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MONITORING PROCESS FOR A MEASUREMENT DEVICE IN AUTOMATION

The invention relates to a procedure to monitor a measuring device used in automation engineering, wherein the measuring device has a capacitive sensor, wherein the capacitive sensor has at least one capacitor, and wherein the at least one capacitor is used for determining or monitoring a process variable. Furthermore, the invention relates to an apparatus for performing the process for monitoring the operational reliability of the measuring device.

In process and automation engineering, field devices are often used, which serve for recording and/or influencing process variables. Serving for recording process variables are measuring devices, such as fill level measuring devices, flowmeters, pressure and temperature measuring devices, pH measuring devices, conductivity measuring devices, etc., which record the corresponding process variables, fill level, flow, pressure, temperature, pH value, and conductivity, respectively. Used for influencing process variables are actuators, such as valves or pumps, via which e.g. the flow of a liquid in a pipeline or the fill level of a medium in a container can be changed. Referred to as field devices are, in principle, all devices which are used near to the process and which deliver, or process, process-relevant information. A large number of such field devices are available from members of the firm Endress + Hauser. In connection with the invention, the term ‘field device’ thus includes all types of measuring devices and actuators. Furthermore, the term ‘field device’ includes also e.g. a gateway, a radio adapter or other bus participants integrated/integrable in a bus system.

Rough conditions of use reign in many industrial plants, so that field devices can experience very high loads. During the planning of an industrial plant, the loadability of the field devices which are to be used should be carefully considered. Main concerns, in such case, are not only the durability of the field devices per se, but, instead, also the reliability and the operational reliability of the measurements technology integrated in the field devices. Themes such as lifetime, self-monitoring and predictive maintenance play an important role here. These considerations hold especially for measuring devices used for recording process variables.

Vortex flowmeters are used, for example, in order to record the flow velocity of a medium in a measuring tube. In order to prevent negative outcomes, the measurement technology applied in vortex flowmeters must deliver reliable measured values and be failsafe. By contrast, in plants in which actuators influence the same or another process variable based on process variables recorded by measuring devices, considerable damage can result when the actuators work based on unreliable measured values. In this sense, vortex flowmeters must not only function, but also work reliably, also in plants, such as, for example, a steam power plant, in which the lines are partially high-pressure lines and are heated to high temperatures.

The example of a vortex flowmeter will be developed further in the following. Vortex flowmeters are in the normal case composed of a measuring tube having a bluff body arranged in the measuring tube. Vortices form in media flowing past this bluff body, provided that the medium or the flow of the medium fulfils certain conditions.

Playing an important role in this connection is the Reynolds number. The Reynolds number is a dimensionless variable, which characterizes the ratio between inertial forces and viscosity forces of a flow system. When the Reynolds number of a system lies in a certain region, vortices are formed in the medium flowing past the bluff body in the measuring tube. The vortices are such that they form a so-called Karman vortex street. The vortices are shed alternately from the surface of a first side of the bluff body and from the surface of a second side of the bluff body. The vortices therefore have different rotational directions, wherein the vortices are always shed with equal distance from one another. This means that the vortex shedding frequency is influenced only by a change of the flow velocity of the flowing medium. The vortex shedding frequency is thus directly dependent on the flow velocity.

Measuring devices which record the vortex shedding frequency have a sensor system or measurement technology, which records the pressure fluctuation as a result of vortex formation. Known is a sensor system, which has a capacitive sensor and a paddle. The paddle protrudes into the measuring tube and is moved from one side to the other under the influence of the vortices. The lateral movements are recorded via a capacitance change. At least one capacitor is arranged in a chamber for recording the capacitance changes, wherein the chamber is sealed from the process. The movement of the paddle is transferred to a movable element within this chamber via a membrane. The membrane serves for sealing the chamber from the process as well as for recording the process pressure.

Publication DE 035 44 198 A1 presents a vortex flowmeter that capacitively measures the frequency of the bluff body and thus the flow rate in a measuring tube. The special capacitor electrode arrangement presented there allows a measurement of the flow rate without falsification by oscillations or vibrations to which the measuring device as a whole might be subjected.

In addition, US patent 8 461 849 B1 describes a method that is used to monitor the operational reliability of a capacitor by multiple charging, as appropriate, and subsequent discharging and determination of the loss resistance. Here, the loss resistance is determined again after each charging phase. The loss resistance is determined here by recording the holding current needed to maintain the test voltage.

Measuring devices for recording process variables are frequently equipped with seals. The seals serve to block, from the electrical, electronic or also mechanical components of the measuring device, moisture originating from the process and/or the environment. If a seal is defective, moisture can strongly influence the operational reliability of the measuring device. For example, the membrane in a vortex flowmeter can in the case of high loading break open, or small cracks can form in the membrane. Thus, in an automated plant, the case can occur that a valve in the plant opens or closes too rapidly. As a result of thereof, a pressure wave forms in a pipeline, which can cause considerable damage. Among other things, the membrane of a vortex flowmeter can be damaged, wherein the damage can involve small openings/cracks, so that medium can penetrate therethrough into the interior. The penetrating moisture can cause short circuits in the electrical and /or electronic components, or over longer periods of time result in corrosion.

Leakage electrical current, which flows between a measuring device electronics and a grounded measuring device housing, can be monitored, in order to detect a defective operating state of a measuring device. For example, known from WO 2009/135764 A1 is a method for monitoring a measuring device, especially a measuring device formed as a measuring and/or switch device of industrial measurement and automation engineering and/or an electronic measuring device. In the case of the known solution, a potential difference is produced between the housing and the measuring device electronics for effecting a leakage current, wherein the leakage current flows through an electrically conductive connection between the housing and the measuring device electronics formed by condensed water. Furthermore, the flowing leakage current is recorded, and a digital state value is generated taking into consideration the recorded leakage current. Then, an alarm signal is generated, which signals the occurrence of a failure in the measuring device - especially a failure caused by the undesired formation of conductive deposits within the housing.

Disadvantageous in the case of the known method is that an electrical current measuring circuit is required for recording the leakage current. Further, this method only measures whether instantaneously an electrically conductive connection is present or not. The method registers a failure only in the case of a leakage current flowing to ground. Predictive maintenance is not possible with the known solution.

Known from US 2013/0207677 A1 is a method for detecting a malfunction of an electrostatic, capacitive sensor, wherein the method includes steps as follows:

- detecting a first detection signal as a function of an electrostatic capacitance, which is detected via a detection electrode, when a first electrical voltage is placed on a shield electrode, which is provided in the vicinity of the detection electrode;
- detecting a second detection signal as a function of an electrostatic capacitance, which is detected via the detection electrode, when a second electrical voltage different from the first voltage is placed on the shield electrode; and
- determining, due to the first detection signal and the second detection signal, whether a disruption of the detection electrode is present.

The disadvantage of the above-described solution is that an additional detection electrode is provided. Additionally, at least two different reference voltages are required.

An object of the invention is to provide a procedure and an apparatus, which monitor the operational reliability of a measuring device used in automation engineering, without requiring additional components.

The object is achieved according to the invention by the procedure of claim 1 and the apparatus of claim 9.

The charge state of the at least one capacitor of the procedure according to the invention can be characterized via different variables. Thus, at least the charge on the capacitor and/or the voltage across the capacitor can be subsumed under the term ‘charge state’ used in conjunction with the invention. The change of the charge state is accordingly determinable in different ways. The loss resistance is the resistance over the path via which a leakage current of the capacitor flows, wherein a leakage current is an electrical current which flows via a path that is not provided for the conduction of current. The information concerning a disruption can have different aspects. From this information, both the occurrence of a disruption can be recognized, as well as also a tendency determined, which lessens the operational reliability of the sensor.

