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Doyle et al.

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[45] June 19, 1973

[54] SHAFT SEAL

[75] Inventors: **Edward F. Doyle,** Dedham; **Thomas LeFeuvre,** Woburn, both of Mass.

[73] Assignee: **Thermo Electron Corporation,** Waltham, Mass.

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[52] **U.S. Cl.** **277/3,** 60/36, 417/901, 277/27, 277/28, 277/59, 277/62

[51] **Int. Cl.** **F16j 15/00**

[58] **Field of Search** 277/3, 12, 17, 27, 277/28, 59, 61, 62, 63, 67, 70, 81, 83, 86; 60/36; 417/901

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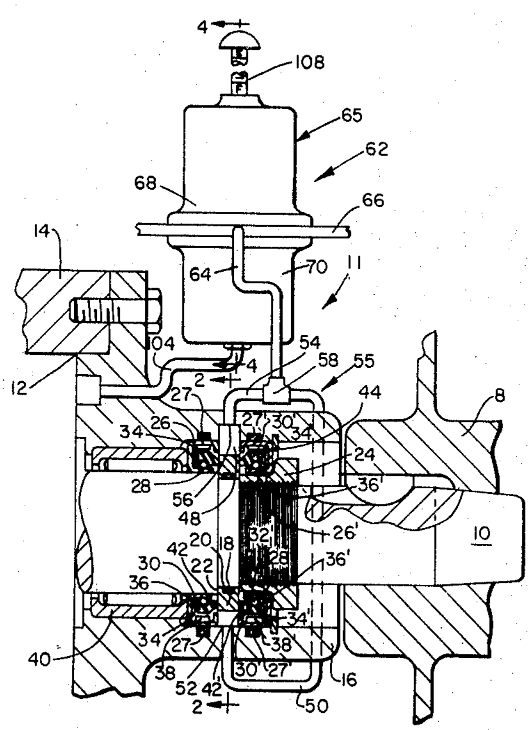
Primary Examiner—Samuel B. Rothberg
Assistant Examiner—Robert I. Smith
Attorney—James L. Neal

[57] **ABSTRACT**

A rotary shaft seal is characterized by a buffer compartment filled with fluid maintained at a pressure which equals or exceeds the pressures along the shaft with which the seal is associated. The relatively high buffer pressure within the seal is effective to prevent passage of material along the shaft from one side of the seal to the other.

In one preferred embodiment, the device for applying pressure to the buffer fluid within the compartment is responsive to the pressures along the shaft adjacent to opposite sides of the seal. The intensity of pressure applied to fluid within the buffer compartment is a function of the pressures along the shaft. This preferred embodiment is an effective driveshaft seal for the expander in a Rankine cycle engine, wherein the pressure applying device responds to both the pressure within the expander and the pressure outside the expander and applies to fluid in the buffer compartment a pressure higher than either of them.

