A condition monitoring system for a cylinder bushing, such as a hydraulic cylinder bushing, comprising at least one electrically conductive wire (220, 222); each wire formed into an annular ring shape. The electrically conductive wire(s) (220, 222) are embedded within a dielectric ring (210) being positioned concentrically about a bushing aperture (138) passing therethrough forming a bushing condition monitoring ring (200). The monitoring ring (200) is integrated within a bushing (136) for use within a hydraulic cylinder (100). The electrically conductive wire(s) (220, 222) are provided in electrical communication with a processing device (400) which monitors a condition capacitance (260) created between each electrically conductive wire(s) (220, 222) and a shaft (130) passing through the bushing aperture (138). A reference capacitance (262) can be obtained between each pair of adjacent located electrically conductive wire(s) (220, 222). The system monitors a change in condition capacitance (260) to determine the condition of the bushing (136).
BUSHING WEAR SENSING DEVICE

Technical Field Of The Invention

The present invention relates to an apparatus of and method for monitoring wear of a bushing integrated within a cylinder, such as a hydraulic or pneumatic cylinder.

Background

Hydraulic cylinders operate by applying pressure to a contained hydraulic fluid. The change in pressure causes a piston to move within a tubular (preferably cylindrically shaped) element commonly referred to as a cylinder barrel. A base or cap end seals the cylinder barrel at one end and a cylinder head seals the cylinder barrel at an opposite end. A shaft is typically attached to one end of the piston. The shaft extends through a bushing seal located in the cylinder head. The motion of the piston is translated to the shaft to operate a mechanical member.

The hydraulic cylinders rely upon a sealed system for reliable functionality. The sealed system relies upon a sealed interface provided between the piston and the internal surface of the cylinder barrel and a sealed interface provided between the shaft and the internal or shaft contact surface of the bushing for optimal operation.

Friction and other forces applied to the bushing by the motion of the shaft passing therethrough degrading the shaft contact surface of the bushing over time. The operation and reliability of the hydraulic cylinder is directly related to the quality of the seal provided between the shaft and the associated bushing. In use monitoring of the condition of the bushing surface can optimize servicing intervals and enhance the overall reliability of the hydraulic cylinder.

Several solutions include a wear detection groove arranged upon an inner peripheral surface of a bushing. The groove may be provided in a variety of configurations. As the interface surface of the bushing wears, the groove gradually decreases until the groove disappears, indicating that the bushing is in need of replacement. These solutions require visual inspection. The visual inspection process is not continuous and is generally accomplished at established time intervals. The visual inspection process is also limited in its precision.
A second known solution integrates an insulated wire is placed in a form of a loop circumscribing the shaft, wherein the loop is positioned between the bushing and the shaft. Wear of the insulation is correlated to the wear of the bushing - shaft interface. As the insulation degrades, a current or signal strength provided through the wire also degrades. The current strength can be monitored, such as by an intensity of a light integrated into a circuit. A drop in current strength is correlated to the wear and ultimately, the directive for servicing the bushing.

Another known solution embeds an integrated sensor into the seal. A first known embedded sensor is inserted radially into the seal and is therefore not conducive to a seal for rotating objects. A second known embedded sensor utilizes a series of circular shaped monitoring devices, each monitoring device being assembled between a pair of adjacently positioned plates. The circular shaped monitoring devices collectively form a capacitive monitoring system. The seal assembly includes multiple components. The components must be assembled together to precise tolerances. The capacitance is only useful for monitoring non-metallic materials, such as rubbers, plastics, and the like. The capacitance measurements are not very precise.

Another known solution embeds a wire within an interior surface of a bushing or bearing. An indicator monitors for continuity of the wire. The circuit is broken when the wire is worn through, thus identifying when the bushing needs servicing. This configuration is limited where the wire monitors only a small portion of the interface surface of the bushing.

Another known solution positions an electrically conductive counter body against a non-conductive sealing material fixed upon an electrically conductive sealing material of a dynamic sealing element. The electrically conductive counter body is placed into a circuit to monitor continuity between the electrically conductive counter body and the electrically conductive sealing material. The non-conductive material retains an open circuit until the non-conductive material is worn through. When the non-conductive material is worn through, the electrically conductive counter body contacts the electrically conductive sealing material closing the circuit. The circuit is monitored to determine when the non-conductive sealing material needs servicing.
Another known solution utilizes an optical fiber system for monitoring a condition of a seal. The fiber optic is embedded in the seal and operatively coupled to an interferometric system. The interferometric system, in combination with a microprocessor, monitors and determines the condition of the seal. This system can be expensive and is limited to a specific region of the seal. The monitored section is equal to a width of the fiber optic strand.