The procedure is used according to the invention in the case of a measuring device which has a capacitive sensor. Then the procedure can be executed with the existing components. A vortex flowmeter includes, for example, both at least one capacitor, as well as also the corresponding electronics necessary for carrying out the procedure. The procedure further enables a targeted monitoring of the at least one capacitor, wherein the at least one capacitor is monitored either at defined points in time and/or during a defined period of time.

An advantageous further development of the procedure of the invention provides that a digital diagnostic value is determined for representing the change in the charge state of the at least one capacitor, the information about the disruption in the operational reliability of the measuring device is obtained by comparing the diagnostic value with a predefined threshold value, and an error message is generated when the predefined threshold value is exceeded. The digital diagnostic value can be determined, for example, in an evaluation unit, by forming the quotient of the charge states at the two consecutive points in time. An evaluation unit provides many options for determining a digital diagnostic value.

The change of the charge state suggests in the normal case a decline of the loss resistance value. The threshold value can be, for example, a value, which is device-specifically determined or set according to the requirements of a safety standard. Especially, the threshold value represents a minimum permitted value of the loss resistance. An exceeding of this threshold value indicates a loss resistance which is too low. The generated error message can serve as an indication of a disruption and/or as an early maintenance suggestion. Such error messages, as a rule, save much time and money.

An advantageous further development of the procedure of the invention provides that the difference in the charge states of the capacitor at the two consecutive points in time is determined, and the information about the disruption in the operational reliability of the measuring device is obtained from the difference.

The determining of the difference can occur in analog form. Thus, a fast and simple opportunity is to record the change of the charge states as a difference, wherein in this case there is also the advantage that a charge injection is canceled or eliminated by subtracting. Charge injection can occur due to stray capacities or disruption pulses, which arise, for example, in circuits with analog and digital components.

In an advantageous further development, a digital difference value, which represents the difference in the charge states, is determined, and the information about the disruption in the operational reliability of the measuring device is obtained by comparing the difference value with a predefined threshold value. An error message is generated if the predefined threshold value is exceeded.

The difference between the states of charge suggests in the normal case a lowering of the loss resistance value. The threshold value can be, for example, a value, which is device-specifically determined or set according to the requirements of a safety standard. In particular, the threshold value represents a minimum permitted value of the loss resistance. An exceeding of this threshold value indicates a loss resistance which is too low. The generated error message can serve as a direct warning and/or as an early maintenance suggestion. For example, in the case of a measuring device, which would function reliably for a long time with a capacitor loss resistance of 30 MΩ, an error message can be output, when, for example, the loss resistance falls below 50 MΩ. As a rule, such error messages save costs and much time and can even be lifesaving.

The procedure of the invention provides that the loss resistance of the at least one capacitor is measured by charging the at least one capacitor a first time with a reference voltage, the charge on the at least one capacitor is determined after a first predefined time period, the at least one capacitor is charged a second time with the reference voltage, and the charge on the at least one capacitor is determined after a second predefined time period, and the first and second predefined time periods are of differently length.

The reference voltage is output from a reference voltage source, wherein reference voltage sources count as fixed components of a field device, since these are required, for example, in order to perform the normal tasks of a measuring device. During the time periods, the at least one capacitor discharges. The first and second predefined time periods are of different length, so that the at least one capacitor can discharge for different a period of time. Thus, distinguishing charges are determined for the first and second points in time, because the discharge occurs at different speed as a function of the previously described loss resistance. The discharging of a capacitor is characterized by means of the so-called RC time constant. The derivation of the RC time constant and the physical principles on which the procedure of the invention is supported are well known to those skilled in the art.

In the case of this measuring of the loss resistance, it plays no role whether the leakage current flows to ground or via a short circuit to another component of the measuring device, because only the charge on the at least one capacitor is measured. The path that the lost charge takes is insignificant. In the same way, it is insignificant for the measurement reliability, where the charge flows to. For measurement reliability, it is only important that the at least one capacitor can store a predefined amount of charge over a predefined time period.

According to the invention, the second predefined time period is shorter than the first predefined time period, such that the corresponding second point in time when the charge state of the at least one capacitor is determined is immediately after the second charging of the at least one capacitor.

The term ‘directly’, is best understood in this context in connection with a so-called system clock of the sensor system. Measuring devices which use a capacitor in order to determine a process variable can function in two different ways. Either the capacitance of a capacitor is continuously observed, or it is recorded in a discrete way. As an example of this discrete way, a capacitor is charged, discharged and recharged, wherein the determining of the instantaneous capacitance of the capacitor occurs in connection with the discharging. The capacitance of a capacitor can be continuously observed by connecting the capacitor to a high-frequency electrical current circuit.

The invention is especially advantageous, when the capacitance is recorded in a discrete way. In this context, a system clock signal is applied, in order to coordinate the charging and discharging of the at least one capacitor. That the second determining takes place "directly" after the second charging of the at least one capacitor means then, in connection with the invention, that it occurs within a period of time which is defined or definable by a low number of clock pulses. A low number means, for example, 5 clock pulses, or especially 1 clock pulse. The system clock pulses a measuring device with a specific frequency.

If, for example, the system clock runs at a frequency of 125 kHz, then a clock pulse occurs every 8 µs. If, for example, the at least one capacitor is charged with a clock signal, then it is connected to the reference voltage source for 8 µs. If "directly after the second charging of the at least one capacitor" is defined by the low number of especially 5 pulses, it takes a maximum of 40 µs after the capacitor is charged a second time until the charge state is determined.

When the second determining of the charge state of the at least one capacitor occurs directly after the second charging, this has the advantage that no additional memory unit is needed, in order in the meantime to store the result of the first determination.

In an advantageous further development, the first charge, which is determined on the at least one capacitor at the first point in time, and the second charge, which is determined on the at least one capacitor at the second point in time, is transmitted to a charge measurement capacitor, and the first and second charge are subtracted such that, in such case, a difference in the charge states is determined electronically.

The two charges of the capacitive sensor can be transmitted to a charge measurement capacitor, for example by means of a charge amplifier circuit, and subtracted. A charge amplifier circuit is a simple integrable component, which in many cases is already provided as a component of a measuring device.

An advantageous further development of the procedure of the invention provides that the at least one capacitor is charged with a precisely defined electrical charge using a charge pump.

The charge pump fulfils the same function as a reference voltage and enables an exact determining of the charge loaded onto the capacitor. Different embodiments of charge pumps exist and are known to those skilled in the art.

The use of a charge pump further enables use of the procedure of the invention also in the case in which the total capacitance changes between the first and second points in time of the procedure.

An advantageous further development of the procedure of the invention provides that a charge state value representing the charge state of the capacitor is determined, and that the charge state value at the first point in time is compared with a first predefined limit value or that at the second point in time is compared with a second predefined limit value, and from this comparison the information about the disruption in the operational reliability of the measuring device is obtained.

It can occur that loss resistance of the at least one capacitor is low enough that the charge state need be determined only once in order to detect that the operational reliability of the capacitor is disrupted. For this case, a charge state value is determined and compared with a limit value. This limit value is fixed with reference to the corresponding capacitor embodiment, in the case of which it is used. In the case of application of a previously described charge pump, it is possible to establish the limit value independently of the measuring-device-specific embodiment.

