

[54] **CAPACITOR FOR SENSING
CONTAMINATED OIL**

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317/248; 324/61 R**

[51] Int. Cl. **H01g 5/16; H01g 7/00**

[58] Field of Search **317/246, 247, 248, 249 R;
324/61 R, 60**

[56] **References Cited**

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[57] **ABSTRACT**

Apparatus to determine the dielectric characteristics of a fluid dielectric material including a rigid mounting with a planar mounting surface, a base electrode on a stem secured to the mounting surface and having a broad disc-like portion at one end of the stem and defining a flat electrode face, a ring electrode concentric with the flat face of the base electrode and having an annular wafer-like shape and a mounting projection extending from the outer edge of the wafer-like ring electrode to the planar surface of the rigid mounting and affixed thereto, and a solid insulating media between the base and ring electrodes and forming the remainder of a container wall adjacent the electrodes, the insulating media being formed of a stable low dielectric material which is substantially insensitive to temperature changes.

16 Claims, 7 Drawing Figures

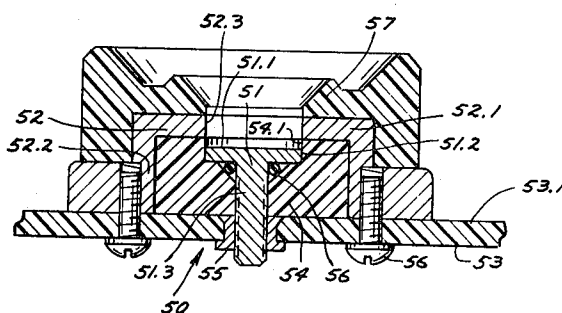


FIG. 1

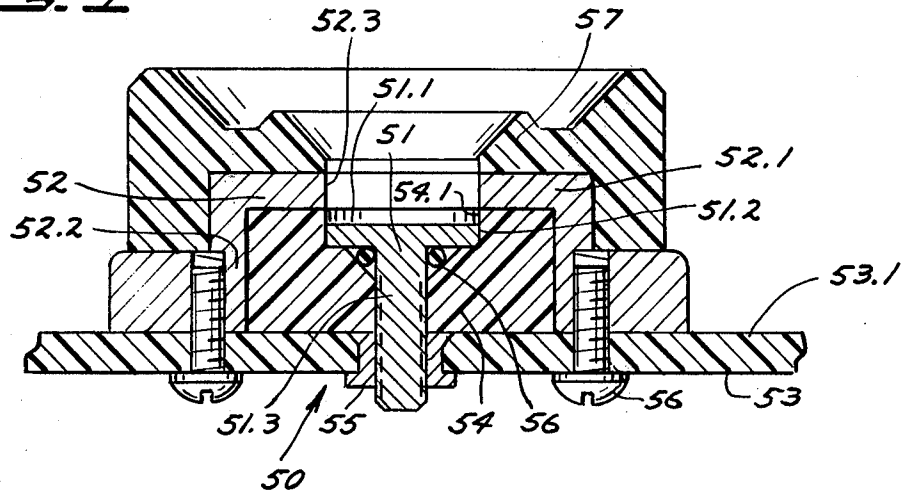
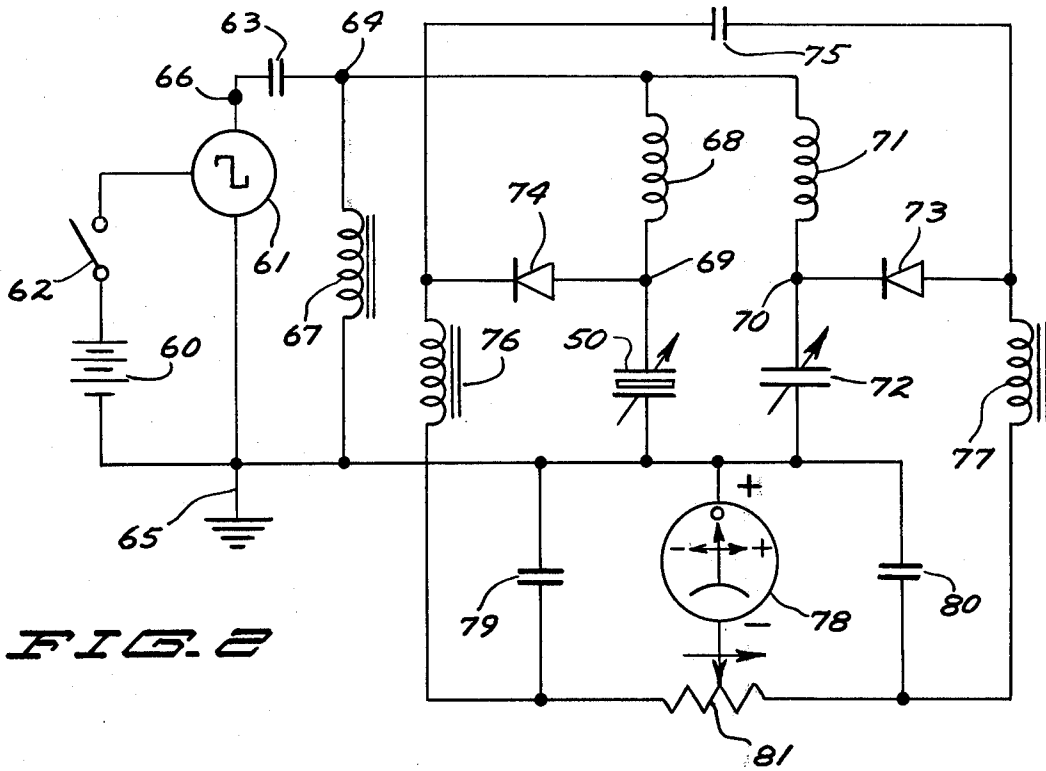


