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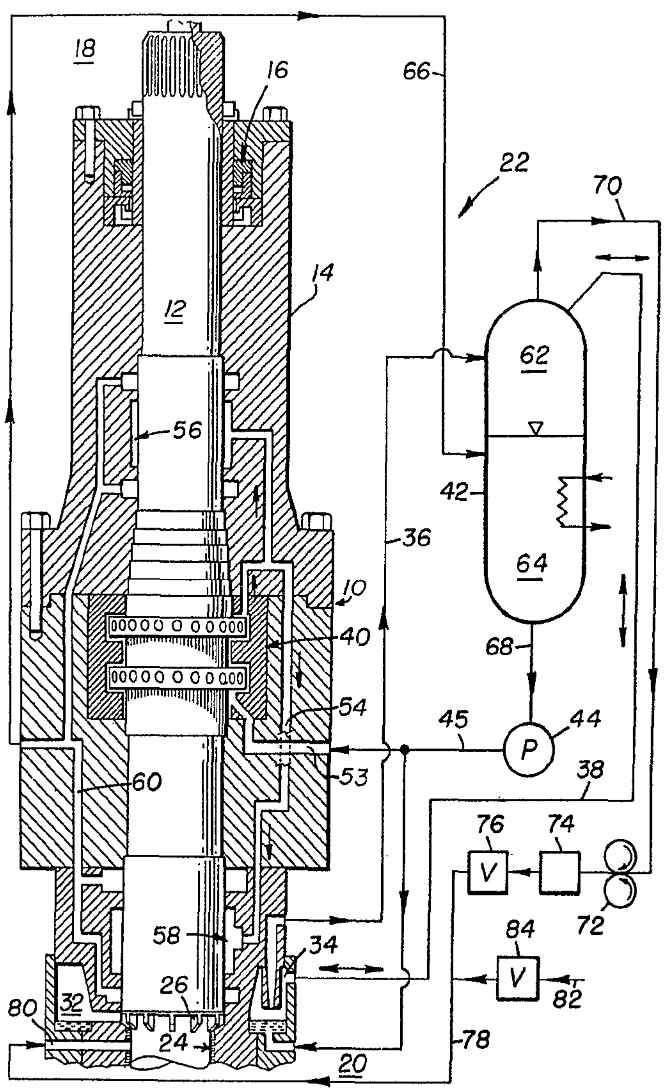
(54) Self-lubricating fluid bearing assembly

(57) A bearing assembly for a shaft (12) extending within a shaft housing (14) comprises two fluid bearings (56, 58) arranged within the shaft housing in spaced apart relation along the shaft, a pump (40) having a rotor (50) formed upon the periphery of the shaft for delivering fluid under pressure to the bearings, and a recirculation circuit for collecting the fluid from the bearings and returning it to the pump.