22 Claims, 10 Drawing Figures



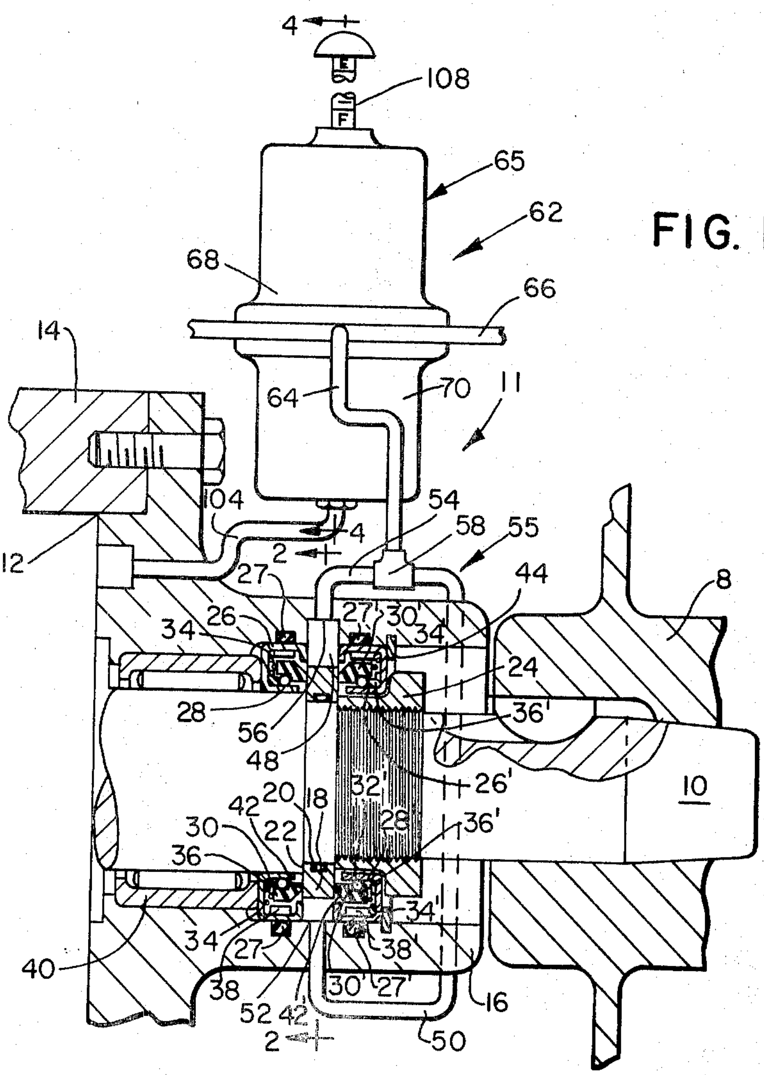


FIG. 1

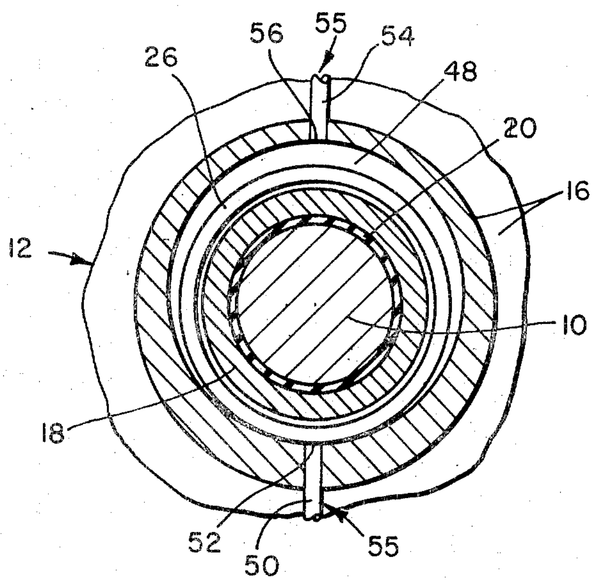


FIG. 2

INVENTORS
EDWARD F. DOYLE
THOMAS LEFEUVRE
BY James L. Neal
ATTORNEY

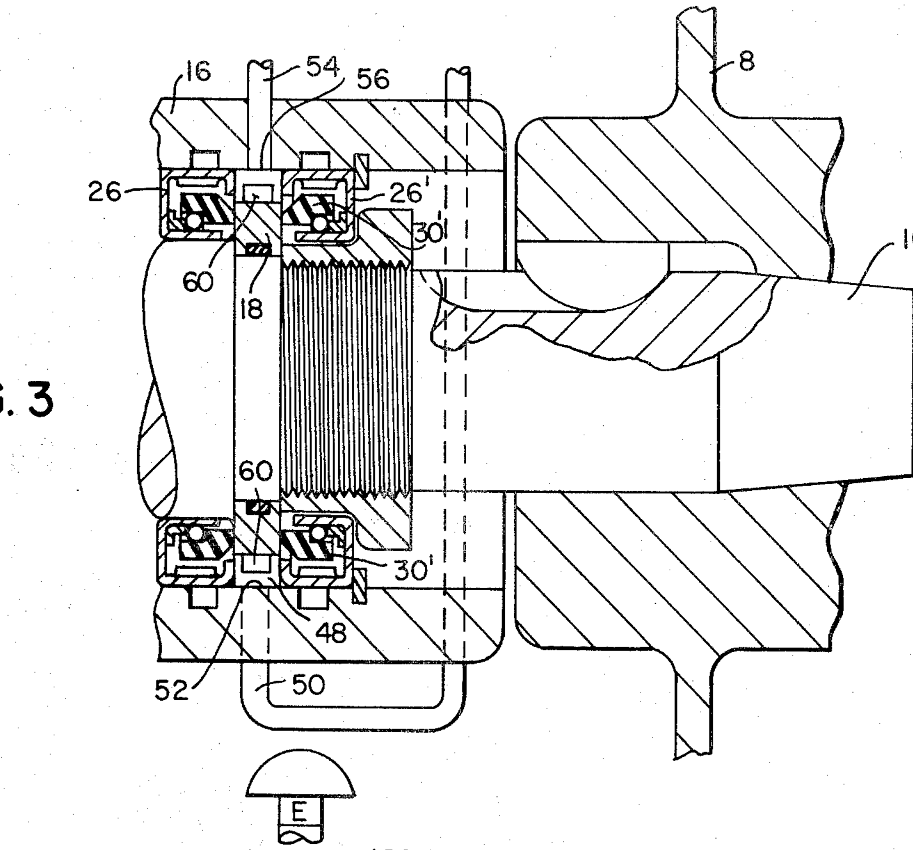


FIG. 3

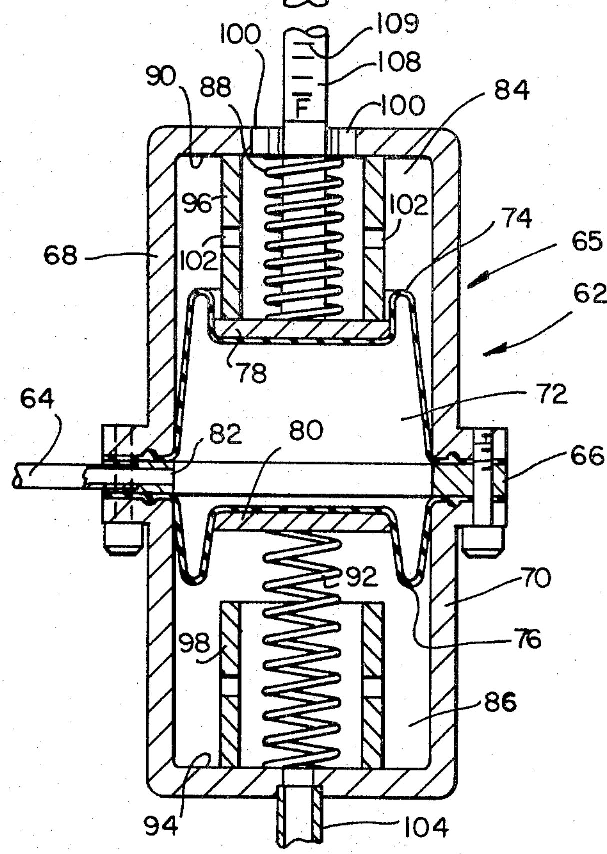


FIG. 4

INVENTORS
EDWARD F. DOYLE
THOMAS LEFEUVRE
BY
James L. Neal
ATTORNEY

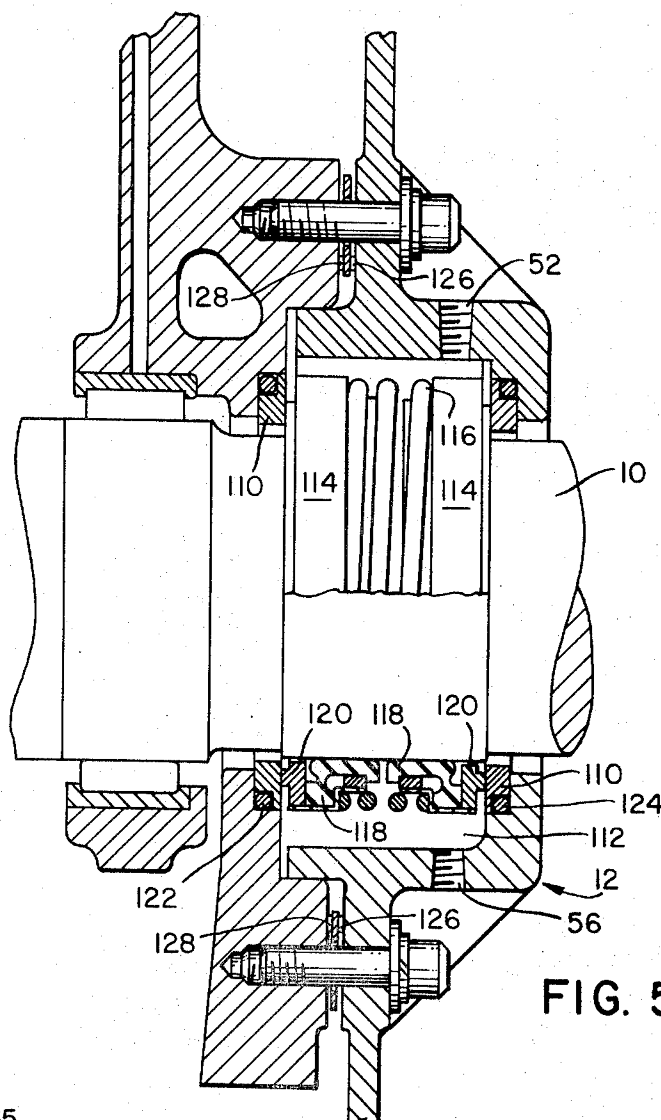


FIG. 5

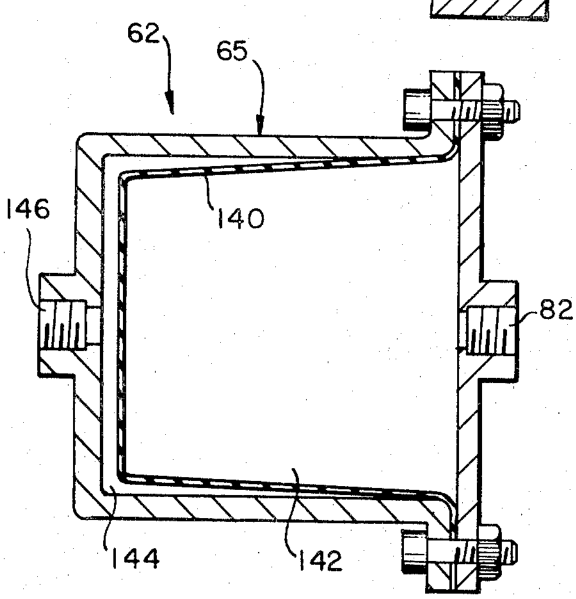


FIG. 6

INVENTORS
EDWARD F. DOYLE
THOMAS LEFEUVRE
BY James L. Neal
ATTORNEY

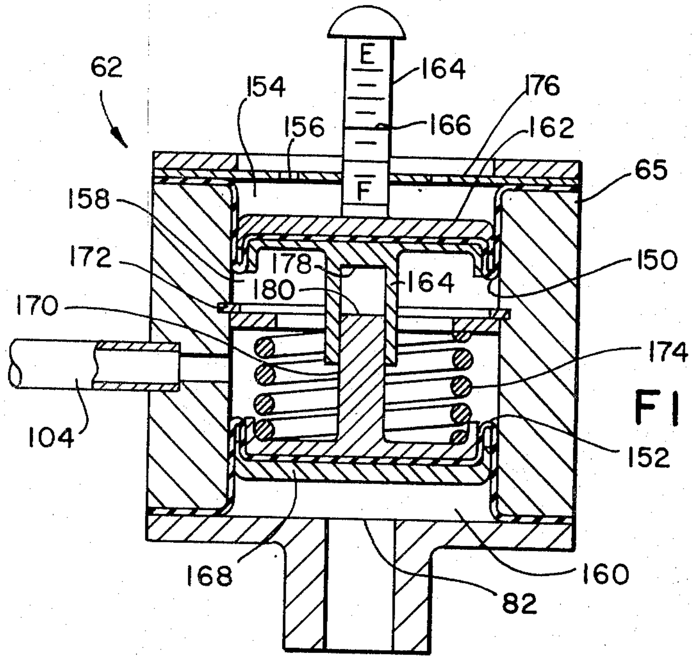


FIG. 7

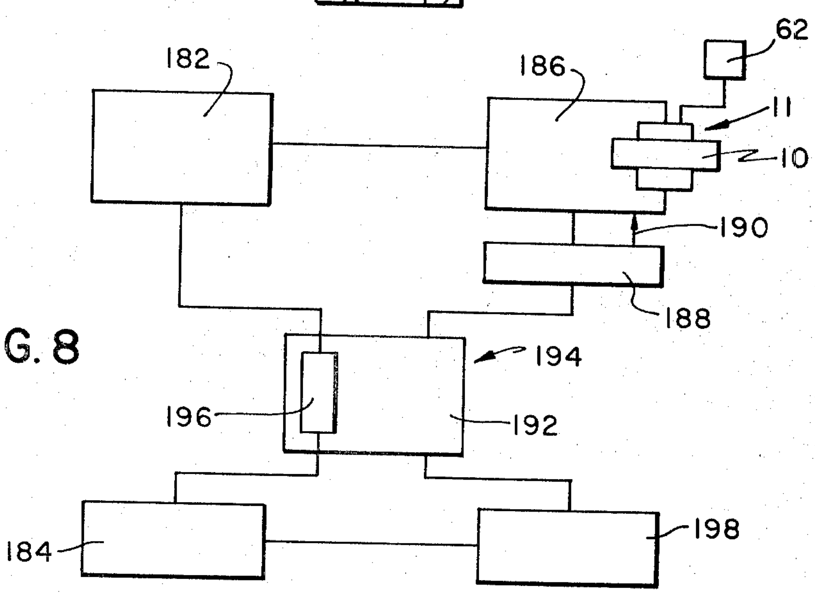


FIG. 8

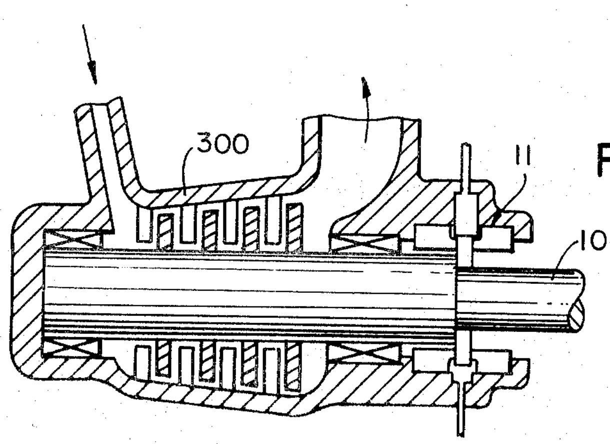


FIG. 10

INVENTORS
