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(54) **SENSOR FOR WEAR MEASUREMENT, METHOD OF MAKING, AND METHOD OF OPERATING SAME**

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F16C 17/02	(2006.01)

(52) **U.S. Cl.**

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(57) **ABSTRACT**

A wear sensor comprising:

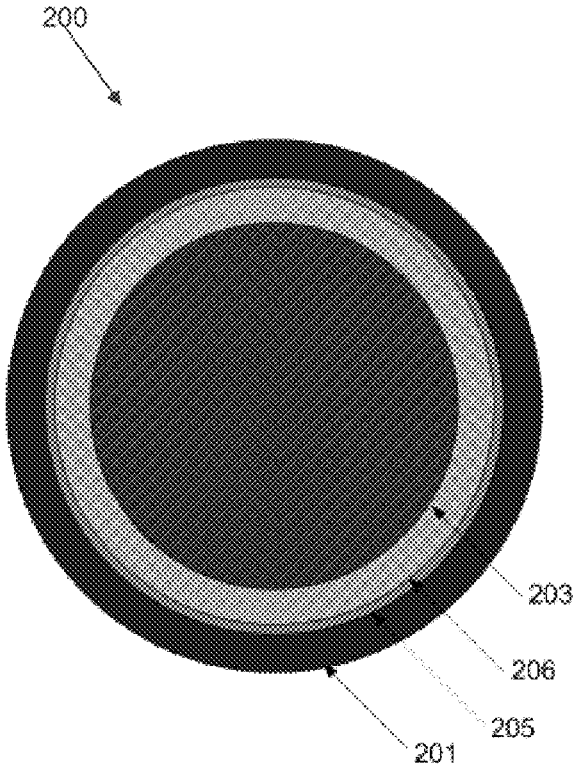
an insulating substrate having a top surface and a bottom surface;

a conductive electrode formed on said top surface of said insulating substrate;

an insulating wear lining material having a first side secured to said top surface of said insulating substrate and conductive electrode, an opposite second side that will be worn down by relative motion between the wear sensor and a moving component;

one or more contact points where the electrical properties between the electrode and the moving component can be measured; and

one or more perforations through the thickness of the substrate and electrode, through which an adhesive may flow, thereby increasing the peel strength between the wear sensor and race or between the wear sensor and the wear liner.



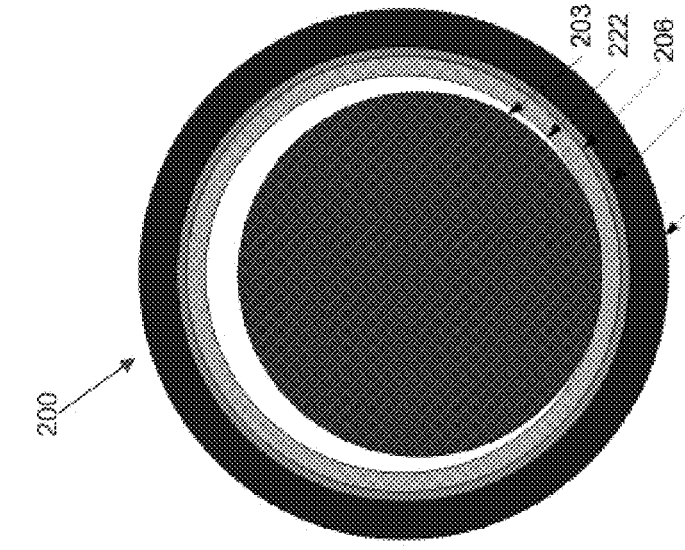


FIG. 1C

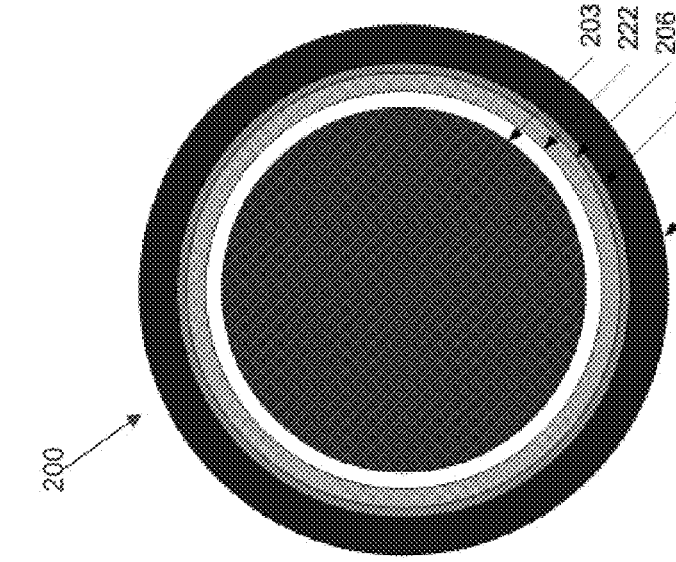


FIG. 1B

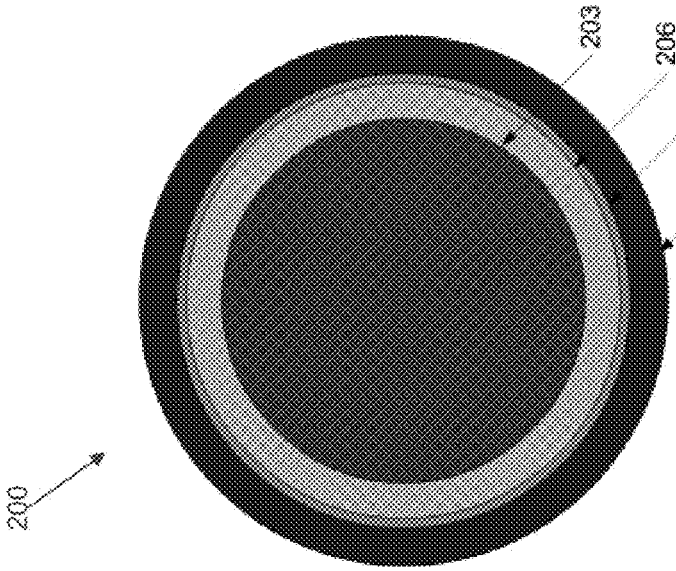


FIG. 1A

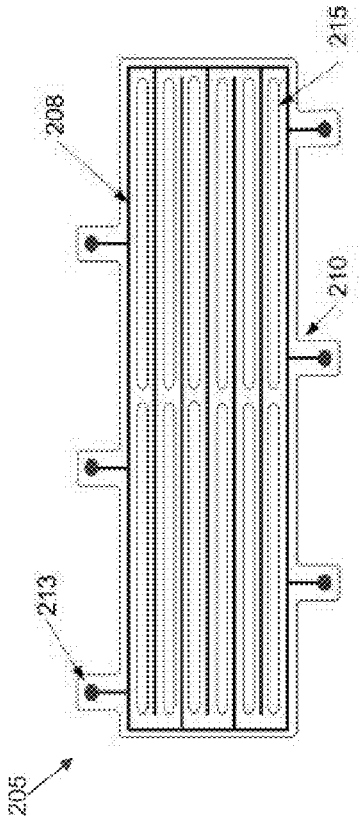


FIG. 2C

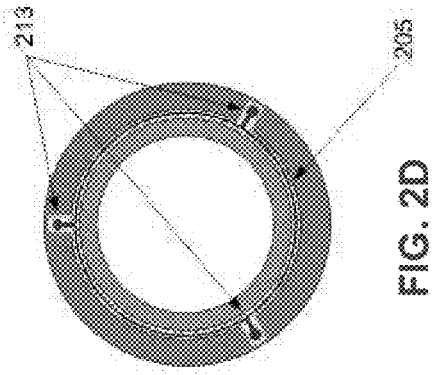
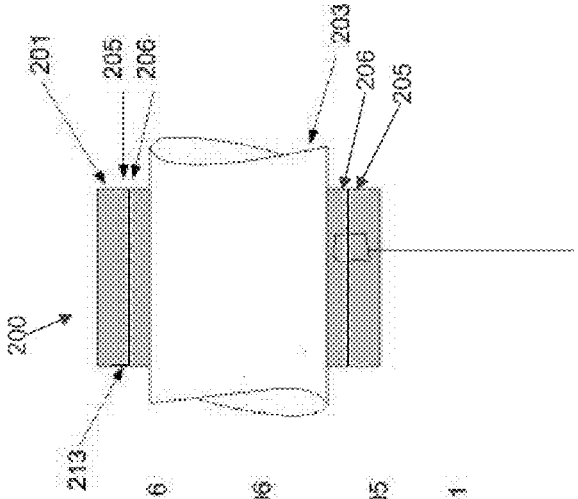


