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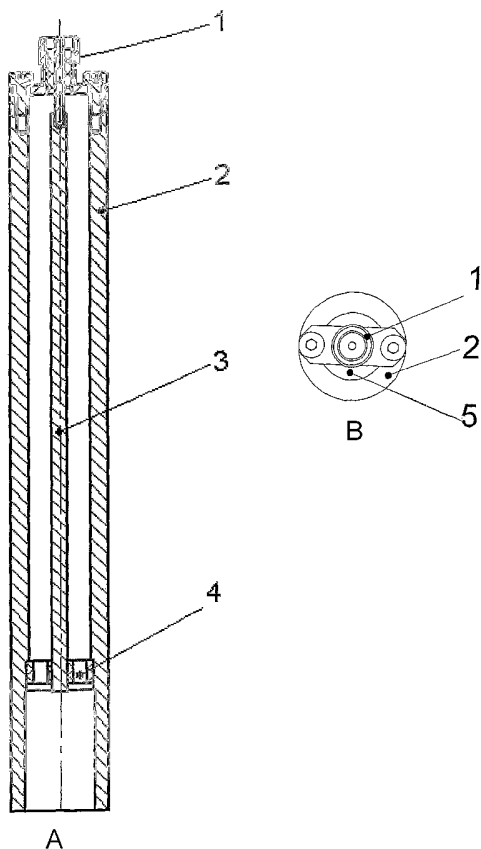
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(54) Title: DETERMINING WATER CONTENT IN OIL-BASED LIQUIDS BY MEASURING THE DIELECTRIC LOSS

(57) Abstract: According to the invention, the method of determining the water content of an oil-based liquid insoluble in water comprises the steps of: - measuring the dielectric loss of the oil-based liquid at a sufficiently high frequency to avoid significant electrolytic effects, and - converting the measured dielectric loss to a percentage water content. The invention also concerns an electrode (figure 1.a) for use in measuring the water content and a tester making use of such electrode.





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DETERMINING WATER CONTENT IN OIL-BASED LIQUIDS BY MEASURING THE DIELECTRIC LOSS

The invention relates to the detection of water in oil-based liquids insoluble in water.

5 Brake fluids, for instance, are used in the hydraulic brake system for vehicles such as cars, buses, trucks, etc. These systems depend largely on the incompressibility of the brake fluid. If the brake fluid begins to boil (because of intense heat generated by use of the brakes), the brake system will be ineffective because the vapour bubbles will be too easily
10 compressed and no pressure can be built up.

The boiling point of brake fluids depends on their specification (DOT-3, DOT-4, DOT-5 etc.) and degrades with water content. The latter increases with time because the brake
15 fluids are highly hygroscopic.

Normally, brake fluids are exchanged in fixed intervals in order to prevent excessive water content build-up. This is a waste of resources. Therefore, brake fluid testers exist on the
20 market, enabling the water content to be assessed so that it can be decided whether the replacement of brake fluid is sensible or not. The maximum admissible water concentration is 4% and replacement is highly recommended when water concentration reaches 3%. Up to 1.5% of water is considered
25 satisfactory.

The existing state of the art comprises the following methods of measuring the water content in brake fluids:

- 30 1 Electrical measurements (resistivity or conductivity of the fluid).
- 2 Boiling of the fluid.
- 3 Optical measurements.
- 35 4 Dielectric measurements.

Electrical measurements detect the (near) DC resistivity or conductivity depending on the water content in the brake fluid in a variety of different embodiments. US Patent 6'119'059 and Japanese Patent Application 51'088'266 use a differential method comparing the resistivity or conductivity of a brake fluid with an unknown water content to the values measured for a standard thus deriving the water content. German patent application DE 3'816'314 describes a galvanic measurement of the brake fluid conductivity. Conductivity or resistivity measurements are easy and fast to perform, but lack the necessary accuracy. In order to improve the accuracy, German Patent Application DE 3'134'954 uses organic acids or salts thereof, alkanolamines, amides or thioamides soluble in the brake fluid and dissociating in any water therein to form ions to increase the measured conductivity. Another embodiment utilizing a resistivity measurement is described in the German Patent Applications DE 4'002'792 and DE 3'522'774. A heated sensing element consisting of electrodes fed with a constant current is used to heat the brake fluid in a measuring cell with stable cellular heat convection. The voltage drop across the immersed heated electrodes is the indicator of the water content.