EDWARD F. DOYLE
THOMAS LEFEUVRE
BY
James L. Neal
ATTORNEY

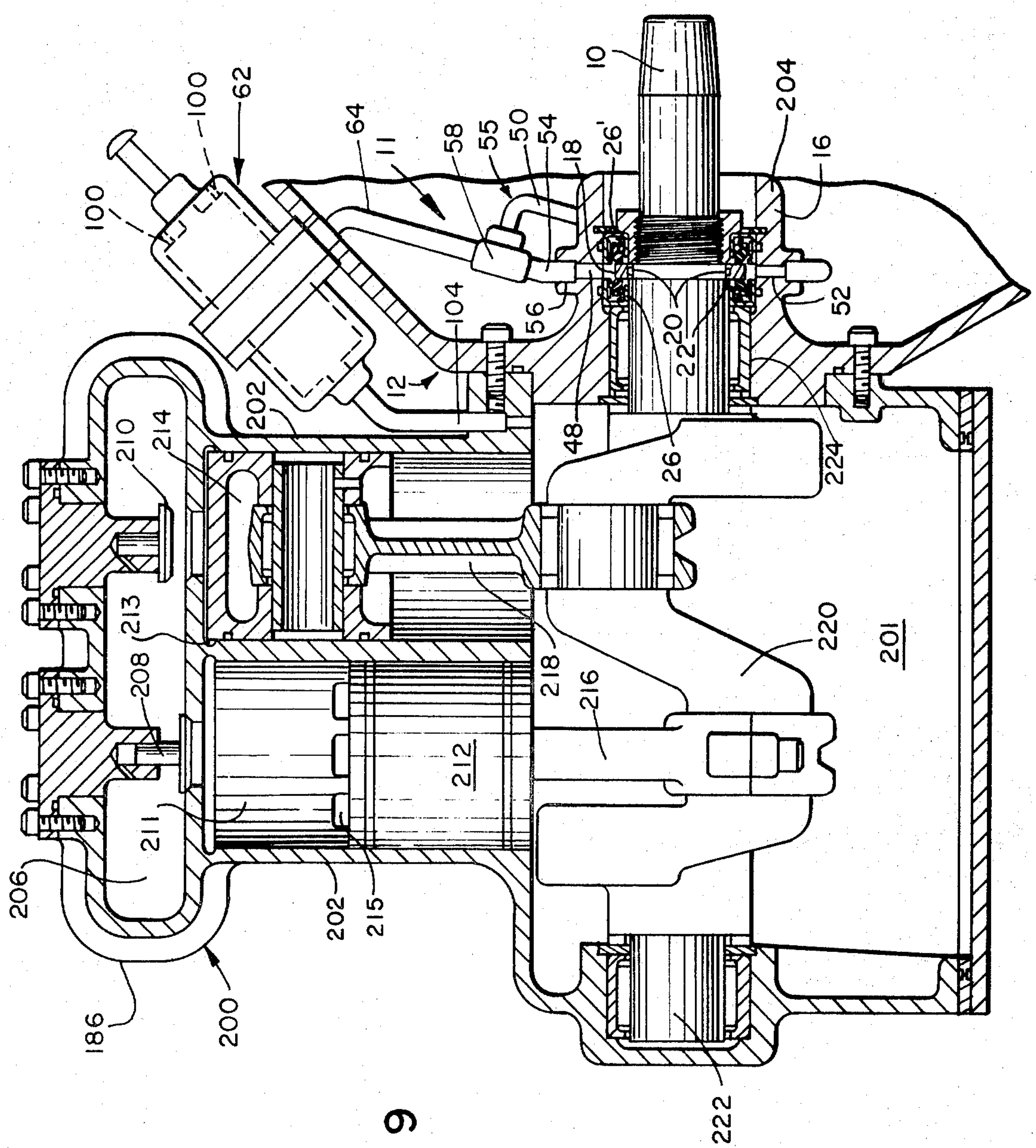


FIG. 9

INVENTORS
EDWARD F. DOYLE
THOMAS LEFEUVRE
BY James L. Neal
ATTORNEY

SHAFT SEAL

BACKGROUND OF THE INVENTION

The passage of a rotary shaft through the casing of a driving or driven apparatus is attended by a sealing problem which is particularly difficult when the pressures within or surrounding the casing are subject to significant variation so that first one and then the other of the pressures is higher. A highly effective seal is required to prevent passage of the material from the surroundings into the casing and to prevent passage of the material from the casing into the surroundings.