This further development is especially advantageous in the case in which a short circuit arises across the at least one capacitor. A short circuit means here nothing other than that the loss resistance has a very small value. In this case, it can occur that the change of the charge state between the first point in time and the second point in time is hardly noticeable, even though the loss resistance is very low. This can result from a too fast discharging of the at least one capacitor, so that the two determinations of the charge state occur at points in time at which the discharge has already largely occurred. A range of loss resistances, in the case of which this principle appears, or in the case of which this further development brings special advantages, is established based on measuring-device-specific variables, such as, for example, the RC time constant.

An advantageous further development of the procedure of the invention provides that loss resistance of the at least one capacitor is recorded in the course of time and a predictive maintenance message is triggered on the basis of a downward trend in the loss resistance over time. Loss resistance values which represent the measured loss resistance can be graphically displayed as a function of time, for example by means of an evaluation unit and a display unit.

Information as regards a remaining time can be output by means of an estimating function, wherein the remaining time characterizes the remaining lifetime, or the remaining time until the at least one capacitor can no longer reliably determine and monitor a process variable. The estimating function can generate the information for example based on extrapolation of a curve, which is fitted to the loss resistance values.

In industrial plants, the time necessary for replacing a measuring device can bring about considerable costs. A predictive maintenance message enables a minimizing of such costs. For example, based on the predictive maintenance message in a plant in which a number of measuring devices are installed, two or more measuring devices can be simultaneously replaced or repaired.

In an advantageous further development of the apparatus of the invention, the control/evaluation unit measures the loss resistance of the at least one capacitor in such a way that the time between the start of the charging process and the second point in time of the charging process is less than half a vortex shedding period. The charging process begins at a point in time when the at least one capacitor is first charged with a reference voltage.

The capacitive sensor of the vortex flowmeter functions in the above-described manner, wherein the sensor has a paddle and the paddle moves back and forth due to pressure changes. While the paddle moves, charging and discharging occur continuously in the normal measurement process. In such case, the capacitance of the at least one capacitor is regularly checked. When the vortex shedding frequency stabilizes over time, the changes of capacitance assume a periodic character, since the paddle moves regularly back and forth. In principle, in order to record the vortex shedding frequency, the capacitive sensor must only test how often the at least one capacitor has a certain capacitance. If there is thus a regular registering of a recurring point in the periodic changes of the capacitance, then this is sufficient to determine the vortex shedding frequency. In connection with the invention, the terminology "zero crossing" refers to this occurrence. Thus, the zero crossings are counted in order to determine the vortex shedding frequency.

The normal measurement process of the capacitive sensor cannot occur from the beginning of the charging process until the second point in time, when the charge state of the at least one capacitor is determined. Therefore, the further development is especially advantageous, for it enables performing the procedure of the invention, without introducing error into the actual measuring function of measuring device.

An advantageous further development of the apparatus of the invention provides that the measuring device has a circuit arrangement with two capacitors, which are connected to a common node or a common electrode, wherein the common node or the common electrode is connected to ground, the capacitors are connected to a reference voltage source via a first switch element, and the capacitors are connected to a charge amplifier via a second switch element.

In a further development, the charge amplifier is integrated into an ASIC circuit.

In a further development, the ASIC circuit has an analog/digital converter, which is connected to the charge amplifier, and the analog/digital converter is connected to a microcontroller or signal processor that serves as an evaluation unit.

The invention will be explained in greater detail based on the following figures, in which:

Fig. 1: shows a vortex flowmeter known from the prior art,

Fig. 2: shows a longitudinal section through the measuring tube of a vortex flowmeter,

Fig. 3: shows the vortices which form behind the paddle, and their rotational directions,

Fig. 4: shows a perspective view of the measuring device corresponding to the viewing angle Z of Fig. 1.

Fig. 5: shows a representative circuit diagram for the measuring device 1 shown in Fig. 4

Fig. 6: shows a circuit diagram of the input circuit 12 of the vortex flowmeter

Figs. 7a-b: show phase diagrams of a normal measurement process and a total capacitance measurement process,

Figs. 8a-c: show an example of an embodiment of the procedure of the invention and a graphical representation of voltage across the capacitors as a function of time,

Fig. 9: shows a circuit diagram of a preferred embodiment of the apparatus for performing the procedure of the invention, and

Fig. 10: shows a graphical representation of a difference curve as a function of the loss resistance.

Fig. 1 shows a vortex flowmeter 1. The measuring device 1 includes a measuring tube 2, a bluff body 3 and a capacitive sensor 4. The sensor 4 includes a paddle 5, which protrudes inwardly into the measuring tube 2. The paddle 5 is coupled to a membrane 6. This membrane 6 serves to seal off the measuring tube 2, so that it is hermetically sealed/pressure-tight. The sensor 4 further includes two electrical wires 8, which are connected to two capacitor electrodes K1, K2, wherein the capacitor electrodes K1, K2 are not shown in Fig. 1. The (not shown) capacitor electrodes K1, K2 form two capacitors Cs1, Cs0, which have a common third electrode K3, 7. The third capacitor electrode K3 is also coupled to the membrane 6. Usually, the three features, paddle 5, membrane 6 and the third electrode K3, 7 are all made of the same electrically conductive material. The measuring tube 2 is inserted into a pipe 11 in a plant by means of first and second flange connections 9, 10.

Further shown in Fig. 1 are vortices W1, W2, W3, W4. The vortices W1, W2, W3, W4 are formed in the medium flowing through the measuring tube. The medium flows from left to right. When the medium flows past the bluff body 3, the vortices W1, W2, W3, W4 are alternately shed from the surface of the bluff body 3. Vortex W1, which lies closest to the bluff body 3, was just shed from the rear side of the bluff body. An arrow shows the rotational direction of this vortex W1. The three additional illustrated vortices W2, W3, W4 have alternately oppositely sensed rotational directions. These are correspondingly shed from different sides of the bluff body 3.

Fig. 2 shows a longitudinal section of the measuring tube 2 of a vortex flowmeter. As in Fig. 1, the medium flows past the bluff body 3 from left to right. Likewise shown are the paddle 5 and the two electrical wires 8.

Media flowing through the measuring tube 2 are described via the Reynolds number. The Reynolds number is a dimensionless number, whose derivation from the Navier-Stokes equation is known to those skilled in the art. In the measuring tube 2 illustrated in Fig. 2, the Reynolds number is calculated for a flowing medium with the assistance of the following equation:

$Re = (\rho * V * d) / \eta$

where:

ρ is the characteristic density of the medium in kilograms per cubic metre;

V is the characteristic flow velocity of the medium in the measuring tube 2 in metres per second;

d is the inner diameter d of the measuring tube 2 in metres; and η is the characteristic dynamic viscosity of the medium in kilograms per second per metre.

Vortices shed from the bluff body 3 over a large range of Reynolds numbers, for example, between 47 and 10^7. The shedding frequency f can be calculated from the equation:

$Sr = (f * \xi) / V$,

where:

f is the vortex shedding frequency in hertz;

ξ is a characteristic dimension of the bluff body 3 in metres;

V is the characteristic flow velocity of the medium in the measuring tube 2 in metres per second; and

Sr is the Strouhal number, wherein the Strouhal number correlates with the Reynolds number for a specified geometry. This correlation is experimentally determined and has, most often, the form:

$Sr = m [1 – (n / Re)]$, wherein

m and n are real numbers. For example:

$Sr = 0.198*[1 – (19.7/Re)]$ for $250 < Re < 2 \times 10^5$, wherein the accuracy of the experimentally determined correlation always plays a role.