Another approach to determine the water content of a brake liquid is to heat the brake fluid up to the boiling point. In European Patent Application 74 415, a heating element is immersed in the fluid and heated with a constant voltage. Upon evaporation of gas bubbles at this sensor, the temperature of the heating element does not increase any further yielding the boiling point and thus the water content of the brake fluid. In a further refinement of this method, the thermoresistor is supplied with a monotonically increasing voltage or current instead of a constant voltage yielding a series of temperature maxima and minima at the heating element around the boiling point of the fluid which can be

correlated to the water content (German Patent Application DE 3'706'501). Another Patent Application (DE 3'221'403) proposes the measurement of the increase of pressure in a closed container in which a defined volume the brake liquid is heated up to the boiling temperature.

Optical methods include absorption measurements (e.g. US Patent 5'739'916, the absorption spectrum changes with changing water content in the fluid) or methods utilizing the addition of an indicator dye (e.g. azo-dyes) to the brake fluid, which changes its colour with increasing water content. This change in colour is detected optically (DE 3'143'589, DE 3'207'027, DE 1983/8025). Another approach relies on measuring the content of copper ions in the brake fluid by a colour change of an indicator strip. The copper content correlates with the age of the fluid and should be a good indication for the water content as well (US2002/0129644).

Dielectric methods rely on measuring the dielectric constant of the brake fluid. German Patent Application DE 4'024'554 mentions just this method for any kind of fluid. A preferred embodiment would be to include the capacitance between two electrodes in an RC oscillator and a PLL to detect whether its oscillating frequency is within a specified window. A later application (DE 4'029'667) proposes carrying out this measurement with two conductive electrodes in a coaxial arrangement. In order to cope with the strong temperature dependence of this kind of measurement, it is proposed in patent application DE 3'940'032 to measure the liquid temperature with a NTC. Another approach is to make a comparison with a reference liquid within a sealed chamber, thermally connected to the liquid under test (UK Patent Application GB 2'302'948). In order to cope with different brake fluid types or brands, it is proposed to use several

sealed chambers, each with a different fluid, selectable by some kind of switch.

5 The invention utilises measurement of dielectric loss at a moderate frequency, far enough from DC to avoid electrolytic effects. Possible frequencies range from 50 Hz to above 3 GHz. Testing some, but not all commercially available brake fluids indicate an accuracy of 0.3% abs (at 300 kHz measurement frequency) is achievable.

10 The invention is based on measuring the dielectric loss instead of the dielectric constant. This measurement has been found to be more sensitive and also more robust.

15 A refinement of the invention is to measure the dielectric loss at at least two different frequencies. This refinement makes it possible to distinguish the influence of the brake fluid itself on dielectric loss from the contribution of water because the dielectric loss of water varies differently with frequency from
20 the dielectric loss of brake fluids. This allows the measurement of the water content of any brake fluid regardless of its brand.

25 The state of the art for dielectric measurement of water content in brake fluids does not cope directly with different brake fluids coming from different manufacturers. The methods proposed in the state of the art (selectable reference fluids or selectable reference curves) imply that the user is well aware of the type or brand of brake fluid under test.

30 A further refinement of the invention is to measure the dielectric loss at at least three different frequencies. This would allow for excluding temperature effects, too.

Prior art copes with temperature dependence just by using thermometers or reference fluids.

5 A still further refinement of the invention introduces an independent measuring point, this time measuring capacitance or resonant frequency in order to deal with varying filling heights of the electrode.

10 The electrodes may be separated from the brake fluid by a dielectric material to avoid corrosion. This could be for example a coating or an injection moulded form.