One situation involving the problem outlined above is presented by the driveshaft of an expander in a Rankine cycle engine. Typically, a rotary driveshaft passes through the expander casing and engages the device to be driven. During operation of the engine, pressure within the expander casing fluctuates over a wide range extending above and below the pressure surrounding the casing, which is typically the ambient atmosphere. During extended periods of non-operation, the pressure in the casing falls to a substantially subatmospheric level due in part to the cooling attending shut-down of the engine. It is essential to prevent passage of fluid within the expander into the atmosphere and to prevent the passage of air into the expander.

Fluids contained within the expander casing include a lubricant,or lubricants, and the working fluid for the Rankine cycle engine. Both fluids are present at the location where the shaft passes through the expander casing. Typically, the working fluid is sufficiently expensive that its conservation becomes an extremely important matter in efficient operation of the Rankine cycle engine. Further, a pre-determined optimum amount of working fluid must be maintained within the system to enable it to operate at peak efficiency. When the pressure in the casing is above atmospheric pressure, fluids in the casing continually tend to be forced out into the atmosphere along the driveshaft. Loss of these fluids is accompanied by a substantial reduction in operating efficiency and a substantial increase in operating expense.

It is also of primary importance in Rankine cycle systems that material in the surrounding environment be kept out of the expander casing. Foreign material entering the casing is distributed throughout the system to the detriment of system performance. The surrounding environment, as pointed out above, is typically the ambient atmosphere. Entry of air into the engine is particularly deleterious to system performance. This detriment apparently results from nitrogen and oxygen, which constitute the major gases in the atmosphere. Nitrogen collects in the condenser of the system and substantially reduces the operating efficiency of the condenser and thereby of the system. Oxygen, in the presence of the working fluid and lubricant, accelerates their rates of thermal decomposition and, accordingly, substantially increases the expense required to operate the system.

SUMMARY OF THE INVENTION

The present invention relates to a seal for preventing movement of material either into or out of a casing along a rotary shaft. The sealing elements include a first means mounted on the shaft forming a first pair of sealing surface areas and a second means mounted on the casing forming a second pair of sealing surface areas in

sealing engagement with the first sealing surface areas. A buffer fluid chamber containing pressurized buffer fluid surrounds the sealing elements. Buffer fluid pressure is maintained sufficiently high that the tendency of buffer fluid to pass between the sealing surfaces at least equals the tendency of material to pass between the sealing surfaces from either inside or outside of the casing. Thereby, passage of material past the sealing surface areas either into or out of the casing is effectively prevented.

Small amounts of the buffer fluid may pass the sealing surfaces and enter the casing or the environment surrounding the casing. Accordingly, the buffer fluid is selected so as not to be harmful to material within the casing or harmful when present in the environment. The buffer fluid may be a suitable lubricating fluid.

The seal is particularly effective when used on the expander driveshaft in a sealed Rankine cycle engine. To prevent passage of the fluid from the expander casing along the driveshaft into the atmosphere and to prevent passage of the atmosphere into the expander casing, the buffer fluid pressure is constantly maintained at a pressure level equaling or above both atmospheric pressure and any anticipated crankcase pressure. In a preferred embodiment of this invention, the buffer fluid pressure is maintained at the desired level by apparatus responsive to both atmospheric pressure and the pressure within the expander casing.

It is a primary object of this invention to provide a rotary shaft seal which prevents passage of material in either direction along a shaft past the seal.

It is a further object of this invention to provide a rotary shaft seal which prevents passage of material in either direction along a shaft past the seal wherein the seal is responsive to pressures surrounding the shaft on opposite sides thereof for maintaining within the seal a buffer pressure which equals or exceeds the pressures surrounding the shaft.

It is also an object of this invention to provide a rotary shaft seal for the expander of a Rankine cycle engine which prevents passage of fluids from the expander to the atmosphere and from the atmosphere into the expander.

A further object of this invention is to provide a rotary shaft seal for the expander of a Rankine cycle engine which is responsive to both the pressure within the expander and atmospheric pressure for maintaining within the seal a buffer pressure which equals or exceeds both the pressure within the expander and the atmospheric pressure.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates a preferred embodiment of the rotary shaft seal of this invention;

FIG. 2 is a cross-sectional view taken along line 2—2 of FIG. 1;

FIG. 3 illustrates an alternate embodiment of the apparatus shown in FIG. 2;

FIG. 4 is a cross-sectional view taken along line 4—4 of FIG. 1;

FIG. 5 presents an alternate embodiment of the rotary shaft seal shown in FIG. 1;

FIG. 6 illustrates an alternate embodiment of the apparatus shown in FIG. 4;

FIG. 7 illustrates another alternate embodiment of the apparatus shown in FIG. 4;

FIG. 8 is a schematic view of a Rankine cycle system according to this invention;

FIG. 9 is a sectional view of a reciprocating piston expander constructed according to this invention; and

FIG. 10 is a schematic view showing a turbine expander constructed according to this invention.

DETAILED DESCRIPTION OF THE DRAWINGS

Referring to FIG. 1, a rotary shaft 10, to which a driven member 8 is attachable, extends through a casing 12, the casing being comprised of parts 14 and 16. A structure 11 establishes a seal between the shaft and the casing.

The sealing structure 11 includes a first sealing element in the form of a ring 18 and a pair of sealing elements 26 and 26'. The sealing ring 18 is affixed to shaft 10 near an outer portion of the casing 12. The sealing ring 18 may be formed of any suitable material such as hardened steel, cast iron or the like. Mounted on the casing 12 are substantially identical sealing elements 26 and 26', each of which sealing engages a separate sealing area of the sealing ring 18, as will be more fully described below. The interface between the sealing ring 18 and the driveshaft 10 is sealed hermetically by static O-ring seal 20. The interface between the the casing 12 and the sealing elements 26 and 26' is provided with hermetic O-ring seals 27 and 27'.

Since the sealing elements 26 and 26' are substantially identical, only sealing element 26 will be described. In sealing element 26', like primed numerals designate like parts.

The sealing element 26 comprises an outer enclosure 28 supporting a sealing ring 30 of suitable material such as carbon, an O-ring 32, spring means 34, means 36 for confining the O-ring 32, and means 38 for confining the carbon sealing ring 30. The carbon sealing ring 30 is positioned for direct engagement with the sealing ring 18 and is pressed into continuous firm sealing engagement by the spring means 34. The O-ring 32 establishes a static seal between the carbon sealing ring 30 and the enclosure 28 to prevent passage of material between the carbon sealing ring and the enclosure. The means 36 maintains the O-ring in proper sealing engagement with the carbon sealing ring and the enclosure 28. The means 38 confines the carbon sealing ring 30 to maintain it in fixed position relative to the enclosure 28, thereby avoiding movement of the carbon sealing ring 30 relative to the shaft 10 when the shaft 10 and the mating ring 18 rotate. The means 38 may engage the carbon sealing ring 30 in a detent, not shown, or in any other suitable manner.

