet.

3. A pump as claimed in claim 1 comprising: cylinder filling means for admitting fluid to be pumped into both ends of each cylinder during the intake stroke.

4. A pump, having a housing with an inlet and an outlet, comprising:
a plurality of cylinders disposed in said housing, each including a reciprocable piston means for pumping fluid in its associated cylinder;
an elongated drive shaft disposed in the housing;
swash plate means connectable to one end of said drive shaft for engaging and moving into each cylinder its associated, reciprocable piston means as said drive shaft rotates and for transferring positive pumping generated forces to said drive shaft;
a thrust plate disposed at the opposite end of said drive shaft; and
means for transferring through the thrust plate to the drive shaft forces opposite those transferred to the drive shaft by the swash plate means.

5. A pump as claimed in claim 4 comprising:
a common manifold for receiving pressurized fluid pumped by each reciprocable piston means;
a check valve associated with each cylinder disposed between the cylinder and the common manifold; and
means for filling both ends of each cylinder during intake.

6. A pump as claimed in claim 5 wherein: said thrust plate comprises a centrifugal impeller for increasing pressure of fluid entering the pump inlet.

7. A pump as claimed in claim 6 comprising: means for changing the tilt of said swash plate means relative to the longitudinal axis of the drive shaft comprising a tube which communicates with fluid at the pump outlet extending through a larger opening in the drive shaft.

8. A variable displacement piston type pump comprising:
a housing having an inlet and an outlet;
a cylinder block disposed in said housing having a plurality of cylinders formed therein;
a plurality of active pistons, one disposed in each of the cylinders, biased to extend from the cylinder;
a swash plate engaging a portion of each piston extending from its associated cylinder and being tiltable and rotatable to engage and move the piston varying distances as a function of swash plate tilt;
drive means for supporting and driving said swash plate and including a shaft extending through said swash plate and said cylinder block;
a thrust plate disposed on the drive shaft opposite said swash plate;
means partially disposed in the cylinders of said cylinder block opposite the active pistons for transferring to said thrust plate an axial force opposite to the force transferred by said swash plate to said drive shaft during pumping operation.

9. A pump as claimed in claim 8 wherein:
said thrust plate comprises a centrifugal pump impeller which communicates with the inlet to boost pressure of incoming fluids.

10. A pump as claimed in claim 8 comprising:
filling means provided for feeding fluid to be pumped into both ends of each cylinder during an intake stroke of its associated active piston.

11. A variable displacement piston type pump, in which a swash plate rotates relative to a plurality of pistons and is adjusted in an angle tilt in order to adjust the travel of the pistons and consequently, the output of the pump, characterized by;
a housing containing a fluid;
a shaft disposed in the housing, one end of the

shaft arranged for being rotatably driven to operate the pump;
the swash plate tiltably supported within the housing by said shaft for displacement about a pivot axis displaced from and transverse to the shaft axis;
at least one cylinder assembly having a cylinder bore extending there through and having at least one piston reciprocally mounted in the cylinder bore, the piston arranged with the swash plate so that the piston stroke varies with the swash plate tilt angle;
means arranged with the housing and the cylinder assembly so that fluid flows from the housing to the cylinder assembly during a pump intake stroke and is blocked from flowing during a pump delivery stroke;
a pump discharge manifold;
check valve means arranged between the manifold and the cylinder and actuated by a fluid pressure difference between the cylinder and the manifold during a delivery stroke of the piston for permitting passage of a fluid from the cylinder to the manifold, whereupon a pressure is created in the manifold;
means for controlling manifold pressure by displacing the swash plate and thereby varying the stroke of the piston; and
means axially fixed to said shaft for providing a reaction force to the swash plate in response to the pumping action of the swash plate.

12. Apparatus as claimed in claim 11, further characterized by:
a means for providing a reaction force includes a second piston disposed within the cylinder and reacting to fluid force from the first piston and arranged so that fluid pressure within the cylinder causes the first and second pistons to exert reactive forces having at least one set of opposite vector components.

13. Apparatus as described in claim 11, further characterized by:
the cylinders being aligned substantially parallel to the drive shaft.

14. Apparatus as described in claim 13, further characterized by:
a shoe interposed between the first piston and the swash plate and bearing against the swash plate in order to transfer forces between the swash plate and the piston.

15. Apparatus as described in claim 14, further characterized by:
the means for providing a reaction force includes a thrust plate which is fixed to said shaft; and
means associated with the second piston to bear against said thrust plate.

16. Apparatus as claimed in claim 15, further characterized by:
said thrust plate comprises a centrifugal pump impeller for increasing the pressure of incoming fluid.

