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A Method for Level and Electrical Conductivity Measurement of Liquid

Salar Basiri[1], Mehdi Farzpourmachiani[2], Jalal Izadi Jorshari[3], Alireza Shafighi Malekshah[4], Ali Farzpourmachiani[5], Saeid Basiri[6], SiminNaghibi Masouleh[7]

[1] Ph.D. Entrepreneurship candidate, Technofest Institute of Technology University (TITU). Erquelinnes, Belgium
[2] Academician member of the European Academy of Sciences,
Assistant Professor in entrepreneurship, Technofest Institute of Technology University (TITU). Erquelinnes, Belgium.
[3] Postdoc. in entrepreneurship, Technofest Institute of Technology University (TITU). Erquelinnes, Belgium
[4] M.Sc. in Electrical Engineering, Technip Energy, Amsterdam, Netherland
[5]Ph.D. in entrepreneurship, Brussels Capital University, Istanbul Branch, Istanbul, Turkyie.
[6] Ph.D. Entrepreneurship candidate, Technofest Institute of Technology University (TITU). Erquelinnes, Belgium
[7] Ph.D. International Law candidate, Technofest Institute of Technology University (TITU). Erquelinnes, Belgium.
Corresponding Author: SalarBasiri

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ABSTRACT: This paper presents an innovative method to measure level and conductivity of liquid simultaneously. Iran patent application for this invention has been filed by authors in August 2013 In Iran patent office, application No.139250140003004040. The invention utilizes a novel method of using three or four electrodes to establish an electrical connection and deriving a set ofequations.

KEYWORDS: Liquid Level Measurement, Conductivity Measurement, Invention, Water level, Electronic Meter

I. INTRODUCTION

The level sensors market was valued at USD 4.38 billion in 2020 and is expected to reach a value of USD 7.45 billion by 2026, registering a CAGR of 10.06% over the forecast period of 2021-2026. The growing needs of Industry 4.0 and the Industrial Internet of Things (IIoT) led to an increased requirement of diagnostics and mobile-led access. Level sensors are becoming a major choice for automation in industries with large-scale manufacturing and storage of liquids or powdered materials [1].

Search in IEEE Explore returns more than 5000 articles about liquid level measurement and search in WIPO patentscope database returns more than 37000 inventions and patent applications. So, this field is relatively important in research and technology development.

International Application No. PCT/CN2017/089493, entitled “Liquid Level Sensing Device and Liquid Level Detection Method”, by Ming HE, and filed by Zhuhai Gree Intelligent Equipment Co., Ltd has disclosed a device comprising a plurality of liquid level measuring units connected sequentially and forming a measurement circuit for achieving multi-stage measurement of the liquid level to be measured, wherein each of liquid level measuring units comprises a resistor and a switch connected to each other in parallel, and resistance values of the resistors in the plurality of liquid level measuring units are different from one another such that total resistance value of the total resistor of the liquid level sensing device is different when measuring by the different liquid level measuring unit [2].

International Application No. PCT/US2016/018416 entitled “Level Sensor”, by Garrett Tetil and filed by TI Group Automotive Systems, LLC has disclosed a level sender for a tank includes a sensor device. The sensor device includes a primary pressure sensor, a reference pressure sensor, and a correction pressure sensor. A primary tube at least partially encloses the primary pressure sensor and extends from an upper region of the tank to a lower region of the tank. A reference tube at least partially encloses the reference pressure sensor and extends from the upper region to the lower region. A correction tube at least partially encloses the correction pressure sensor. The correction tube at least partially encloses the correction pressure sensor in the upper region. The sensor device further includes a processor coupled to the primary, reference, and correction pressure sensors to determine a level of liquid within the tank based on pressure measurements within the primary, reference, and correction tubes [3].

International Application No. PCT/JP2020/019420, entitled "Water Level Monitoring System and Water Level Monitoring Method", by Takashi Yamazaki, and filed by Mitsubishi Electric Corporation has disclosed a water level monitoring system comprises a water level information acquisition unit, a water quality information acquisition unit, a meteorological information acquisition unit, and a processing unit. The water level acquisition unit acquires water level information that indicates the water level of a reservoir or a river being monitored. The water quality information acquisition unit acquires water quality information that indicates the quality of water being monitored. The meteorological information acquisition unit acquires meteorological information including information pertaining to the amount of rain in a zone being monitored or a zone corresponding to the zone being monitored. The processing unit changes an acquisition period, which is the period for acquiring water level information, by the water level acquisition unit, on the basis of the water level information acquired by the water level information acquisition unit, the water quality information acquired by the water quality information acquisition unit, and the meteorological information acquired by the meteorological information acquisition unit [4].

Despite these and other improvement in the field of car safety control, still further improvement and reliable device and method are necessary. This paper describes an innovative method for this issue.