The elements 18, 26 and 26' of the sealing structure 11 are mounted adjacent the journal box where the driveshaft 10 passes through the casing 12. The sealing ring 18 is firmly pressed against a shoulder 22 of the driveshaft by a threaded retaining member 24. The sealing element 26 abuts a journal bearing 40. The bearing face 42 of the carbon sealing ring 30 associated with the sealing element 26 is positioned in sealing engagement with one surface area of the sealing ring 18. The sealing element 26' is positioned so that its bearing surface 42' sealingly engages an opposite surface area of the sealing ring 18. The sealing element 26' is firmly secured in position by a retaining ring 44.

Surrounding the points of sealing engagement between the sealing elements 26, 26' and 18 is a compartment 48 for containing a buffer fluid. The compartment is so formed that buffer fluid contained therein will be continuously present at the interface between the sealing ring 18 and the sealing rings 30 and 30'.

When the driveshaft 10 is rotated, heat is generated due to the frictional engagement between the sealing ring 18 and the carbon sealing rings 30 and 30'. This heat builds up in the buffer fluid within the compartment 48. Accordingly, a method of circulating and cooling the buffer fluid is required. The amount of heat generated is such that the buffer fluid temperature may be maintained at the proper level by circulation of the buffer fluid through a closed cooling loop 55. The cooling loop is formed by lines 50 and 54 which lead from buffer fluid outlet 52 and buffer fluid inlet 56, respectively, and are connected by coupling 58. Circulation of the buffer fluid may be produced by any convenient means. For example, a pumpingstructure may be included within the sealing structure 11 or a pump, not shown, may be installed along the closed loop 55.

In FIG. 1, pumping action is produced by cooperation between the sealing element 18 and the buffer fluid compartment 48 in a manner which is best described with reference to FIG. 2. The buffer fluid compartment 48 is formed eccentrically within the casing 12 so that the central axes of the sealing ring 18 and of the buffer fluid compartment 48 do not coincide. When heat is generated by frictional engagement between the sealing elements, the sealing ring 18 acts as an impeller within the compartment 48 to build a relatively high pressure adjacent the outlet 52 and a relatively low pressure adjacent the inlet 56. The small pressure differential created in this manner is enough to establish the required flow of buffer fluid through the loop 55. The heat exchange which takes place along the lines forming the loop is sufficient to maintain the temperature of the buffer fluid at the appropriate level.

An alternate embodiment of buffer fluid pump is illustrated in FIG. 3. In this embodiment, the sealing ring 18 and the buffer fluid compartment 48 are concentrically formed within the casing 10. The sealing ring 18 has formed thereon a series of vanes 60 which serve as impellers to build a pressure differential between the inlet 56 and the outlet 52.

For the sealing structure 11 to prevent passage of fluid or other material in either direction along the driveshaft 10 under any and all circumstances, the pressure of the buffer fluid must constantly be maintained at a level equal to or higher than the pressure surrounding the shaft at opposite sides of the sealing elements 26 and 26'.

To provide the required buffer fluid pressure, there is provided a pressure source 62 joined by a connecting line 64 to the loop 55. The pressure source 62 may operate in a number of ways to maintain the required pressure level in the buffer fluid compartment 48. One preferred embodiment is illustrated in FIGS. 1 and 4. A housing 65 comprises support means 66, a first end section 68 and a second end section 70. Formed within the housing 65 is a hermetically sealed buffer fluid reservoir 72. The reservoir 72 is defined by a first flexible diaphragm means 74 and a second flexible diaphragm means 76. The flexible diaphragm means 74 and 76 include within their central portion rigid plates 78 and 80, respectively. A buffer fluid level indicator 108 bearing indicia 109 extends from plate 78 through chamber 84. Within the reservoir 72 is established a port 82 which communicates with the connecting line

64. Adjacent one side of the reservoir is a first pressure chamber **84** formed by first end section **68**; adjacent the other side of the reservoir is a second pressure chamber **86** formed by the second end section **70**. A compression spring **88** is interposed between plate **78** and surface **90** of the first end section **68**. Interposed between the plate **80** and surface **94** of the second end section **70** is a compression spring **92**. The springs constantly exert pressure on the plates and thus on the buffer fluid within the reservoir **72**. In addition, pressure is applied to the buffer fluid within the reservoir **72** by pressure within the pressure chambers **84** and **86**. The additional pressure applied to the buffer fluid is substantially equivalent to either the pressure in the first pressure chamber **84** or the second pressure chamber **86**, as will be explained in more detail below. Within the first pressure chamber **84** is a stop **96** for limiting movement of the plate **78**; within the second pressure chamber **86** is a stop **98** for limiting movement of the plate **80**.

The first and second pressure chambers are provided for applying pressure to the buffer fluid in response to the pressure surrounding the driveshaft on opposite sides of the sealing elements **26** and **26'**. In the embodiment of FIG. **1**, for example, the sealing element **26'** is exposed to a zone of pressure outside the casing **12** and the sealing element **26** is exposed to pressure inside the casing **12**. Accordingly, the first pressure chamber **84** is constructed to respond to pressure outside the casing by direct communication through ports **100** and **102**. Also, a line **104** extends from the second pressure chamber **86** to the interior of the casing **12** to enable the second pressure chamber to respond to pressure within the casing **12**.

Operation of the sealing structure **11** depicted in FIGS. **1**, **2** and **4** will now be described. The sealing structure prohibits communication between the first pressure zone on one side of the sealing elements **26** and **26'** and a second pressure zone on the opposite side of these sealing elements, regardless of pressure fluctuations or of which pressure is higher than the other. The buffer fluid chamber **48**, the loop **55**, the line **64**, and the reservoir **72** are all filled with buffer fluid. The pressure applied to the reservoir **72** by the springs **88** and **92** is transmitted to the buffer fluid within the compartment **48** by means of the line **64** and the loop **55**. The springs thus constitute a pressure source constantly acting on the buffer fluid.

The first pressure chamber **84** is at a first pressure level corresponding to the pressure level outside the casing **12** and the second pressure chamber **86** is at the pressure level of the interior of the casing. A pressure equivalent to the higher pressure of the pressures within the chambers **84** and **86** is applied to the reservoir **72**, in addition to the pressure applied to the reservoir by opposed springs **88** and **92**. That is, when pressure in the second pressure chamber **86** exceeds pressure in the first chamber **84**, the first and second flexible diaphragm means **74** and **76** flex so that the reservoir **72** advances toward the stop **96** until the stop is abutted by the plate **78**. The springs continue to act upon the reservoir while a force equivalent to the pressure in the second pressure chamber **86** is applied thereto.Conversely, when pressure in the first pressure chamber **84** exceeds the pressure in the second pressure chamber **86**, the first and second flexible diaphragm means flex to permit the reservoir **72** to advance toward the stop **98** until this stop is abutted by the plate **80**. In this condition, pressure substantially equivalent to the relatively high pressure in the chamber **84** is applied to the buffer fluid in addition to the pressure applied thereto by the springs.

The springs **88** and **92** are preferably calibrated so that pressure on the buffer fluid within the compartment **48** always exceeds pressures surrounding sealing elements **26** and **26'**. However, the springs may be calibrated to apply a minimum force effective only to overcome any frictional resistance within the pressure source **62** or eliminated entirely. In the latter event, the buffer fluid pressure will substantially equal the highest of the pressures surrounding the sealing elements **26** and **26'**. Since the pressure across the sealing faces of elements **18**, **26** and **26'** is always characterized by either equilibrium or relatively high buffer fluid pressure, there is never a tendency for material to pass along the shaft **10** from one side of the sealing elements **26** and **26'** to the other side of these sealing elements.

There is a tendency for a small amount of buffer fluid to pass between the sealing faces of the sealing ring **18** and the carbon sealing rings **30** and **30'**. In event of passage, a small portion of the buffer fluid may be lost either to one side or the other of the sealing elements **26** and **26'**. Fluid which passes from the buffer fluid compartment **48** is replenished from the reservoir **72**. As the fluid is exhausted from the reservoir, flexible diaphragm means **74** and **76** advance toward each other to reduce reservoir volume. The reservoir may or may not need periodic recharging of buffer fluid depending on the life of the system within which the sealing structure **11** is used. Within the practical limits of reservoir size, the supply of buffer fluid has been found sufficient for extended periods.