FIG. 2D



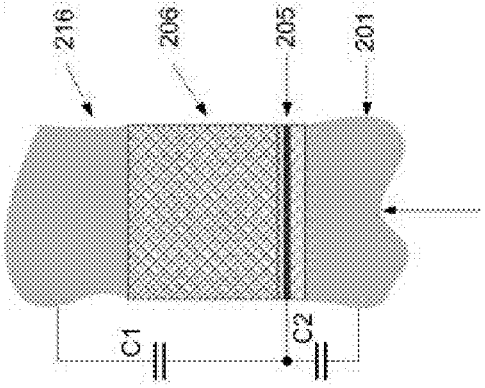


FIG. 2A

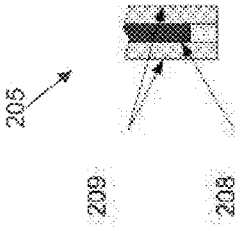


FIG. 2B

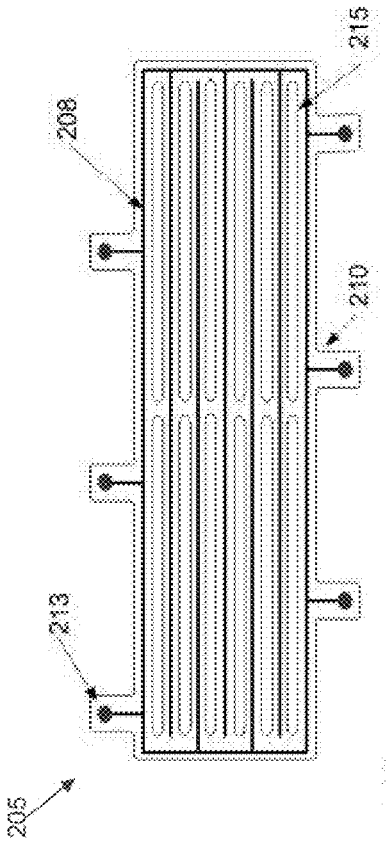


FIG. 3C

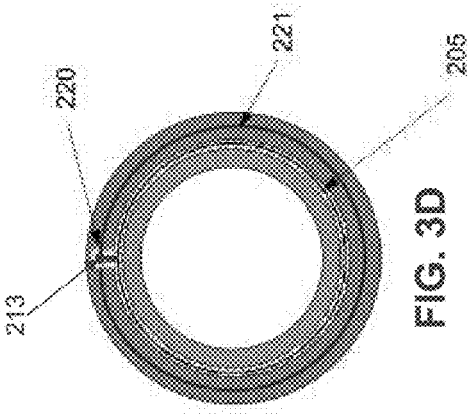


FIG. 3D

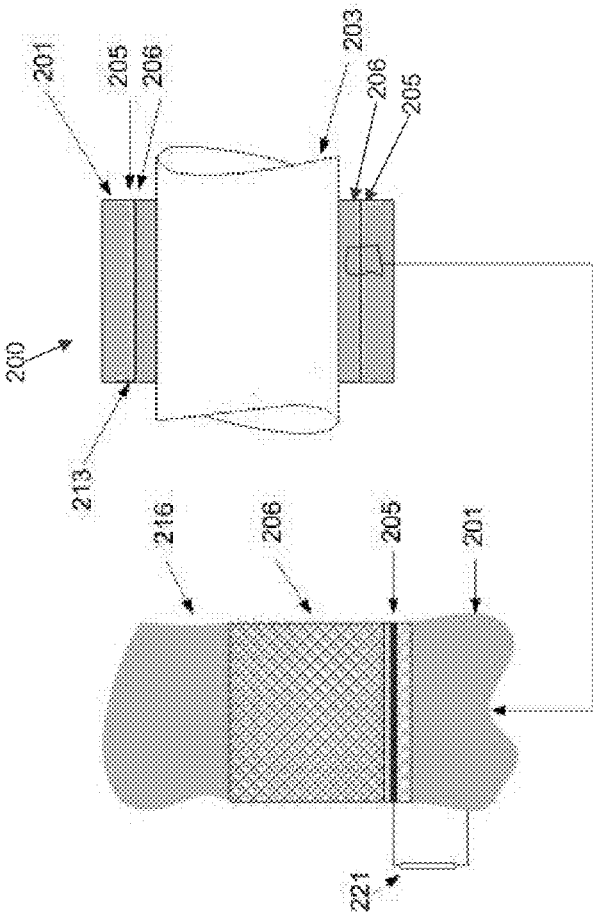


FIG. 3A

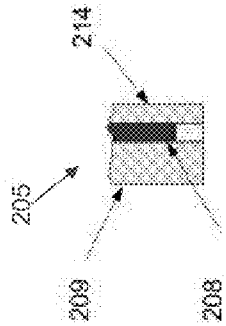


FIG. 3B

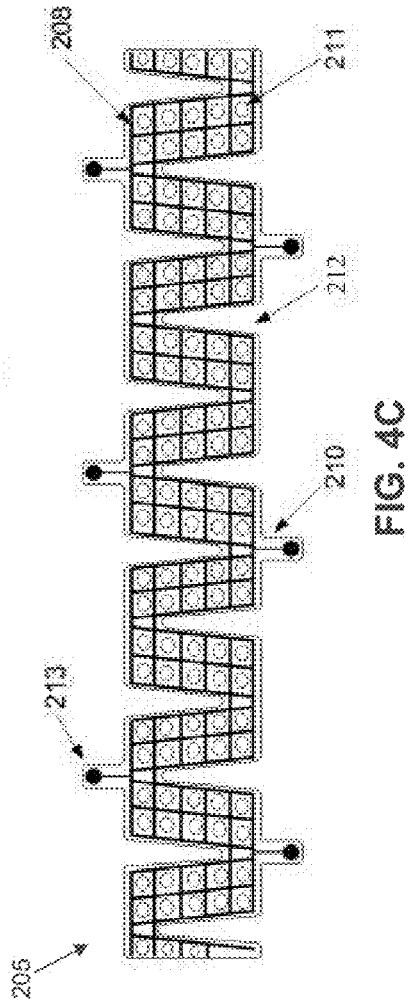