FIGURE I



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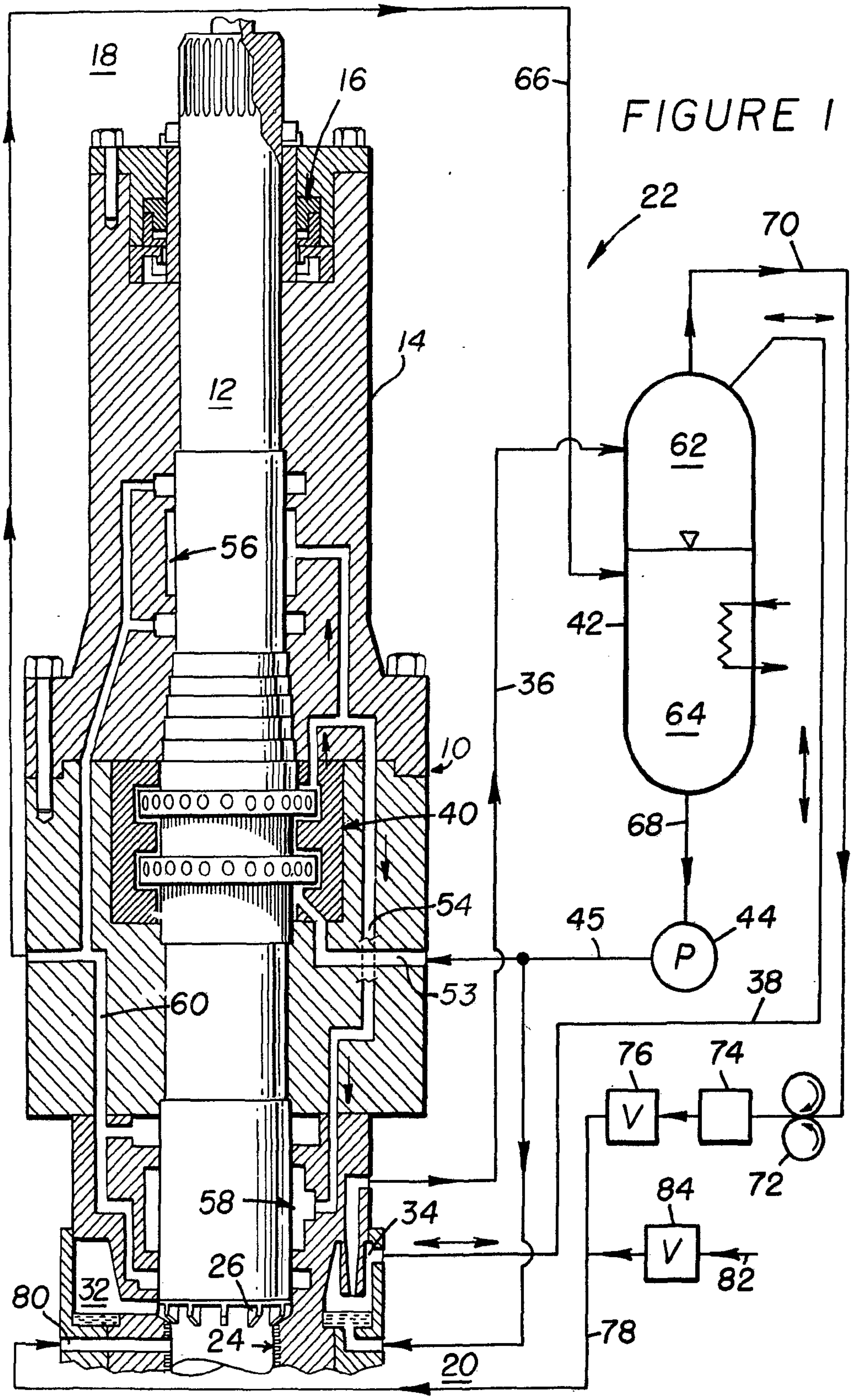

18
16
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FIGURE I
22
70
14
12
62
56
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10
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45
44
P
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60
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V
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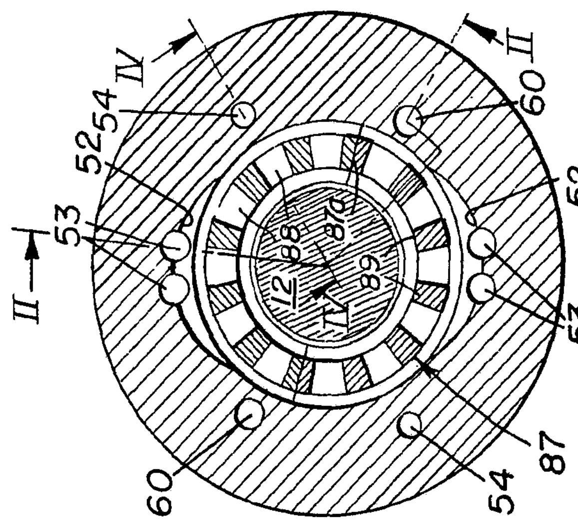