Used as characteristic dimension of the bluff body 3 is a so-called characteristic width ξ. For a cylindrical bluff body 3, this is the diameter of the bluff body 3. Fig. 2 shows a characteristic width ξ by way of example as the diameter.

When the Reynolds number lies in a certain range, vortices W are shed from the bluff body 3 with a certain frequency f, wherein $f = Sr * (V/ \xi)$.

The frequency f is recorded by a capacitive sensor 4. In Fig. 2, the paddle 5 and the capacitive sensor 4 sit directly behind the bluff body 3. The vortices W1-W4 shed by the bluff body 3 exert forces on the paddle 5, and bring about, in such case, slight fluctuations.

The vortices W1-W6 and their rotational directions are shown in Fig. 3.

Fig. 4 shows a perspective view of the measuring device from the viewing angle Z of Fig. 1. Shown are the two capacitor electrodes K1, K2 and likewise the two associated electrical wires 8. Fig. 4 shows further a vortex W1. The arrows are provided, in order to indicate the rotational direction of the vortex W1. The vortex W1 presses the paddle 5 laterally. In order to illustrate the effect of the pressing forces, the movement of the paddle 5 is shown bigger than actual, i.e. enlarged. In a real measuring device, the movement of the paddle 5 is scarcely noticeable. The movement is forwarded via the membrane 6 to a rod 7, which sits between the first and second electrodes K1, K2 of the capacitors Cs0, Cs1. This rod 7 serves as third electrode K3, wherein the rod 7 is shared by the two capacitor electrodes K1, K2. Thus, there are two capacitors Cs1, Cs0. The capacitances of the two capacitors Cs1, Cs0 change with the movement of the rod 7. The vortex shedding frequency f can thus be determined based on the changes of the capacitance.

Fig. 5 shows a representative circuit diagram for the measuring device 1 of Fig. 4. The circuit can be referred to as "input circuit" 12. The input circuit contains a first capacitor Cs1 and a second capacitor Cs2. The two capacitors Cs1, Cs2 have a common electrode K3, which is connected to ground M. This electrode K3 represents the rod 7 of Fig. 4.

As already described above, a change of the capacitance can be recorded in a discrete way. In Fig. 5, the first capacitor Cs1 has a first connection X1 and the second capacitor Cs0 a second connection X2. Via these two connections X1, X2, the capacitors Cs1, Cs0 are charged with a reference voltage V_{REF} and then discharged for determining the capacitance. The connections X1, X2 can by way of example be connected to an ASIC circuit (application specific integrated circuit).

Fig. 6 shows a circuit diagram of the input circuit 12 of the vortex flowmeter 1. In Fig. 6, the two connections X1, X2 of Fig. 5 are joined. It should be noted that the total capacitance of the two capacitors Cs0, Cs1 remains unchanged. If the two connections X1, X2 are joined, the two capacitors Cs0, Cs1 can be connected together to a reference voltage source V_{REF} via a first switch element S1. As a result, the capacitors can be charged with the reference voltage V_{REF}. A loss resistance R_L is shown in Fig. 6. As described above, the loss current path does not represent an intentionally provided electrical current path, but, instead, a path via which a leakage current flows.

Fig. 6 shows further a second switch element S2. Via this second switch element S2, the joined connections X1, X2 of the two capacitors Cs0, Cs1 can be connected to a charge amplifier Qv. An embodiment of the charge amplifier Qv is shown in Fig. 9. The functioning of the charge amplifier Qv is described in connection with Fig. 9.

In a vortex flowmeter 1, it is only necessary to determine the vortex shedding frequency f. This can happen in different ways. For example, in a vortex flowmeter 1 with two capacitors Cs0, Cs1, the zero crossings can be counted. The arrangements of the capacitors Cs0, Cs1, as shown in Figs. 4 to 6, can be referred to as DSC sensors (i.e. "differential switched capacitor sensors"). A zero crossing occurs when the capacitances of the two electrodes K1, K2 are equal. This happens each time the rod 7 moves from one side to the other as it oscillates. This corresponds, of course, to the movement of the paddle 5 and, furthermore, to the shedding of a vortex from the bluff body 3. Thus, a zero crossing corresponds to a vortex.

An opportunity for detecting a zero crossing exists when, after the two capacitors Cs0, Cs1 are charged, the two connections X1, X2 are connected to a comparator. This example of an embodiment is not shown in the drawing. In such an embodiment, a zero crossing is detected based on a level change in the output signal of the comparator. Such an embodiment has the disadvantage that it can be easily disturbed by noise. Furthermore, the midpoint of the rod 7 can drift.

The midpoint of the rod 7 is the rest position of the rod 7 or the position of the rod 7 in absence of pressure forces. The midpoint of the rod 7 corresponds further to the position, at which the capacitances of the capacitors Cs0, Cs1 are equal to one another. It is possible that the capacitances are different at the midpoint of the rod 7. In this case, reference is made to a "static offset".

A second opportunity for counting the zero crossings is described based on the measurement process illustrated in Figs. 7a,b. shown in Fig. 7a are four blocks, which represent four different phases P0, P1, P2, P3 of the measurement process. The width of each block corresponds to the time, during which its respective phase P0, P1, P2, P3 is running. The four phases P0, P1, P2, P3 are continuously repeated. Fig. 7a shows only one repetition.

In the first phase P0 of the measurement process, the two capacitors Cs0, Cs1 are charged with different voltages. In such case, the first connection X1 is connected to a positive or negative reference voltage V_{POS}, V_{NEG}, and the second connection X2 is accordingly connected to a negative or positive reference voltage V_{NEG}, V_{POS}. Thus, the one capacitor Cs0, Cs1 is charged positively and the other capacitor Cs1, Cs0 negatively, wherein the absolute magnitude of the positive and negative reference voltages V_{POS}, V_{NEG} are equal.

In the second phase P1, the capacitors Cs0, Cs1 are discharged. During discharging, the charges of the two capacitors Cs0, Cs1 are loaded together onto a charge measurement capacitor C_f. Thus, a difference between the capacitances is determined. The charges are added on the charge measurement capacitor C_f, wherein the charges are opposite. Thus, a first charge difference of the absolute magnitude of the charge is arrived at, which corresponds, furthermore, to a difference of the capacitances.

In the third phase P2, the capacitors Cs0, Cs1 are recharged. The third phase P2 is the opposite of the first phase P0. The capacitor Cs0, Cs1, which was charged in the first phase P0 with a positive charge, is charged with a negative charge in the third phase P2. In the same way, the other capacitor Cs1, Cs0, which was first negatively charged, is positively charged in the third phase P2.

In the fourth phase P3, the capacitors Cs0, Cs1 are once again discharged, and a second charge difference of the absolute magnitude of the charge, which corresponds, furthermore, to a difference of the capacitances, is determined. In the fourth phase P3, furthermore, the first and second charge differences of the second and fourth phases P1, P3 are subtracted from one another. The charge difference of the second phase P1 is a charge, which is opposite to the charge difference of the fourth phase P3. Thus, in the case of a subtraction of the first charge difference from the second charge difference, or likewise the second from the first, an addition of the absolute magnitudes of the two charge differences occurs. This serves to strengthen the measurement signal as well as to suppress or eliminate disruption elements that are present, such as charge injection or an offset.

The measurement signal is, of course, recorded and processed further, for example digitized. Preferably, the normal measurement process runs a number of times within a time interval defined by the reciprocal of the vortex shedding frequency. In other words, the vortex flowmeter 1 should record a number of charge differences, especially between the points in time at which a first vortex W2 is shed and a second vortex W1 is shed. Thus, the position of the paddle 5 is determined at many points in time and the zero crossings counted.

