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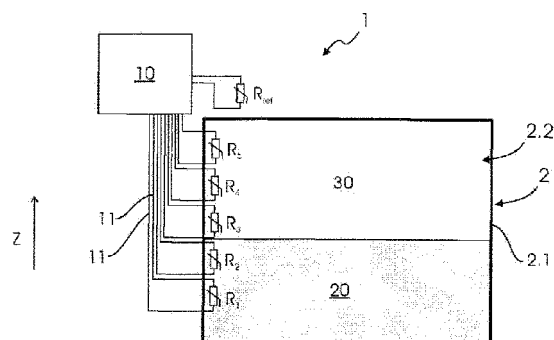
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Liquid Level Detection System.

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The invention relates to a liquid level detection system (1) for a liquid tank (2). In order to provide inexpensive and reliable means for liquid level detection, the invention provides that the liquid level detection system comprises at least one heating element (R_1 - R_5), disposed at least proximate to an inner cavity (2.2) of the liquid tank (2), and a measurement device (10), which is configured to: - apply a time-dependent electrical signal to each heating element (R_1 - R_5) to heat up the heating element (R_1 - R_5) - for each heating element (R_1 - R_5), detect a quantity that depends on a temperature of the heating element (R_1 - R_5), - determine a time-dependent change of the quantity in response to the electrical signal, and - detect a liquid level based on the time-dependent change of the quantity for each heating element (R_1 - R_5).

**Fig. 1)**

Liquid Level Detection System

Technical field

[0001] The invention relates to a liquid level detection system and to a liquid level detection method.

Background of the Invention

[0002] For many applications, it is desirable or even necessary to detect the liquid level of a liquid inside a tank. One example for this is a fuel tank for a vehicle. Another example is a water tank like e.g. a water tank for the windscreen washer of a vehicle. Today, a variety of methods for detecting a liquid level are known. These include capacitive, ultrasonic, potentiometer, pressure, radar or thermal mass (or thermal inertia) methods. However, some tanks, e.g. fuel tanks in modern cars, have complex three-dimensional shapes that make it difficult to reliably detect the fuel level. Presently known fuel level detection systems are either not reliable enough or very expensive.

[0003] This is in particular true for presently known detection systems employing thermal mass methods. The main reason for this is that commonly available cheap heating elements and sensors have a high production tolerance (sometimes more than 10%) and cannot be used effectively for a quick and reliable measurement result.

Object of the invention

[0004] It is thus an object of the present invention to provide inexpensive and reliable means for liquid level detection.

[0005] This problem is solved by a system according to claim 1 and by a method according to claim 15.

General Description of the Invention

[0006] The invention provides a liquid level detection system for a liquid tank. The liquid tank may in particular be a fuel tank of a vehicle or a water tank of a windscreen washer of a vehicle, e.g. a land vehicle like a car. However, the liquid level detection system could also be used with other vehicles like air or water

vehicles or with devices that are not self-propelled. The liquid tank is of course adapted for containing liquid, which could be e.g. fuel, water, hydraulic liquid or the like. The liquid tank can be made of any suitable material; in particular, it can be made of plastic.

[0007] The liquid level detection system comprises at least one heating element, being disposed at least proximate to an inner cavity of the liquid tank. "At least proximate to the inner cavity" in this context means that the heating element(s) can be either disposed proximate to the inner cavity or inside the cavity. In case of several heating elements, all heating elements may be identical or at least some heating elements may be different.

[0008] Each heating element is disposed at least proximate to an inner cavity of the liquid tank. During operation, the inner cavity is normally partially filled with liquid and partially filled with air. Here and in the following, "air" is a simplified term that is meant to include not only air but other mixtures of gases that may be present inside the liquid tank. Normally, these gases also contain vaporised liquid from the tank and possibly other components. By being disposed at least proximate to the inner cavity, heat transfer between the respective heating element and the inner cavity is possible. If the temperature of the heating element increases, heat is transferred to the inner cavity, especially to a region of the inner cavity that is close to the heating element. The heating element could be disposed immediately adjacent or inside the inner cavity so that heat is transferred directly between the heating element and a medium in the inner cavity, i.e. either liquid or air. However, it is possible that the heating element is separated from the inner cavity by an additional material layer as will also be discussed below.

[0009] Further, the liquid level detection system comprises a measurement device that is configured to apply a time-dependent electrical signal to each heating element to heat up the heating element. The measurement device may comprise one or several units. It may be disposed in the vicinity of the liquid tank or even on the liquid tank, but could also be spaced-apart from the liquid tank. For instance, in a vehicle like a car, the measurement device could be disposed in any suitable location, e.g. in a location that allows for easy maintenance and exchange, if necessary. The measurement device could also be realised by a device that has a plurality of functions, some of which do not refer to the liquid

level detection system. It is understood that at least some functions of the measurement device can be software-implemented. The measurement device is configured to apply a time-dependent electrical signal to each heating element. This includes the possibility that the same electrical signal is applied to each heating element as well as the possibility that different electrical signals are applied to different heating elements. The electrical signal could e.g. be a defined voltage signal or a defined current signal.