FIGURE 3

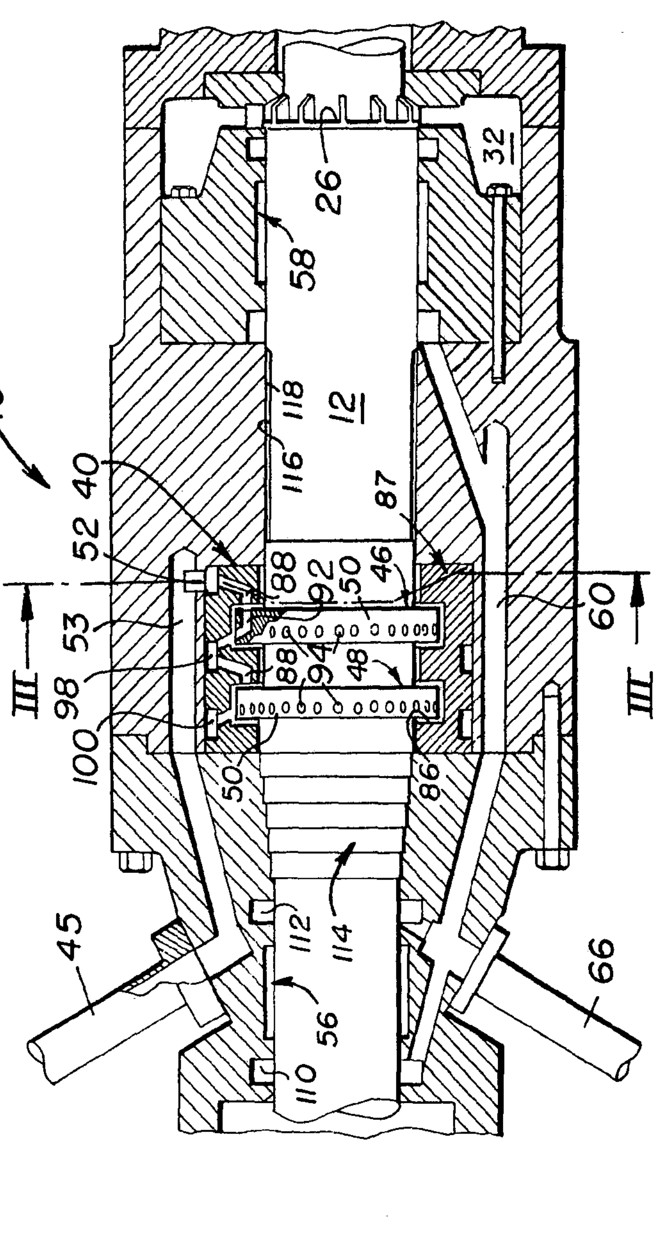

FIGURE 2

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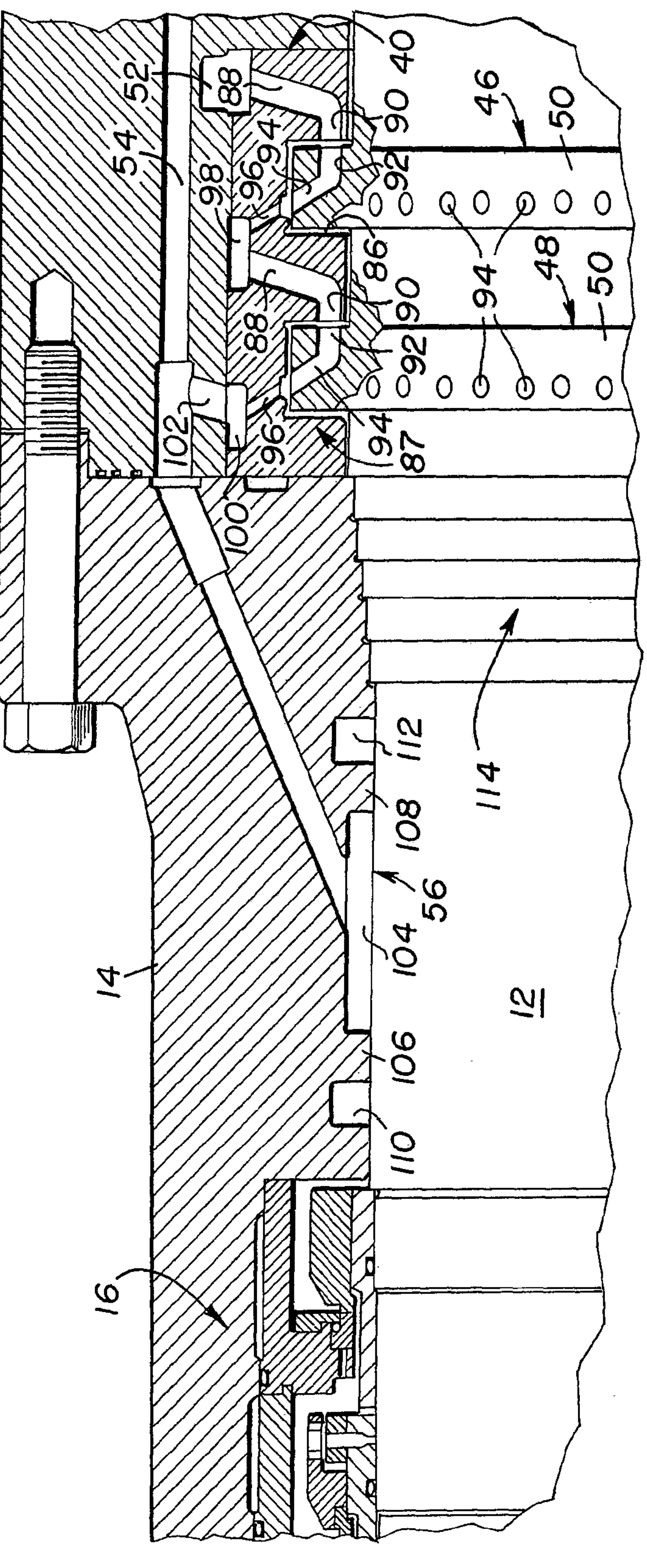

FIGURE 4

SPECIFICATION

Self-lubricating fluid bearing assembly

The invention relates to a self-lubricating fluid bearing assembly and more particulary to such a bearing assembly employed in a seal system for a shaft extending between two regions containing different fluids which are to be isolated from each other.

The invention is described below in a preferred embodiment comprising a fluid circulator of the type shown and described in U.S. Patent Specification No. 3,520,640. Even more particularly, the preferred embodiment includes a seal system for a shaft extending between separate fluid containing regions as is shown and described in U.S. Patent Specification 3,887,197. However, the present invention is not limited to a fluid circulator of the type covered by the first patent specification noted above and it is not limited to a seal system of the type covered by the second patent specification noted above.

A circulator of the type described in the above noted patent specification is employed for circulating fluid in the form of a gas coolant in a nuclear reactor, the power for the circulator being provided by a shaft located within the primary containment vessel for the reactor. Under such circumstances, it is necessary to isolate the reactor coolant, such as helium or carbon dioxide, from the fluid region at the other end of the drive shaft.

Such a seal system is described in U.S Patent Specification 3,887,197 for providing a seal along the length of a shaft extending between two fluid regions. Within that seal system, separate fluid seals or bearings are formed about the periphery of the shaft and are respectively supplied with lubricating fluids compatible with each other and with the respectively adjacent regions, the fluid lubricants from the two bearings being collected in common and then separated for resupply to the respective fluid seals. Preferably, the seal system includes one fluid seal supplied with a compressible gas, the other fluid seal being supplied with an incompressible fluid such as water to facilitate their separation.