An example will now be described. If a vortex flowmeter 1 with a bluff body 3 having a characteristic width ξ of about 3 mm should record flow velocities up to 125 m/s, the paddle 5 must be able to record vortex shedding frequencies f over a range from about 1 Hz up to about 4000 Hz. The paddle 5 and membrane 6 must, as a mass spring system, consequently, have a corresponding resonant frequency greater than 4000 Hz. Furthermore, the normal measurement process should be able to repeat a number of times within a period of time which amounts to 1/4000 of a second. If the measurement process transpires at least four times in 1/4000 of a second, then a measurement is made every 1/16000 second. As shown in Fig. 7a, one repetition of the measurement process requires at least 8 clock pulses of a system clock. It follows, consequently, that a system clock of at least 128 kHz must be used.

In Fig. 7b, the normal measurement process transpires once. The normal measurement process is thereafter interrupted, and a measurement process for determining the total capacitance of the two capacitors is performed. This measurement process is composed of two phases G0, G1. In the first phase G0, the two connections of the capacitors Cs0, Cs1 are connected together to a reference voltage source V_{REF}. The capacitors Cs0, Cs1 are thereby charged to a reference voltage V_{REF}. In the second phase G1, the capacitors Cs0, Cs1 are discharged. In such case, the total capacitance of the capacitors Cs0, Cs1 is determined. A total capacitance value or a charge state value for representing the total charge of the capacitors Cs0+Cs1 can then be determined and stored. The total capacitance measurement is important not only for detecting a short circuit, such as already described above, but also for calculating a static offset.

Figs. 8a and 8b show an example of an embodiment of the procedure of the invention. In Fig. 8a, the normal measurement process is carried out regularly. In Fig. 8b, the normal measurement process is interrupted and replaced by a measurement process for determining a leakage current. This alternate measurement process is composed of four phases L0, L1, L2, L3.

In the first phase L0, in the same manner as in the first phase of the measurement process for determining the total capacitance G0, the two connections X1, X2 of the capacitors Cs0, Cs1 are connected together to a reference voltage source V_{REF} and the capacitors charged thereby to a reference voltage V_{REF}.

In the second phase L1, a first time period is firstly allowed to expire. After this first time period, at a first point in time T1, the charge state of the two capacitors is determined by discharging the capacitors Cs0, Cs1 by means of a charge amplifier Qv.

In the third phase L2, in exactly the same manner as in the first phase L0, the two connections of the capacitors are connected together to the reference voltage source V_{REF}, and the capacitors Cs0, Cs1 thereby charged to the reference voltage V_{REF}.

In the fourth phase L3, a second time period is firstly allowed to expire. After this second time period, at a second point in time T2, the charge state of the two capacitors Cs0, Cs1 is determined by discharging the capacitors by means of a charge amplifier Qv. The charge state of the second phase L1 and the charge state of the fourth phase L3 are subtracted from one another for forming a difference in a manner similar to the charge difference formation of the last phase of the normal measurement process. Options for discharge and difference forming are described in greater detail in connection with Fig. 9.

Fig. 8c is a graphical representation of the voltage across the capacitors Cs0, Cs1 as a function of time. The time axes in Figs. 8a-c are the same. The change of voltage shown in Fig. 8c corresponds, consequently, to the changes which occur during the measurement process shown in Fig. 8b. Shown in Fig. 8c are four curves A, B, C, D, wherein the curves A, B, C, D represent the voltage changes for four cases. The loss resistance value in the four cases has four different sizes. Curve A shows the case in which the loss resistance is the greatest, and curve D shows the case in which the loss resistance is the smallest. Fig. 8c shows the capacitor charging curves for the first and third phases L0, L2 of the measurement process for determining the leakage current. The curves A,B,C,D behave equally, or almost equally, for these phases L0, L2 in the four different cases. These are shown, consequently, with only a single curve.

In the second and fourth phases L1, L3, time periods are allowed to expire. The discharging curve for a capacitor, which is connected in parallel with a resistor/loss resistance, is known to those skilled in the art. The charge Q(t) on the capacitors is:

$Q(t) = C^* V_{REF} *\exp(-t/RC)$,

where

C is the capacitance,

V_{REF} is the reference voltage,

t is the time and

R is the loss resistance value.

In Fig. 8c, first of all, at the two points in time T1, T2, the charge states A1, B1, C1, D1 and A2, B2, C2, D2 of the capacitors are determined. By means of the determined charge states, differences of the charge states are recorded for the four different cases.

Known to those skilled in the art are various methods for discharging capacitors for determining capacitances, or for determining the charge on capacitors or the voltage across capacitors.

Likewise, many are the options for forming a difference of the charges or voltages equally using analog as well as digital methods. Fig. 9 shows one such option for discharging the capacitors.

Fig. 9 shows a circuit diagram of a preferred form of embodiment of the apparatus for performing the procedure of the invention. The input circuit 12 is exactly as shown in Figs. 5 and 6. The input circuit 12 is connected via a second switch S2 to the charge amplifier Qv. The charge amplifier Qv comprises an operational amplifier Op having an inverting input E1 and a non-inverting input E2. The non-inverting input E2 is connected to ground M, to which also the third electrode K3 of the input circuit 12 is connected. The operational amplifier Op further includes an output E3, wherein the output E3 and the inverting input E1 of the operational amplifier Op are connected via a feedback path. The feedback path includes a third switch element S3 as well as a charge measurement capacitor C_f connected in parallel with the third switch element S3.

The circuit of Fig. 9 functions in the following way. The circuit is used in two phases Φ1, Φ2. In the first phase Φ1, the charge measurement capacitor C_f is discharged. This occurs via a simple short circuit via the third switch element S3. In the first phase Φ1, thus the third switch element S3 is closed and then re-opened.

In the second phase Φ2, the second switch element S2 is closed. Because the non-inverting input E2 of the operational amplifier Op lies at ground M, the inverting input E1 lies at a so-called "virtual ground". Consequently, the entire charge, which is stored on the capacitors Cs0, Cs1 of the input circuit 12, is compelled to transfer to the charge measurement capacitor C_f. The charge moves, in such case, in the direction shown by the arrows. The output voltage V_0 of the operational amplifier Op corresponds accordingly to the voltage across the charge measurement capacitor C_f, wherein this voltage is directly proportional to the charge which was transmitted from the input circuit.

A difference of the charge states can be recorded by means of this voltage. For example, the voltage from a first passage through these phases Φ1, Φ2 can be placed in a sample hold circuit and then in the case of a second passage can be subtracted from a second voltage. In another example, the voltages can be immediately digitized and then processed by means of an evaluation unit. In an additional example, the charge from the capacitors Cs1, Cs0 can be immediately added or subtracted in the charge measurement capacitor C_f, especially when the capacitors Cs1, Cs0 are charged the first time with the positive reference voltage +Vref and the second time with the negative reference voltage -Vref. Those skilled in the art will appreciate that the procedure of the invention can be executed by means of many types of difference forming.

Fig. 10 shows a graphical representation of a difference curve as a function of the loss resistance R[leak], R_L. The Y-axis shows, in this case, a decimal value representing the difference value. The difference value is a difference of the voltages of the charge measurement capacitor C_f as well as the magnitude of the charge difference of the sensor capacitors Cs1, Cs0 at the two points in time T1, T2. A decimal value of about 32000 represents in this case no change of the charge state of the capacitors.