The sealing structure **11** operates in the manner described, whether or not the driveshaft **10** is rotating within the casing **12**, and is therefore equally effective when the system in which it is used is operating and when the system is not operating.

The amount of buffer fluid in reservoir **72** at any given time is measured by reading indicia **109** on the buffer fluid indicator means **108** with respect to a reference point, such as the surface of housing **65**. To obtain a reading, the indicator means **108** must be in the fully advanced position so that the plate **80** abuts the stop **98**. In this position, the indicia **109** provides a reading of the distance between the plates **78** and **80** and therefore of the volume of fluid within the reservoir **72**. When the pressure in the chamber **84** exceeds the pressure in the chamber **86**, the plate **80** will be caused to abut the stop **98** so that the position of the indicator **108** inherently provides a reading of the reservoir contents. Further advancement of the indicator means **108** is prohibited by the resistance of the stop **98** and the buffer fluid within the reservoir **72**. When the pressure in the chamber **86** exceeds that in the chamber **84** (the condition shown in FIG. **4**), the indicator means is advanced against a resistance level which is a function of the pressure differential between the two pressure chambers. When a second resistance level resulting from engagement of the plate **80** with the stop **98** is encountered, the indicator means **108** is fully advanced and a reading may be taken.

Various alternate embodiments of the sealing structure **11** will now be described. Like numerals will be used to designate like parts.

FIG. 5 illustrates an alternate embodiment of the sealing structure involving primarily the sealing elements interposed between the driveshaft **10** and the casing **12**. Mounted within the casing **12** are a pair of opposed static sealing rings **110** between which is formed a buffer fluid chamber **112** eccentric with respect to the longitudinal axis of the driveshaft **10**. Mounted on the driveshaft **10** are a pair of assemblies **114** biased away from each other into engagement with the sealing rings **110** by a compression spring **116**. Each of the assemblies **114** comprises a means **118** which provides a static seal between the shaft **10** and the assemblies **114** and positions a rotary carbon sealing ring **120** in sealing engagement with the static sealing ring **110**. O-rings **122, 124, 126** and **128** hermetically seal the buffer fluid chamber **112** from the zones of pressure present along the driveshaft **10**. Inlet **56** and outlet **52** are provided to connect the chamber **112** with the pressure source **62**, in the manner described above in connection with FIGS. **1, 2** and **4**. It will be appreciated that the embodiment of FIG. **5** operates substantially in the same manner as the one described in connection with FIGS. **1, 2** and **4** except that the static sealing elements are mounted on the casing **12** and rotary sealing elements are mounted on the driveshaft **10**.

In connection with FIGS. **6** and **7**, there will be described two other embodiments of the sealing structure **11** primarily involving the pressure source **62**. FIG. **6** shows one embodiment of pressure source **62** for applying force to the buffer fluid independent of pressures surrounding the driveshaft **10**. A housing **65** is provided with a flexible bellows diaphragm **140** which divides the interior of the housing **65** into a buffer fluid reservoir **142** and a pressure chamber **144**. The housing **65** is provided with a port **82** for connection to the line **64** to establish communication with the loop **65**. There is further provided a port **146** for the admission of compressed gas into the pressure chamber **144**. Compressed gas admitted through port **146** fills the pressure chamber **144** to provide sufficient pressure on buffer fluid within the buffer fluid reservoir **142** to maintain the buffer fluid within the buffer fluid compartment **148**, shown in FIG. **1**, at a level which equals or exceeds the pressures surrounding the driveshaft **10** on opposite sides of the elements **26** and **26'**. The pressure applied to the reservoir **142** by the source of compressed gas is calibrated to always provide at least the minimum pressure required for compartment **148**.

The pressure source **62** shown in FIG. **7** includes a housing **65** divided into three sections by a first flexible diaphragm means **150** and a second flexible diaphragm **152**. The flexible diaphragm means **150** and **152** provide hermetic sealing between the three sections of the interior of the housing **65**.

A chamber **154** is provided with ports **156** which establish communication with one pressure zone. A chamber **158** communicates through line **104** with another pressure zone. A buffer fluid reservoir **160** communicates through a port **82** and the line **64** with the loop **55** and thence with the compartment **48**. The diaphragm means **150** includes a rigid plate-like structure **162**. From structure **162**, a sleeve **164** projects into chamber **158** and a projection **164** extends through the chamber **154**. The projection **164** forms a fluid level indicator. Indicia **166** thereon serves to indicate the amount of fluid present within the buffer fluid reservoir **160**. The diaphragm means **152** includes a second plate-like structure **168** from which projection **170** extends upward into the chamber **158** and telescopes within the sleeve **164**. A retaining means **172** is mounted within the chamber **158**. Opposed between the retaining means **172** and the structure **168** is a compression spring **174**.

The spring **174** continuously applies pressure to buffer fluid within the reservoir **160** and thus to fluid within the compartment **48**. When the pressure in the chamber **158** is greater than the pressure in the chamber **154**, the diaphragms **150** and **152** are urged apart from each other. (The diaphragm **150**, as shown in FIG. **7**, is in the transitory state, moving away from the diaphragm **152**.) The diaphragm **150** advances to the partition **176** and the diaphragm **152** is pressed firmly against buffer fluid in the reservoir **160**. Under this condition, the pressure of the fluid within the chamber **158** is imparted to buffer fluid within the reservoir **160** in addition to the pressure applied thereto by the spring **174**. When the pressure within the chamber **154** exceeds that within the chamber **158**, the diaphragm **150** advances toward the diaphragm **152**. This advancement continues until the terminal portion **178** of the sleeve **164** engages the terminal portion **180** of the projection **170**. When this occurs, the projection and the sleeve are effectively coupled together so that pressure within the chamber **154** is applied to buffer fluid within the reservoir **160** in addition to pressure applied thereto by the spring **174**.

The fluid level indicating means **164** provides for the determination of the amount of buffer fluid within the reservoir **160**. When the pressure in chamber **154** exceeds that in chamber **158**, the diaphragms are effectively coupled as described above, and the indicia **166** on the projection **164** will indicate the amount of fluid within the reservoir **160**. In this circumstance, the projection **154** will not be susceptible of further downward movement into the housing **65**. When the pressure in chamber **168** exceeds that in chamber **154**, the diaphragm **150** will be pressed against the member **176** and the indicia **166** on the projection **164** will indicate that the reservoir is full. When the reservoir is indicated full, to determine that this is actually a correct reading, the projection **164** must be pressed inwardly of the housing **165**, against the force applied thereto by the pressure differential between the chambers **158** and **154**, until a second level of resistance is encountered beyond which the projection is no longer movable. The reading at the second level of resistance is the correct indication of the amount of fluid within the reservoir **160**. If upon pressing the projection **164** inwardly on the housing **165**, it is immediately immovable, the reservoir **160** is full of buffer fluid.

Turning now to FIGS. **8** and **9**, there will be described a Rankine cycle system constructed according to this invention to prevent passage of the fluid from the system into the atmosphere and passage of material from the atmosphere into the system.