FIG. 2

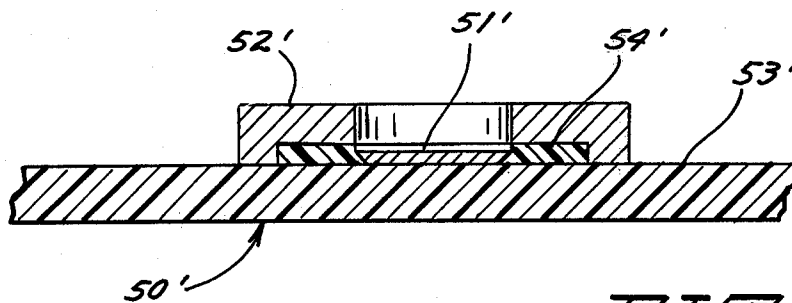
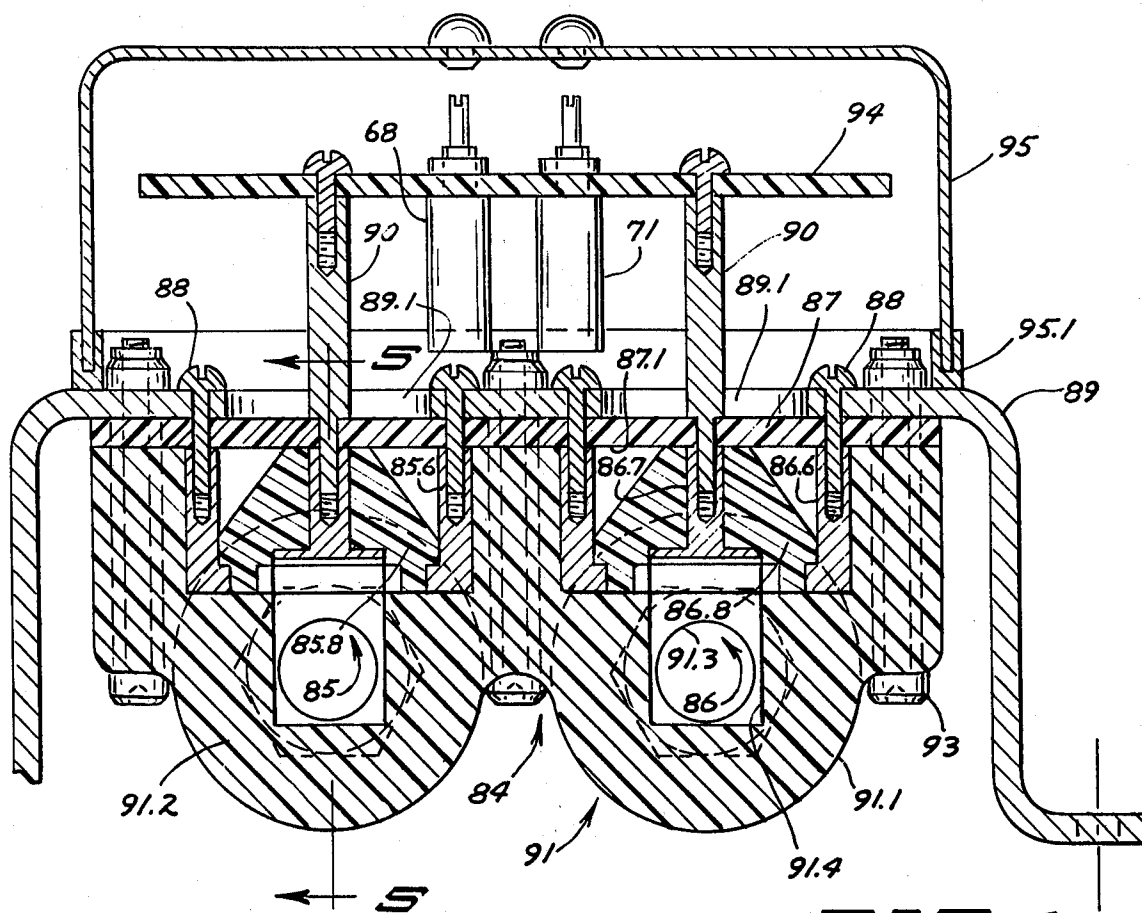
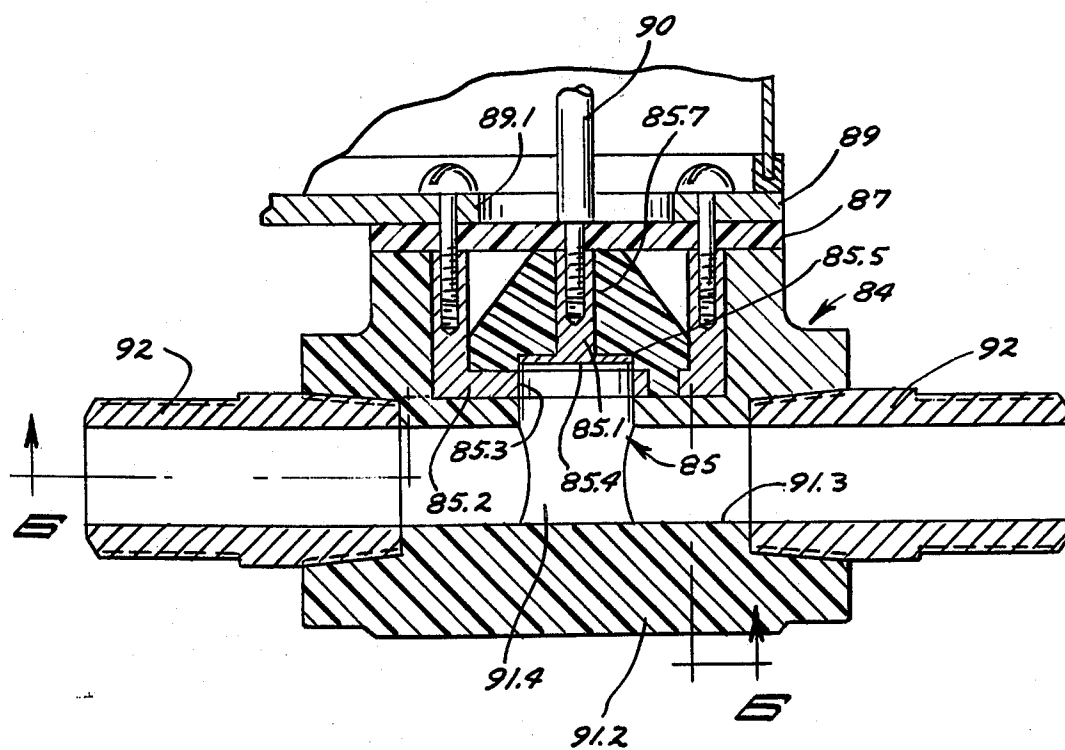