In the case of a very low loss resistance R_L, the capacitors completely discharge before the first point in time in the second phase L1 and also before the second point in time in the fourth phase L3. There is, in this case, no change to detect. Therefore, the difference value is very low. In the case of a very high loss resistance R_L, there is, of course, likewise little change of the charge state. In this graphical presentation, a turning point is provided at 7 MΩ. If the loss resistance lies below 7 MΩ, a difference of the charge state at the two points in time T1, T2 can no longer provide information concerning the operational reliability of the capacitive sensor.

The expected change of the charge state of the two capacitors Cs0, Cs1 is given by the following formula:

delta Q(t) = C*Vref*(exp(-T/RC) - exp(-kT/RC)), where T corresponds to the shorter time period, and kT corresponds to the longer time period, wherein the time of the longer time period corresponds to exactly k-times the shorter time period. The time periods T, kT can be interpreted likewise as a pulse T and a number k of pulses kT.

Furthermore, a threshold value S_{WERT} is shown in Fig. 10, wherein the threshold value is established so that an error message is output when the loss resistance falls under 20 MΩ.

List of Reference Signs

1	vortex flowmeter
2	measuring tube
3	bluff body
4	capacitive sensor
5	paddle
6	membrane
7	rod
8	two electrical wires
9	first flange connection
10	second flange connection
11	pipe in a plant
12	input circuit
W1-6	vortices
S1-3	switch element
Op	operational amplifier
E1-3	inverting/non-inverting input and output of the Op
Qv	charge amplifier
F_L	flow direction
ξ	characteristic width of the bluff body
d	inner diameter of the measuring tube
K1-3	capacitor electrodes
X1-2	connections of the capacitors

Cs0, Cs1 first/second capacitor

V_{REF} reference voltage, reference voltage source

R_L,R[leak] loss resistance

S_{WERT} threshold value

P0-3 phases of the normal measurement process

G0-1 phases of the total capacitance measurement process

L0-3 phases of the process for determining a leakage current

Φ1-2 phases for use of a circuit

Fremgangsmåde til monitorering af et måleapparat inden for automatiseringsteknikken

Patentkrav

1. Fremgangsmåde til monitorering af et måleapparat (1) inden for automatiseringsteknikken, hvor måleapparatet (1) er en hvirvelstrømsmåler (1) med et målerør (2), et opdæmningslegeme (3), der er placeret i målerøret og frembringer hvirvler, en kapacitiv sensor (4), som er tilordnet opdæmningslegemet (3), og som ved hjælp af mindst én kondensator (Cs0, Cs1) optager hvirvelafløsningsfrekvensen i en Von Karmans Vortex Street, der frembringes af opdæmningslegemet (3),

hvor der måles en tabsmodstand (R_L) i mindst den ene kondensator (Cs0, Cs1), idet ladetilstanden af mindst den ene kondensator (Cs0, Cs1) bestemmes på et første tidspunkt (T1) og på et derpå følgende andet tidspunkt (T2), hvor tabsmodstanden (R_L) måles, idet i det mindste den ene kondensator (Cs0, Cs1) oplades en første gang med en referencespænding (V_{REF}), ladningen på mindst den ene kondensator (Cs0, Cs1) bestemmes efter et første på forhånd fastlagt tidsrum, hvor mindst den ene kondensator (Cs0, Cs1) oplades en anden gang med referencespændingen (V_{RFF}), og hvor ladningen på mindst den ene kondensator (Cs0, Cs1) bestemmes efter et andet på forhånd fastlagt tidsrum,

kendetegnet ved, at

det andet på forhånd fastlagte tidsrum er kortere end det første på forhånd fastlagte tidsrum, således at det pågældende andet på forhånd fastlagte tidsrum (T2), på hvilket bestemmelsen af ladetilstanden af mindste den ene kondensator (Cs0, Cs1) udføres, indtræffer umiddelbart efter den anden opladning af mindst den ene kondensator (Cs0, Cs1),

og at der på baggrund af en ændring af ladetilstanden mellem det første tidspunkt (T1) og det andet tidspunkt (T2) indhentes information om en fejl i måleapparatets (1) funktionsdygtighed.

2. Fremgangsmåde ifølge krav 1, kendetegnet ved, at der beregnes en digital diagnoseværdi til repræsentation af ændringen af ladetilstanden af mindst den ene kondensator (Cs0, Cs1),

at informationen om fejlen i måleapparatets (1) funktionsdygtighed indhentes, ved at diagnoseværdien sammenlignes med en defineret grænseværdi (S_{WERT}), og

at en fejlmelding genereres, når den definerede grænseværdi (S_{WERT}) overskrides,

3. Fremgangsmåde ifølge krav 1, kendetegnet ved, at der bestemmes en difference mellem kondensatorens (Cs0, Cs1) ladetilstande på de to efter hinanden følgende tidspunkter, og

at informationen om en fejl i måleapparatets (1) funktionsdygtighed indhentes på baggrund af denne difference.

4. Fremgangsmåde ifølge krav 3, kendetegnet ved, at der beregnes en digital differenceværdi, der repræsenterer differencen mellem ladetilstandene,

at informationen om en fejl i måleapparatets (1) funktionsdygtighed indhentes, ved at diagnoseværdien sammenlignes med en foruddefineret grænseværdi (S_{WERT}), og

at en fejlmelding genereres, når den foruddefinerede grænseværdi (S_{WERT}) overskrides.

5. Fremgangsmåde ifølge krav 5, kendetegnet ved, at den første ladning, der bestemmes på

mindst den ene kondensator (Cs0, Cs1) på det første tidspunkt (T1),

samt den anden ladning, der bestemmes på mindst den ene kondensator (Cs0, Cs1) på det andet tidspunkt (T2), overføres til en ladningsmålekondensator (C_f), og at den første og den anden ladning trækkes fra, således at der elektronisk beregnes en difference mellem ladetilstandene.

6. Fremgangsmåde ifølge et eller flere af ovenstående krav, kendetegnet ved, at mindst den ene kondensator (Cs0, Cs1) ved hjælp af en ladepumpe oplades med en nøjagtigt defineret elektrisk ladning.

7. Fremgangsmåde ifølge et eller flere af ovenstående krav, kendetegnet ved, at der beregnes en ladetilstandsværdi til repræsentation af kondensatorens (Cs0, Cs1) ladetilstand, og at ladetilstandsværdien på det første tidspunkt (T1) sammenlignes med en første foruddefineret grænseværdi eller på et andet tidspunkt (T2) med en anden foruddefineret grænseværdi, og at informationen om en fejl i måleapparatets (1) funktionsdygtighed indhentes på baggrund af denne sammenligning.

8. Fremgangsmåde ifølge et eller flere af ovenstående krav, hvor tabsmodstanden (R_L) på mindst den ene kondensator (Cs0, Cs1) registreres i et tidsmæssigt forløb, og at der på baggrund af en faldende tendens ved tabsmodstanden (R_L) i tidsperioden udløses en forudseende vedligeholdelsesmelding.

9. Anordning udført til gennemførelse af fremgangsmåden til overvågning af funktionsdygtigheden på et måleapparat (1) ifølge et eller flere af kravene 1 til 8, kendetegnet ved, at måleapparatet (1) er en hvirvelstrømsmåler (1) med et målerør (2), et opdæmningslegeme (3), der er placeret i målerøret og frembringer hvirvler, en kapacitiv sensor (4), som er tilordnet opdæmningslegemet (3), og som ved hjælp af mindst den ene kondensator (Cs0, Cs1) optager hvirvelafløsningsfrekvensen i en Von Karmans Vortex Street, der frembringes af opdæmningslegemet (3), og en regulerings-/analyseenhed, der bestemmer tabsmodstanden (R_L) på mindst den ene kondensator (Cs0, Cs1), og som genererer information om en fejl i måleapparatets (1) funktionsdygtighed.