FIG. 4C

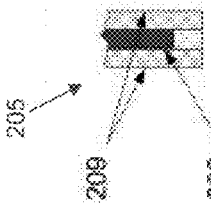


FIG. 4B

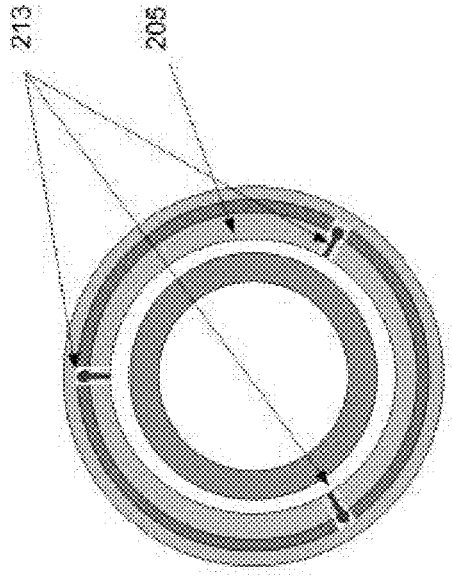


FIG. 4D

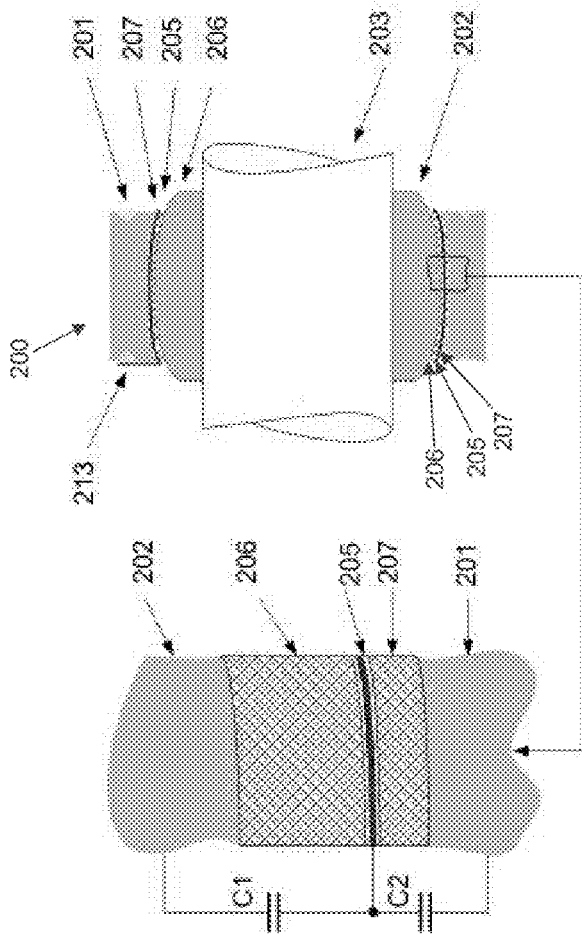


FIG. 4A

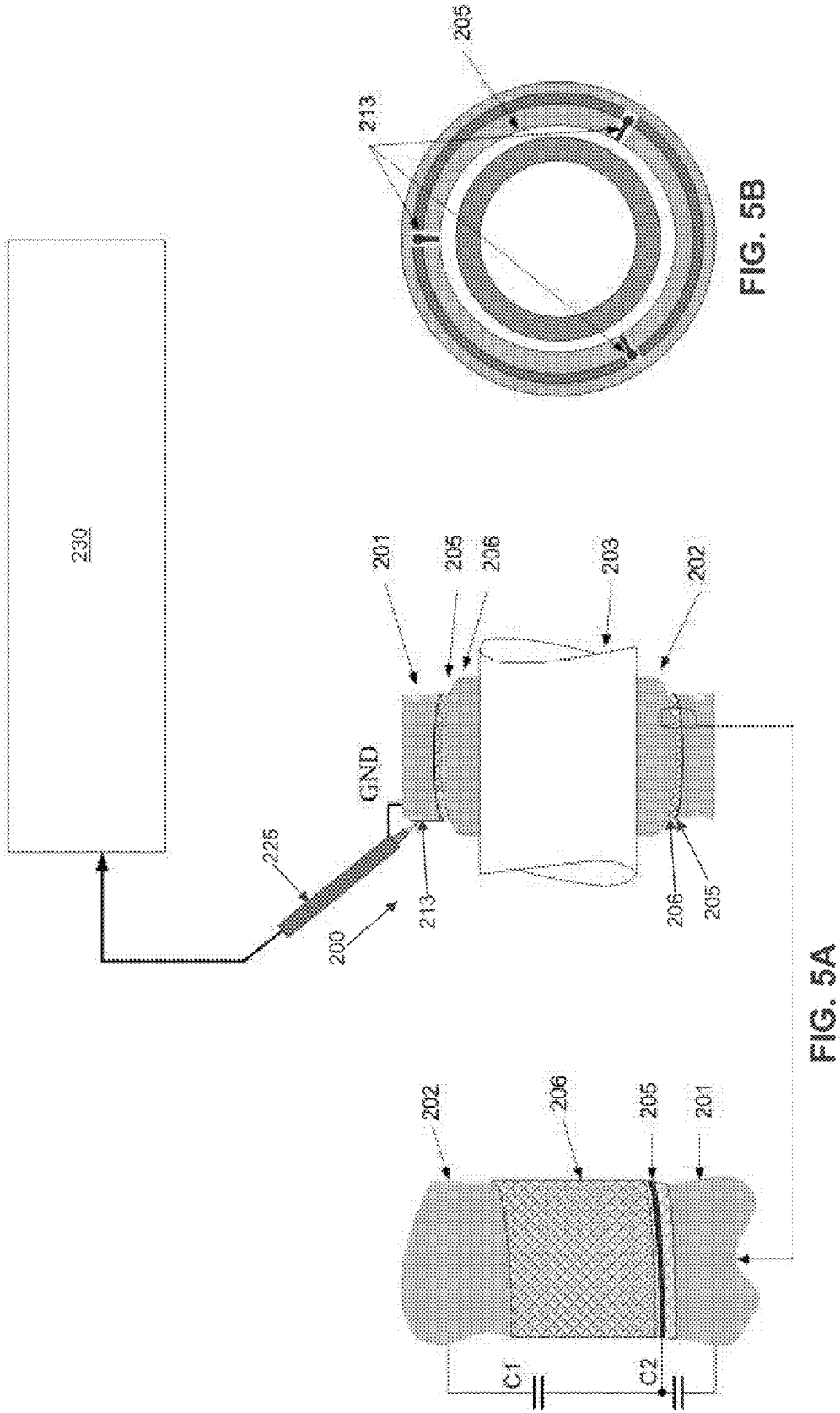

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FIG. 5B

FIG. 5A

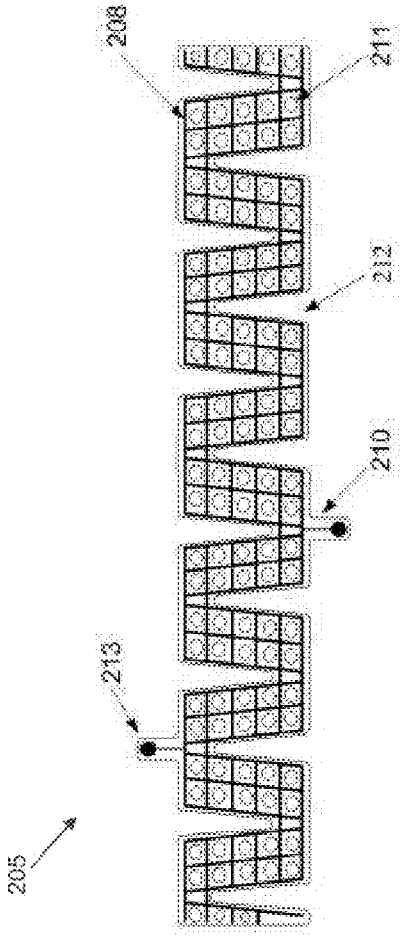


FIG. 6C

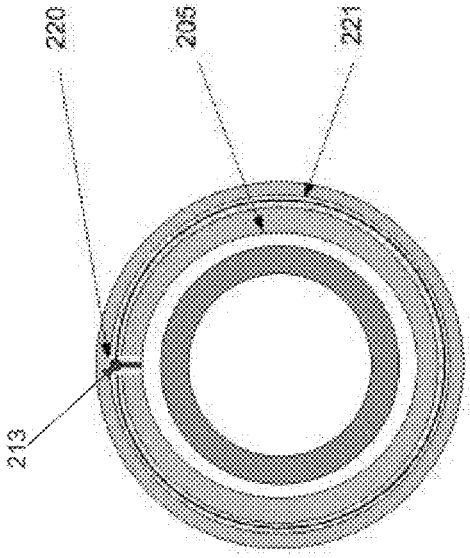