15 A possible embodiment is the excitation of the fluid with a time varying voltage and measurement of the corresponding current flowing through the brake fluid. The electrodes could be two parallel pieces of wire or a coaxial arrangement. The latter would also be suitable for high frequency measurement techniques, measuring return loss instead of voltages and currents.

20 It must be noted that the excitation waveforms need not necessarily be sinusoidal. A possible embodiment of the invention could be the application of a step function and subsequent data acquisition of one or more points for some nanoseconds to milliseconds after the step to enable a transient analysis to be made.

30 Moreover, the dielectric constant itself can be measured which gives another indication of the water content. This can be used in combination with the dielectric loss measurements, thus yielding an even more robust measurement.

35 The embodiments of the invention have to address three issues: (A) the form of the electrodes, (B) the way the measurement is done and (C) the way data are processed.

(A) The form of the electrodes

5 A possible arrangement of the electrodes is illustrated in Figures 1a and 1b:

10 A coaxial connector (1) is flanged on an outer conductor (2) consisting of aluminum or another conductive metal, such that a gap (5) remains so that air can flow through it. The inner conductor of the coaxial connector is soldered to the inner conductor (3) of the coaxial arrangement. Tilting of the inner conductor (3) is avoided by introducing a perforated dielectric spacer (4) consisting of a low loss material such as PE. The perforation serves to let the brake fluid flow through the dielectric spacer. In this way the coaxial arrangement can be filled with brake fluid. Clearly the electrodes could take many other forms, the requirements being a relatively stable mechanical structure in which the brake fluid can be introduced between the electrodes in a repeatable manner.

20

(B) Possible arrangements of the measurement apparatus

(B.1) Utilizing a Network Analyser

25 As shown in Figure 2 the electrodes are dipped into the brake liquid under test (14) and are connected to one port (7) of a vector network analyser (6) [for example of the type HP 8753] with S-Parameter test set via a single coaxial cable (8) with mating connectors at each end. The vector network analyser (6) is calibrated and measures the return loss (S11) of the electrodes (9) at different frequencies.

30

(C.1)

This return loss can be converted into complex impedance with the following formula:

$$Z = Z_0 * (1+S_{11}) / (1-S_{11})$$

5

Where S_{11} is the (complex) return loss, Z_0 is the reference impedance (normally 50 Ohms) and Z is the resulting complex impedance. This impedance is an indication of the dielectric constant and the dielectric loss. With appropriate lookup tables or formulae these numbers yield the approximate water content of the brake fluid under test (14). Provided the liquid height within the electrodes is well-defined, the real part of the impedance at 300 kHz is roughly inversely proportional to the water content of the liquid under test plus a constant depending on the type of brake fluid and the geometry and conductivity of the electrodes, as in the following formula:

10
15

$$\text{Water Content} = c_1 / \text{Re}(Z) - c_2 + \text{a small error}$$

20

Where c_1 depends mostly on the liquid height within the sensor and c_2 on the liquid type. For a known electrode, c_1 could be derived from the imaginary part of the impedance, for example $c_1 = c_4 / (1 / \text{Im}(Z) - c_3)$, where c_3 and c_4 are constant for a given type of sensor. c_2 can be derived from measurements at substantially higher frequencies than 300 kHz, for example 3 MHz or 100 MHz. This is best achieved with the use of lookup tables or empiric formulae.

25

(B.2) Microprocessor, ADC, DAC

30

Another possible arrangement shown in Figure 3 is to connect the electrodes (9) to an ADC (Analog to Digital Converter) (13), a Resistor R (12) and the resistor to a DAC (digital to analog converter) (11). The ADC and DAC are connected with their respective digital lines to a microprocessor (10).

35

The microprocessor (10) will command the DAC (11) to generate a voltage waveform, which could be sinusoidal swept frequency, a step function or other arbitrary waveform.
5 The ADC (13) will measure the voltage applied to the electrodes (9) and the difference between the voltage at the output of DAC and the voltage measured at the input of the ADC is proportional to the current flowing into the electrodes.