17. Apparatus as described in claim 15, further characterized by:
means for admitting fluid to both ends of each cylinder during an intake stroke.

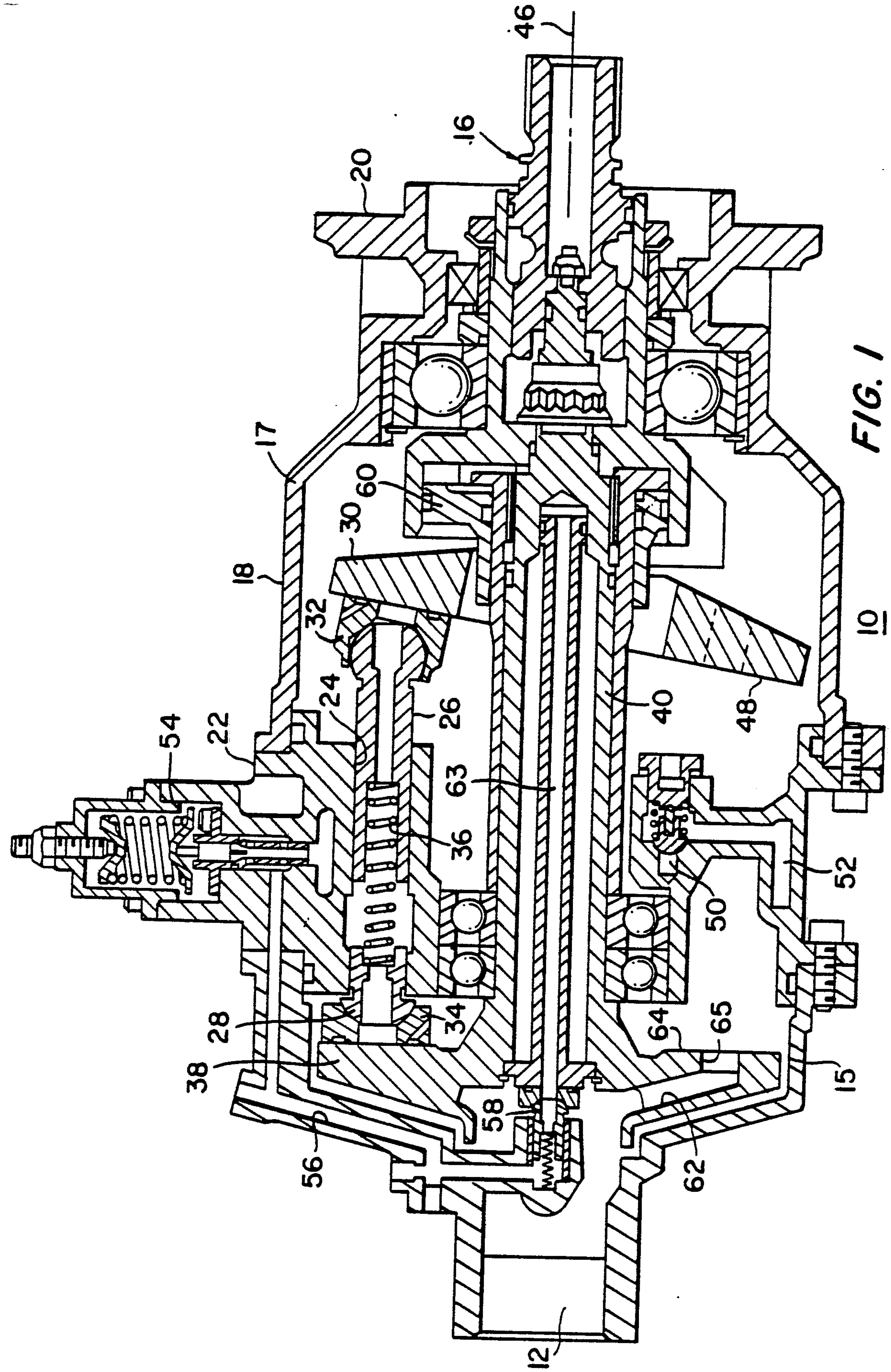
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FIG. 1