FIG. 3



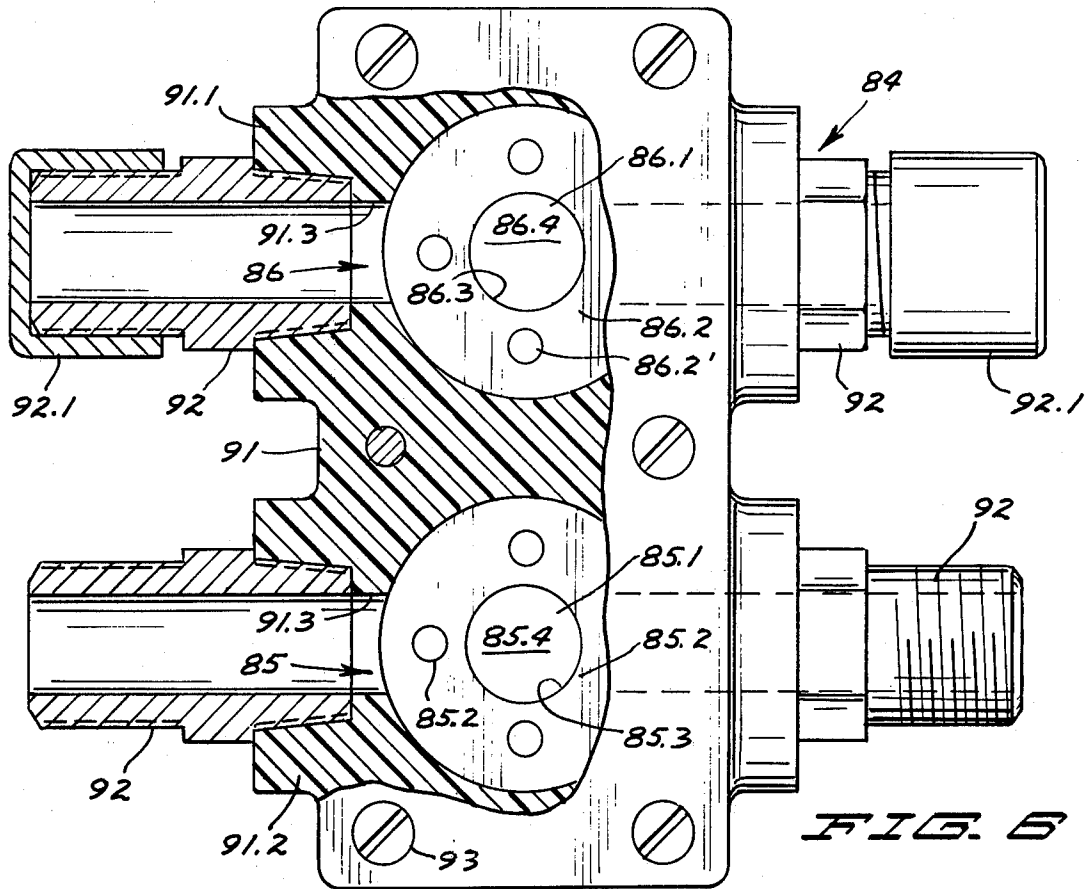


FIG. 6

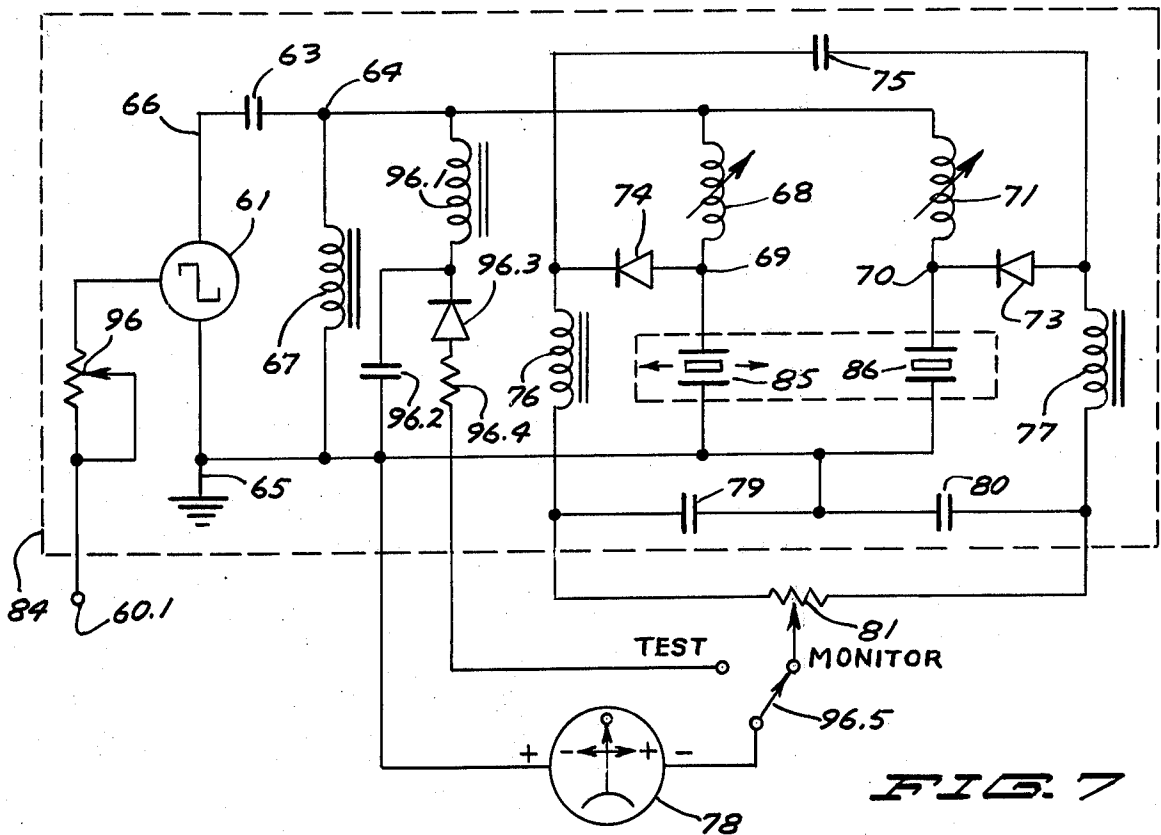


FIG. 7

CAPACITOR FOR SENSING CONTAMINATED OIL**BACKGROUND OF THE INVENTION**

Reference is made to U.S. Pat. No. 3,746,974 entitled "Oil Permittivity Sensor".

When the dielectric characteristics of a material can be determined, significant conclusions can be reached about the material itself. Low dielectric materials are essentially non-conductive of electrical current and include many liquid materials such as various oils and petroleum products including lubricating oil, hydraulic fluids, kerosene and gasoline, and other liquids such as alcohol, molten plastics such as polyethylene, ABC, styrene, and other liquid materials such as molten glass, printing ink, molten rubber, etc. Low dielectric gases include many common gaseous materials such as methane, natural gas, automobile and diesel exhaust gases, combustion flue gases, air, Freon, and the sulfites and sulfates.

It has been found that as many such dielectric materials are used, impurities and contaminants will be picked up in the material. By sensing and measuring the dielectric characteristics of these materials, the presence and the relative quantity of such impurities or contaminants can be determined. Of course, the dielectric characteristics of samples being measured will be compared to predetermined normal characteristics so that proper conclusions can be drawn as to the nature of the samples being tested.

It should further be noted that high dielectric materials, which are relatively conductive, exhibit the same general characteristics such that the dielectric characteristics of the material will vary with the purity or impurity of the material. To determine the dielectric characteristics of high dielectric material will permit significant conclusions as to the nature of the material and the contaminants which may be contained therein.

IMPORTANT CONSIDERATIONS RELEVANT TO THE PRESENT INVENTION

The dielectric constants for various materials vary extremely widely. For certain materials, the dielectric constant is 1, and for other materials the dielectric constant is as high as 12,000. For any particular percentage change in the dielectric constant, the actual change in the dielectric constant of a low dielectric material will be very significantly smaller than the actual change in the dielectric constant of a high dielectric material.

This concept becomes extremely significant when measuring dielectric changes in low dielectric liquids such as lubricating and hydraulic oils. It has been found through correlated laboratory tests that often a 5 percent change in a lubricating oil's dielectric constant represents the entire range of measurement, from a new and unused oil to an oil containing such oxides and contaminants that the oil is unfit for further use; and, similarly, in the case of hydraulic oils, frequently a 2.5 percent change in the dielectric constant is the full range of change from new and unused oil to an oil so contaminated that it is unfit for further use as a hydraulic oil. The dielectric constants of hydraulic and lubricating oils are 2.0 and 2.2, respectively, in new and unused condition, and therefore the changes in the actual dielectric constants of 0.05 and 0.11, respectively, represent the total dielectric measurement ranges of these oils. These relationships emphasize that the sensor for determining the dielectric characteristics of the fluid

must be extremely sensitive and stable so that results can be relied upon.

Furthermore, temperatures of the oil may vary widely in test conditions, particularly where lubricating oil in an engine is being monitored as it recirculates. The minute changes in dielectric characteristics must be measured even though ambient temperatures of the air at the exterior of the engine may vary 100°F., and temperatures of the dielectric material being sampled will vary as much as 300°F.

By contrast, to the hydraulic oil, a 2.5 percent change in the dielectric constant of water is an increment approximately 39 times larger than the increment of change of the hydraulic oil. It is important that the sensor be able to detect these large changes in dielectric characteristics as well as the extremely minute changes.

Whereas in the prior art, it is asserted that the dielectric constant of lubricating oil decreases 400 percent from 100°F. to 200°F., that assertion, which has been popularly accepted, is false. The dielectric constant of oil does not change significantly with the temperature of the oil, within the range of 15°F. to 350°F.

BRIEF SUMMARY OF THE INVENTION

The present invention is a sensor which has maximum sensitivity to low dielectric material and maximum stability throughout wide changes in temperatures.