Another known solution integrates transducers within sliding seals to monitor the condition of the seal. The transducers emit a wireless signal comprising data in the form of discrete measurement values and/or a status of an associated circuit. Wireless communications may not be reliable. Balancing of rotating equipment is essential to long-term reliability. The weight of the transducers may impact the operation and long-term reliability of the equipment.

Another known solution integrates an acoustic wave device. The acoustic wave device utilizes an input transducer for generating a mechanical acoustic wave using a piezoelectric substrate and an output transducer for receiving the resulting acoustic wave and generating an output signal based upon the wave propagation between the input and output transducers. Limitations of this solution include expense of the transducers, weight and balance affects by the inclusion of the transducers, reliability of the transducers (particularly when subjected to mechanical shock, thermal changes, and the like), and other reliability impacts.

Another known solution integrates a magnetic interface onto an antifriction bushing. The sensor includes a giant magneto resistance element arranged at a distance from a magnetic coder. The coder forms a multipole magnet with a pair of poles. Magnetic measurements are limited in their precision. The cover needs to be assembled to the moving component (such as a shaft) in a manner to avoid interfering with the balance of the moving component. Addition of any weight to a moving object increases inertia of the object, thus increasing the required acceleration forces required to cause and maintain motion of the moving component.

Another known solution integrates strain gauges into a seal. The system monitors the status of the strain gauges to determine when the seal needs servicing. Strain gauges are limited to a system that monitors a change in the shape of the material. A strain gauge
might not identify wear of a seal, or more specifically, when material is removed from abrasion.

Each of the above known solutions has their limitations. There seems to be room for improvement,
SUMMARY OF THE INVENTION

The present invention is directed to an apparatus and respective method for monitoring a condition of a bushing or bearing within a cylinder, such as a hydraulic or pneumatic cylinder.

In a first aspect of the present invention, an apparatus for monitoring a condition of bearing or bushing, the apparatus comprising:

- a bushing having a bushing aperture extending axially therethrough;
- a monitoring ring receiving groove extending radially outward from the bushing aperture;
- a monitoring ring positioned within the monitoring ring receiving groove, the monitoring ring comprising:
  - a dielectric ring fabricated of a dielectric material and provided in an annular shape having a concentrically located aperture, and
  - a plurality of electrically conductive wires embedded within said dielectric material, each wire shaped into an annular ring, each electrically conductive annular wire being radially arranged about a central longitudinal axis of the concentrically located aperture; and
  - a conductive interface assembly comprising a plurality of pairs of conductive interfaces, each pair of conductive interfaces provided in electrical communication with a respective end of the respective electrically conductive annular wire.

In a second aspect, the system further includes a processing device comprising a set of digital instructions for monitoring and analyzing electrical properties of each electrically conductive annular wire obtained via said conductive interface.

In another aspect, the processing device further comprising an input device for receiving an electrical signal from said conductive interface.

In another aspect, each conductive annular ring is provided in electrical communication with the processing device via an electrically conductive interface.
In another aspect, each electrically conductive wire is fabricated of an electrically conductive material, such as copper, gold plated conductive material, aluminum, silver plated conductive material, steel, and the like.

In another aspect, the dielectric ring is fabricated of plastic, composite material, nylon, rubber, Polyether ether ketone, polyester, and the like. It is preferred that the material of the dielectric ring is of a lower hardness and density compared to the material of the bushing.

In another aspect of the present invention, a method of determining a condition of bearing or bushing, the method comprising steps of:

integrating a bushing into a cylinder, such as a hydraulic or pneumatic cylinder, the bushing comprising:

- a bushing aperture extending axially through said bushing,
- a monitoring ring receiving groove extending radially outward from the bushing aperture;

a monitoring ring positioned within the monitoring ring receiving groove, the monitoring ring comprising:

- a dielectric ring fabricated of a dielectric material and provided in an annular shape having a concentrically located aperture, and
- a plurality of electrically conductive wires embedded within said dielectric material, each wire shaped into an annular ring, each electrically conductive annular wire being radially arranged about a central longitudinal axis of the concentrically located aperture; and

a conductive interface assembly comprising a plurality of pairs of conductive interfaces, each pair of conductive interface provided in electrical communication with a respective end of the respective electrically conductive annular wire;

providing electrical communication between each said pair of conductive interfaces and a processing device; and
monitoring said bushing condition monitoring ring for changes in capacitance between each electrically conductive wires and said shaft to determine a condition of the bushing.