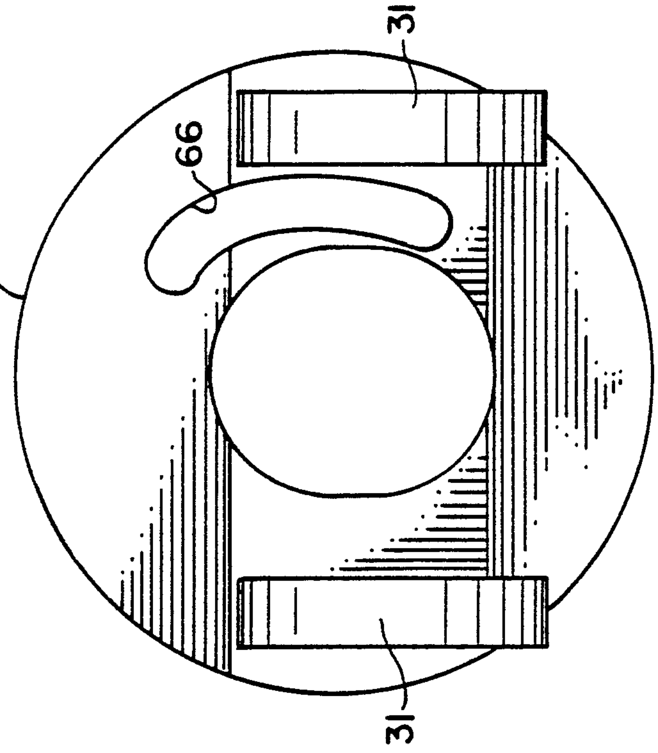

FIG. 3

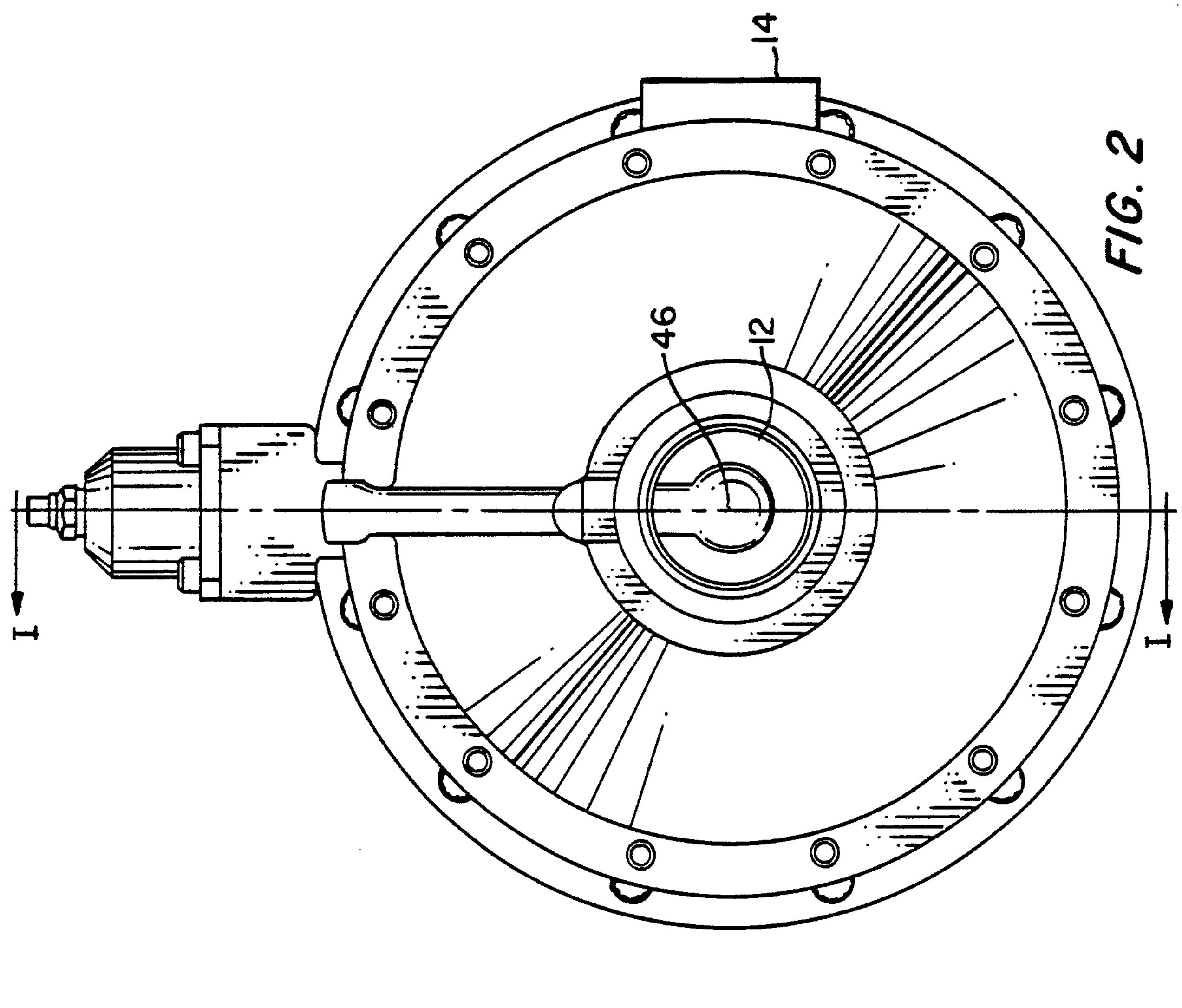

FIG. 2

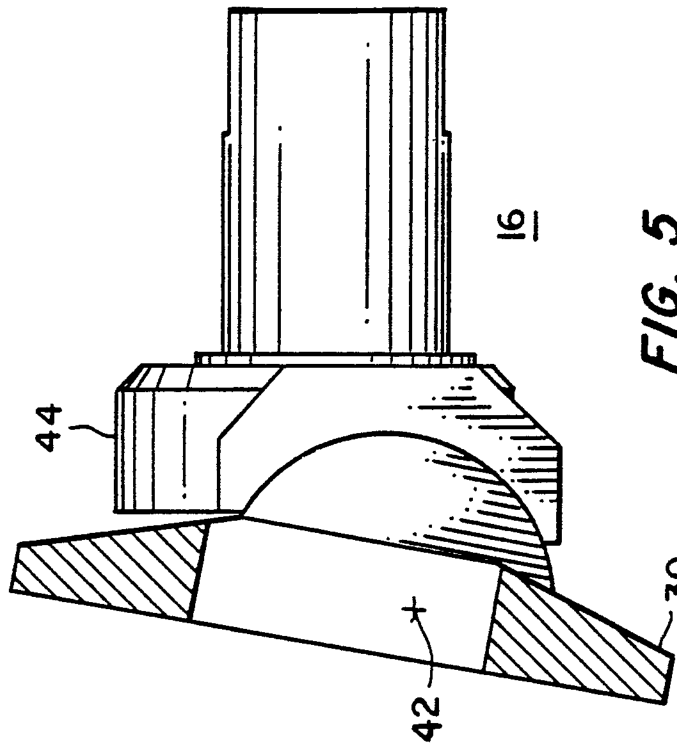

FIG. 5