The Rankine cycle system is described briefly in connection with FIG. **8**. A vapor generator **182** heats organic working fluid fed thereto by a pump **184**. The vaporized working fluid is then directed to an expander **186** which expands the vapor through a substantial temperature and pressure drop to produce work and rotate the driveshaft **10**. The working fluid then passes from the expander **186** through a separator **188** which removes any lubricants from the organic working fluid, which lubricants are returned to the expander by a line **190.** The working fluid then enters the vapor side **192** of a regenerator **194** and gives up some of the heat energy remaining therein to working fluid passing through the liquid side **196** of the regenerator. From the vapor side **192** of the regenerator, the working fluid passes through the condenser **198** and is fully condensed. The pump **184** then drives the condensed working fluid through the liquid side **196** of the regenerator **194** and back to the vapor generator **182.** The working fluid is heated as it is driven through the liquid side of the regenerator by exhaust vapor passing through the vapor side of the regenerator. The vapor generator **182** vaporizes the working fluid and the cycle is repeated.

FIG. **9** illustrates a reciprocating expander for a Rankine cycle system of the type shown in FIG. **8.** The expander is provided with a casing **200** comprising parts **202** and **204.** Within the casing **200** is a vapor inlet manifold **206** and valves **208** and **210** cooperatively arranged with respect to reciprocating pistons **212** and **214.** Each of the pistons have associated therewith a piston rod **216** and **218.** The piston rods are connected to a crankshaft **220** which is supported within the casing **200** at one end by a journal box **222.** A driveshaft **10** extends from the opposite end of the crankshaft and is supported in the casing **200** by a journal box **224.** Adjacent the journal box **224** are sealing elements **18, 26** and **26'** surrounded by a buffer fluid compartment **48.** The sealing elements, compartment and other associated parts are constructed and mounted in substantially the same fashion as described above in connection with FIG. **1.** Lines **50** and **54** extend from the compartment **48** to form the loop **55** which is connected by line **64** to the pressure source **62.** Extending from the pressure source **62** is a line **104** establishing communication between pressure source and the interior of the casing **200.** The line **104** should enter the casing **200** at a place relatively near the journal **224** so that it may enable the pressure source **62** to accurately sense the pressure adjacent the sealing element **26.**

The operation of the apparatus of FIG. **9** will now be described in connection with the buffer fluid compartment as shown in FIG. **2** and the pressure source as shown in FIG. **4.**

The expander **186** is characterized by wide variations of internal pressures. The pressure in the casing **200** may extend to levels well above atmospheric pressure under certain conditions and, under other conditions, drop substantially below atmospheric pressure. Consequently, the shaft seal is required to prevent passage of material from within the casing to the atmosphere when the casing pressure is relatively high and to prevent passage of material from the atmosphere into the casing when the casing pressure is relatively low.

Vaporized working fluid admitted into the inlet manifold **206** from the vapor generator **182** is alternately directed first into cylinder **211** and then into cylinder **213** by valves **208** and **210,** respectively, in a typical manner understood in the art. Working fluid is exhausted from the cylinders through exhaust ports of the type shown at **215** in the cylinder **211.** Alternate reciprocation of the pistons **212** and **214** results from the admission into the cylinders **211** and **213** and exhaust therefrom of vaporized working fluid. Reciprocation of the pistons rotates the crankshaft **220** which in turn causes the driveshaft **10** to rotate within the casing **200.**

When the Rankine cycle expander is operating and the driveshaft **10** is rotating within the casing **200,** the sealing ring **18** acts as an impeller to circulate buffer fluid through the cooling loop **55.** If any buffer fluid passes between the sealing ring **18** and the sealing elements **26** and **26',** it is replenished from the reservoir **72.** During operation, when the pressure in the casing **200** exceeds atmospheric pressure, the casing pressure is transmitted through line **104** to the second pressure chamber **86** of the pressure source **62.** This pressure is then applied by the pressure source **62** to the buffer fluid system. There is also applied to the buffer fluid system the pressure resulting from compression springs **88** and **92.** The result is that the pressure of the buffer fluid within the buffer fluid compartment **48** is equal to the pressure in the casing **200** plus the pressure from the compression springs **88** and **92.** On the other hand, during long periods of shut-down of the Rankine cycle system, the pressure within the casing **200** typically drops below atmospheric pressure. Under this circumstance, the first pressure chamber **84** which communicates with the atmosphere by means of ports **100** and **102** is subjected to a relatively high pressure which overcomes the influence of the pressure within the second pressure chamber **86.** The atmospheric pressure is then applied to the buffer fluid system together with the pressure of compression springs **88** and **92** so that buffer fluid within the buffer fluid compartment **48** is subjected to a pressure equal to the atmospheric pressure plus the pressure applied by the compression springs.

Expanders are characterized by sealing arrangements between the pistons and cylinders which permit passage of working fluid past the pistons and cylinders into the portion of the expander casing which contains lubricant, with the result that working fluid becomes intermixed with the lubricant. The tendency of material to pass from the interior of the epxander to the exterior thereof along the driveshaft establishes the potential loss of both working fluid and lubricant. For example, in the expander **186** of FIG. **9,** working fluid tends to pass between the cooperating piston and cylinder assemblies to the portion **201** of the casing **200** which serves as a lubricant containing crankcase. The crankcase **201** thus contains a mixture of lubricant and working fluid which passes through the journal **224** and would tend to pass between the sealing element **18** and sealing elements **26** and **26'** except for the pressure of buffer fluid within the compartment **48.**

FIG. **10** is a schematic view showing a turbine **300** embodying this invention. The sealing structure **11** is interposed between the casing of the turbine **300** and its driveshaft **10** to prevent passage of material from one side of the sealing structure to the other along the driveshaft. It should be understood that this invention is not limited to expanders but may be used on pumps and other apparatus wherein an effective shaft seal is required.

This invention has been described by several preferred embodiments. It will be apparent that modifications and changes may be made without departing from the scope of the invention as set forth in the following claims.

We claim:

1. A shaft seal interposed between relatively rotatable shaft means and casing wall means through which said shaft means extends, said casing wall means having a first pressure zone on one side thereof and a second pressure zone on the other side thereof, said shaft seal comprising:

a. first sealing means mounted in fixed relationship to said shaft means and forming first and second sealing surface areas each surrounding said shaft means;

b. second sealing means mounted in fixed relationship to said casing wall means and forming first and second sealing surface areas, said first and second surface areas formed by said second sealing means mating in sealing engagement with said first and second sealing surface areas of said first sealing means, respectively;

c. means forming a buffer fluid compartment communicating with said first and second sealing means at their points of sealing engagement;

d. first means communicating with said first pressure zone;

e. second means communicating with said second pressure zone; and

f. means responsive to said first and second communicating means for applying to buffer fluid within said compartment a pressure which at least substantially equals the greater of the pressures in said first and second pressure zones, thereby to inhibit passage of material along said shaft means from either of said pressure zones to the other.

2. A shaft seal according to claim **1** wherein said pressure applying means is responsive to the pressures in both said first and second pressure zones.

3. A shaft seal according to claim **1** wherein said pressure applying means comprises:

a. means forming a hermetically sealed expansible chamber communicating with said buffer fluid compartment; and

b. means responsive to both the pressure in said first pressure zone and the pressure in said second pressure zone for applying to said expansible chamber and thereby to said compartment a pressure at least substantially equaling the greater of either the pressure in said first pressure zone or the pressure in said second pressure zone.

4. A shaft seal according to claim **3** wherein said pressure applying means further comprises means for constantly applying pressure to said expansible chamber and thereby to said compartment in addition to the pressure applied thereto by said means responsive to the pressures in said first and second pressure zones, whereby the pressure applied to said compartment exceeds the greater of either the pressure in said first pressure zone or the pressure in said second pressure zone.

5. A shaft seal according to claim **3** wherein said expansible chamber comprises a buffer fluid reservoir.

6. A shaft seal according to claim **1** wherein said means responsive to said first and second communicating means is in hermetically sealed fluid connection with said buffer fluid compartment.