In another aspect, the method can be enhanced by monitoring a capacitance between adjacent electrically conductive wires.

The present invention provides several advantages over the known art, including a low cost of implementation, a minimal impact from any additional weight, and a highly precise measuring system.

The system may record and analyze the data over time to predict service intervals based upon recorded history of wear measured against run time.

It is an apparatus and respective method of continuously monitoring a bushing or bearing seal without adding weight to the shaft/piston.

These and other features, aspects, and advantages of the invention will be further understood and appreciated by those skilled in the art by reference to the following written specification, claims and appended drawings, which follow.
BRIEF DESCRIPTION OF THE DRAWINGS

For a fuller understanding of the nature of the present invention, reference should be made to the accompanying drawings in which:

FIG. 1 presents an exemplary hydraulic cylinder assembly;

FIG. 2 presents an isometric view of an exemplary bushing monitoring insert;

FIG. 3 presents a side section view of the bushing monitoring insert, the section taken along section line 3–3 of FIG. 2;

FIG. 4 presents a magnified section view of the bushing monitoring insert, the magnified section taken about a circular section identified in FIG. 3; and

FIG. 5 presents an exemplary schematic block diagram of the monitoring system.

Like reference numerals refer to like parts throughout the several views of the drawings.
MODES FOR CARRYING OUT THE INVENTION

The following detailed description is merely exemplary in nature and is not intended to limit the described embodiments or the application and uses of the described embodiments. As used herein, the word "exemplary" or "illustrative" means "serving as an example, instance, or illustration." Any implementation described herein as "exemplary" or "illustrative" is not necessarily to be construed as preferred or advantageous over other implementations. All of the implementations described below are exemplary implementations provided to enable persons skilled in the art to make or use the embodiments of the disclosure and are not intended to limit the scope of the disclosure, which is defined by the claims. For purposes of description herein, the terms "upper", "lower", "left", "rear", "right", "front", "vertical", "horizontal", and derivatives thereof shall relate to the invention as oriented in FIG. 1. Furthermore, there is no intention to be bound by any expressed or implied theory presented in the preceding technical field, background, brief summary or the following detailed description. It is also to be understood that the specific devices and processes illustrated in the attached drawings, and described in the following specification, are simply exemplary embodiments of the inventive concepts defined in the appended claims. Hence, specific dimensions and other physical characteristics relating to the embodiments disclosed herein are not to be considered as limiting, unless the claims expressly state otherwise.

Piston driven cylinders, such as the exemplary cylinder assembly 100, which can be a hydraulic or pneumatic cylinder, illustrated in FIG. 1, are generally operated by high pressure air or hydraulic fluid. The term hydraulic cylinder is used in the meaning of using either a fluid, such as a hydraulic fluid, or a gas, such as pressurized air. The hydraulic cylinder assembly 100 is fabricated having a cylinder head 112 extending between a cylinder barrel 110 and a cylinder base 114. The cylinder barrel 110 is fabricated of a tubular material suitable for retaining a pressurized medium. The cylinder barrel 110 is enclosed with the inclusion of cylinder head 112 at a head end of the cylinder head 112 and a cylinder base 114 at a base end of the cylinder head 112. A base seal 116 is combined with the cylinder base 114 to provide a seal at the base end of the cylinder barrel 110. A bushing 136 is combined with the cylinder head 112 to provide a seal at the head end of the cylinder barrel 110. A sealed chamber 118 is created within an interior of the hydraulic cylinder assembly 100.
A piston 120 is slideably assembled within the sealed chamber 118. The piston 120 is fabricated having an exterior shape and peripheral size that is substantially equal to an interior shape and peripheral size of the sealed chamber 118. At least one piston seal and rings 122 is provided about a peripheral edge of the piston 120 forming a fluid seal between the interior periphery of the sealed chamber 118 and the exterior periphery of the piston 120, while enabling motion of the piston 120 along a longitudinal axis thereof. A piston tie rod 130 is attached to the piston 120 by a piston rod attachment 132. The bushing 136 provides a sealed passageway for the piston tie rod 130 to exit from within the sealed chamber 118 for engagement with other mechanically operative members. The piston tie rod 130 slideably passes through a bushing aperture 138 of the bushing 136.