[0010] As the electrical signal is applied, e.g. if an electrical current flows through the resistive heating element, electrical energy is converted into heat, which in turn leads to a temperature increase of the respective heating element. For example, if the amplitude of time-dependent signal increases – starting from zero or a nonzero value – the temperature of the heating element increases. However, if the heating element is disposed proximate to a region that is filled with air, the heat transfer from the heating element will be considerably smaller than if the heating element is disposed proximate to a region that is filled with liquid. This is mostly due to the different thermal capacities. For instance, normal air has a specific thermal capacity of 1.005 kJ/(kg*K) while typical liquids have a specific thermal capacity between 1.5 and 2.5 kJ/(kg*K), or even higher (e.g. 4.182 kJ/(kg*K) for water). Moreover, since the thermal capacity is the product of the specific thermal capacity and the mass, it has to be taken into account that the density of air is much lower (by approximately a factor of 10^{-3}) than the density of any liquid. Therefore, when considering a given volume (e.g. 1 cm³) in a region in the vicinity of the heating element, the thermal capacity of this volume is about 1000 times higher if it is filled with liquid than if it is filled with air. Therefore, the heat transfer from the heating element and therefore its heating behavior significantly depend on whether it is disposed next to a region that is filled with liquid, one that is filled with air or one that is partially filled with air and partially filled with liquid.

[0011] The measurement device is also configured to detect, for each heating element, a quantity that depends on a temperature of the heating element, determine a time-dependent change of the quantity in response to the electrical signal, and detect a liquid level based on the time-dependent change of the quantity for each heating element. The quantity that depends on the temperature of the heating element may in particular be a temperature-dependent resistance,

as will be further described below. Either way, the quantity is not used as such, but a time-dependent change of the quantity is considered. Any detection or measurement of the quantity is not used as such, but with reference to another value, normally a previous detection, i.e. a difference between two values is taken. It is clear that due to the time-dependent nature of the electrical signal, the temperature of the heating element changes as a function of time. Due to the relatively high production tolerances of heating elements and/or sensors, however, it is hardly possible to determine the absolute temperature with sufficient accuracy. However, if one considers not the temperature (or rather, the quantity depending on the temperature) as such, but its change, fairly accurate results can be obtained. In other words, the quantity that depends on the temperature is considered to have an unknown offset, therefore absolute values cannot be considered reliable, but differences or changes in the quantity are sufficiently accurate.

[0012] Therefore, when considering the time-dependent change of the quantity, it is possible to deduce the heating behaviour with relatively high accuracy as far as temperature changes, not absolute temperatures, are considered. For example, if the heating element is disposed next to a volume that is filled with air and the electrical signal increases, the temperature of the heating element increases rather quickly in response to the electrical signal. Even if the quantity detected by the measurement device does not allow for an accurate detection of the absolute temperature, it is possible to accurately determine a time-dependent change, one could also say a gradient or slope, of the quantity. Therefore, the inventive system can use relatively cheap heating elements and/or sensors with relatively high tolerances regarding the absolute temperature. The drawbacks of this "absolute" tolerance are overcome by the inventive measurement concept.

[0013] According to one embodiment, the system comprises a plurality of heating elements disposed at different vertical positions at least proximate to the inner cavity of the liquid tank. Herein, "different vertical positions" refer to a vertical direction, which is the direction of gravity when the liquid tank is installed and used as intended. Referring to a tank in a car, for example, these are different positions along the Z-axis of the car. Based on the heating behavior of the heating elements, it can be deduced which heating elements are disposed in the vicinity of

liquid (i.e. below the liquid level) and which are disposed in the vicinity of air (i.e. above the liquid level). A heating element may also be disposed in the vicinity of both liquid and air (i.e. at the liquid level) and will show an intermediate heating behavior. Since the locations of the heating elements are known, the liquid level inside the liquid tank can be detected or determined.

[0014] Alternatively or additionally, the system may comprise at least one heating element extending along a vertical region at least proximate to the inner cavity of the liquid tank. In other words, this single heating element extends along a (substantial) distance along the vertical direction. This may in particular be an elongate, e.g. stripe-shaped heating element. Depending on the liquid level in the liquid tank, a smaller or larger portion of the heating element is disposed next to a volume that is filled with liquid. This, in turn, affects the heating behaviour of the heating element. If e.g. only 10% of the heating element are disposed next to a liquid-filled volume, it will heat up considerably quicker than if e.g. 80% are disposed next to a liquid-filled volume. In this embodiment, the measurement unit can be configured to determine the fuel level within the vertical region based on the time-dependent change of a quantity that depends on the temperature of the heating element.