FIG. 6D

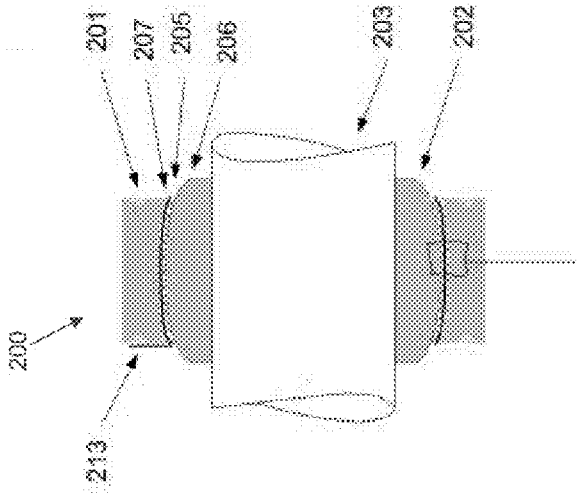


FIG. 6A

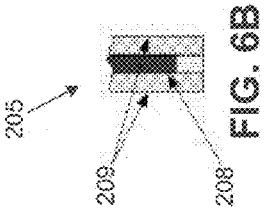
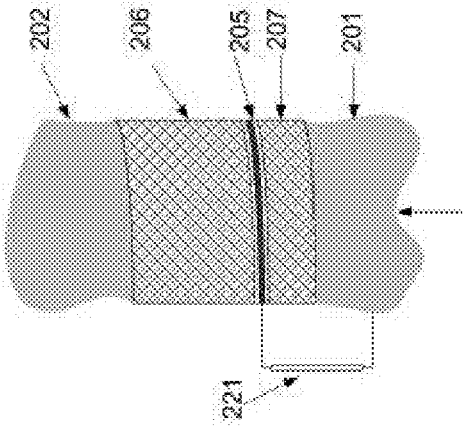


FIG. 6B



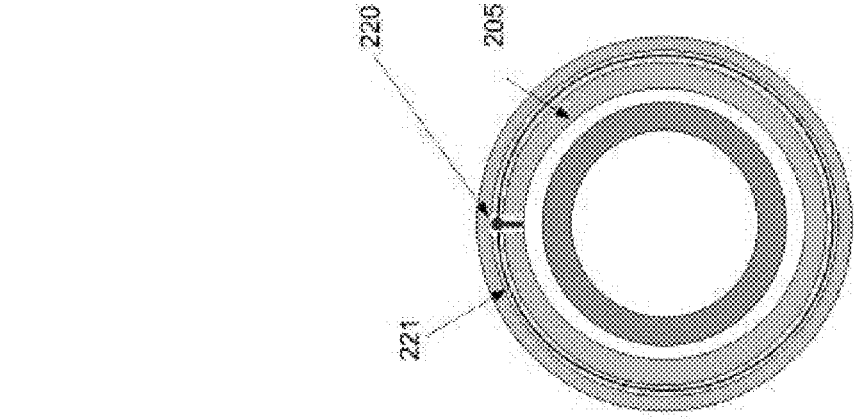

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FIG. 7B

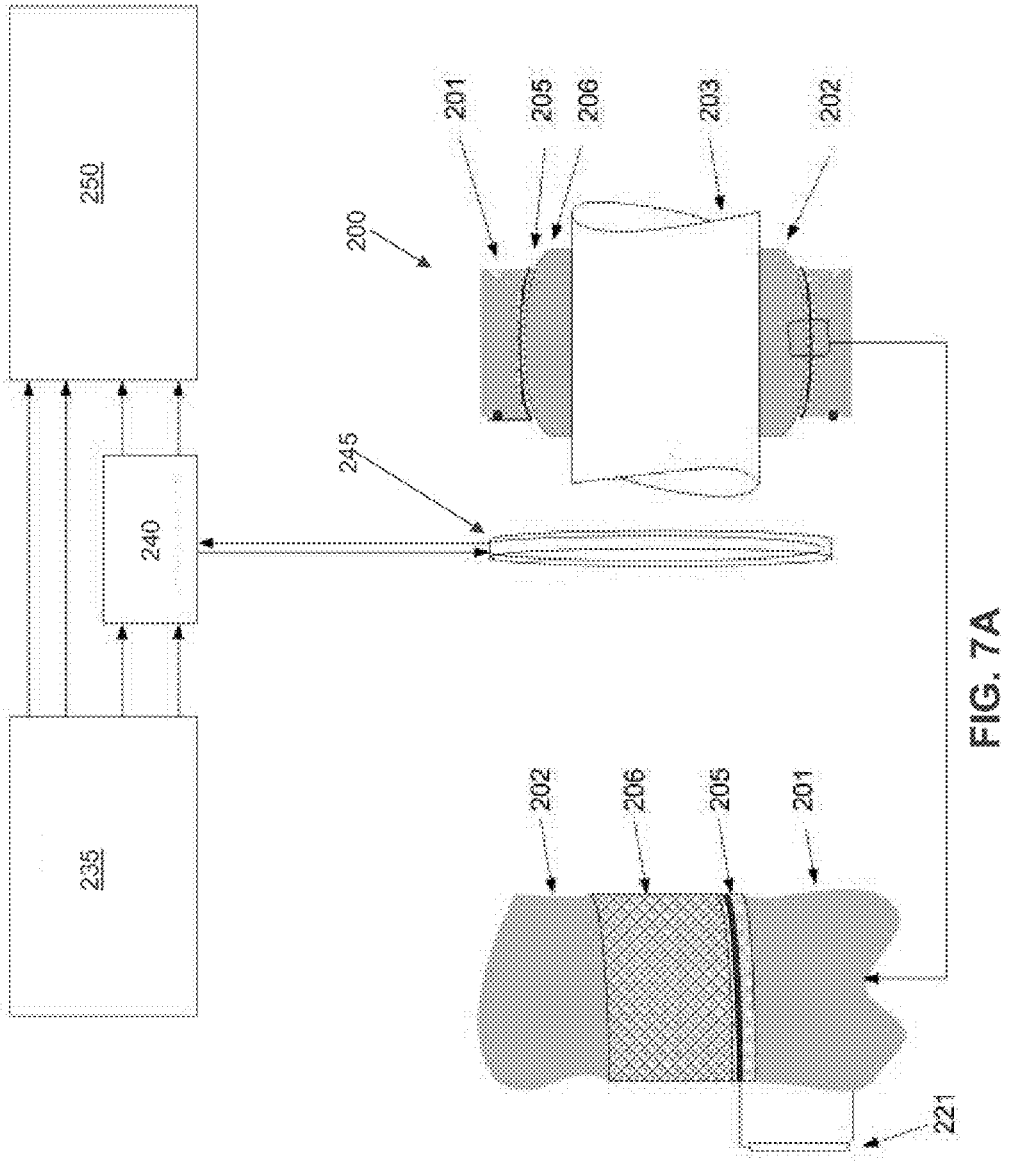
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FIG. 7A