The components used in an outer structure of the hydraulic cylinder assembly 100 can be fabricated of a metallic material, a composite material, a polymer, a plastic material, and the like. The bushing 136 can be fabricated of brass, a polymer, and the like. The piston tie rod 130 is commonly fabricated of a solid or tubular metallic material, but could be manufactured of any other material, such as a composite, a plastic, and the like, suitable for the application.

An operational medium is utilized to operate the hydraulic cylinder assembly 100. The operational medium can be a pressurized gas (air, nitrogen, and the like) or a fluid (such as hydraulic fluid, oil, water, and the like). Operation of the hydraulic cylinder assembly 100 is completed by adjusting pressure of an operational medium within one or both sections of the sealed chamber 118 as segmented by the position of the piston 120. The change in pressure applies a force to the respective side of the piston 120. The resulting force causes the piston 120 to slideably move within the sealed chamber 118, in turn causing the piston tie rod 130 to move accordingly. A first pressure may be applied through a connection 150 suitable for, for example, hydraulic oil, located through the bushing 136 (as shown), the cylinder head 112, or any other reasonable location within a head side of the piston 120. Pressure applied to the operational medium on the head side of the piston 120 drives the piston 120 towards the base side of the sealed chamber 118. This draws the piston tie rod 130 inward into the sealed chamber 118. A second pressure may be applied through a connection 154 suitable for, for example, high pressure air, located through the base seal 116 (as shown), the cylinder base 114, or any other reasonable location within a base side of the piston 120. Pressure applied to the
operational medium on the base side of the piston 120 drives the piston 120 towards the head side of the sealed chamber 118. This drives the piston tie rod 130 outward from the sealed chamber 118. The piston tie rod 130 may be coupled to the mechanically operative member by a tailrod 134 or any other coupling interface.

A number of factors can contribute to the overall force exerted by the piston tie rod 130 upon a mechanically operative member coupled thereto. Examples of several factors include the surface area of a face of the piston 120, the pressure of the operational medium, the compressive properties of the operational medium, the maximum allowable pressure contained within the sealed chamber 118, and the like.

The bushing 136 is commonly fabricated of a material designed to wear at a quicker rate than the piston tie rod 130, thus governing the servicing of the hydraulic cylinder assembly 100. The concern is wear of the bushing aperture 138 during use. Motions of the piston tie rod 130 passing through the bushing aperture 138 causes wear on the bushing aperture 138. Friction, non-linear motion, non-axial forces, and the like can contribute to degradation of the condition of the bushing aperture 138 of the bushing 136.

A bushing condition monitoring ring 200 can be integrated into the bushing 136 as illustrated in FIG. 2, with details shown in section views presented in FIGS. 3 and 4. The bushing condition monitoring ring 200 includes a series of electrically conductive wire 220, 222 encased within a dielectric ring 210. Each electrically conductive wire 220, 222 is formed into a loop. The plurality of electrically conductive wire 220, 222 is positioned where they are embedded within the dielectric ring 210. The dielectric ring 210 is preferably formed about the placed electrically conductive wire 220, 222 using any forming process, such as poured molding, injection molding, and the like. The dielectric ring 210 is sized and shaped to fit within a monitoring ring receiving groove 250 of the bushing 136. The dielectric ring 210 includes a centrally located aperture, wherein the centrally located aperture is of a size, shape, and position matching the bushing aperture 138 when the dielectric ring 210 is inserted into the monitoring ring receiving groove 250. A first conductive interface 240 extends in electrical communication from a first end of the electrically conductive wire 220 and a second conductive interface 241 extends in electrical communication from a second end of the electrically conductive wire 220. The first conductive interface 240 and second conductive interface 241 provide an electrical
interface between a processing device 400 (FIG. 5) and the respective electrically conductive wire 220. The second electrically conductive wire 222 and any additional wires include a similar arrangement. In the exemplary embodiment, a first conductive interface 242 extends in electrical communication from a first end of the second electrically conductive wire 222 and a second conductive interface 243 extends in electrical communication from a second end of the second electrically conductive wire 222. The first conductive interface 242 and second conductive interface 243 provide an electrical interface between a processing device 400 (FIG. 5) and the second electrically conductive wire 222.