Within the above-noted system, each of the separated fluids is returned to the respective fluid seal by means of a supply system external to the shaft and fluid seal assembly. For example, water for the one fluid seal is supplied under pressure by means of an external water supply including a high pressure pump operated separately from the shaft and an emergency water accumulator system in order to assure at least a temporary supply of water lubricant to the seal in the event of failure of the external pump. Thus, although a seal system of the type described in the above-noted patent specification is quite effective, it is relatively complex and requires a number of operating components external to the rotating shaft and seal assembly.

Accordingly, there has been found to remain a need for a relatively simple and reliable, self-lubricating fluid bearing which may preferably be employed in a fluid seal assembly for a shaft extending between two separate fluid regions, and it is the object of the invention to fill this need.

In accordance with the invention, there is provided a self-lubricating fluid bearing assembly for supporting a shaft for rotation within a shaft housing, comprising:

a first and a second fluid bearing (56; 58) formed in spaced apart relation within the shaft housing (14) for supporting the shaft (12), the fluid bearings each including a fluid inlet (104) and an exhaust (110, 112),

a lubricating pump (40) arranged between the fluid bearings, the pump being formed with a rotor (50) mounted upon a peripheral portion of the shaft for rotation therewith and a stator (87) formed by an adjacent portion of the shaft housing, the pump including an inlet (52) for receiving lubricating fluid and an outlet (54) in communication with the inlets (104) of the two fluid bearings to supply fluid under pressure thereto, and a recirculating circuit for receiving fluid from the exhausts of the fluid bearings and returning it to the pump inlet. The lubricant for the fluid bearing may be any suitable fluid, for instance, oil, but is preferably an incompressible fluid such as water.

Preferably the bearing assembly of the invention is used as a portion of a seal system generally of the type described in U.S. Patent Specification 3,887,197 wherein the fluid lubricant for the bearing is sealed from communication with one fluid region, a fluid seal being formed about a peripheral portion of the shaft in communication with the other fluid region, lubricating fluids from the fluid bearing and seal being collected together, separated and resupplied respectively to the fluid bearing and fluid seal. The invention will be explained further by way of example with particular reference to the accompanying drawings, in which:

FIGURE 1 is a schematic view, with parts in section, of a seal system including a self-lubricating fluid bearing assembly according to the present invention;

FIGURE 2 is an enlarged axially sectioned, fragmentary view taken along section II—II of FIGURE 3 which illustrates an axially sectioned housing supporting a rotatable shaft extending between two fluid regions, including a self-actuating pump formed at the interface between the shaft and housing;

FIGURE 3 is a view taken along section line III—III of Figure 2; and

FIGURE 4 is a fragmentary view taken along section line IV—IV of FIGURE 3. The drawings show a self-lubricating fluid bearing assembly 10 for supporting a shaft 12 within a housing 14.

Within the preferred embodiment described below, the bearing assembly 10 is formed as a journal bearing adjacent a high pressure or "non-leakage" seal assembly 16 which isolates the fluid or journal bearing from a first fluid region 18. Within the preferred embodiment, the first fluid region 18 is the environment. As shown in FIGURE 1, the leftward end of the shaft is adapted for interconnection with an external drive unit, preferably an electrical motor (not shown). However, the first fluid region 18 could also be in communication with a turbine drive assembly (not shown) operated for example by a fluid such as steam. In that event, a seal assembly similar to the one indicated at 16 would also be necessary between the bearing assembly 10 and the first fluid region even though intermingling of the steam would be permissible with water lubricant in a hydrostatic bearing.

Within the preferred embodiment as illustrated in FIGURE 1, the shaft 12 extends from the environment 18 through the housing 14 into a second fluid region 20. In a nuclear reactor of the type referred to above, for example, coolant for the reactor is contained within the second fluid region and the shaft 12 operates means (not shown) for circulating a coolant such as helium gas through the reactor.

In such an environment, the bearing assembly 10 is preferably part of an overall seal system or assembly 22 serving to isolate very high pressure coolant fluid within the second fluid region from the first fluid region or environment 18.