The sensor has two electrodes insulated from each other to form a capacitor. One electrode, which may be referred to as the base electrode, has a flat horizontal electrode surface, the edge of which has a certain shape such as a circle; and the base electrode is ordinarily ungrounded for applying a signal or voltage to it. The ungrounded base electrode is formed of metal, such as aluminum or beryllium copper, and extends downwardly from the electrode surface to a horizontal reference plane lying parallel to the electrode surface. The base electrode is supported at said reference plane.

The second or ring electrode is ordinarily grounded and is formed of the same material as the ungrounded base electrode. The ring electrode is supported at the same reference plane from which the ungrounded base electrode is supported. The grounded ring electrode has an inner annular electrode surface of uniform width lying normal to the spaced from the flat electrode surface of the base electrode, the flat and annular electrode surfaces having similar surface areas. The annular surface of the ring electrode has the same shape and orientation as the edge of the flat electrode surface and is uniformly spaced from said edge. Accordingly, the annular electrode surface lies normal to the reference plane and the end edges of the annular electrode surface lie parallel to the reference plane.

The ring electrode extends horizontally outwardly in all directions from the annular surface and has a depending leg portion spaced outwardly from the ungrounded base electrode and extending down to the reference plane at which the ring electrode is supported.

A rigid insulator of a material with stable characteristics, such as mica filled fluorocarbon, surrounds the sides of the base electrode and underlies the ring electrode so as to leave both the flat and annular electrode surfaces exposed and confronting each other and cooperatively defining a sample chamber or space to con-

fine a quantity of the dielectric material, the characteristics of which are to be determined.

In one form, the sample chamber is increased in height, above the ring electrode by an impervious wall to materially increase the depth of the sample of dielectric liquid.

In another form, the sensor may be wholly confined in a non-metallic flow line as for lubricating oil in an engine, so that the entire quantity of oil in the lubrication system is continually being sensed as to its characteristics.

Another aspect of our invention is a monitoring apparatus to continuously sense and determine the dielectric characteristics of a dielectric material. A capacitance bridge incorporates a pair of capacitance sensors previously described, wherein one of the sensors monitors and senses the continuously change test sample of low dielectric material as the material circulates and recirculates during use. The second sensor continuously monitors and senses the characteristics of an unused sample of such material to provide a norm against which a comparison is made in the bridge circuit.

Although the second sensor is virtually unaffected by the temperature of the sample, the unused sample is maintained at the same temperature as the continuously changing test sample. Furthermore, the utilization of the second sensor readily facilitates initial balancing of the capacitive bridge circuit and eliminates other capacitors which may be severely affected by temperature.

Because the flat and annular electrode surfaces are oriented normal to each other, the sensor has a minimum of static capacity. Supplying oil between the electrodes to constitute the dielectric will have the maximum effect upon the capacity of the sensor; and there will be a maximum change in the dielectric characteristics between new and used oil. Maximum capability is thereby achieved.

The electrode surfaces confront each other obliquely and the electrodes are closest to each other only along spaced and juxtaposed edges.

BRIEF DESCRIPTION OF DRAWINGS

FIG. 1 is a section view taken on an upright plane through a sensor embodying the present invention.

FIG. 2 is a schematic circuit diagram of a preferred circuit for use in connection with the sensor of FIG. 1.

FIG. 3 is a section view taken on an upright plane through a modified form of sensor.

FIG. 4 is a transverse section view through another form of sensor embodied in an apparatus for continuously sensing and monitoring the dielectric characteristics of a liquid such as the lubricating oil of an internal combustion engine.

FIG. 5 is a detail section view taken approximately at 5—5 of FIG. 4.

FIG. 6 is a bottom plan view of the apparatus of FIG. 5 and being partly broken away and shown in section along a broken line 6—6 as illustrated in FIG. 5.

FIG. 7 is a schematic circuit diagram of a preferred form of bridge circuit for use in connection with the apparatus of FIGS. 4 — 6.

DETAILED DESCRIPTION OF THE INVENTION

The form of sensor illustrated in FIG. 1 embodies all of the essential characteristics of the sensor for determining the dielectric characteristics of a fluid. The sen-

sor is indicated in general by numeral 50 and has a base electrode 51 and a ring electrode 52, both of which are formed of the identical material which is preferably a heat treated beryllium copper compound with a low coefficient of linear expansion, but other metals, including aluminum, are acceptable. Both the base electrode and ring electrode are supported by and anchored securely to a rigid mounting panel 53 which has very stable characteristics so as to hold the electrode 51 and 52 in stationary relation with respect to each other; and the mounting panel 53 may be an epoxy resin sheet or a fiberglass panel. The upper surface 53.1 of the mounting panel defines a reference plane from which both the electrodes will expand or contract with temperature variations.

The sensor 50 also includes an insulator 54 between all portions of the electrodes 51, 52, with the exception of the active capacitor faces thereof. The insulator 54 is preferably a low dielectric material with stable dielectric characteristics and expansion and contraction characteristics over wide temperature changes, and a typical material may be mica filled fluorocarbon.

More specifically, with respect to the sensor 50, it will be noted that the base electrode 51 has a substantially flat electrode face 51.1 which lies substantially parallel to the top surface or reference plane 53.1 of the mounting. In this particular form, the electrode face 51.1 is circular in shape and has a circular peripheral edge, but the face might have some other regular or irregular shape. The principal portion of the electrode 51, is substantially disc-shaped, and the peripheral side 51.2 of the disc-shaped portion of the electrode is substantially cylindrical in shape. This side 51.2 may, in some forms of sensor, be beveled or tapered to be somewhat conical in shape in a downwardly convergent direction.

The base electrode 51 has a mounting stem 51.3 of substantially reduced thickness as compared to the diameter of the circular electrode face. The stem 51.3 is threaded and is threadably mounted in an internally threaded socket sleeve 55 which is carried on a rigid with the mounting plate 53. In this form, a sealing O-ring or gasket 56 seals the upper portion of stem 51.3 to the insulation block 54 to prevent any migration of the dielectric material being tested.

The ring electrode 52 has a flat wafer-shaped portion 52.1 which lies parallel to the electrode face 51.1 and to the upper surface or reference plane 53.1 of the mounting panel. The upper and lower surfaces of the substantially annular wafer-shaped portion 52.1 of the ring electrode are preferably smooth and parallel to each other. The ring electrode 52 also has a mounting projection in the form of a cylindrical wall 52.2 extending from the annular wafer-shaped portion 52.1 of the ring electrode to the upper surface or reference plane 53.1 of the mounting panel. The cylindrical wall 52.2 is formed integrally of and in one piece with the annular wafer-shaped portion of the ring electrode, and if desired, the projection portion 52.2 could be in the form of spaced legs around the periphery of the ring electrode instead of being a continuous cylindrical wall. It will be recognized that the lower edge of the cylindrical mounting projection 52.2 bears against the mounting panel 53, and is secured thereto by screws 56 which are screwed into tapped apertures in the ring electrode 52.

The ring electrode 52 defines an annular electrode face 52.3 which, in the form illustrated, is cylindrically shaped and of the same diameter as the flat electrode face 51.1; and the annular electrode face 52.3 is positioned in spaced and coaxial relation to the flat electrode face 51.1. In the event that the flat electrode face 51.1 has a shape other than circular, then the annular electrode face 52.3 would also have that similar shape, identical to the shape of the peripheral edge of the flat electrode face 51.1, and the annular electrode face 52.3 would also have the same size and orientation as the flat electrode face 51.1.

The annular electrode face 52.3 must be oriented substantially perpendicular to the flat electrode face 51.1 and to the top surface or reference plane 53.1 of the mounting panel.