[0015] According to one embodiment, each heating element has a temperature-dependent resistance and the measurement device is configured to detect the resistance as the quantity that depends on the temperature of the heating element. In this embodiment, each heating element may also be referred to as a sensor element, because it can be used as a sensor to detect its own temperature. Each of the heating elements, which in this embodiment may also be referred to as thermistors, may comprise a PTC (positive temperature coefficient) element or an NTC (negative temperature coefficient) element. All heating elements may be identical or at least some heating elements may be different, e.g. having different temperature coefficients. For example, some heating elements may comprise a PTC element and others may comprise an NTC element. The temperature-dependent resistance may be realised by any suitable material, e.g. a metal, a semiconductor or combinations of metals and/or semiconductors. However, other materials like PTC rubber could also be used. Semiconductor materials having NTC or PTC characteristics could be used as well. E.g. a PN junction (diode)

could be used as a heating element having a temperature-dependent resistance. In some embodiments, at least one heating element has a resistance that increases in a non-linear way as a function of the temperature. For example, the above-mentioned PTC rubber has an exponentially increasing resistance. While herein reference is made to a temperature-dependent electrical resistance, it is understood that this corresponds to a temperature-dependent resistivity. In principle, the resistance of a heating element corresponds to the certain temperature. However, due to production tolerances, it is hardly possible to determine the absolute temperature with sufficient accuracy. However, if the time-dependent change of the resistance is considered, this allows to monitor or the (relative) change of the temperature with reasonable accuracy. It is understood that the temperature change does not need to be calculated explicitly.

[0016] According to another embodiment, the system may comprise at least one temperature sensor connected to the measurement device, wherein at least one temperature sensor is disposed adjacent each heating element and the measurement device is configured to detect the quantity that depends on the temperature of the heating element using the temperature sensor. In other words, the temperature of each heating element is "measured" by at least one temperature sensor that is disposed adjacent to the heating element, normally in thermal contact with it. Any type of temperature sensor known in the art may be used, while it is preferred to use simple sensor types in order to save costs. It should be noted that each of the temperature sensors may have a temperature - dependent resistance as described above referring to the heating elements. In this case, the measurement device could detect the resistance of the temperature sensor as the quantity that depends on the temperature of the heating element.

[0017] It is conceivable to deduce whether a region near a specific heating element is filled with air or with liquid by a single measurement. For example, if the measurement is performed a certain time after the activation of the electrical signal, the temperature – and therefore the quantity that depends on the temperature – at the time of the measurement may be considerably different depending on whether the region next to the heating element is filled with air or with liquid. If some reference value for the quantity is available, e.g. corresponding to the absence of an electrical signal, it is possible to determine the change of the

quantity by comparing the measurement with the reference value. However, it is preferred that measurement device is configured to estimate the liquid level based on a time-evolution of the change of the quantity. In other words, the measurement device performs a plurality of measurements one after another. It is possible to detect the time-evolution of individual resistances or e.g. the time-evolution of a quantity that depends on two or more resistances. This embodiment is particularly advantageous since it is possible to monitor the response of the heating element to the electrical signal as a function of time. As the electrical signal starts, the heating element begins to warm up and the time evolution of this process largely depends on the medium in the neighboring region. If the medium is liquid, the heating element will react slowly, while it will react quicker if the medium is air. Also, the resistance (and the temperature) reached after some time will usually remain lower if the medium is liquid. It would therefore be conceivable to take into account various parameters of the time-evolution, e.g. the gradient of the quantity, the quantity at different points in time or the "asymptotic" value of the quantity, i.e. the value of the quantity that is reached or approached after a sufficiently long time.

[0018] The electrical signal applied to the individual heating element could have various forms. It could be an alternating signal (e.g. a sinusoidal signal) or a pulse signal that has a nonzero value for an activation time and is zero for a deactivation time afterwards. The deactivation time can be chosen sufficiently long to ensure that each heating element has cooled down to the temperature it had before the electrical signal was activated. Preferably, the measurement device is configured to apply an electrical signal comprising at least one step function. This means that the electrical signal remains constant for certain time interval and is then changed abruptly to a different value. For example, the electrical signal could be zero for the deactivation time, and then it could be increased to a non-zero value, at which it is kept for the activation time. The response of the individual heating element to the step function (also referred to as the step response) can be evaluated at different points in time.

[0019] According to one embodiment, the measurement device is configured to detect the resistance of at least one heating element. In this context, "detecting" refers to measuring at least one quantity from which the resistance can be

calculated, irrespective of whether the measurement device explicitly calculates the resistance. For instance, the measurement device could be configured to apply an electrical voltage of known magnitude to the respective heating element and measure the current through the heating element, whereby the resistance of the heating element is implicitly known. Alternatively, the measurement device could be configured to apply an electrical current of known magnitude to the respective heating element and measure the voltage.

[0020] It is preferred that each heating element is individually connected to the measurement device. The connection is normally by a pair of conductors, e.g. wires or conductor paths. By individually connecting the heating elements, it is possible to detect the individual resistance of each heating element and to evaluate the individual time evolution of this resistance.