That portion of the overall seal system 22 arranged to the right of the bearing assembly 10, as seen in FIGURE 1, is generally similar to the combination illustrated and claimed in U.S. Patent Specification 3,887,197. Accordingly, those components are only briefly described below followed by a more detailed description of the bearing assembly 10 and the manner in which it is combined and operated within the overall seal system 22.

In accordance with the detailed description of the above-noted patent specification, a labyrinth seal 24 is formed between the shaft and housing adjacent the second fluid region 20. Helium from the labyrinth seal passes into the bearing assembly 10 through a stepped portion 26 which tends to direct the helium, along with some leakage water from the shaft 12, into a large annular cavity 32. The water and helium tend to separate within the annular cavity 32, water in the lower portion of the cavity along with some entrained helium being drawn off by a jet pump 34 and directed into a discharge line 36. Separated helium gas from the annular cavity 32 tends to flow through a separate pressure equalizing line 38. The water and helium are respectively recirculated to the bearing assembly 10 and the helium coolant circuit as described in greater detail below.

Lubricant for the bearing assembly 10, preferably water, is delivered to the pump 34 and to a pump 40 forming a portion of the hydrostatic bearing from a recirculating system including a surge tank 42 and a small pump 44. The recirculating pump 44 is not essential for operation of the bearing assembly 10 but merely serves to provide hydrostatic bearing load capacity at zero speed for the shaft 12 and during depressurization operation of the reactor to prevent or suppress cavitation.

The pump 40 is preferably of multi-stage construction and is formed about the periphery of the shaft 12 with one or more stages such as those indicated at 46 and 48 (Fig 2). It is noted that the pump 40 could also be of single-stage construction, if desired. Each of the pump stages 46 and 48 includes a rotor 50 arranged upon the periphery of the shaft 12 for rotation therewith.

Recirculated fluid from the surge tank 42 and recirculating pump 44 is directed through multiple supply passages 53 into inlets 52 of the pump 40 from where it passes through the pump stages 46 and 48 and is delivered under pressure through passages 54 to bearings 56 and 58 arranged upon opposite sides of the pump 40. The fluid from the passages 54 acts as a lubricant within the bearings 56 and 58 and then enters common exhaust passages 60 through which it is returned to the surge tank 42.

The surge tank 42 permits effective separation of the helium and water, helium gas being indicated in an upper portion of the surge tank at 62 with water being indicated in a lower portion of the tank at 64. Each common exhaust passage 60 is in communication with a lower portion of the surge tank by means of an exhaust conduit 66. Water and entrained helium from the discharge line 36 and helium from the discharge line 38 are both communicated into the upper portion of the surge tank.

Line 38 effectively serves as a pressure equalizing line between the upper, helium containing portion of the surge tank 42 and the annular collection cavity 32. Thus, helium gas may flow in either direction through the conduit 38 for that purpose.

Water is drawn from the surge tank by the recirculation pump 44 through a conduit 68 in communication with the bottom of the surge tank. Helium gas in the upper portion of the surge tank is drawn off through another conduit 70 and passed through a compressor 72, helium dryer 74 and control valve 76 from where it is returned through a conduit 78 to an inlet 80 for the labyrinth seal 24. Thus, both the water and helium are recycled back to the overall seal assembly 22 in generally a closed circuit. However, it is commonly necessary to add some makeup helium which is supplied from a branch conduit 82 through another control valve 84 into the conduit 78 for communication to the inlet of the labyrinth seal.

The construction and manner of operation for the bearing assembly 10 is described in greater detail below. As noted above, each stage of the pump 40 includes a rotor 50 which is formed upon the periphery of the shaft 12. Each rotor 50 is formed as an annularly projecting land upon the shaft 12. Each annular land or rotor 50 is disposed within an annular recess 86 formed by a cylindrical pump housing element 87 in the housing 14. The pump housing element 87 is split at 87a as may be best seen in FIGURE 3 to permit assembly of the pump 40.