The relative spacing between the peripheral edge of the flat electrode face 51.1 and the lower peripheral edge of the annular electrode face 52.3 is fixed and controlled by the electrodes 51 and 52 themselves in their relationship with the mounting panel 53, and the insulation 54, which is considerably weaker in its strength characteristics than the metal of the electrodes, does not have any appreciable effect on the physical relationship maintained between the two electrodes.

The flat and annular electrode faces 51.1 and 52.3 preferably have approximately the same areas, but the annular electrode face 52.3 may have an area somewhat less than the area of the flat electrode face 51.1. It is highly preferable that the width of the annular wafer-shaped portion 52.1 of the ring electrode 52, as measured across the lower surface in a direction outwardly from the annular electrode face 52.3 to the cylindrical mounting projection 52.2 be the same as the distance from the center of the flat electrode face 51.1 to the peripheral edge thereof, which in this situation wherein the flat electrode face 51.1 is circular, is equal to one-half the diameter thereof.

It is important that there is no space between the periphery of base electrode 51 and the insulation 54, and further that the insulation engage and seal against the lower surface of the ring electrode 52. The insulation 54 is shaped to have an opening receiving the mounting stem 51.3 and to define a wall 54.1 coextensive with the annular electrode face 52.3 and extending between the annular electrode face and the peripheral edge of the flat electrode face 51.1. The insulation 54 is relatively yieldable as compared to the substantially rigid electrodes 51, 52 which have rather high strength characteristics in relation to the low strength characteristics of the insulation. It will be noted that the coextensive annular electrode face 52.3 and the wall 54.1 of the insulation cooperatively define the periphery of a container or chamber, the bottom of which is formed by the flat electrode face 51.1 of the base electrode. The periphery of this container is extended upwardly by an overlying plastic shroud 57 which seals downwardly against the ring electrode 52 and has a central opening coextensive with the annular electrode face for the purpose of increasing the depth of the chamber or compartment which will confine the sample of fluid material being tested.

In one embodiment of the sensor 50, the diameters of the flat electrode face 51.1 and the cylindrical annular electrode face 52.3 may be 0.5 inches. The width or height of the cylindrical annular electrode face 52.3

will be approximately 0.125 inches. The internal diameter of the cylindrical mounting projection 52.2 of the ring electrode 52 will be 1.0 inches; and the spacing between the edges of the electrodes is uniformly 0.044 inches around the entire periphery thereof.

The sensor 50 is peculiarly adapted to be self-compensating to temperature variations as to resist any changes of inherent capacity by virtue of the physical relationships or changes of physical relationships of the parts of the sensor itself. The principal physical characteristics which control capacity are the surface areas of the flat electrode face 51.1 and the annular electrode face 52.3; and the average distance between the capacitor plates or electrode faces, and, as in the present situation wherein the electrode faces are circular and cylindrical, the average distance between these electrode faces will be from a point on the annular electrode face midway along the length of it to a point on the flat electrode face located a distance inwardly from the annular edge thereof equal to one-third the diameter. As temperature changes, all portions of the sensor 50, and particularly all portions of the electrodes will change to the same temperature. The diameter and area of the circular flat electrode face 51.1 will enlarge with increased temperature; the diameter of the cylindrical annular electrode face 52.3 will enlarge identically with the enlargement of the diameter of the flat electrode face because the width of the annular wafer-shaped portion 52.1 of the ring electrode, measured at the lower surface of the wafer-shaped portion 52.1, is the same as half the diameter of the disc-shaped portion of the electrode 51. The width or height of the annular electrode face 52.3 will also enlarge with increased temperature to the extent that the enlarged area of the annular electrode face 52.3 will remain the same as the enlarged area of the flat electrode face 51.1.

The height of the cylindrical mounting projection or wall 52.2 of ring electrode 52 will also enlarge with an increase in temperature, and the distance from the top surface or reference plane 53.1 of the mounting panel to the annular wafer portion 52.1 of the ring electrode will accordingly increase. In a similar manner, the length of the base electrode 51, from the top surface or reference plane 53.1 of the mounting panel to the electrode face 51.1 will enlarge with an increase in temperature. As a result, the location of the flat electrode face 51.1 relative to the location of the cylindrical electrode face 52.3 will change slightly, but only to the extent as to proportionately offset the change in the electrode surface area of the sensor.

With respect to the capacity of the sensor, the capacity is determined by the basic formula:

$$C_p = K A / kd$$

where C_p is the active sensor capacity, K is the dielectric of the liquid material being measured, A is the area of either of the electrode surfaces if the areas thereof are equal, otherwise A is the area of the smaller of the electrode surfaces, k is a constant which varies with units of measure, and d is the average distance between the areas of the electrode faces exposed to the dielectric material under measure.

Whereas the area of the annular electrode face 52.3 will be at least as small as the area of the flat electrode face, the area (A) will be the area of the annular electrode face 52.3 which may be expressed:

$$A = \pi DT$$

where D is the diameter of the ring electrode face 52.3 and T is the length of the annular electrode face 52.3 in direction perpendicular to the reference plane 53.1.

The average distance (d) between the flat and annular faces of the base and ring electrodes is measured between a point midway the height of the ring electrode face 52.3 and a point on the flat electrode face 51.1 located a distance inwardly from the periphery thereof equaling one-third the diameter. The average distance (d) may be expressed therefore as follows:

$$d = \sqrt{(T/2 + X)^2 + (D/3)^2}$$

where X is the spacing between the peripheral edge of the flat electrode face 51.1 and the nearest edge of the ring electrode 52.3.

Through the use of these basic concepts, it can be readily determined that there is no change in the active capacity of the sensor (C_p), even with a temperature change of as much as 300°F. and wherein the base and ring electrodes are assumed to be formed of aluminum.

Although there is shunt capacity between the surfaces of the electrodes 51 and 52 which are not exposed to the dielectric material being measured, changes in temperature of the sensor does not produce any discernible change in the shunt capacity as the temperature is changed. The shunt capacity (C_s) is proportional to the fraction A/d wherein A is the area of the smaller of the inactive surfaces of the base and ring electrodes, and in this situation, the peripheral areas of the base electrode; and wherein d is the average distance between the inactive electrode areas of the two electrodes. This average distance, as relates to the inactive surface areas is the distance from the point on the ring electrode where the inner periphery of the cylindrical mounting projection or wall 52.2 meets with the flat lower surface of the wafer portion 52.1 thereof, and to a point on the base electrode half way along the cylindrical side surface 51.2 thereof. It can be determined that temperature changes of as much as 300°F. produce no change in the shunt capacities (C_s) in this sensor 50.

The sensor 50 may be used to determine the dielectric characteristics of high dielectric material as well as low dielectric material. In the event that a high dielectric liquid is to be tested, one of the electrode surfaces will be coated with an insulating material such as a thin film of Teflon. The sensor 50 may then be employed in the same way as has been described in connection with determining the dielectric characteristics of low dielectric material.