[0021] Preferably, a plurality of heating elements are disposed sequentially with respect to a vertical direction of the liquid tank. In this embodiment, a plurality of heating elements are disposed one above the other with respect to the vertical direction. Optionally, they can be equally spaced along the vertical direction. In general, mostly depending on the geometry of the liquid tank, the respective heating elements are not disposed vertically above each other, but laterally offset.

[0022] To ensure a sufficiently good thermal connection between the heating elements and the inner cavity of the liquid tank while at the same time providing mechanical stability, it is preferred that at least one heating element is at least indirectly mounted on the tank wall. For instance, the respective heating element could be disposed on an inner surface of the tank wall, i.e. a surface that faces the inner cavity. Likewise, at least one temperature sensor, if present, can be at least indirectly mounted to the tank wall. This embodiment ensures a good connection to the tank wall, thereby stabilising the position of the respective heating element, as well as an excellent thermal connection to the medium (liquid or air) inside the inner cavity. However, it is also conceivable to dispose the respective heating element on an outer surface of the tank wall, which faces away from the inner cavity. As long as the thickness of the tank wall is not too high, the thermal contact between the heating element and the inner cavity is still sufficient to distinguish between heating elements that are disposed proximate to a region that is filled with air or a region that is filled with liquid.

[0023] According to a preferred embodiment, at least one heating element is disposed on an electrically isolating substrate, which substrate is connected to a tank wall of the liquid tank. Normally, a plurality of heating elements are disposed on such an isolating substrate, which could be made of PET or other suitable material. The heating element(s) could be printed onto the substrate along with any necessary circuitry. The substrate along with the heating element(s) could be regarded as a pre-fabricated heating unit that is connected to the tank wall. It is conceivable to use one heating unit for different types of liquid tanks or for different mounting positions on a specific liquid tank. Also, at least one temperature sensor, if present, can be disposed on the electrically isolating substrate.

[0024] In particular, the electrically isolating substrate can be a flexible foil substrate. The flexible foil substrate is usually rather thin (e.g. less than 1 mm) and can be easily integrated in any location of the vehicle tank. In particular, such a foil substrate can be adapted to the shape of any kind of tank wall. Any conductor paths connected to the heating elements (and, optionally the temperature sensors) could also be printed onto the flexible foil substrate, e.g. with conducting ink or the like, so that they do not affect the flexibility of the heating unit. Finally the PTC or NTC resistive material of the heating elements may be printed or deposited onto the substrate so that the resistive material partially overlaps the conductor paths, thereby ensuring the electrical connection between the conductor paths and the heating elements.

[0025] On the other hand, it is conceivable that at least one heating element is directly connected to the tank wall. In other words, the respective heating element is not pre-fabricated with an isolating substrate which is connected to the tank wall along with the (at least one) heating element, but it is directly connected to the tank wall. E.g. the heating element could be glued to the tank wall. Any necessary circuitry connected to the heating element could be connected to the tank wall in the same way. Alternatively, the heating element could be integrated into the tank wall as the liquid tank is moulded.

[0026] Apart from connecting the heating elements (with or without an isolating substrate) to one of the inner or the outer surface of the tank wall, it is possible that at least one heating element is disposed inside the tank wall. In this case, any circuitry connected to the heating element is normally at least partially disposed

inside the tank wall as well. By disposing the heating element inside the tank wall, a good thermal connection to the inner cavity is guaranteed. Also, there is a good mechanical connection to the tank wall and the heating element can be protected from mechanical damage and/or detrimental chemical influences.

[0027] In this context, it is preferred that at least one heating element is molded into the tank wall. In other words, the heating element is integrated into the tank wall as the tank wall is molded. It is also possible that one or several heating elements connected to an isolating substrate are molded into the tank wall along with the substrate. During the production process, the entire heating unit could be placed inside a mould for forming the tank wall, where they are embedded into the plastic material of the tank wall during the molding process.

[0028] Any preferred positions mentioned herein with reference to the heating elements can also be preferred positions for the temperature sensors, if present.

[0029] In general, it is possible to determine whether there is liquid in the region next to a specific heating element just by evaluating one or several measurements relating to the heating element. However, in some cases it may be useful to compare the measurement(s) with a reference measurement. According to one embodiment, the liquid level detection system comprises at least one reference element disposed to be at a distance from liquid inside the liquid tank, independently of the liquid level. In other words, the reference element is disposed at the location that is never proximate to a region filled with liquid, no matter what the current liquid level is. For example, the reference element could be disposed on the outside of the liquid tank, in a top region that is always above the liquid level. The reference element could even be spaced-apart from the liquid tank. The reference element could be disposed inside the tank, but above a theoretical maximum liquid level of the liquid tank, i.e. the highest liquid level that is possible for this tank. However, the reference element could also be laterally offset from the inner cavity of the liquid tank so that that any heat exchange with liquid inside the tank can be neglected. Finally the reference element could be arranged inside the tank in a region where it is always surrounded by liquid.