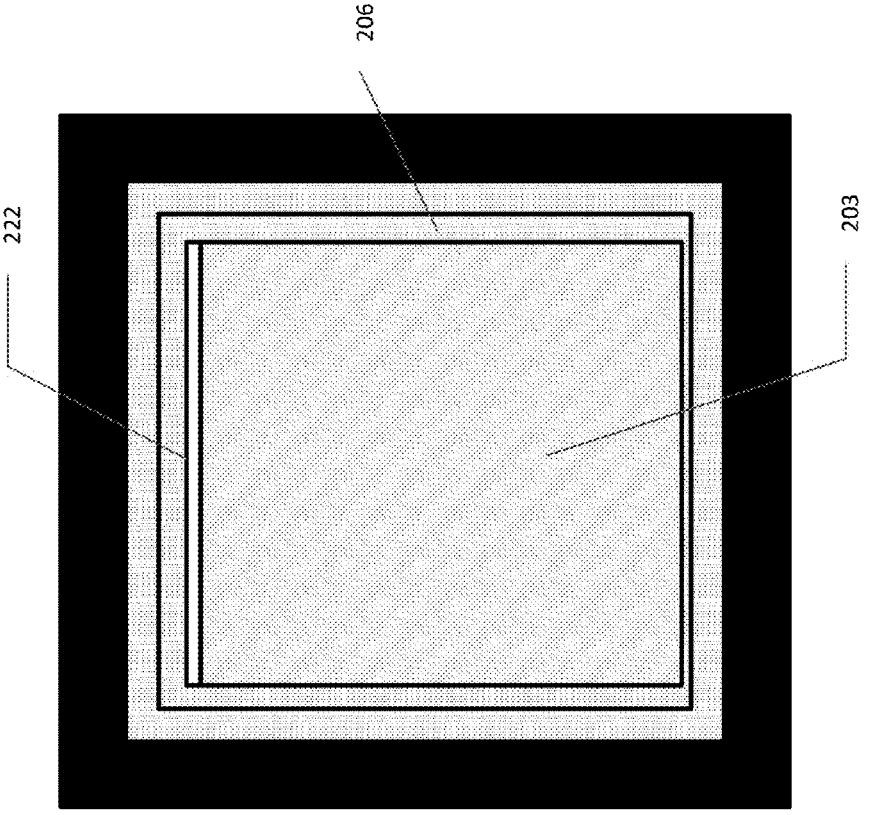

FIG. 8B

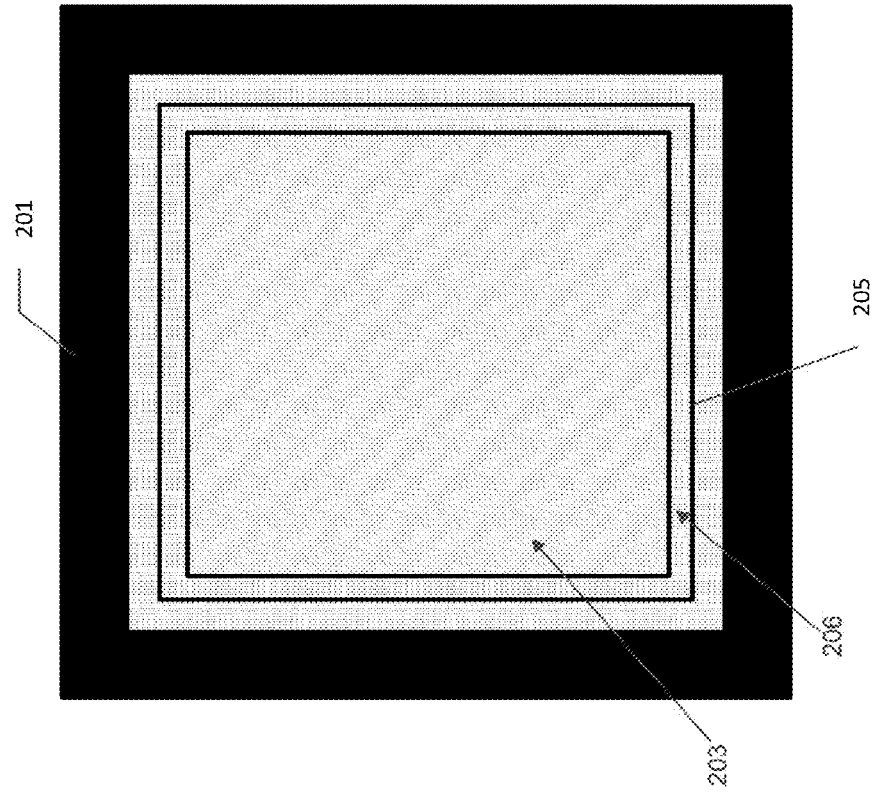

FIG. 8A

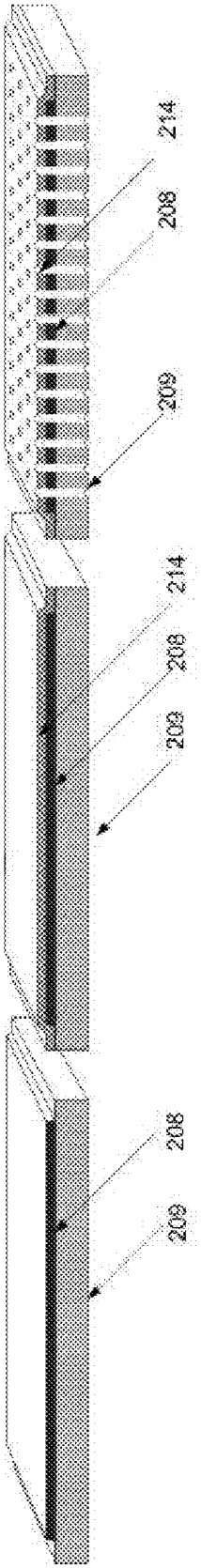

FIG. 9C

FIG. 9B

FIG. 9A

SENSOR FOR WEAR MEASUREMENT, METHOD OF MAKING, AND METHOD OF OPERATING SAME

REFERENCE TO PENDING PRIOR PATENT APPLICATION

[0001] This patent application claims benefit of pending prior U.S. Provisional Patent Application Ser. No. 61/713,735, filed Oct. 15, 2012 by Iosif Izrailit et al. for SENSOR FOR WEAR MEASUREMENT, METHOD OF MAKING, AND METHOD OF OPERATING SAME (Attorney's Docket No. NANO-19 PROV), which patent application is hereby incorporated herein by reference.

FIELD OF THE INVENTION

[0002] This invention relates to wear sensing devices in general, and more particularly to a sensor suited to the measurement of wear in bearings that employ a low friction wear lining material, instead of balls or rollers to support the load. More particularly, the invention relates to the electrical measurement of capacitance or other electrical impedance parameters between a movable surface and an electrode, which may be positioned within or on the back side of the wear liner, and its correlation to wear.

BACKGROUND OF THE INVENTION

[0003] Condition based maintenance programs rely upon inspection to identify those parts that are nearing their end of life. Bearings are no exception to this rule. The replacement of a bearing before it is fully worn out may be wasteful, but waiting too long to replace a bearing can be catastrophic in some applications, particularly with rotorcraft and aircraft. It is known in the art to place sensors inside a bearing to measure wear. Discenzo (U.S. Pat. No. 7,551,288) disclosed a system for monitoring bearing wear that employed an optical fiber embedded in the bearing and operatively coupled to an interferometric system. Such a system will measure wear at only one point, and that point may not coincide with the area of maximum wear. Bearings with multiple optical fibers were disclosed to try to remedy this defect, but the overall complexity required for this measurement rendered the solution cost prohibitive.