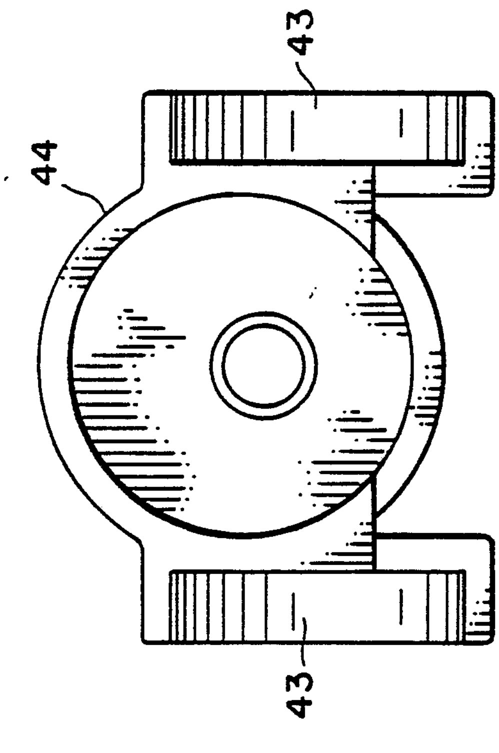

FIG. 4

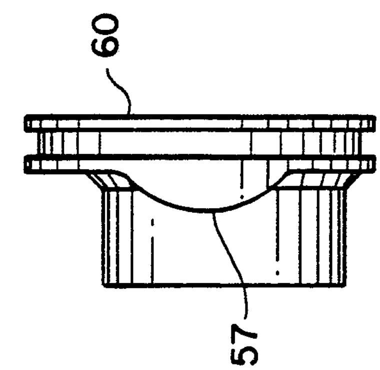

FIG. 6

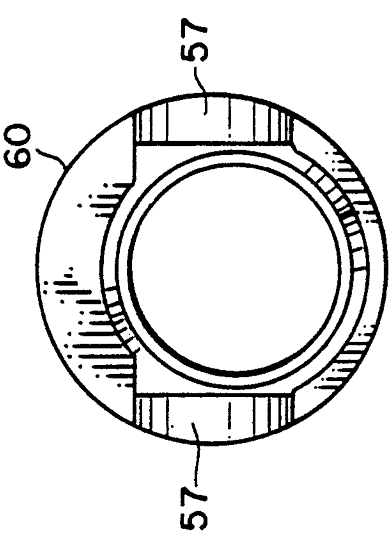

FIG. 7