10 (C.2) The time varying values for currents and voltages can be converted to complex frequency dependent impedances

$$Z(f) = R * \text{FFT}(\text{ADC values}) / \text{FFT}(\text{DAC values} - \text{ADC values})$$

15 These frequency dependent impedances could be fed into the above-mentioned formulae. Alternatively, the values measured from the ADC can be directly fed into an algorithm that extracts the water content, without going through the FFT (fast Fourier transform) procedure. Applying a relatively slow
20 rectangular waveform using the DAC and taking some quick consecutive samples using the ADC could for example achieve this. This would yield a step response which in turn can be converted to water content by the use of appropriate formulae or lookup tables or by digital filtering, i.e. the
25 implementation of a finite or infinite impulse response (FIR or IIR) filter with appropriate tap weights and with consecutive non-linear processing. The measurement could be further improved by repetition and averaging.

30 The invention may be used in a brake fluid tester for use in garages for maintaining cars or other vehicles giving a fast and convenient check on brake fluid condition.

It could also be incorporated in a built-in brake fluid tester in cars or other vehicles as part of a built-in diagnostic system or a retrofitted brake fluid tester.

- 5 Although the present invention is mainly described with reference to water detection in brake fluids, it must be understood that it may also apply to other oil-based liquids, the properties of which would become degraded with water content. Such would be the case for compressor oil, industrial
10 hydraulic oil, hydraulic clutch liquids, engine oils in general and all lubrication liquids, in particular within the automotive industry.

Claims

- 1 A method of determining the water content of oil-based
5 liquid insoluble in water comprising the steps of:
- measuring the dielectric loss of the oiled-based liquid at
a frequency sufficiently great to avoid significant
electrolytic effects, and
 - converting the measured dielectric loss to a percentage
10 water content.
- 2 A method as claimed in claim 1 in which the dielectric loss
is measured at two distinct frequencies and the water
content is derived from the two dielectric loss
15 measurements.
- 3 A method as claimed in claim 1 or claim 2 in which the
dielectric loss is measured at three distinct frequencies and
the water content is derived from the three dielectric loss
20 measurements.
- 4 A method as claimed in claim 1, claim 2 or claim 3 in which
the oil-based liquid is brake fluid
- 25 5 An electrode for use in measuring the water content of oil-
based liquid insoluble in water comprising an inner
conductor, an outer conductor surrounding the inner
conductor, a coaxial connector having its inner conductor
coupled to one end of the inner conductor of the electrode,
30 and its outer conductor coupled to one end of the outer
conductor of the electrode, and a perforated dielectric
spacer at the other end of the inner conductor of the
electrode holding it in fixed relation with the outer conductor
of the electrode.