[0004] It is the goal of this invention to provide a sensor that will detect wear in any location within the bearing, and enable timely replacement, using a cost effective method.

SUMMARY OF THE INVENTION

[0005] These and other objects are addressed by the provision and use of a novel insulating wear liner with a sensor for detecting wear on a bearing. More particularly, a sensor having an electrode can be inserted in, or on the back of, a wear liner in a bearing for monitoring the wear of the wear liner by monitoring the impedance parameters such as capacitance, inductance, and resistance, or a combination thereof, between the electrode and a movable component, such as a shaft.

[0006] In one form of the present invention, there is provided a wear sensor comprising:

[0007] an insulating substrate having a top surface and a bottom surface;

[0008] a conductive electrode formed on said top surface of said insulating substrate;

[0009] an insulating wear lining material having a first side secured to said top surface of said insulating substrate and conductive electrode, an opposite second side that will be worn down by relative motion between the wear sensor and a moving component;

[0010] one or more contact points where the electrical properties between the electrode and the moving component can be measured; and

[0011] one or more perforations through the thickness of the substrate and electrode, through which an adhesive may flow, thereby increasing the peel strength between the wear sensor and race or between the wear sensor and the wear liner.

[0012] In another form of the present invention, there is provided a wear sensor comprising:

[0013] a conductive filament that is deposited on or woven into an insulating, wear resistant material, such that the capacitance between the conductive filament and a moving component increases as the wear resistant material is worn away.

[0014] In another form of the present invention, there is provided a method for sensing wear in a sleeve bearing for a moving component, the method comprising:

[0015] providing a wear sensor comprising:

- [0016] an insulating substrate having a top surface and a bottom surface;
- [0017] a conductive electrode formed on said top surface of said insulating substrate;
- [0018] an insulating wear lining material having a first side secured to said top surface of said insulating substrate and conductive electrode, an opposite second side that will be worn down by relative motion between the wear sensor and a moving component;
- [0019] one or more contact points where the electrical properties between the electrode and the moving component can be measured; and
- [0020] one or more perforations through the thickness of the substrate and electrode, through which an adhesive may flow, thereby increasing the peel strength between the wear sensor and race or between the wear sensor and the wear liner;

[0021] positioning the wear sensor inside of a wear liner of a sleeve bearing; and

[0022] measuring at least one electrical property between the electrode of the wear sensor and the moving component so as to determine the wear in the sleeve bearing.

BRIEF DESCRIPTION OF THE DRAWINGS

[0023] These and other objects, features and advantages of the present invention will be more fully disclosed or rendered obvious by the following detailed description of the preferred embodiments of the invention, which is to be considered together with the accompanying drawings wherein like numbers refer to like parts and further wherein:

[0024] FIG. **1**A illustrates a new sleeve bearing with a sensor inserted into a wear liner in accordance with the present invention;

[0025] FIG. **1**B illustrates a symmetrically worn sleeve bearing with a sensor inserted into a wear liner in accordance with the present invention;

[0026] FIG. **1**C illustrates a non-concentrically worn sleeve bearing with a sensor inserted into a wear liner in accordance with the present invention;

[0027] FIGS. **2**A-**2**D illustrate a sleeve bearing with a capacitive sensor inserted into a wear liner in accordance with the present invention, wherein the capacitive sensor is to be measured with a probe contact;

[0028] FIGS. **3**A-**3**D illustrate a sleeve bearing with a capacitive sensor inserted into a wear liner in accordance with the present invention, wherein the sleeve bearing comprises an antenna with significant inductance for creating a resonant LC circuit;

[0029] FIGS. **4**A-**4**D illustrate a spherical bearing with a capacitive sensor inserted into a wear liner in accordance with the present invention, wherein the capacitive sensor is to be measured with a probe contact;

[0030] FIGS. **5**A and **5**B illustrate a method of interrogating a capacitive sensor inserted into a wear liner of a spherical bearing in accordance with the present invention, using a capacitance meter;

[0031] FIGS. **6**A-**6**D illustrate a spherical bearing with a capacitive sensor inserted into a wear liner in accordance with the present invention, and wherein the spherical bearing comprises an antenna with significant inductance for creating a resonant LC circuit;

[0032] FIGS. **7**A and **7**B illustrate a method of interrogating the capacitive sensor described in FIGS. **6**A-**6**D with a tracking generator, matching network, interrogating antenna, and a spectrum analyzer;

[0033] FIG. **8**A illustrates a new square telescoping bearing with a sensor inserted into a wear liner in accordance with the present invention;

[0034] FIG. **8**B illustrates a worn square telescoping bearing with a sensor inserted into a wear liner in accordance with the present invention; and

[0035] FIGS. **9**A-**9**C depict a process flow for producing the wear liner of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0036] The present invention comprises an insulating wear liner with a sensor that is positioned either within the liner or placed on the non-wearing surface of the liner. The sensor is comprised of a conductive electrode and one or more pads for interrogating the electrical properties of the sensor. The liner is situated between the race and the moving part.

[0037] By way of example but not limitation, a sensor may be positioned inside of the wear liner of a sleeve bearing, and the capacitance between the wear liner and the shaft can be calculated in the new condition of the shaft and wear liner, and after wear by a shaft.

[0038] Looking now at FIG. **1**A, FIG. **1** illustrates a new sleeve bearing with a sensor inserted into the wear liner according to this invention.

[0039] The new, unused sleeve bearing is assembled with a shaft which has radius R_{shaft}. The shaft is centered in the bearing, concentric with the race, which has a radius R_{race}. The sensor conductive electrode is positioned inside the liner, having radius R_{sensor}, such that all three are concentric and $R_{race}>R_{sensor}>R_{shaft}$.

[0040] We assume the liner has a uniform dielectric constant of $\in$. The new bearing, with no wear, will have a capacitance C_{new} between the sensor and the shaft, which is given by:

$$C_{new} = \frac{2\pi\varepsilon_0\varepsilon}{\ln\left(\frac{R_{sensor}}{R_{shaft}}\right)}$$

[0041] Table 1 shows a calculation of capacitance for a new shaft bearing.

TABLE 1

Calculation of capacitance for new liner in a sleeve bearing

NEW LINER		inch	Value	Metric Unit
Wear liner thickness	T	0.012	0.00030	m
sensor position	Sp	0.006	0.00015	m
Diameter of Shaft	Dsh	0.500	0.01270	m
Diameter of Race	Dr = Dsh + 2T	0.524	0.01331	m
Diameter of Sensor	Ds = Dsh + 2Sp	0.512	0.01300	m
Bearing Length	L	0.500	0.01270	m
Dielectric constant of liner	e	2	2	
Permittivity of vacuum	e0		8.85E−12	F/m
Radius of shaft	Rsh = Dsh/2		0.00635	m
Radius of race	Rr = Dr/2		0.00665	m
Radius of sensor	Rs = Ds/2		0.00650	m
Capacitance sensor-shaft	C = 2 * pi * e * e0/(ln(Rs/Rsh)		4689.2	pF/m
Capacitance Bearing, pF	Cb = C * L		59.6	pF

[0042] There will also be capacitance between the sensor electrode and the outer race, but this value should be constant over the life of the bearing. Between the sensor electrode and the moving shaft, there will be wear. Accordingly, the thickness of the wear liner will decrease, and the shaft will exhibit more play. One aspect of this invention is the effect of concentricity on the measured capacitance of a sensor embedded in a wear lining. We recognize two wear modes that could occur, concentric uniform or non-concentric non-uniform.