Functionally, the system is based upon an application of one or more capacitive displacement sensors. A capacitive displacement sensor is a non-contact device capable of high-resolution measurement of the position and/or change of position of any conductive target; in this case, a conductive version of the shaft or piston tie rod 130. The capacitive displacement sensor is also able to measure the thickness or density of non-conductive materials, thus capable of monitoring the condition of a non-conductive dielectric ring 210 and/or a non-conductive version of the piston tie rod 130.

Capacitive displacement sensors can be used to make very precise thickness measurements. Capacitive displacement sensors operate by measuring changes in position. In a condition where the part to be measured has any curvature or deformity, such as the exemplary shaft 130, the distance between the part to be measured and the surface it is placed upon can be accurately measured by using two capacitive sensors to measure a single part. Capacitive sensors are placed on either side of the part to be measured. By measuring the parts from both sides, curvature and deformities are taken into account in the measurement and their effects are not included in the thickness readings. The bushing condition monitoring ring 200 integrates capacitive displacement sensing technology therein to monitor the condition of the bushing aperture 138 of the bushing 136, the surface of the piston tie rod 130, and the gap therebetween.

The bushing condition monitoring ring 200 is integrated into a monitoring system shown in an exemplary block diagram illustrated in FIG. 5. The series of electrically conductive interfaces 240, 241, 242, 243 are provided in electrical communication with a processing device 400 by an electrically conductive carrier. The bushing condition monitoring ring 200 is provided in electrical communication with the processing device.
400 via the series of electrically conductive interfaces 240, 241, 242, 243. The processing
device 400 includes common digital data processing components, include a motherboard,
at least one microprocessor, memory, a data recording device, digital instructions (such as
software, firmware, and the like), input/output controllers, data communication devices,
and the like. A user input device 420 and a user output device 420 are connected in signal
communication to the processing device 400 through the input/output controllers.

The processor monitors the capacitance output signals 260, 262 generated by the
electrically conductive wire 220, 222 of the bushing condition monitoring ring 200 to
determine the condition of the bushing 136. The system compares a condition capacitance
260 measured between each electrically conductive wire 220, 222 and the piston tie rod
130 against a reference capacitance 262 measured between the electrically conductive
wire 220 and second electrically conductive wire 222 to determine any change in
condition of the bushing aperture 138. The processing device 400 would measure and
record the condition capacitance 260 and the respective condition capacitance 260
determined from each electrically conductive wire 220, 222. The system would monitor
the condition continuously, over a period of time-spaced intervals, at random intervals,
upon a manual request, or any other reasonable timeframe or other basis for monitoring
the condition of the bushing 136.

The processing device 400 could record the condition capacitance 260 over time
and compare the history of the condition capacitance 260 and the current condition
capacitance 260 to determine the resulting change thereof. The change in condition
capacitance 260 can be correlated to a condition of the bushing 136, the shaft 130, and/or
the interface therebetween. As the bushing wears, the distance to the shaft/piston
changes, it becomes smaller, thus changing a measured capacitance. The processing
device 400 could record the reference capacitance 262 over time to include considerations
for any other changes in the system, such as temperature, and the like.

It is understood that the electrically conductive wire 220, 222 can be provided in
the form of a wire, a planar material formed in an annular ring providing a planar surface
in parallel with the surface of the shaft 130, and the like.

The exemplary monitoring ring receiving groove 250 is shown located proximate
a central portion of the bushing 136. It is understood that the monitoring ring receiving
groove 250 can be formed at either end of the bushing aperture 138, formed at both ends of the bushing aperture 138 for integrating a bushing condition monitoring ring 200 at each end thereof, or formed along the central location of the bushing aperture 138. In a configuration where the monitoring ring receiving groove 250 is centrally formed (as illustrated, the assembly could additionally include a filler annular ring 252 extending from the exposed edge of the bushing condition monitoring ring 200, 300 to the respective edge of the bushing.