The pump 40 may be designed to act as a radial or axial flow compressor. Within the preferred embodiment illustrated in the drawings, each of the pump stages is designed for radial flow. Water from the inlet 52 flows through a plurality of wide radial slots 88 formed by webs 89 and then into an annular supply chamber 90 (Fig. 4) in communication with a corresponding annular chamber 92 in the rotor 50.

Within the rotor 50, a large number of ports 94 project radially outwardly from the annular chamber 92 toward corresponding but smaller radially extending ports 96 formed by the pump housing 87 radially outwardly from the annular land 50. The ports 96 communicate with an annular diffuser passage 98 which interconnects the adjacent pump stages 46 and 48. Accordingly, the second pump stage 48 includes a similar combination of slots 88, annular chambers 90 and 92 in register with each other and ports 94 and 96 also in register with each other. The ports 96 formed by the housing 14 in the second pump-stage 48 are in communication with an annular chamber 100 from which pressurized fluid or water is directed into the supply passage 54 through an interconnecting conduit 102.

Each of the bearings 56 and 58 is of similar construction. Accordingly, the following description and numerical labels for the bearing 56 also apply to the other bearing 58. The bearing 56 includes an annular supply chamber 104 for receiving fluid under pressure from the supply passage 54. The supply chamber 104 is in communication with bearing regions formed between the periphery of the shaft 12 and annular lands 106 and 108 arranged on opposite sides of the supply chamber 104. Pressurized fluid or water passing from the chamber 104 through the bearing regions adjacent the lands 106 and 108 is received by annular drain passages 110 and 112, each of which is in communication with the exhaust passage 60. The bearing 56 is separated from the output or high pressure side of the pump 40 by simple stepped labyrinth seal, generally indicated at 114, formed by the housing 14 and shaft 12 to minimize leakage of high pressure fluid from the pump 40 toward the bearing 56. Between the low pressure side of the pump 40 and other bearing 58, both the shaft 12 and housing 14 are formed with axially elongated, shallow recesses 116 and 118 in order to minimize frictional flow effects between the shaft and housing.

It is particularly noted that pump 40 is adated to provide pressurization the bearings 56 and 58 in accordance with the operating speed of the shaft 12 within the housing 14. In common with most predominantly hydrostatic bearings, bearing load capacity or "stiffness" increases with increasing fluid supply pressure caused by an increase in rotating speed for the shaft in order to counteract unbalance and rotor vibration phenomena. The shaft-mounted pump 40 produces pressure rise proportional to the square function of its rotating speed. Thus bearing stiffness within each of the bearings 56 and 58 is approximately proportional to the pressure supplied to the bearings and thus is also approximately proportional to the square function of the rotating speed of the shaft.

The configuration for the shaft 12 within the bearings 56 and 58 is such that the bearings are substantially more flexible. Thus, the natural frequency for the shaft within the bearings, that is, "critical speed", is generally dependent upon bearing stiffness. The natural frequency for the shaft 12 within each of the bearings 56 and 58 is also nearly proportional to the square root function of the rotating speed for the shaft. Accordingly, with the pump 40 having its rotors directly mounted upon the shaft 12, the pump 40 and the bearings 56 and 58 may readily be designed so that their critical speed is maintained above the actual rotating speed of the shaft for all operating speed ranges. This characteristic is particularly important where the bearing assembly 10 is contemplated for wide operating speed ranges in order to assure that the rotor bearing system is not in resonance during any portion of its operation.

In operation, the pump 40, bearings 56 and 58 and the recirculating system including the drain conduit 66, surge tank 42 and recirculating pump 44 provide a closed system which is directly dependent upon operating speed of the shaft 12 to maintain proper pressurization within the bearings 56 and 58. At the same time, helium gas from the labyrinth seal 24 is separated from water within the surge tank 42 and resupplied to the labyrinth seal after passing through various conditioning components 72—78.