[0030] If a reference element is present, the measurement device can be configured to detect at least one resistance difference between the resistances of a reference element and a heating element. This resistance difference is then the

quantity that depends on the temperature of the heating element. In general, this can also refer to individually detecting the resistances of the reference element of the heating element and determining (e.g. calculating) the difference afterwards. On the other hand, the measurement device could directly detect a quantity that is representative of the resistance difference. For example, if the same electrical current is applied to both the reference element and the heating element, the voltage drop at each element is proportional to its resistance. Therefore, if the measurement device can detect the voltage difference, the resistance difference can be detected without detecting the resistances individually. Due to the tolerances of the resistances, the resistance difference cannot be expected to be approximately zero, even if the temperature of the reference element of the heating element are identical. However, as the time-dependent change of the resistance difference is monitored, it is possible to identify whether the region near the heating element is filled with liquid or with air if the resistance difference remains more or less constant, i.e. the change of the resistance difference remains below a certain threshold, it is assumed that the heating element is disposed in the vicinity of the same medium as the reference element.

[0031] Moreover, at least one reference element and at least one heating element can be connected by a circuit that is configured to detect the resistance difference. In particular, this can be a bridge circuit, e.g. a Wheatstone bridge. It is understood that by connecting the heating element of the reference element in a Wheatstone bridge, together with two identical resistors, any resistance difference can be detected by measuring the bridge voltage. It is possible to use a 4-wire configuration or a 6-wire configuration. In the first case, a single pair of wires is used to apply a voltage to the bridge circuit. In the second case, a second pair of wires is used to measure the voltage between the terminals of the bridge circuit.

[0032] The invention further provides a liquid level measurement method for a liquid tank, wherein at least one heating element is disposed proximate to an inner cavity of the liquid tank. The method comprises applying a time-dependent electrical signal to each heating element to heat up the heating element. It further comprises, for each heating element, detecting a quantity that depends on a temperature of the heating element, determining a time-dependent change of the quantity in response to the electrical signal, and detecting a liquid level based on

the time-dependent change of the quantity for each heating element. All these terms have been described above with respect to the inventive system and therefore will not be explained again. It is understood that the method steps may be performed by a measurement device as described above.

[0033] Preferred embodiments of the inventive method correspond to those of the inventive system.

Brief Description of the Drawings

[0034] Further details and advantages of the present invention will be apparent from the following detailed description of not limiting embodiments with reference to the attached drawing, wherein:

Fig. 1 is a schematic view of a an inventive liquid level detection system;

Fig. 2A is a diagram showing an electric signal;

Fig. 2B is a diagram showing the time evolution of a temperature;

Fig. 3 shows a first circuit with a sensor element and a reference element;

Fig. 4 shows a second circuit with a sensor element and a reference element;

Fig. 5 shows a third circuit with a sensor element and a reference element;

Fig. 6 is a schematic view of a first embodiment of a sensor unit for an inventive liquid level detection system;

Fig. 7 is a schematic view of a second embodiment of a sensor unit for an inventive liquid level detection system;

Fig. 8 is a schematic view of a third embodiment of a sensor unit for an inventive liquid level detection system; and

Fig. 9 is a cross-sectional view showing a tank wall with sensor units.

Description of Preferred Embodiments

[0035] Fig.1 schematically shows an inventive liquid level detection system 1 in a liquid tank 2 – like a fuel tank for a vehicle a water tank for the windscreen washer –, which has a tank wall 2.1 and an inner cavity 2.2. The inner cavity 2.2 is partially filled with liquid 20 and partially filled with air 30 (or a gas mixture that may contain vaporised liquid). A plurality of heating elements R_1 - R_5 are disposed proximate to

or inside the inner cavity 2.2. They may e.g. be mounted on the tank wall 2.1. Each heating element R_1 - R_5 is individually connected to a measurement device 10 by a pair of conductors 11. The heating elements R_1 - R_5 are sequentially disposed along a vertical direction Z of the liquid tank 2. As can be seen in fig. 1, a first and second heating element R_1 , R_2 are disposed below the liquid level, while a third, fourth and fifth heating element R_3 , R_4 , R_5 are above the liquid level. The liquid level detection system 1 further comprises a reference element R_{ref} that is also connected to the measurement device 10. While the heating elements are disposed next to a region of the inner volume that can be filled with liquid 20 or with air 30, depending on the liquid level, the reference element R_{ref} is disposed in a location where it is always at a distance from the liquid 20, irrespective of the liquid level. For instance, the reference element may be disposed outside the liquid tank 2. All heating elements R_1 - R_5 and the reference element R_{ref} have a temperature-dependent resistance and may also be referred to as thermistors. Each of them may comprise a PTC element or an NTC element. All elements R_1 - R_5 , R_{ref} may be identical or at least some elements R_1 - R_5 , R_{ref} may have different properties.