Since many modifications, variations, and changes in detail can be made to the described preferred embodiments of the invention, it is intended that all matters in the foregoing description and shown in the accompanying drawings be interpreted as illustrative and not in a limiting sense. Thus, the scope of the invention should be determined by the appended claims and their legal equivalence.
<table>
<thead>
<tr>
<th>Ref. No.</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>100</td>
<td>hydraulic cylinder assembly 100</td>
</tr>
<tr>
<td>110</td>
<td>cylinder barrel 110</td>
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<td>bushing 136</td>
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<tr>
<td>420</td>
<td>user output device 420</td>
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</table>
What is claimed is:

1. A bushing condition monitoring system, the system comprising:

   a bushing (136) having a bushing aperture (138) extending axially therethrough;

   a monitoring ring receiving groove (250) extending radially outward from the bushing aperture (138);

   a bushing condition monitoring ring (200) positioned within the monitoring ring receiving groove (250), the bushing condition monitoring ring (200) comprising:

   a dielectric ring (210) fabricated of a dielectric material and provided in an annular shape having a concentrically located aperture, and

   at least one electrically conductive wire (220, 222) embedded within said dielectric ring (210), each at least one electrically conductive wire (220, 222) shaped into an annular ring, each electrically conductive annular wire (220, 222) being radially arranged about a central longitudinal axis of the concentrically located aperture to provide a condition capacitance; and

   a conductive interface assembly comprising a plurality of pairs of conductive interfaces (240 & 241)(242 & 243), each pair of conductive interfaces provided in electrical communication with a respective end of the respective at least one electrically conductive annular wire (220, 222).

2. A bushing condition monitoring system as recited in claim 1, further comprising:

   a processing device (400) comprising an input device for receiving an electrical signal from said electrically conductive interface (240, 241, 242, 243) and digital instructions for monitoring and analyzing electrical properties of each at least one electrically conductive electrically conductive annular wire (220, 222) obtained via said electrically conductive interface (240, 241, 242, 243).
3. A bushing condition monitoring system as recited in claim 2, wherein the processing device (400) is operated by a set of digital instructions, said set of digital instructions directing said processing device (400) to monitor said condition capacitance over at least one of:

- continuously,
- a predetermined time interval,
- a random time interval, and
- upon a manual request.

4. A bushing condition monitoring system as recited in claim 1, wherein each electrically conductive annular ring (220, 222) is fabricated of one of copper, steel, aluminum, brass, and gold.

5. A bushing condition monitoring system as recited in claim 1, wherein the dielectric ring (210) is fabricated of one of plastic, composite material, nylon, rubber, Polyether ether ketone, or polyester.

6. A bushing condition monitoring system as recited in claim 1, wherein the dielectric ring (210) is fabricated of a material having a lower hardness and density compared to the material of the bushing (136).

7. A bushing condition monitoring system, the system comprising:

- a bushing (136) having a bushing aperture (138) extending axially therethrough;
- a monitoring ring receiving groove (250) extending radially outward from the bushing aperture (138);
a bushing condition monitoring ring (200) positioned within the monitoring ring receiving groove (250), the bushing condition monitoring ring (200) comprising:

- a dielectric ring (210) fabricated of a dielectric material and provided in an annular shape having a concentrically located aperture, and
- a plurality of electrically conductive wires (220, 222) embedded within said dielectric ring (210), each electrically conductive wire (220, 222) shaped into an annular ring, each electrically conductive annular wire (220, 222) being radially arranged about a central longitudinal axis of the concentrically located aperture to provide a condition capacitance;

- a conductive interface assembly comprising a plurality of pairs of conductive interfaces (240 & 241)(242 & 243), each pair of conductive interfaces provided in electrical communication with a respective end of the respective electrically conductive annular wires (220, 222); and

- each electrically conductive annular ring (220, 222) is provided in a parallel arrangement with an adjacent electrically conductive annular ring (220, 222), providing a reference capacitance therebetween.

8. A bushing condition monitoring system as recited in claim 7, further comprising:

- a processing device (400) comprising an input device for receiving an electrical signal from said electrically conductive interface (240, 241, 242, 243) and digital instructions for monitoring and analyzing electrical properties of each electrically conductive electrically conductive annular wire (220, 222) obtained via said electrically conductive interface (240, 241, 242, 243).

9. A bushing condition monitoring system as recited in claim 8, wherein the processing device (400) is operated by a set of digital instructions, said set of digital instructions directing said processing device (400) to monitor said condition capacitance and said reference capacitance over at least one of:
continuously,
a predetermined time interval,
a random time interval, and
upon a manual request.

10. A bushing condition monitoring system as recited in claim 7, wherein each electrically conductive annular ring (220, 222) is fabricated of one of copper, steel, aluminum, brass, and gold.

11. A bushing condition monitoring system as recited in claim 7, wherein the dielectric ring (210) is fabricated of one of plastic, composite material, nylon, rubber, Polyether ether ketone, or polyester.