CLAIMS

1. A self-lubricating fluid bearing assembly for supporting a shaft for rotation within a shaft housing, comprising a first and a second fluid bearing (56; 58) formed in spaced apart relation within the shaft housing (14) for supporting the shaft (12), the fluid bearings each including a fluid inlet (104) and an exhaust (110, 112), a lubricating pump (40) arranged between the fluid bearings, the pump being formed with a rotor (50) mounted upon a peripheral portion of the shaft for rotation therewith and a stator (87) formed by an adjacent portion of the shaft housing, the pump including an inlet (52) for receiving lubricating fluid and an outlet (54) in communication with the inlets (104) of the two fluid bearings to supply fluid under pressure thereto, and a recirculating circuit for receiving fluid from the exhausts of the fluid bearings and returning it to the pump inlet.

2. The bearing assembly of Claim 1, wherein the pump includes multiple stages (46, 48) each of the multiple stages having a rotor mounted upon a peripheral portion of the shaft for rotation therewith.

3. The bearing assembly of Claim 1 or 2, wherein each rotor (50) is formed by an annular projecting land upon the shaft, a split pump

housing (87) forming an annular recess (86) for receiving the annular land, the annular land and an adjacent portion of the housing forming passages (88, 92) in register with each other and in communication with the inlet and the outlet of the pump to develop a pressure differential thereacross.

4. The bearing assembly of Claim 3, wherein a radially inward portion of the annular land and axially aligned portion of the pump housing form annular passages (90, 92) in communication with each other and with the inlet of the pump, radially arranged passages (94, 96) being formed by the annular land and a radially aligned portion of the pump housing for respective communication with the said annular passages (90, 92) and with the outlet 54 of the pump.

5. The bearing assembly of Claim 2, wherein the multiple stages (46, 48) of the pump are similar and the pump includes an outlet for the first stage (46) comprising an annular diffusion passage (98) forming an inlet for the second stage (48).

6. The bearing according to any one of Claims 1 to 5, further comprising seal means (114) formed intermediate the high pressure side of the pump and the adjacent fluid bearing.

7. The bearing assembly according to any one of Claims 1 to 6, wherein the shaft extends through the shaft housing between first and second fluid regions containing fluids which are to be isolated from each other, comprising a first seal (16) arranged in sealing relation between the shaft housing and shaft adjacent the first fluid region (18) and a second seal (24) arranged in sealing engagement between the shaft housing and shaft in communication with the second fluid region (20), the first and second fluid bearings (56; 58) being arranged respectively adjacent the first and second seals.

8. The bearing assembly of Claim 7, wherein the first fluid region (18) comprises the environment surrounding the shaft housing, the second fluid region (20) containing a fluid to be isolated from the environment.

9. The bearing assembly of Claim 1, wherein the pump 40, first and second fluid bearings (56; 58) and recirculating circuit are adapted for operation with an incompressible lubricating fluid.

10. The bearing assembly of Claim 9, wherein the incompressible fluid is water.

11. The bearing assembly of Claim 7, wherein the second fluid region (20) is a coolant-containing portion of a nuclear reactor and the shaft is adapted for driving a circulator for the reactor coolant.

12. The bearing assembly of Claim 7, wherein the fluid contained in the second fluid region (20) is a gas, the second seal (24) being a labyrinth seal in communication with the gas in the second fluid region, the pump (40) and fluid bearings (56, 58) being adapted for operation with an incompressible fluid readily separable from the gas in the second fluid region and further comprising a collection cavity (32) arranged intermediate the second seal (24) and the adjacent second fluid bearing (58) for receiving leakage gas escaping across the labyrinth seal from the second fluid region and incompressible fluid from said fluid bearing, and means for separating the gas and incompressible fluid and returning said incompressible fluid to the inlet of the pump.

13. The bearing assembly of Claim 12, wherein the recirculating circuit includes a surge tank (42) for receiving exhaust fluid from the bearings and gas and incompressible fluid from the drain cavity (32), the surge tank including a circulation pump (44) for returning the incompressible fluid to the lubricating pump (40).

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