7. In a Rankine cycle system including

an expander having means forming a working fluid chamber and

a rotary shaft extending from said working fluid chamber into an environmental zone, wherein the pressure in said working fluid chamber rises above environmental zone pressure during certain conditions and drops below environmental zone pressure during certain other conditions, a shaft seal comprising:

a. a first sealing means on said shaft in fixed, fluid tight relationship thereto and having first and second sealing surface areas surrounding said shaft;

b. second sealing means in fixed, fluid tight relationship to said means forming said working fluid chamber and having first and second sealing surface areas in sealing engagement with said first and second sealing surface areas, respectively, of said first sealing means;

c. means forming a buffer fluid compartment in communication with said first and second sealing means at their points of engagement for maintaining a supply of buffer fluid at said points of engagement; and

d. means in hermetically sealed fluid communication with said compartment constantly applying pressure to buffer fluid therein which at least equals the greater of either the pressure in said working fluid chamber or the pressure in said environmental zone, said pressure being applied during both operating and non-operating conditions of the Rankine cycle system, thereby to eliminate the tendency of material to pass along said shaft from said working fluid chamber into said environmental zone when pressure in said working fluid chamber is above environmental zone pressure and from said environmental zone into said working fluid chamber when pressure in said working fluid chamber is below environmental zone pressure.

8. In a Rankine cycle system according to claim **7** a shaft seal wherein said pressure applying means applies to buffer fluid within said compartment a pressure greater than either the pressure of said working fluid chamber or the pressure of said environmental zone.

9. In a Rankine cycle system according to claim **7** a shaft seal wherein:

a. said first sealing means comprises an annular flange surrounding said rotary shaft;

b. said second sealing means comprises a pair of annular sealing surfaces for sealing engagement with opposite sides of said annular flange; and

c. said buffer fluid compartment surrounds said annular flange along and between the points of engagement of said annular flange with said pair of annular sealing surfaces.

10. In a Rankine cycle system according to claim **9** a shaft seal further comprising means forming a fluid inlet and a fluid outlet for said buffer fluid compartment wherein said buffer fluid compartment surrounds said annular flange, eccentrically thereof, whereby rotary movement of said annular flange within said buffer fluid compartment during operation of the Rankine cycle system produces a pumping action for drawing buffer fluid into said compartment through said inlet and expelling buffer fluid from said compartment and through said outlet.

11. In a Rankine cycle system according to claim **10** a shaft seal further comprising:

a. means connecting said inlet and outlet means to form a closed loop in which said buffer fluid travels; and

b. reservoir means communicating with said closed loop for providing a continuing supply of buffer fluid to replenish any buffer fluid which passes from said compartment into said working fluid chamber or said environmental zone.

12. In a Rankine cycle system according to claim **11** a shaft seal wherein:

a. said reservoir means comprises a flexible, hermetically sealed buffer fluid confining means; and

b. said means constantly applying pressure applies pressure to said flexible, hermetically sealed fluid confining means for exerting pressure on buffer fluid in said compartment.

13. In a Rankine cycle system according to claim **10** a shaft seal wherein said means constantly applying pressure is responsive to the pressure in said environmental zone and the pressure in said working fluid chamber.

14. In a Rankine cycle system according to claim **10** a shaft seal wherein said means constantly applying pressure comprises:

a. spring means for continuously applying pressure to said buffer fluid confining means; and

b. means responsive to the pressure in said working fluid chamber and the pressure in said environmental zone for applying to said buffer fluid confining means a pressure in addition to pressure applied thereto by said spring means, which at least substantially equals the higher of the pressures in the aforesaid zones,whereby the buffer fluid pressure in said compartment always exceeds both the pressure in said working fluid chamber and the pressure in said zone of environmental pressure to prohibit passage of material along said shaft from said zone into said working fluid chamber or from said working fluid chamber into said zone.

15. In a Rankine cycle system according to claim **7** a shaft seal further comprising:

a. fluid conduit means having both inlet and outlet means connected to said buffer fluid compartment to form a closed loop; and

b. means forming a pump for causing fluid in said compartment to travel through said closed loop during rotation of said shaft.

16. In a Rankine cycle system according to claim **7,** a shaft seal wherein said pressure applying means comprises:

a. first means communicating with pressure external of said chamber;

b. second means communicating with pressure internal of said chamber; and

c. means responsive to said first and second communicating means for applying to buffer fluid within said compartment a pressure at least substantially equal to the greater of either said first or second pressure levels.

17. In a Rankine cycle system including an expander casing means forming a chamber to contain fluid lubricant and organic Rankine cycle working fluid, the interior and exterior of said chamber being characterized by different pressure levels, and

rotary drive shaft means extending through said casing, a shaft seal comprising:

a. first sealing means in fixed, fluid tight relationship to said shaft means and having a first surface portion and a second surface portion;

b. second sealing means in fixed, fluid tight relationship to said expander casing means and in sealing engagement with both said first and second surface portions of said first sealing means;

c. means forming a buffer fluid compartment in communication with said first and second sealing means at their points of sealing engagement for maintaining a supply of buffer fluid at said points of engagement;

d. hermetically sealed compressible reservoir means in fluid communication with said compartment;

e. first means for continuously applying pressure to said reservoir means and thereby to buffer fluid within said compartment; and

f. second means for continuously applying pressure to said reservoir means to thereby continuously pressurize buffer fluid within said compartment in addition to pressure applied thereto by said first pressure applying means, the magnitude of which is functionally related to the greater of either the pressure internal of said chamber or the pressure external of said chamber.

18. In a Rankine cycle system according to claim **17** a shaft seal wherein said second pressure applying means applies pressure to said buffer fluid which is at least substantially as great as the greater of either the pressure within said chamber or the pressure without said chamber, whereby the pressure applied to said buffer fluid within said compartment is always greater than either the pressure within said chamber or the pressure without said chamber.

19. In a Rankine cycle system according to claim **18,** a shaft seal wherein said compressible reservoir is for buffer fluid.

20. In a Rankine cycle system according to claim **19** a shaft seal further comprising means for indicating the amount of buffer fluid in said reservoir.

21. In a Rankine cycle system according to claim **17,** a shaft seal wherein said second pressure applying means comprises:

a. first means communicating with pressure external of said chamber for applying to said reservoir means a first pressure level having a magnitude substantially equal to said external pressure;

b. second means communicating with pressure internal of said chamber for applying to said reservoir means a second pressure level having a magnitude substantially equal to said internal pressure; and

c. means associated with said reservoir means and responsive to said first and second communicating means for applying to buffer fluid within said compartment a pressure at least substantially equal to the greater of either the pressure internal of said chamber or the pressure external of said chamber.

22. A shaft seal interposed between relatively rotatable shaft means and casing wall means through which said shaft means extends, said casing wall means having a first pressure zone on one side thereof and a second pressure zone on the other side thereof, the pressure in said first pressure zone being greater than the pressure in said second pressure zone under some conditions and less than the pressure in said second zone under other conditions, said shaft seal comprising:

a. first sealing means mounted in fixed relationship to said shaft means and forming first and second sealing surface areas each surrounding said shaft means;

b. second sealing means mounted in fixed relationship to said casing wall means and forming first and second sealing surface areas, said first and second surface areas formed by said second sealing means mating in sealing engagement with said first and second sealing surface areas of said first sealing means, respectively;

c. means forming a buffer fluid compartment communicating with said first and second sealing means at their points of sealing engagement; and

d. means in hermetically sealed fluid communication with said compartment for continuously applying to buffer fluid within said compartment, under all conditions, a pressure which at least substantially equals the greater of the pressures in said first and second pressure zones, thereby to inhibit passage of material along said shaft means from either of said pressure zones to the other under all conditions.

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