[0043] To illustrate uniform wear, we consider a bearing that is worn with perfect symmetry so that some of the wear liner is removed from its entire circumference. Next, we position the shaft in perfect concentricity with the race and

sensor electrode. FIG. **1**B illustrates a symmetrically worn sleeve bearing with a sensor inserted into the wear liner according to the present invention.

[0044] In this arrangement, there are two capacitors in series, one made of air C_{air}, and another made from the remaining liner C_{liner} The air gap, having thickness W, will have a capacitance based on the radial gap, $R_{liner}=R_{shaft}+W$. The capacitance of that gap will follow:

$$C_{air} = 2\pi\varepsilon_0\left(\frac{\varepsilon_{air}}{\ln\left(\frac{(R_{shaft}+W)}{R_{shaft}}\right)}\right)$$

[0045] Likewise, the wear liner will have a capacitance based on its thickness, equal to $R_{sensor}-R_{liner}$, or $R_{sensor}-(R_{shaft}+W)$

$$C_{liner} = 2\pi\varepsilon_0\left(\frac{\varepsilon_{liner}}{\ln\left(\frac{R_{sensor}}{R_{shaft}+W}\right)}\right)$$

[0046] The total capacitance, C_T, will follow that of two capacitors in series; $C_T=(C_{air}\times C_{liner})\ (C_{air}+C_{liner})$. Table 2 shows the result of this calculation.

TABLE 2

Concentrically worn sleeve bearing

CONCENTRIC WEAR		inch	Value	Metric Unit
Wear liner thickness	T	0.012	0.000305	m
sensor position	Sp	0.006	0.000152	m
Diameter of Shaft	Rsh = Dsh/2	0.500	0.012700	m
Diameter of Race	Rr = Dr/2	0.524	0.013310	m
Diameter of Sensor	Rs = Ds/2	0.512	0.013005	m
Bearing Length	L	0.500	0.012700	m
Dielectric constant of liner	e	2	2	
Permittivity of vacuum	e0		8.85E−12	F/m
Radius of shaft	Rshaft		0.00635	m
Radius of race	Rr		0.00665	m
Radius of sensor	Rsensor		0.00650	m
Wear	W	0.004	0.00010	m
Radius of liner	Rliner = Rshaft + Wear		0.00645	m
Capacitance shaft to liner	Cair = 2 * pi * e0(1/ln(Rliner/Rshaft)		3503	pF/m
Capacitance liner to electrode	Cliner = 2 * pi * e0(e/ln(Rsensor/Rliner)		14180	pF/m
Total Capacitance/m	CT = (Cair * Cliner)/(Cair + Cliner)		2809	pF/m
Capacitance	C = CT * L		35.7	pF

[0047] The resulting capacitance is lower than the value calculated in Table 1 for the new bearing. We note that this is the case only if the shaft is held at the center. If loaded, the shaft will be non-concentric and the following example will apply.

[0048] Next, to illustrate the non-concentric, non-uniform case, we consider a bearing that has been loaded and worn preferentially on one side. The result is that the shaft is no longer concentric with the sensor. FIG. **1**C illustrates a non-concentrically worn sleeve bearing with a sensor inserted into the wear liner according to the present invention.

[0049] The capacitance of two cylinders eccentrically located one inside the other with radii (R_{shaft}) and (R_{sensor}), respectively, but with the centers of the two cylinders having a distance (W) apart, will be larger than in the concentric case. Ignoring the replacement of the worn-away dielectric with air, the capacitance would be:

$$C = 2\pi\varepsilon_0\varepsilon\left(\frac{1}{a\cosh(-(W^2-R_{shaft}^2-R_{sensor}^2)/2R_{shaft}R_{sensor})}\right)$$

[0050] The capacitance is calculated for an eccentrically worn sleeve bearing in Table 3.

TABLE 3

Non-concentric wear of a sleeve bearing

WORN LINER		inch	Value	Metric Unit
Wear liner thickness	T	0.012	0.000305	m
sensor position	Sp	0.006	0.000152	m
Diameter of Shaft	Dsh	0.500	0.012700	m
Diameter of Race	Dr = Dsh + 2T	0.524	0.013310	m
Diameter of Sensor	Ds = Dsh + 2Sp	0.512	0.013005	m
Bearing Length	L	0.500	0.012700	m
Dielectric constant of liner	e	2	2	
e0	e0		8.85E−12	F/m
Radius of shaft	Rsh = Dsh/2		0.006350	m

TABLE 3-continued

Non-concentric wear of a sleeve bearing

WORN LINER		inch	Value	Metric Unit
Radius of race	Rr = Dr/2		0.006655	m
Radius of sensor	Rs = Ds/2		0.006502	m
Eccentric Wear	W	0.004	0.000102	m
Capacitance/m shaft to sensor	C = 2 * pi * e * e0 * (1/(acosh(−(W^2 − Rsh^2 − Rs^2)/2Rsh * Rs)		6440.4	pF/m
Capacitance of Bearing	Cb = C * L		81.8	pF

[0051] In Table 3, we see that the capacitance is significantly higher for the non-concentric worn bearing than for the new bearing. A notable aspect of this invention is that the capacitance between a metallic shaft and a sensor placed inside or behind the wear liner will increase with concentric or non-concentric wear, as long as the shaft is loaded. The capacitance is an inverse function of the liner thickness. Accordingly, the capacitance increases rapidly as the liner thickness approaches zero.

[0052] Between the two previous examples, we expect to find the non-uniform, non-concentric case to be prevalent, as the loading and wear of bearings is rarely uniform. As such, we can relate the wear of a bearing to a measurable increase in capacitance between the shaft and the sensor.

[0053] The capacitance measurement can be made at different frequencies. A standard frequency for capacitance measurement is 10 kHz. Measurements taken at a higher frequency improve the sensitivity of the measurement, but also increase the error due to interference. The optimal frequency for accuracy will depend on the electromagnetic interference in the environment surrounding the bearing. The measurement of Q factor, which can be calculated from the active and inductive current components in the sensor, provides information about the status of the liner. If at any point the gap between the sensor and the ball approaches zero, Q will drop rapidly toward zero. It will also be electrically shorted at this point. A Q under 5 indicates that the bearing needs immediate replacement, and a Q above 20 indicates a bearing with good health. The electrical shorting of the sensor and ball can also be used as an indicator that the wear liner has failed in at least one spot, and therefore needs replacement.

[0054] Turning again to FIG. **1**, FIG. **1**A illustrates a new sleeve bearing (without wear) **200**, comprising an outer race **201**, a movable shaft **203**, a wear liner **206** and a sensor **205** inserted into wear liner **206**.

[0055] FIG. **1**B illustrates the sleeve bearing **200** of FIG. **1**A after symmetric wear of wear liner **206**. The symmetric wear of wear liner **206** results in a worn sleeve bearing **200** having an equal air gap **222** between wear liner **206** and movable shaft **203**, with erosion of all wear on sleeve bearing **200** lining up to sensor **205**.

[0056] FIG. **1**C illustrates an asymmetrically, a non-concentrically worn sleeve bearing **200** with a sensor **205**, where shaft **203** is closer to sensor **205** in one location than in another location. An air gap **222** is created by the removed material.

[0057] Looking now at FIG. **2**A, FIG. **2**A illustrates a sensor **205** for a sleeve bearing **200**, comprising a race **201**, a shaft **203**, a sensor **205** and a wear liner **206**. Sensor **205** comprises a conductive trace **208** sandwiched between a lower and upper layer of insulating substrate **209** which may be of differing thicknesses (FIG. **2**B). When sensor **205** is laid flat (FIG. **2**C), conductive trace **208** can be seen in detail, along with tabs **210** that extend from sleeve bearing **200**. Slots **215** formed on sensor **205** assist in the flow of adhesive between layers. Electrode pads **213** are positioned on the surface of tabs **210** which can be probed with a capacitance meter to measure the capacitance between one electrode pad and shaft **203** (FIG. **2**D).