[0036] In order to detect the liquid level, the measurement device 10 applies an electrical signal to each of the heating elements R_1 - R_5 . A possible time-evolution of the electrical signal is shown in fig. 2A. In this case, the electrical signal comprises a step function that is zero up to a time t_0 and is then abruptly increased to a nonzero value. In this case, the measurement device comprises a voltage source, so that the electrical signal corresponds to a well-defined voltage V . Fig. 2B shows the temperature T_2 of the second heating element R_2 as well as the temperature T_3 of the third heating element R_3 as a function of time. Up to the time t_0 , both temperatures T_2 , T_3 remain constant. As the electrical signal increases to a nonzero value, each heating element R_2 , R_3 starts to heat up. However, there are distinct differences between the second heating element R_2 , which is disposed next to a region filled with liquid 20, and the third heating element R_3 , which is disposed next to a region filled with air 30. For instance, the gradient of the temperature T_3 is considerably higher than the gradient of the temperature T_2 . Consequently, for a certain point in time after t_0 , the temperature T_3 is higher than the temperature T_2 . In particular, the difference between the temperatures T_2 , T_3

increases at least for some time after t_0 . Also, the asymptotic values that are assumed after a sufficiently long time for T_2 and T_3 differ considerably. This difference is largely due to the different thermal capacitance of the medium near the respective heating element R_2 , R_3 . Even the specific thermal capacitance of air 30 is lower than that of most liquids 20. Moreover, the density of a typical liquid 20 is higher than that of air 30 by a factor of approximately 10^3 , which largely affects the actual thermal capacitance of a given volume near the respective heating element R_2 , R_3 . Therefore, the heat transfer from the second heating element R_2 to the neighboring liquid 20 is considerably higher than the transfer from the third heating element R_3 to the neighboring air 30. Since all heating elements R_1 - R_5 have a temperature-dependent resistance, the time-evolution of this resistance also depends on the medium near the heating element R_1 - R_5 . The actual time-evolution of the resistance depends on the relation between the temperature and the resistance (PTC, NTC, linear, nonlinear).

[0037] The measurement device 10 can determine whether a specific heating element R_1 - R_5 is disposed above or below the liquid level based on the time-evolution of the individual resistances in response to the electrical signal, thereby detecting the liquid level. However, since the resistance of each heating element R_1 - R_5 has a considerable tolerance, it is impossible to accurately determine the temperature by considering the resistance as such. Rather, the measurement device 10 determines a time-dependent change of the resistance, which is largely independent of tolerances regarding the absolute resistance. Since the electrical signal in this case comprises a step function, the time evolution of the resistance can also be referred to as the step response of the resistance. The measurement device 10 may detect the current flowing through each heating element R_1 - R_5 , whereby the resistance is at least implicitly known, since the voltage of the electrical signal is known. If the temperatures are expected to differ considerably after some time past the time t_0 and a reference value, e.g. corresponding to the absence of an electrical signal, a single measurement could be taken for a given point in time and the resistance could be compared with the reference value to determine the resistance change. To further enhance the reliability, several measurements for different points in time after t_0 could be performed, thereby obtaining several values for the time-dependent change of the resistance. It is also

possible to compare the measurements taken for each of the heating elements R_1 - R_5 with a measurement taken for the reference element R_{ref} . Due to the tolerances mentioned above, the difference between the resistances for a given point in time cannot be expected to be particularly small even if the respective heating element R_1 - R_5 is disposed above the liquid level. However, the time-dependent change of the resistance difference can be considered. If the resistance difference changes considerably as a function of time, i.e. the change of the resistance difference is above a threshold value, it can be assumed that the respective heating element R_1 - R_5 is disposed next to liquid 20, i.e. below the liquid level. If the change is below a threshold, it can be assumed that the respective heating element R_1 - R_5 is disposed above the liquid level. In order to compare the resistances, they could either be detected individually or their difference could be detected. The latter option is illustrated in figs. 3 - 5, where the first heating element R_1 and the reference element R_{ref} are connected by a bridge circuit 12 that allows to directly detect the resistance difference. In fig. 3, the first heating element R_1 and the reference element R_{ref} are connected in series on one side of the bridge circuit, while two identical resistors R are connected on the other side of the bridge. As the measurement device 10 applies an electrical signal to the bridge circuit, it also detects the bridge voltage V_b . Fig. 4 shows a slightly different embodiment, where the first heating element R_1 and the reference element R_{ref} each are connected in series with a resistor R on different sides of the bridge circuit. While fig. 3 and fig. 4 show a 4-wire measurement, fig. 5 shows a variation of the fig. 4 with a 6-wire measurement, where a first and second measurement voltage V_{m1} , V_{m2} at the connection points of the bridge circuit 12 are detected by the measurement device 10. With this configuration, the accuracy can be increased and the measurement is less influenced by the resistance of the conductors connecting the bridge circuit 12 to the measurement device 10.