10. Anordning ifølge krav 10, kendetegnet ved, at regulerings-/analyseenheden udfører målingen af tabsmodstanden (R_L) på mindst den ene kondensator (Cs0), Cs1) på en sådan måde, at tidsrummet mellem begyndelsen af opladningsprocessen og det andet tidspunkt for opladningsprocessen udgør mindre end en halv hvirvelafløsningsperiode.

11. Anordning ifølge krav 9 eller 10, kendetegnet ved, at måleapparatet (1) er forsynet med en kredsløbsanordning med to kondensatorer (Cs0, Cs1), der er sluttet til en fælles knude eller til en fælles elektrode (K3), hvor den fælles knude eller den fælles elektrode (K3) er forbundet til stel (M),

at kondensatorerne (Cs0, Cs1) er sluttet til en referencespændingskilde (V_{REF}) via et første kontaktelement (S1), og at kondensatorerne (Cs0, Cs1) er sluttet til en ladningsforstærker (Qv) via et andet kontaktelement (S2).

12. Anordning ifølge krav 11, kendetegnet ved, at ladningsforstærkeren (Qv) er integreret i et

ASIC-kredsløb.

13. Anordning ifølge krav 12, kendetegnet ved, at ASIC-kredsløbet er forsynet med en analog/digital-omformer, der er sluttet til ladningsforstærkeren (Qv), og at analog/digital-omformeren er sluttet til en mikrocontroller eller signalprocessor, der anvendes som analyseenhed.

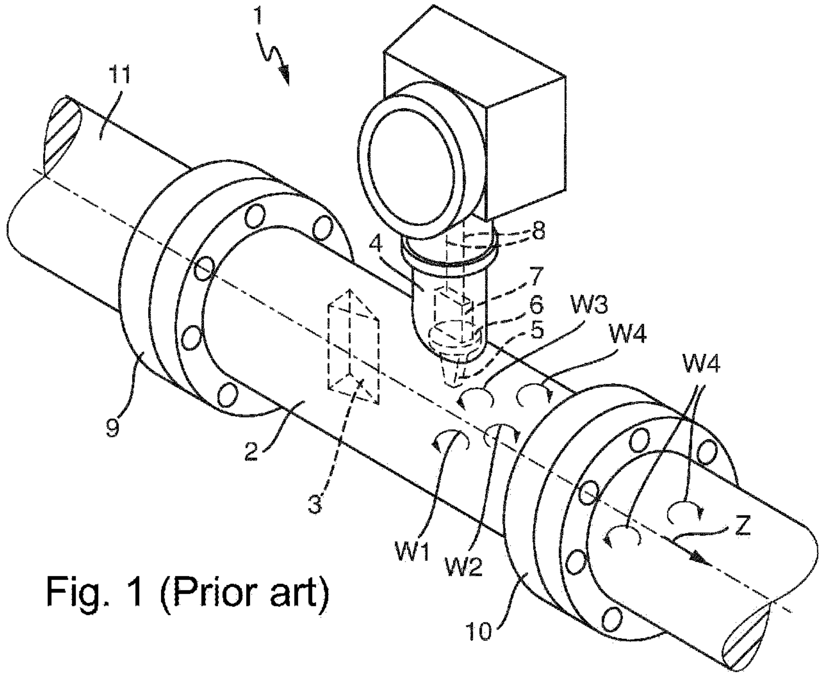

Fig. 1 (Prior art)

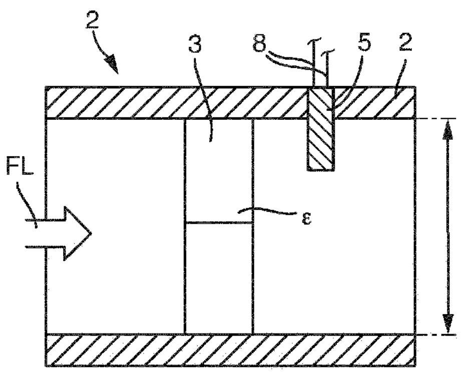

Fig. 2 (Prior art)

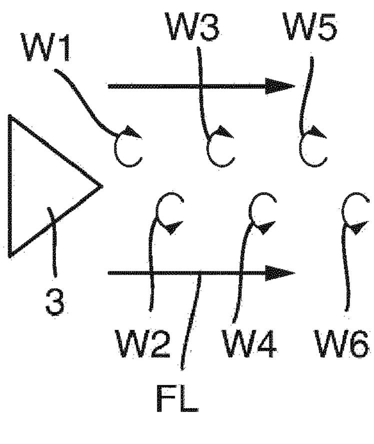

Fig. 3 (Prior art)

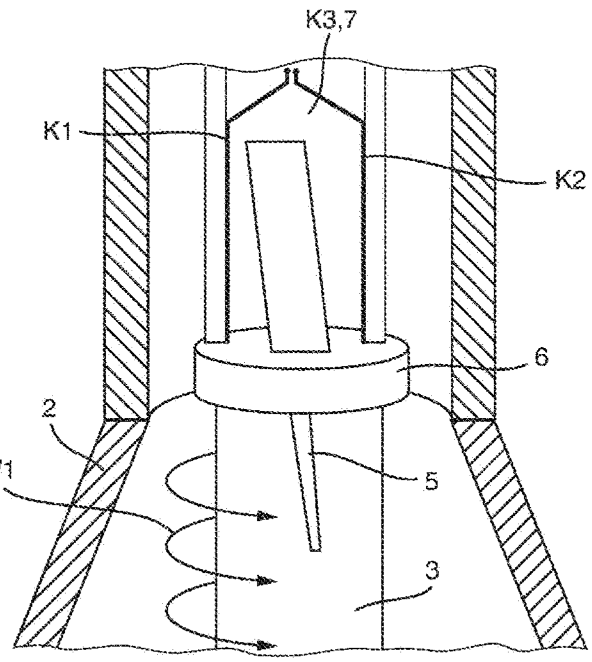

Fig. 4 (Prior art)

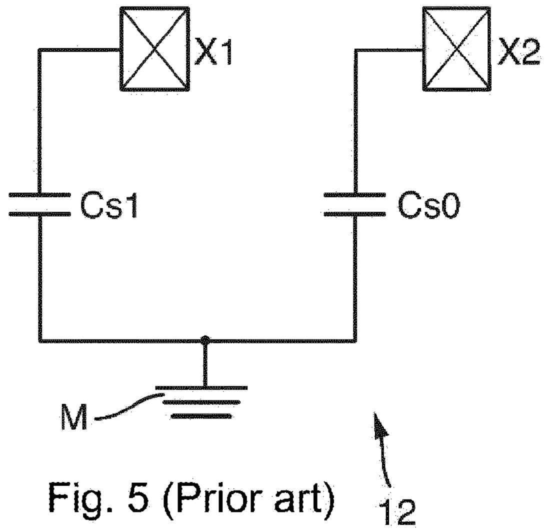

Fig. 5 (Prior art)