The circuit illustrated in FIG. 2 provides a capacitance bridge whereby the change in capacitance in the sensor 50 may be detected and measured. In the circuit, a mercury type battery 60 of five to twelve volts has one side connected to ground 65 and the other side connected to an on-off single pole switch 62 through which power may be supplied into the oscillator 61. The oscillator must be fairly stable at a fixed frequency between 2.5 and 10.0 MHz, and also provides a constant 5.0 to 10.0 VAC output under no load conditions. The capacitor 63, as well as the capacitors 79 and 80, is a 0.02 uF, 16 VDC ceramic disc type condenser. Capacitor 63 couples the output of oscillator 61 into the measuring output at point 64 and provides DC isolation between point 64 and ground 65. The coil 67, as well as coils 76 and 77, is a molded powdered iron core, 2.5

mH choke providing low resistance path for DC measuring currents while offering high impedance to AC current at the oscillator frequency. Coil 67 is connected between point 64 and ground 65. The coil 67 may be replaced by a 500 to 1,500 ohm resistor with only a minimum effect upon circuit operation. The coils 68 and 71 may be molded, fixed or variable inductance coils whose value depend primarily upon the capacitance value of sensor 50 and of capacitor 72. If the sensor is fixed in the relative positioning of the base electrode and ring electrode, the coil 68 will be a variable inductance coil, in order to provide for initial circuit tuning; and if the sensor 50 is slightly variable whereby the base electrode may be adjusted slightly with respect to the ring electrode, the coil 68 may be a fixed inductance coil. Coil 68 and sensor 50 form a series resonant circuit condition which produces a maximum AC voltage in proportion to the impedance value of sensor 50 between the ground 65 and the midpoint 69 between coil 68 and sensor 50. It will be recognized that the ring electrode is connected to ground 65 and the base electrode is connected to the point 69 in the circuit.

The capacity of the capacitor 72 must be equal in value with the capacity of sensor 50 with a pure state dielectric material contained in the sensor, and if the sensor is fixed, the capacitor 72 is fixed, and if the sensor 50 is adjustable or variable, then the capacitor 72 will be variable. The capacitor 72 is connected at one side to ground 65 and at the other side through a circuit connection to the coil 71 which forms a resonant circuit condition with the capacitor 72 which produces a maximum AC voltage, in proportion to the impedance value of capacitor 72, between ground 65 and point 70 which is midway between the capacitor 72 and coil 71.

A pair of diodes 73 and 74 are respectively connected to points 70 and 69 to provide a low impedance path in one direction only for AC electron current flow from point 70, through diode 47 and through capacitor 75 and diode 48 to the point 69. Capacitor 75 which is connected in series with the diodes 73 and 74 is of the same value and type as capacitor 63 and provides a low impedance path for AC current and a DC blocking action for DC voltages rectified by diodes 47 and 48.

Coils 76 and 77 are respectively connected to the midpoints of the circuits between diode 74 and condenser 75 and diode 73 and condenser 75, and the coils 76 and 77 are interconnected with each other through a resistor 81 which is a wire wound resistor and has a center tap connected to one side of a galvanometer 78, the other side of which is connected directly to the ground. The capacitors 79 and 80 are respectively connected to opposite ends of the wire wound resistor 81 and to ground 65.

The resistor 81 is a low wattage type, between 50 and 2,000 ohms, whose purpose can be either to provide a zeroing adjustment or a measuring scale for DC electron currents flowing in opposite directions between points 70 to ground 65 and between ground 65 to circuit point 69 through meter 78. The meter 78 is a 25 to 200 microamp DC galvanometer with a zero center or offset zero scale which may function either as a measuring scale or as an indicator and thereby display any differences in DC currents flowing through it in opposite directions.

To calibrate the circuit of FIG. 2 for a particular range of liquid dielectric material being tested in sensor

50, the pure state of the liquid dielectric material, representing a midpoint in the measurement range, is placed in the sensor 50, filling it to the top. Next a vacuum tube voltmeter, set to 0 to 5.0 VAC scale, is connected between points 66 and ground 65 and switch 62 is shorted across with a jumper wire. Resistor 81 is also shorted across with a jumper wire between the underground ends of capacitors 79 and 80. While observing the vacuum tube voltmeter, either the sensor 50 or the inductor 68, whichever is variable, is adjusted until the vacuum tube voltmeter reading is an absolute minimum AC voltage. Then, while observing both the vacuum tube voltmeter and meter 78, either the capacitor 72 or inductor 71, whichever is the variable, is adjusted until the vacuum tube voltmeter reads a still further absolute minimum AC voltage, and simultaneously, the meter 78 pointer is directly on its zero indication point. Thereafter, remove the vacuum tube voltmeter connections from point 66 and ground 65 and remove both jumper wires from across switch 62 and resistor 81. When the pure state or unused dielectric material is removed from the sensor 50, the circuit completely calibrated and ready for use.

In one example of operation, the meter 78 of FIG. 2 may be considered as a measuring scale. A sample of low dielectric liquid material in its pure and unused state is placed in the sensor 50 as in the previous calibration process and switch 62 is closed to energize the oscillator. Any deviation of the meter 78 pointer away from zero is noted and adjusted to an exact zero by rotating the arm of the adjustment resistor or potentiometer 81. The reference standard of pure and unused dielectric material is then removed from the sensor 50 which is wiped clean. Thereafter, and without further adjusting anything in the circuit, another sample of the same type and brand of liquid, but used, will be placed in the sensor 50.

If the sample then in the sensor 50 contains a contaminant not previously contained in the reference sample, the meter 78 will indicate a positive deviation in direct proportion to the percentage change in the amount of contaminant in the liquid test sample. Likewise, if the second test sample had contained less contaminants than the original reference sample, the meter would indicate a negative deviation.

The meter scale may be divided into increments of measure representing percent, dielectric constant, or mere numbers for convenience of deviation measurements. Of course, the meter may be supplemented or replaced by a chart recorder to record the readout.

In the event lubricating oil of an engine is being sampled, the normal meter deviation will be a positive measurement, indicating the normal buildup of oxidized particles. However, if there is a negative deviation on the meter, then it will be determined that there is some other contaminant being found in the oil which might be a small quantity of fuel.

In summary, with respect to the sensor 50 and the bridge circuit illustrated in FIG. 2, the dielectric characteristics of a liquid material can be determined by sensing and measuring the material in its pure and unused state and subsequently sampling the same material after it has been used for a period of time. The nature of the change in the dielectric characteristic can permit the conclusion of the nature of the material for performing the function it is desired to perform. The sensor 50 is insensitive to temperature changes, even up to

a temperature change of 300°F. It is important that the remainder of the components in the circuit of FIG. 2 be maintained at fairly constant temperature because the value of the other circuit components such as the variable capacitor 72 may change.

In FIG. 3, another form of sensor 50' is illustrated. This sensor has a disc-shaped base electrode 51' and a ring electrode 52'. A quantity of stable insulating material 54' confines the sides of base electrode 51' and separates the base electrode at its sides from the ring electrode 52'.

In this form illustrated in FIG. 3, the peripheral sidewall of the base electrode 51' is tapered so as to be somewhat conically shaped, converging in a downward direction. The base electrode 51' is secured as by adhesive or mechanical means to the top surface or reference plane of a rigid mounting panel 53'. Although this form of sensor has no stem on the base electrode, both the base electrode and the ring electrode are supported by and secured to the top surface or reference plane of the mounting panel. The ring electrode has all the characteristics of that described in connection with the ring electrode of FIG. 1 with the exception that the cylindrical mounting projection of ring electrode 52' and extending from the annular wafer-shaped portion thereof to the mounting panel 53' is somewhat shorter than the corresponding cylindrical mounting projection of sensor 50 in FIG. 1.

The beveled or conically tapered side of the base electrode 51 leaves only a rather sharp edge at the periphery of the flat electrode face thereof so that the stray capacity between the base electrode 51' and the ring electrode 52' is considerably reduced. The conically tapered side of the base electrode does not squarely confront any of the lower surfaces of the ring electrode 52', but is disposed at extremely sharp angles with respect to all of the lower surfaces of the ring electrode 52' so as to reduce the stray capacity.