[0038] Fig. 6 shows a first embodiment of a heating unit 3 that can be used for an inventive liquid level detection system 1. It comprises a flexible PET foil substrate 4, onto which the heating elements R_1 - R_5 and corresponding conductors 11 have been printed. On one edge, the conductors 11 are shown to end at a connector 13 that could be used to establish a mechanical and/or electrical connection to the measurement device 10 or to an intermediate connector cable.

[0039] Fig. 7 shows a second embodiment of a sensor unit 3, which is largely similar to the embodiment shown in fig. 6. However, here only one heating element R_1 is disposed on the foil substrate 4, which however is elongate and stripe-shaped, so that when mounted to the liquid tank 2, it extends along a vertical region along the vertical direction Z. It is understood that the heating behavior of the heating element R_1 depends on how much of it is disposed next to a region filled with liquid 20. Thus, by monitoring its resistance, a time-dependent change of the resistance can be determined, from which it can be estimated how much of the heating element R_1 is below the liquid level.

[0040] Fig. 8 shows a third embodiment of a sensor unit 3, which is also similar to the embodiment shown in fig. 6. It differs in that a temperature sensor S_1 - S_5 is disposed next to each heating element R_1 - R_5 . The temperature sensor S_1 - S_5 should be in thermal contact with the respective heating element R_1 - R_5 in order to measure its temperature. The heating elements R_1 - R_5 are shown as thermistors having a temperature-dependent resistance, but this is not necessary in this context. Each of the temperature sensors S_1 - S_5 is connected to the connector 13 via conductors 11. When connected to the sensor unit 3 via the connector 13, the measurement unit 10 can apply an electrical signal to each of the heating elements R_1 - R_5 while at the same time detecting a quantity representative of the temperature of each heating element R_1 - R_5 via the corresponding temperature sensor S_1 - S_5 . The temperature sensors S_1 - S_5 can be any suitable type of sensor, e.g. they may also be thermistors.

[0041] In each of figs. 6 to 8, the sensor unit 3 is highly flexible and therefore can be adapted to a great variety of shapes. For example even if the tank wall 2.1 has a highly complex shape as shown in fig. 9, the sensor unit 3 can be connected closely either to an outer surface 2.3 or an inner surface 2.4 of the tank wall 2.1, e.g. by gluing the foil substrate 4 onto the tank wall 2.1. Alternatively, the entire sensor unit 3 could be moulded into the tank wall 2.1. For example, the sensor unit 3 could be placed inside a mould for forming the tank wall 2.1, where it is embedded in the plastic material of the tank wall 2.1.

List of Reference Symbols

1	liquid level detection system
2	liquid tank
2.1	tank wall
2.2	inner cavity
2.3	outer surface
2.4	inner surface
3	sensor unit
4	foil substrate
10	measurement device
11	conductor
12	bridge circuit
20	liquid
30	air
R	resistor
R_1 - R_5	heating element
R_{ref}	reference element
S_1 - S_5	temperature sensor
V_b	bridge voltage
V_{m1} , V_{m2}	measurement voltage
Z	vertical direction

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ANSPRÜCHE

1. Flüssigkeitspegel-Erkennungssystem (1) für einen Flüssigkeitstank (2), umfassend:
 - 5 - mindestens ein Heizelement (R_1 - R_5), das zumindest in der Nähe eines inneren Hohlraums (2.2) des Flüssigkeitstanks (2) angeordnet ist, und
 - 10 - eine Messvorrichtung (10), die dafür ausgelegt ist:
 - ein zeitabhängiges elektrisches Signal an jedes Heizelement (R_1 - R_5) anzulegen, um das Heizelement (R_1 - R_5) zu erwärmen,
 - für jedes Heizelement (R_1 - R_5) eine Größe zu erkennen, die von einer Temperatur des Heizelements (R_1 - R_5) abhängt,
 - eine zeitabhängige Änderung der Größe in Reaktion auf das elektrische Signal zu bestimmen, und
 - 15 • basierend auf der zeitabhängigen Änderung der Größe für jedes Heizelement (R_1 - R_5) einen Flüssigkeitspegel zu erkennen.
2. Flüssigkeitspegel-Erkennungssystem gemäß Anspruch 1, dadurch gekennzeichnet, dass es mehrere Heizelemente (R_1 - R_5) umfasst, die an verschiedenen vertikalen Positionen zumindest in der Nähe des inneren Hohlraums (2.2) des Flüssigkeitstanks (2) angeordnet sind.
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3. Flüssigkeitspegel-Erkennungssystem gemäß Anspruch 1 oder 2, dadurch gekennzeichnet, dass es mindestens ein Heizelement (R_1 - R_5) umfasst, das sich entlang eines vertikalen Bereichs zumindest in der Nähe des inneren Hohlraums (2.2) des Flüssigkeitstanks (2) erstreckt.
- 25 4. Flüssigkeitspegel-Erkennungssystem gemäß einem der vorstehenden Ansprüche, dadurch gekennzeichnet, dass jedes Heizelement (R_1 - R_5) einen temperaturabhängigen Widerstand aufweist und die

Messvorrichtung (10) dafür ausgelegt ist, den Widerstand als die Größe zu erkennen, die von der Temperatur des Heizelements (R_1 - R_5) abhängt.