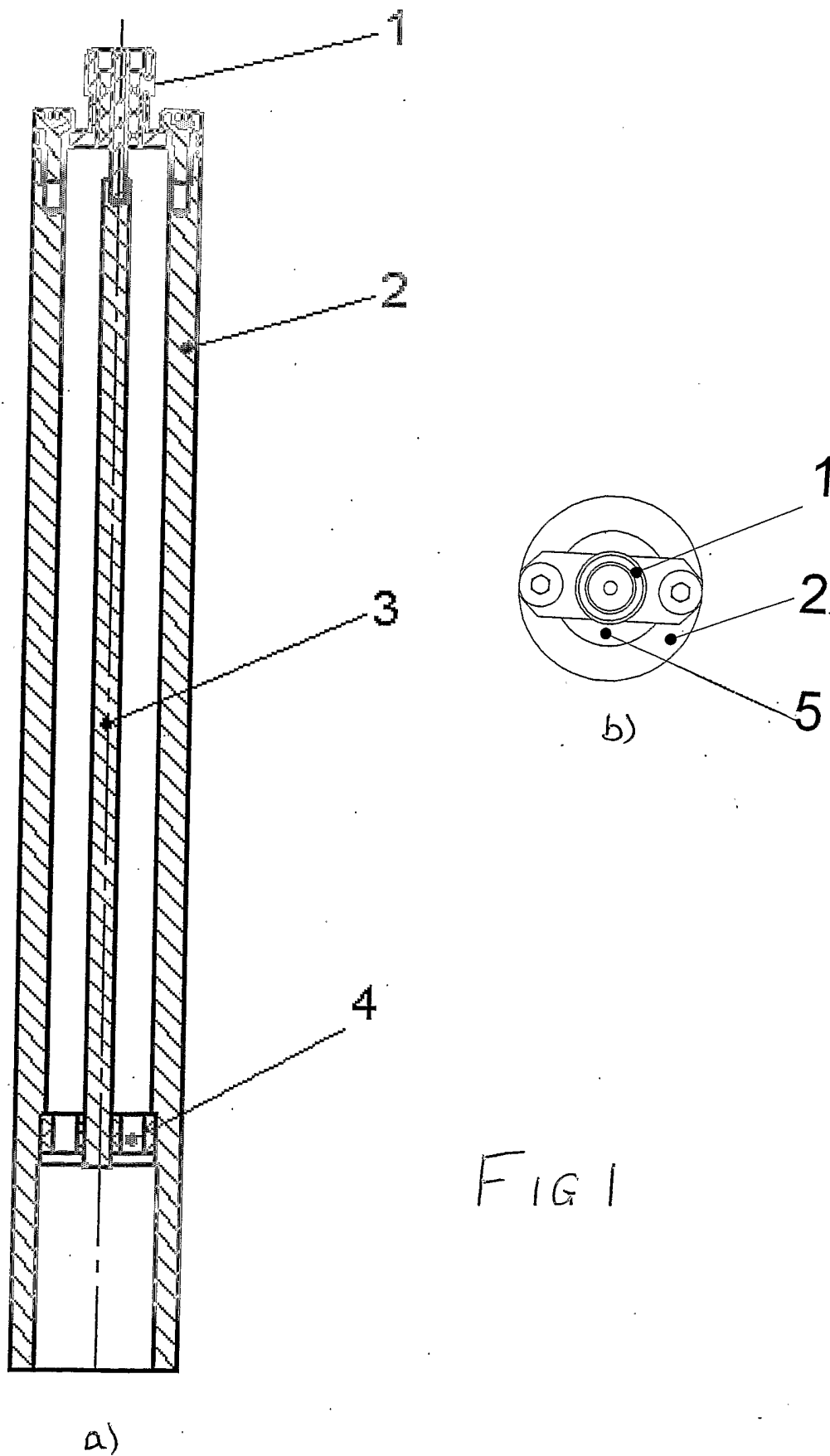
35

6 An electrode as claimed in claim 5 wherein the oil-based liquid is brake fluid.

5 7 An oil-based liquid tester comprising a pair of electrodes for insertion into said liquid to be tested, means for applying an alternating waveform to the electrodes, the alternating waveform having a sufficiently high frequency that significant electrolytic effects are avoided, means for measuring the dielectric loss of the electrodes when immersed in the liquid,
10 and means for determining the water content of the liquid from the dielectric loss measurement.