12. A bushing condition monitoring system as recited in claim 7, wherein the dielectric ring (210) is fabricated of a material having a lower hardness and density compared to the material of the bushing (136).

13. A bushing condition monitoring system, the system comprising:
a cylinder barrel (110) having a cylinder head (112) attached to a first end thereof and a cylinder base (114) attached to a second, opposite end thereof, the cylinder barrel (110), cylinder head (112), and cylinder base (114) collectively defining a hydraulically sealed chamber (118).
a bushing (136) having a bushing aperture (138) extending axially therethrough, said bushing being integrated into said cylinder head (112);
a shaft (130) passing the bushing aperture (138);
a piston (120) attached to said shaft (130), wherein said piston is slideably positioned within said sealed chamber (118);

a monitoring ring receiving groove (250) extending radially outward from the bushing aperture (138);

a bushing condition monitoring ring (200) positioned within the monitoring ring receiving groove (250), the bushing condition monitoring ring (200) comprising:

   a dielectric ring (210) fabricated of a dielectric material and provided in an annular shape having a concentrically located aperture, and

   a plurality of electrically conductive wires (220, 222) embedded within said dielectric ring (210), each electrically conductive wire (220, 222) shaped into an annular ring, each electrically conductive annular wire (220, 222) being radially arranged about a central longitudinal axis of the concentrically located aperture to provide a condition capacitance;

   a conductive interface assembly comprising a plurality of pairs of conductive interfaces (240 & 241)(242 & 243), each pair of conductive interfaces provided in electrical communication with a respective end of the respective electrically conductive annular wires (220, 222); and

   each electrically conductive annular ring (220, 222) is provided in a parallel arrangement with an adjacent electrically conductive annular ring (220, 222), providing a reference capacitance therebetween.

14. A bushing condition monitoring system as recited in claim 13, further comprising:

   a processing device (400) comprising an input device for receiving an electrical signal from said electrically conductive interface (240, 241, 242, 243) and digital instructions for monitoring and analyzing electrical properties of each electrically conductive electrically conductive annular wire (220, 222) obtained via said electrically conductive interface (240, 241, 242, 243).
15. A bushing condition monitoring system as recited in claim 14, wherein the processing device (400) is operated by a set of digital instructions, said set of digital instructions directing said processing device (400) to monitor said condition capacitance and said reference capacitance over at least one of:

continuously,

a predetermined time interval,

a random time interval, and

upon a manual request.

16. A bushing condition monitoring system as recited in claim 13, wherein each electrically conductive annular ring (220, 222) is fabricated of one of copper, steel, aluminum, brass, and gold.

17. A bushing condition monitoring system as recited in claim 13, wherein the dielectric ring (210) is fabricated of one of plastic, composite material, nylon, rubber, Polyether ether ketone, or polyester.

18. A bushing condition monitoring system as recited in claim 13, wherein the dielectric ring (210) is fabricated of a material having a lower hardness and density compared to the material of the bushing (136).
## INTERNATIONAL SEARCH REPORT

### A. CLASSIFICATION OF SUBJECT MATTER

<table>
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### ADD.

According to International Patent Classification (IPC) or to both national classification and IPC.

### B. FIELDS SEARCHED

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Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched.

### C. DOCUMENTS CONSIDERED TO BE RELEVANT

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<tr>
<th>Category</th>
<th>Citation of document, with indication, where appropriate, of the relevant passages</th>
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<td>A</td>
<td>WO 2011/069519 Al (SKF AB [SE]; Ziegler Sébastian [NL]; Herdier Romain [NL]; Wit De Frank) 16 June 2011 (2011-06-16) claim 1; figures la, lb</td>
<td>1, 7, 13</td>
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<td>EP 2 182 341 A2 (Bosch Gmbh Robert [DE]) 5 May 2010 (2010-05-05) claim 1; figure 2</td>
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<td>EP 1 956 275 Al (Bosch Gmbh Robert [DE]) 13 August 2008 (2008-08-13) claim 1; figure 1</td>
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Further documents are listed in the continuation of Box C. See patent family annex.

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## Date of the actual completion of the international search

22 February 2013

Date of mailing of the international search report

01/03/2013

Name and mailing address of the ISA:

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
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Fax: (+31-70) 340-3016

Authorized officer

Kri kori an, Olivier

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