The form of the invention illustrated in FIGS. 4 - 7 includes a dual sensor unit indicated in general by numeral 84, including a pair of sensors 85 and 86. The sensors 85 and 86 are identical to each other. These sensors have base electrodes 85.1 and 86.1, and ring electrodes 85.2 and 86.2 which define inwardly facing cylindrical annular electrode faces 85.3, 86.3 in perpendicular and spaced relation with the flat electrode faces 85.4, 86.4 of the base electrodes. The base and ring electrodes of sensors 85 and 86 are constructed and arranged substantially identically with the electrodes of the sensor 50 described and illustrated in connection with FIG. 1, with a few exceptions as will be pointed out.

The base electrodes 85.1, 86.1 have conically shaped side surfaces 85.5 which converge in a direction away from the ring electrodes and converge toward the rigid mounting panel 87 which is common to both the sensors 85, 86. In this dual unit 84, the base and ring electrodes of both sensors 85 and 86 are suspended in depending relation from the mounting panel 87. The cylindrical mounting projections or walls 85.6, 86.6 of the ring electrodes, bear against the lower surface or reference plane 87.1 of the mounting panel 87 and are clamped thereagainst by screws 88 which are screwed into tapped apertures in the cylindrical wall portions 85.6, 86.6 of the ring electrodes.

Screws 88 also serve to clamp the sensing unit 84 to a rigid mounting bracket 89 which has enlarged openings 89.1 adjacent each of the sensors 85, 86.

The mounting stems 85.7, 86.7 of the base electrodes bear against the lower surface or reference plane 87.1 of the rigid mounting panel 87 and are clamped thereagainst by the reduced threaded ends of mounting studs 90 which are screwed into tapped apertures extending axially of the mounting stems.

The insulators 85.8, 86.8 which separate the base and ring electrodes and cooperate therewith in defining a chamber to contain the liquid dielectric material to be measured, have a conical exterior shape to be spaced from substantial portions of the cylindrical mounting projections or walls 85.6, 86.6 whereby to define annular air spaces for the purpose of reducing stray capacity because of the low dielectric constant (1.0) of air. The insulators 85.8, 86.8 are molded integrally of the ring electrodes 85.2, 86.2 which are apertured at 85.2' and 86.2' to receive small plugs of the insulator and thereby affixedly position the insulators with respect to the ring electrode.

A single plastic molding 91 defines housing 91.1 and 91.2 which enclose sensors 86 and 85 respectively. Each of the housings has a longitudinal flow passage 91.3 extending therethrough in a direction transversely of the axes of the base and ring electrodes. The flow passages 91.3 in the plastic molded housings have threaded nipples or pipe fittings 92 threaded into the housings for flow communication and to facilitate connection to pipe fittings. The housings are provided with enlarged transverse bores 91.4 extending transversely of the flow passages 91.3 and oriented in concentric alignment with the respective sensors 85, 86 so as to provide open flow communication between the flow passages 91.3 and the sensors 85, 86.

The plastic molding 91 defining the housings which are sealed to sensors 85, 86, is affixed to the mounting bracket 89 and panel 87 by clamping bolts 93.

The plastic molding has cylindrical openings to receive the ring electrodes 85.2, 86.2 and to snugly seal against the exterior or lower flat surfaces thereof and the peripheral cylindrical wall surfaces of the mounting projections 85.6, 86.6. As a result, the sensors 85, 86 are exposed only to the dielectric material which is flowing in the passage of the particular housing 91.1, 91.2.

It is intended that the sensor unit 84 be employed for the purpose of continually sensing and monitoring the dielectric characteristics of a low dielectric liquid material in use, such as the lubricating oil of an internal combustion engine. The flow passage through housing 91.2 will be connected at the fittings 92 to the flow line for the recirculating lubricating oil of the engine so that oil at engine temperature will be continuously supplied and constantly changed at the sensor 85. A quantity of low dielectric material, and in this case lubricating oil, in new and unused condition is supplied into the flow passage of housing 91.1 so as to be constantly exposed to the sensor 86 and to fill the chamber adjacent the base and ring electrodes thereof. Closure caps 92.1 are applied to confine the quantity of new and unused liquid low dielectric material at the sensor 86 to provide a norm to which reference will be made in comparing the characteristics of recirculating oil being sensed and monitored by the sensor 85. Because the sensor 86 is mounted in close proximity with the sensor 85, and

from the same mounting bracket, the sample of oil in the sensor 86 will be substantially the same temperature as the recirculating sample of lubricating oil being continuously exposed to sensor 85.

The mounting post or studs 90 also carry a fiberglass circuit board 94, which will carry substantial portions of the capacitance bridge circuit illustrated in FIG. 11. The fiberglass panel 94 will carry a pair of variable coils 68 and 71 with rotary adjustment pins to vary the inductance thereof. The circuit board and the components thereon and also the coils 68, 71 are enclosed within and confined by a housing 95 which is clamped downwardly against the mounting bracket 89 and sealed thereto by gasket 95.1.

With respect to the bridge circuit illustrated in FIG. 7 which is a part of the sensor unit 84, substantially the entire bridge circuit is the same as illustrated in FIG. 2, and the same numerals on all of the identical components and circuit points are repeated in FIG. 7 to show the very substantial similarity. The principal difference in the circuit of FIG. 11 is the addition of a fail-safe circuit to indicate that the circuit is operating properly. In this regard, a single pole double throw switch 96.5 is inserted between the meter 78 and the wiper of potentiometer 81. The second pole of the switch 96.5 is connected directly to a current limiting resistor 96.4 of approximately 27,000 ohms. The resistor 96.4 is connected in series with a diode 96.3, identical in characteristics to diodes 73, 74, and the diode 96.3 rectifies the negative half cycle of AC voltage appearing at point 64 at the oscillator frequency. The diode 96.3 is connected in series with a coil 96.1 which is identical to coil 67, and coil 96.1 is connected directly to point 64 of the circuit. The midpoint between the diode 96.3 and coil 96.1 is connected to ground 65 through a capacitor 96.3 and is identical to capacitors 79, 80 as to block DC current to ground, but effectively pass AC voltages of the oscillator frequency to ground 65. The combined purpose of coil 96.1, diode 96.3 and resistor 96.4 is to provide a fail-safe indication on meter 78 when switch 96.5 is placed in test position. Once the circuit is calibrated, the AC voltage appearing across circuit point 64 to ground 65 remains nearly constant and serves as an indication the circuit functioning properly.

Also in this circuit, the supply of voltage is provided at terminal 60.1, and, as in the circuit of FIG. 2, a voltage of 5 to 10 volts DC is supplied to the oscillator 61. The variable resistor 96 between the power supply terminal 60.1 and the oscillator 61 will vary the input voltage supplied to the oscillator. Variable resistor 96 is a 100 ohm wire wound resistor.

In this circuit of FIG. 7, the sensor 85 is exposed to the flowing liquid dielectric material, as indicated by the arrows. This sensor 85 replaces the sensor 50 of FIG. 2. The variable capacitor 72 of FIG. 2 is replaced by the other sensor 86 of unit 84 which contains a small pure state sample of the unused dielectric liquid which is being recirculated and monitored by sensor 85. The unit 84 provides a direct comparison of the dielectric constant of the liquid dielectric material being sensed and monitored. It may be desirable that the meter and test switch 96.5 be located at a position remote from the unit 84, and in the case of a stationary combustion engine as used in power generating plants, the meter may be several miles away.

As hereinbefore explained, neither of the sensors 85 or 86 will vary the effective capacity thereof by reason of a change of temperature. The use of the second sensor 86 provides a constant reference to the norm against which the comparison is made. The variable inductance coils 68, 71 are exposed to identical conditions within the cover 95 of the unit and after they are originally adjusted to balance the system will remain in balance with each other.