8 An oil-based liquid tester as claimed in claim 7 wherein the oil-based liquid is brake fluid.

15



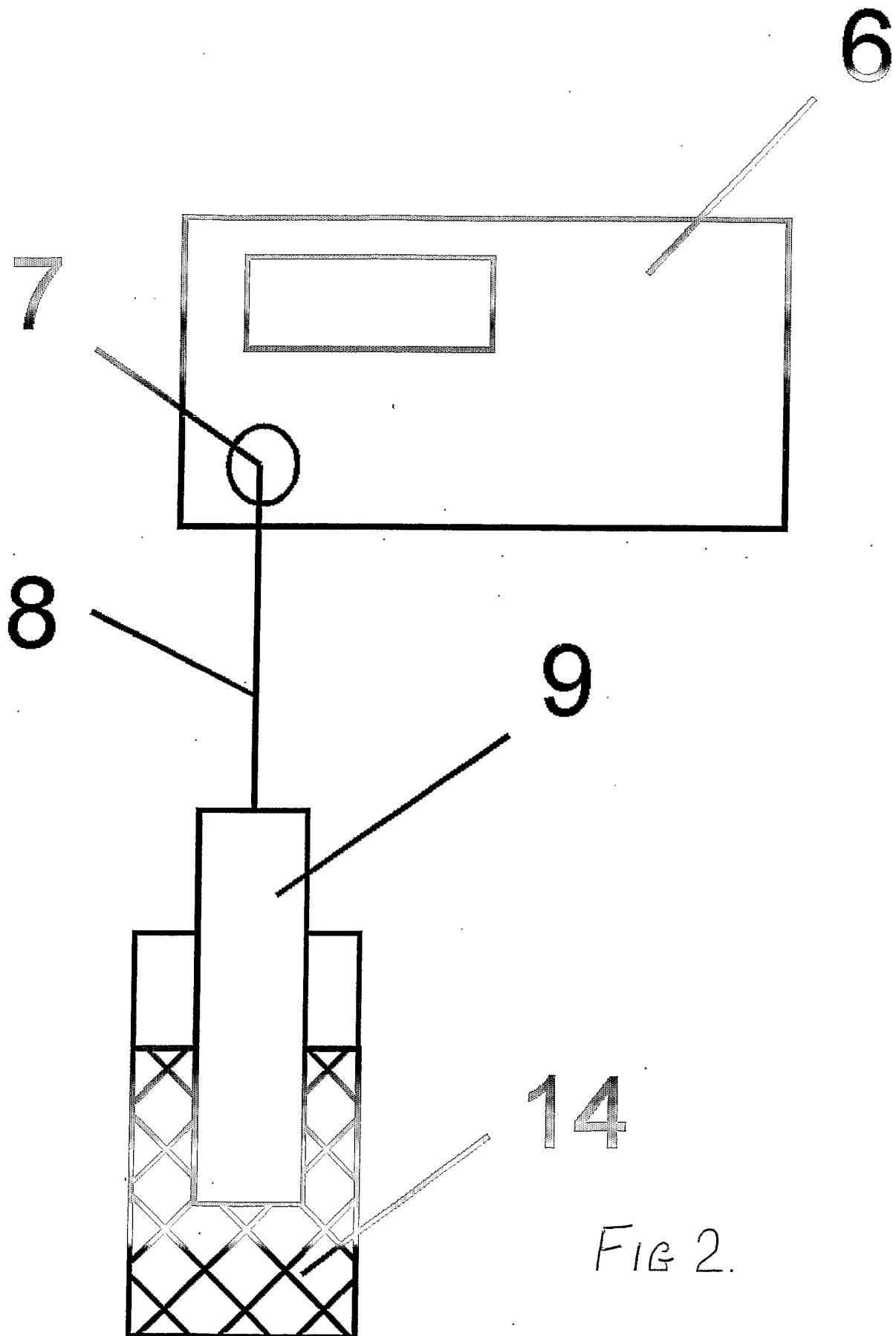


FIG 2.