- 5 5. Flüssigkeitspegel-Erkennungssystem gemäß einem der vorstehenden Ansprüche, dadurch gekennzeichnet, dass es mindestens einen Temperatursensor umfasst, der mit der Messvorrichtung (10) verbunden ist, wobei mindestens ein Temperatursensor angrenzend an jedes Heizelement (R_1 - R_5) angeordnet ist und die Messvorrichtung (10) dafür ausgelegt ist, die Größe, die von der Temperatur des Heizelements (R_1 - R_5) abhängt, unter Verwendung des Temperatursensors zu erkennen.
- 10 6. Flüssigkeitspegel-Erkennungssystem gemäß einem der vorstehenden Ansprüche, dadurch gekennzeichnet, dass die Messvorrichtung (10) dafür ausgelegt ist, den Flüssigkeitspegel basierend auf einer Zeitentwicklung der Änderung der Größe zu schätzen.
- 15 7. Flüssigkeitspegel-Erkennungssystem gemäß einem der vorstehenden Ansprüche, dadurch gekennzeichnet, dass die Messvorrichtung (10) dafür ausgelegt ist, ein elektrisches Signal, das mindestens eine Schrittfunktion umfasst, anzulegen.
- 20 8. Flüssigkeitspegel-Erkennungssystem gemäß einem der vorstehenden Ansprüche, dadurch gekennzeichnet, dass mindestens ein Heizelement (R_1 - R_5) zumindest indirekt an einer Tankwand (2.1) des Flüssigkeitstanks (2) montiert ist.
- 25 9. Flüssigkeitspegel-Erkennungssystem gemäß einem der vorstehenden Ansprüche, dadurch gekennzeichnet, dass mindestens ein Heizelement (R_1 - R_5) auf einem elektrisch isolierenden Substrat (4) angeordnet ist, wobei das Substrat (4) mit der Tankwand (2.1) verbunden ist.
10. Flüssigkeitspegel-Erkennungssystem gemäß einem der vorstehenden Ansprüche, dadurch gekennzeichnet, dass das elektrisch isolierende Substrat (4) ein flexibles Foliensubstrat ist.

11. Flüssigkeitspegel-Erkennungssystem gemäß einem der vorstehenden Ansprüche, dadurch gekennzeichnet, dass mindestens ein Heizelement (R_1 - R_5) in die Tankwand (2.1) geformt ist.
- 5 12. Flüssigkeitspegel-Erkennungssystem gemäß einem der vorstehenden Ansprüche, dadurch gekennzeichnet, dass es mindestens ein Referenzelement (R_{ref}) umfasst, das so angeordnet ist, dass es sich, unabhängig vom Flüssigkeitspegel, in einem Abstand zu der Flüssigkeit (20) innerhalb des Flüssigkeitstanks (2) befindet.
- 10 13. Flüssigkeitspegel-Erkennungssystem gemäß einem der vorstehenden Ansprüche, dadurch gekennzeichnet, dass die Messvorrichtung (10) dafür ausgelegt ist, mindestens einen Widerstandsunterschied zwischen den Widerständen eines Referenzelements (R_{ref}) und eines Heizelements (R_1 - R_5) zu erkennen.
- 15 14. Flüssigkeitspegel-Erkennungssystem gemäß einem der vorstehenden Ansprüche, dadurch gekennzeichnet, dass mindestens ein Referenzelement (R_{ref}) und mindestens ein Heizelement (R_1 - R_5) durch eine Schaltung (12) verbunden sind, die dafür ausgelegt ist, den Widerstandsunterschied zu erkennen.
- 20 15. Flüssigkeitspegel-Erkennungsverfahren für einen Flüssigkeitstank (2), wobei mindestens ein Heizelement (R_1 - R_5) zumindest in der Nähe eines inneren Hohlraums (2.2) des Flüssigkeitstanks (2) angeordnet ist, wobei das Verfahren umfasst:
- Anlegen eines zeitabhängigen elektrischen Signals an jedes Heizelement (R_1 - R_5), um das Heizelement (R_1 - R_5) zu erwärmen,
 - 25 - Erkennen, für jedes Heizelement (R_1 - R_5), einer Größe, die von einer Temperatur des Heizelements (R_1 - R_5) abhängt,
 - Bestimmen einer zeitabhängigen Änderung der Größe in Reaktion auf das elektrische Signal, und

- Erkennen eines Flüssigkeitspegels basierend auf der zeitabhängigen Änderung der Größe für jedes Heizelement (R_1 - R_5).