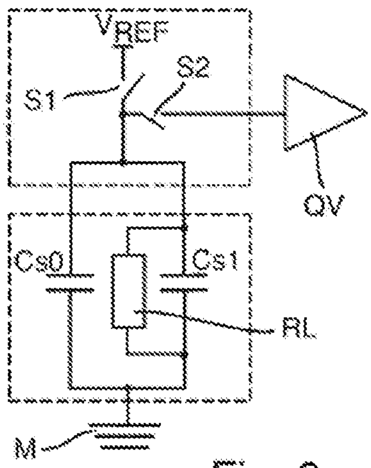

Fig. 6

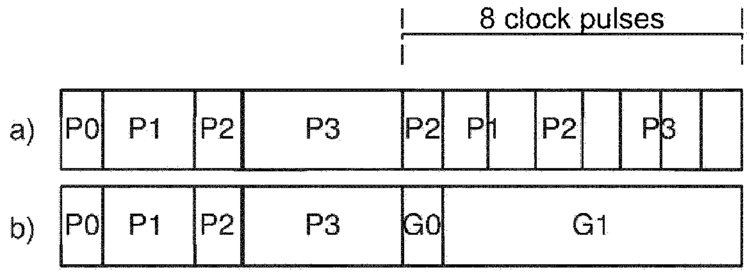
8 clock pulses
a)
P0
P1
P2
P3
P2
P1
P2
P3
b)
P0
P1
P2
P3
G0
G1

Fig. 7

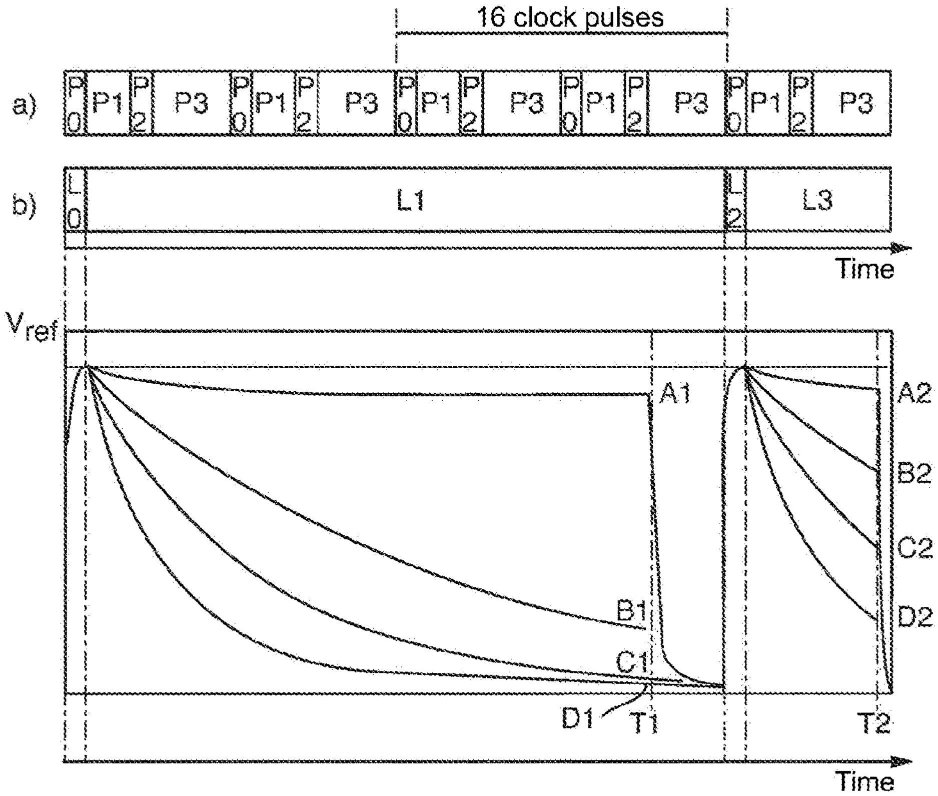
16 clock pulses
a)
P0
P1
P2
P3
b)
L0
L1
L2
L3
Time
Vref
A1
B1
C1
D1
T1
A2
B2
C2
D2
T2
Time

Fig. 8

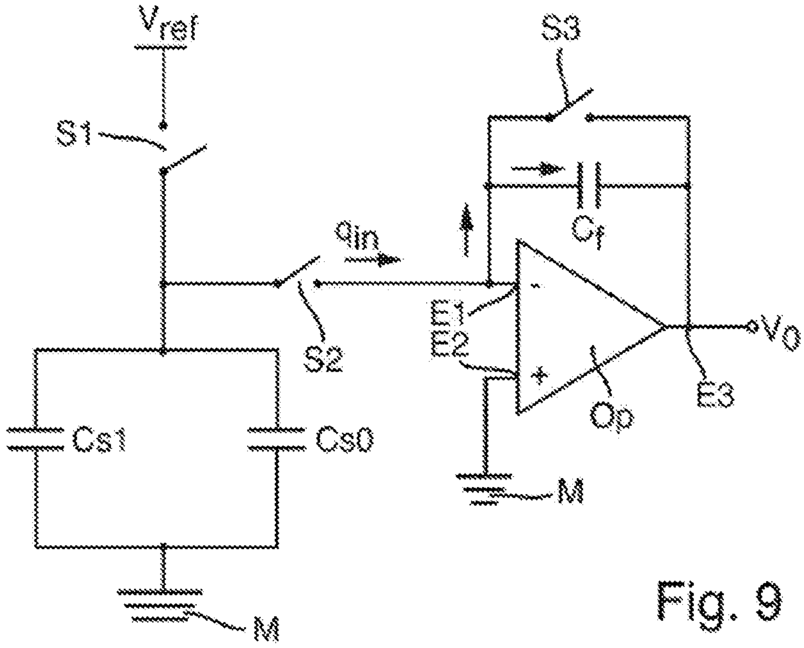
Vref
S3
S1
qin
Cf
E1
E2
S2
Vo
E3
Op
Cs1
Cs0
M
M

Fig. 9

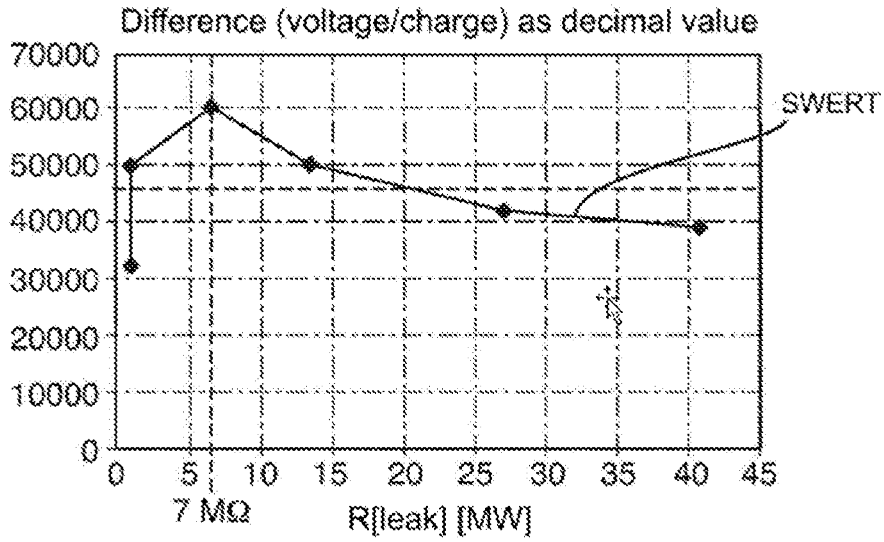
Difference (voltage/charge) as decimal value
70000
60000
50000
40000
30000
20000
10000
0
0
5
10
15
20
25
30
35
40
45
SWERT
7 MΩ
R[leak] [MW]

Fig. 10