[0058] Looking now at FIG. **3**A, FIG. **3**A illustrates a sensor **205** for a sleeve bearing **200**, comprising a race **201**, a shaft **203**, a sensor **205** and a wear liner **206**. Sensor **205** comprises a conductive trace **208** sandwiched between a lower layer of insulating substrate **209** and an upper layer of insulating substrate **214** (FIG. **3**B). When sensor **205** is laid flat (FIG. **3**C), conductive trace **208** can be seen in detail, along with tabs **210** that extend from sleeve bearing **200**. Slots **215** formed on sensor **205** assist in the conformation of the sensor to surface variations, and to flow of adhesive between layers. Electrode pads **213** are positioned on the surface of tabs **210** which can be taken together as a connection point **220** for an antenna **221**.

[0059] FIG. **4**A illustrates a spherical bearing **200** comprising a race **201**, a ball **202**, a shaft **203**, a sensor **205**, a wear liner **206** and an insulator **207**. Sensor **205** comprises a conductive trace **208** sandwiched between two layers of insulating substrate **209** (FIG. **4**B). When sensor **205** is laid flat (FIG. **4**C), conductive trace **208** can be seen in detail, along with tabs **210** that extend from sleeve bearing **200**. Holes **211** formed on sensor **205** assist in the flow of adhesive between layers. Strain relief cuts **212** formed on sensor **205** enable sensor **205** to deform into a more conformal shape. Electrode pads **213** are positioned on the surface of tabs **210** for the interrogation of sensor **205** (FIG. **4**D). Viewed end on, after installation, electrode pads **213** may be touched with one probe of a capacitance meter.

[0060] Looking now at FIGS. **5**A and **5**B, FIGS. **5**A and **5**B, illustrate a method of interrogating sensor **205**. As shown in FIG. **5**A, a probe **225** of a precision capacitance meter **230** makes contact with an electrode pad **213** on the circumference of spherical bearing **200**. Assuming that race **201** and shaft **203** are both conductive and electrically connected elsewhere, the capacitance measured by the precision capacitance meter shall be comprised of the capacitance between ball **202** and sensor **205**, which is electrically in series with the capacitance between sensor **205** and race **201**.

[0061] FIG. **6**A illustrates a spherical bearing **200** comprising a race **201**, a ball **202**, a shaft **203**, a sensor **205**, a wear liner **206** and an insulator **207**. Sensor **205** comprises a conductive trace **208** sandwiched between two layers of insulating substrate **209** (FIG. **6**B). When sensor **205** is laid flat (FIG. **6**C), conductive trace **208** can be seen in detail, along with tabs **210** that extend from sleeve bearing **200**. Holes **211** formed on sensor **205** assist in the flow of

adhesive between layers. Strain relief cuts **212** formed on sensor **205** enable sensor **205** to deform into a more conformal shape. Electrode pads **213** are positioned on the surface of tabs **210** for the interrogation of the sensor (FIG. **4**D). Viewed end on, after installation, tabs **210** and electrode pads **213** are connected at a point **220** to an antenna **221**, which may be mounted on the face of race **201**.

[0062] Looking now at FIGS. **7**A and **7**B, FIGS. **7**A and **7**B illustrate a method of interrogating sensor **205** wirelessly. A signal produced by a tracking generator **235** is coupled through a matching network **240** to a loop antenna **245**, which interacts with sensor antenna **221**, for measuring bearing wear remotely. The output frequency of tracking generator **235** is varied over time, and at one moment will match the frequency of the LC circuit created by the sensor's capacitance and the antenna's inductance. At that moment, a spectrum analyzer **250** will detect the resonance frequency. The shift in resonant frequency shift from the change in sensor capacitance will correspond to the reduction in the wear liner thickness. Preferably, sensor antenna **221** may be placed in a detent, which is a circumferential groove in bearing race **201**.

[0063] FIG. **8**A illustrates a new square telescoping bearing with a sensor inserted into the wear liner in accordance with the present invention.

[0064] FIG. **8**B illustrates a worn square telescoping bearing with a sensor inserted into the wear liner in accordance with the present invention.

[0065] One illustrative procedure for producing a device according to the present invention is shown in FIGS. **9**A-**9**C. In FIG. **9**A, there is shown an insulating substrate **209** with a metallic coating **208**. In FIG. **9**B, a second layer of insulator **214** is applied to sandwich the electrode, which may be patterned. In FIG. **9**C, at least one hole or a pattern is cut out, producing a sensor that can be inserted into a bearing. Holes in the sheet are expected to improve the bonding with the substrate.

[0066] Turning back to FIG. **8**A, FIG. **8**A is an end-view of a new, un-worn telescoping structure comprising an outer sleeve **201**, an inner shaft **203** and a wear lining **206**, which has been instrumented with a sensor **205** part-way through wear lining **206**. In FIG. **8**B, wear liner **206** has been worn, leaving an air gap **222** and a reduced lining thickness on one side. The capacitance of this system can be modeled as the sum of the four parallel plate capacitors. Capacitance in this system is equal to the product of the permittivity of free space $\in_0$, the dielectric constant $\in$ and the area A divided by the distance d: $C=\in\in_0 A/d$.

[0067] Comparing FIG. **8**A to FIG. **8**B, the lining thickness on the sides is unchanged, but in FIG. **8**B the upper and lower distances are changed. At the bottom, the thickness of wear lining **206** has been reduced by wear, and a corresponding air gap **222** has opened up above shaft **203** at the top. The upper capacitor will have a lower value than before as the distance between shaft **203** and sensor **205** is increased by air gap **222**. The lower capacitor will have a much higher value than before, as it has a distance between shaft **203** and sensor **205** that is reduced by the same distance as air gap **222**. The increase in capacitance for the lower capacitor will more than make up for the decrease in capacitance for the upper capacitor. This is clear because the function 1/d is nonlinear. It approaches infinity as the quantity 'd' gets small, and it approaches zero as 'd' gets large.

[0068] We note that a similar type of measurement could be made if the wear liner material was conductive, and the resistance was measured as a function of wear.

[0069] There are two methods to measure the capacitance of the sensor. The first is to measure the value directly with a probe and a capacitance meter. The other alternative is to measure the resonant frequency of the combination of the sensor's capacitance and the attached antenna's inductance. A similar measurement could be implemented using an inductive sensor and a distributed capacitor to create the resonant circuit.

[0070] The preceding examples should be construed as non-limiting, as other methods of implementing the sensor are possible. Also, other methods can be used to measure the wear in addition to capacitance, including inductance and resistance.

MODIFICATIONS OF THE PREFERRED EMBODIMENTS

[0071] It should be understood that many additional changes in the details, materials, steps and arrangements of parts, which have been herein described and illustrated in order to explain the nature of the present invention, may be made by those skilled in the art while still remaining within the principles and scope of the invention.

1.-**6**. (canceled)

7. A wear sensor comprising:

a conductive filament that is deposited on or woven into an insulating, wear resistant material, such that the capacitance between the conductive filament and a moving component increases as the wear resistant material is worn away.

8. A wear sensor according to claim **7** wherein the conductive filament is a carbon fiber.

9. A wear sensor according to claim **7** wherein the conductive filament is a carbon nanotube yarn.

10. A wear sensor according to claim **7** wherein the conductive filament is a metal wire.

11. A wear sensor according to claim **7** wherein the conductive filament is a metal coated fiber.

12. (canceled)

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