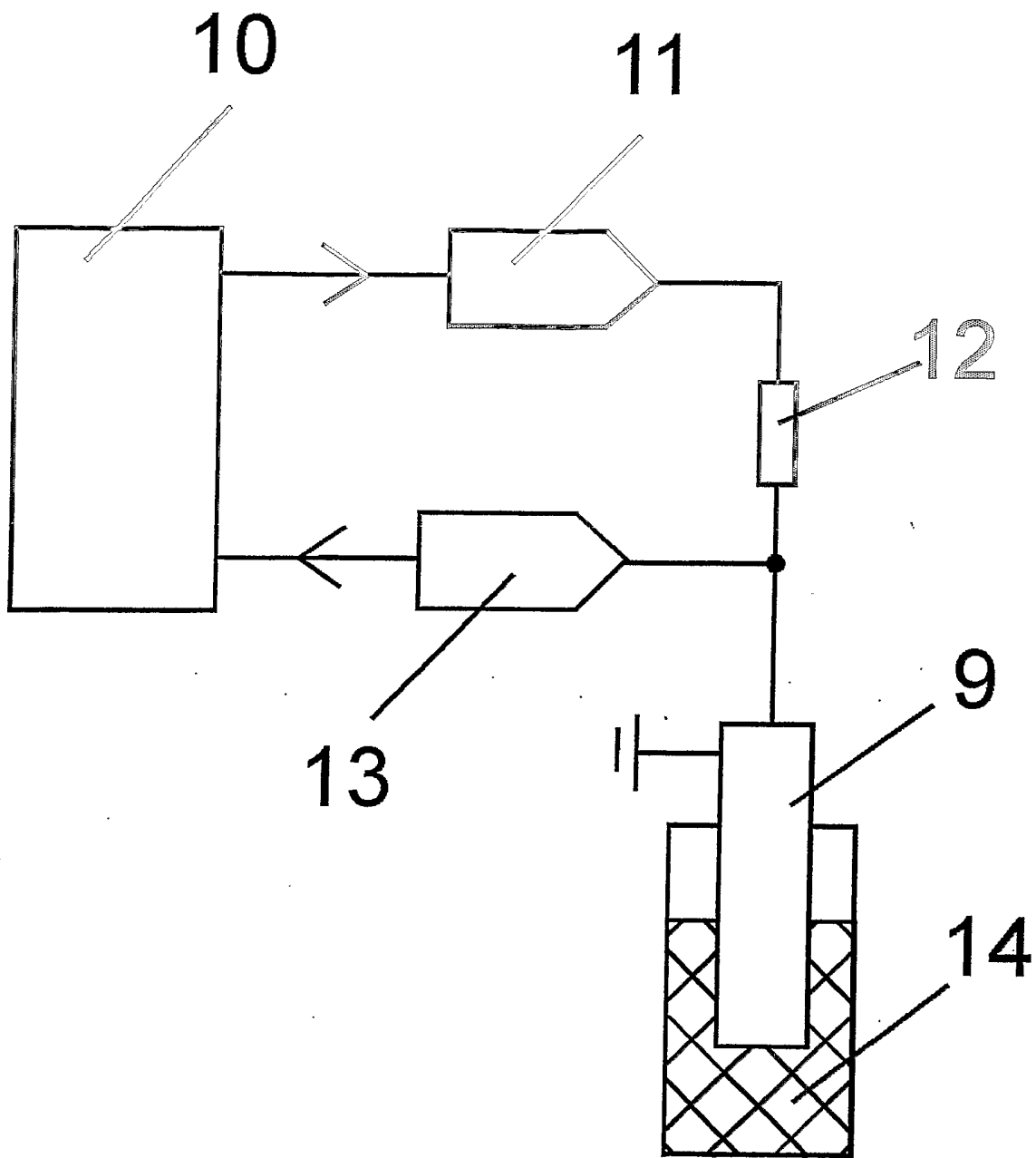


FIG 3

INTERNATIONAL SEARCH REPORT

International Application No
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A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 G01N33/28 G01N27/06 G01N27/22

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 G01N

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

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 03/012413 A (NILSEN PAAL J ;PIASECKI WOJCIECH (PL); ABB SP Z O O (PL)) 13 February 2003 (2003-02-13) the whole document ----	1,2,7
X	US 6 182 504 B1 (GAISFORD GREGORY SCOTT) 6 February 2001 (2001-02-06) claims 1-10 ----	1,7
X	US 6 459 995 B1 (COLLISTER CHRISTOPHER JOHN) 1 October 2002 (2002-10-01) column 4, line 33 -column 5, line 58 column 11, line 34 -column 12, line 26 ----	5
A	US 5 973 503 A (BARTEN AXEL ET AL) 26 October 1999 (1999-10-26) claims 13,16 -----	5

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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INTERNATIONAL SEARCH REPORT

Information on patent family members

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