In the use of the sensors as described herein, there is no requirement as to the orientation of the sensors with respect to the vertical. The sensors must only be completely exposed over their entire electrode surface areas to the dielectric material, the dielectric characteristics of which are being measured. In the sensing of the dielectric characteristics of a high dielectric material, the electrode face of one of the electrodes, or of both of the electrodes may be very thinly coated with an insulating material, preferably at a thickness of 0.005 to 0.010 inches.

It will be seen that we have provided a new and improved sensor for determining the dielectric characteristics of a fluid dielectric material with a high degree of accuracy so that conclusions can be drawn as to the nature of the dielectric material and any contaminants that may be contained therein. The sensor is characterized by a base electrode with a flat electrode face which forms one end of a container or chamber wherein the fluid dielectric material is confined. A ring electrode with an annular electrode face is disposed normal to the flat electrode face of the base electrode, and is spaced from the peripheral edge of the base electrode face. Both the base electrode and the ring electrode are mounted on and secured to a rigid mounting at a common reference plane; the diameters of the flat and cylindrical electrode faces are identical, and the width of the wafer-shaped portion of the ring electrode is the same as half the diameter of the flat electrode face. In certain forms of the sensor, the base electrode may be adjustable slightly with respect to the ring electrode for initial tuning. Both the flat electrode face and the annular electrode face are oriented parallel to the reference plane of the rigid mounting. An insulator of stable low dielectric material which is substantially insensitive to temperature changes and is of such strength as to yield to the substantial strength of the similar metal in the base and ring electrodes, is provided between the ring and base electrodes to confine the liquid dielectric material in the chamber or container and also to minimize stray or shunt capacity between the base electrode and the ring electrode. A capacitance bridge which is highly sensitive to change in capacity of the sensor is used for detecting changes in the capacity produced by variances in the dielectric characteristics of the fluid dielectric material. In a continuous monitoring form for monitoring the characteristics of a supply of liquid during use, a second sensor containing a quantity of the same nature of liquid, but in a pure and unused state, is utilized as a reference or norm against which the comparison is made to the characteristics of the material being used and recirculated.

What is claimed is:

1. A sensor for determining the dielectric characteristics of a fluid medium, comprising:
 - means defining a rigid mounting lying in a plane,
 - a rigid metallic base electrode having a generally flat electrode face lying substantially parallel to said

plane and also having an annular edge at the periphery of the face, said base electrode being secured to said rigid mounting,

a rigid ring electrode of the same material as the base electrode and spaced from the base electrode, the ring electrode having an inwardly facing annular electrode face conforming to the size and shape and orientation of the annular edge of the base electrode face, said annular electrode face lying substantially perpendicular to the flat face of the base electrode and having an annular end edge adjacent the flat electrode face and uniformly spaced from the flat electrode face around the periphery thereof, said ring electrode having a width, in a direction outwardly from the annular electrode face, equal to the distance from the center of the flat electrode face to the annular edge thereof, said ring electrode also being secured to said rigid mounting, and

fluid sealing insulator means disposed between the base and ring electrodes and closing the space between the annular edges of the electrodes, the insulator means being formed of a solid insulating low dielectric material with characteristics of minimum change of dielectric constant in response to changes in temperature, and said insulating material having strength characteristics considerably weaker than the material of the electrodes to allow limited relative movement between the electrodes during temperature induced expansion and contraction, and said insulating means cooperating with the electrodes in defining an open ended fluid medium-confining chamber with the base electrode forming one end of the chamber and the ring electrode forming a portion of the peripheral wall of the chamber.

2. The sensor according to claim 1 and the area of the annular electrode face being substantially equal to the area of the flat electrode face.

3. The sensor according to claim 2 and the area of the flat electrode face being at least as large as the area of the annular electrode face.

4. The sensor according to claim 2 and the flat electrode face of the base electrode being circular, and said annular electrode face also being circular.

5. The sensor according to claim 2 and the base electrode having a mounting stem extending toward and secured to the rigid mounting and having a thickness significantly less than the distance across the flat electrode face.

6. The sensor according to claim 2 and the ring electrode being substantially flat and lying substantially parallel with the flat electrode face of the base electrode.

7. The sensor according to claim 6 and said ring electrode having a mounting projection at the outer periphery of the electrode and extending to said rigid mounting.

8. The sensor according to claim 7 and said mounting projection comprising a cylindrical wall formed integrally of and in one piece with the flat portion of the ring electrode.

9. The sensor according to claim 7 and the base electrode having a mounting stem extending to said rigid mounting and having a thickness significantly less than the distance across the flat electrode face, the space between the stem of the base electrode and the mounting

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projection of the ring electrode being filled with insulating medium including a portion of said fluid sealing insulator means.

10. The sensor according to claim 1 wherein the sensor is oriented to position the open-ended chamber in upright position with the base electrode forming the bottom end of the chamber, and insulating means defining a peripheral wall above the ring electrode to extend the chamber upwardly and facilitate confining an increased depth of the fluid medium.

11. The sensor according to claim 1 and a housing having a flow passage therethrough and through which said fluid medium may flow, said housing embracing the sensor and providing open flow communication between said passage and said open-ended fluid medium confining chamber for renewing the fluid medium in the chamber with the fluid medium from the passage.

12. The sensor according to claim 1 and the base electrode having a beveled side wall adjacent said annular edge, said beveled side wall facing obliquely away from the ring electrode.

13. The sensor according to claim 1 and said base electrode being movable toward and away from the ring electrode to vary the spacing therebetween and to vary the capacitance of the sensor.

14. The sensor according to claim 13 and said base electrode having a disc portion defining said flat electrode face and also having a threaded stem extending to and being threaded into the rigid mounting to facilitate adjustment of the base electrode relative to the ring electrode.

15. A sensor for determining the dielectric characteristics of a fluid medium, comprising:

- means defining a rigid mounting lying in a plane,
- a rigid metallic base electrode having a generally flat electrode face lying substantially parallel to said plane and also having an annular edge at the periphery of the face, said base electrode engaging and being secured to said rigid mounting at the plane,
- a rigid ring electrode of the same material as the base

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electrode and spaced from the base electrode, the ring electrode having an inwardly facing annular electrode face conforming to the size and shape and orientation of the annular electrode of the base electrode face, said annular electrode face lying substantially perpendicular to the flat face of the base electrode and said annular electrode face being uniformly spaced from the flat electrode around the periphery thereof; said ring electrode having a thickness in a direction across the annular electrode face, and also having a width in a direction outwardly from the annular face of such magnitudes as to cause the area of the annular electrode face to change corresponding to the change of the base electrode face with change in temperature and proportionately to the change in spacing between the electrode faces of the base and ring electrodes as the electrodes extend from or contract toward the reference plane of the rigid mounting in response to such change in temperature, and fluid sealing insulator means disposed between the base and ring electrodes and closing the space between the peripheries of the electrodes, the insulator means being formed of a solid insulating low dielectric material with characteristics of minimum change of dielectric constant in response to changes in temperature, and said insulating material having strength characteristics considerably weaker than the material of the electrodes to allow limited relative movement between the electrodes during temperature induced expansion and contraction, and said insulating means cooperating with the electrodes in defining an open ended fluid medium-confining chamber with the base electrode forming one end of the chamber and the ring electrode forming a portion of the peripheral wall of the chamber.

16. The sensor according to claim 15 and said annular electrode face having an area at least as small as the area of the flat electrode face of the base electrode.

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