II. SIMULTANEOUSLY MEASUREMENT OF LEVEL AND CONDUCTIVITY

This invention is used to measure the depth or level of liquids. In this invention, the depth and electrical conductivity of the liquid can be measured simultaneously and can be stored or sent. This invention is used to measure the depth of liquids in tanks, wells and canals.

The method used for the invention is based on simultaneous use of three or four conductive electrodes of different lengths or cross-sections. By using these electrodes and a specific reference resistance or capacitor, a kind of resistance or capacitance divider circuits are formed between electrodes or between electrodes and reference resistance and capacitor, then by means of the measured data, two equations and two unknowns or one equation and one unknown has been derived. Finally, values of liquid depth or electrical conductivity or both are obtained by solving them.

To obtain the parameters of the equations, alternating voltage or current is applied to the electrodes and the reference resistor or capacitor. The electrode here means a corrosion-resistant conductor that is placed in the liquid and can have different dimensions and cross-sectional shapes based on the accuracy required in the measurement. Also, the electrode can be implemented by means of PCB manufacturing techniques. It should be noted that in any implementation of this invention, considering accuracy, cost, maximum depth and other design variables, proper reference resistor or capacitor in combination with electrodes have been used to measure the described electrical parameters.

In the invention, three different types of arrangements for the electrodes and the reference resistor or capacitor can be implemented by means of electro-mechanical relays. The reason for using relay are because of their very small resistance between their contacts in a defined connection state, the absence of self-contained and capacitive components and a suitable frequency response. In the following, these three types of configurations and arrangements have been described. An embodiment of the invention can implement any combination of these arrangements between the electrodes and the reference resistor or capacitor.

The first arrangement: in this case, four electrodes are used. The electrodes are divided into two pairs of long and short electrodes where are placed opposite to each other. Short electrodes can be wider than long electrodes. The way to make the liquid depth measurement probe is in such a way that the short electrode pair is located below the long electrode pair. The minimum depth of the liquid is such that all the short electrode and the initial part of the long electrode are placed in the liquid (Figure 1). The source of voltage or alternating current is connected to the first

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electrode of the long electrode pair. The second electrode of the long electrode pair is connected to the first electrode of the short electrode pair and then connected to the intermediate pass filter and RMS value measurement circuit. The second electrode of the short electrode pair is also connected to the zero-potential reference (earth connection). In this way, a resistive or capacitive voltage divider has been formed between the pair of short and long electrodes, and the change in the height of the liquid causes a change in the RMS output voltage, and by measuring this voltage, the height of the liquid could be obtained. This type of arrangement is able to measure the height of the liquid regardless of the electrical conductivity. This arrangement can be used even in cases where there are significant changes in the electrical conductivity of the liquid. In this case, only one equation exists between liquid depth and voltage.

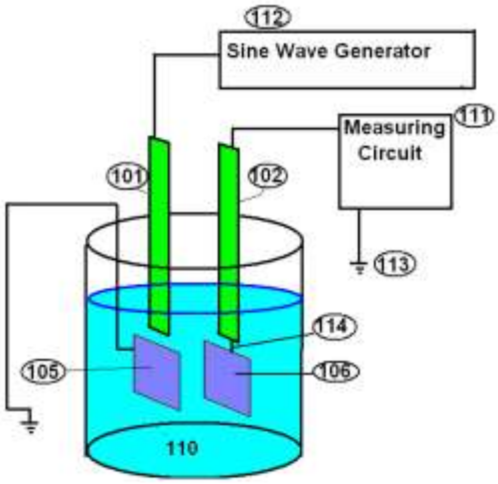

Figure 1. First arrangement of electrodes in the invention

The second arrangement: in this case, similar to the first arrangement, four electrodes are used. The way the electrodes are placed is similar to the first arrangement but their electrical connection is different. In this arrangement, reference resistor or capacitor (a known impedance) has been used (Figure 2). An alternating current or voltage source is connected to the reference impedance. The second end of the reference impedance is connected to the first electrode of the long electrode pair, and from this connection to the band pass filter and RMS voltage measurement circuit, then the second electrode of the long electrode pair is connected to the ground connection. In this way, a resistive or capacitive voltage divider has been formed between the reference resistance or capacitor and the long electrode pair. In the same way, the reference resistor or capacitor can be placed in series with the short electrode pair by switching the relays. In this way, the voltage values of the resistive or capacitive division between the reference resistor or capacitor, and the pair of electrodes can be measured. By measuring the amplitude of the alternating wave and value of the reference resistor or capacitor, the values of the resistance or capacitance between the long electrode pair ZLE and the short electrode pair ZSE are obtained. Then ZSE has been used to calculate electrical conductivity and ZLE / ZSE ratio is used to calculate liquid height. It is more appropriate to use the reference resistor and form the resistance equivalent to the liquid placed between the two electrodes. In this case, there are two equations between liquid depth and electrical conductivity and measured voltages that can be solved independently.

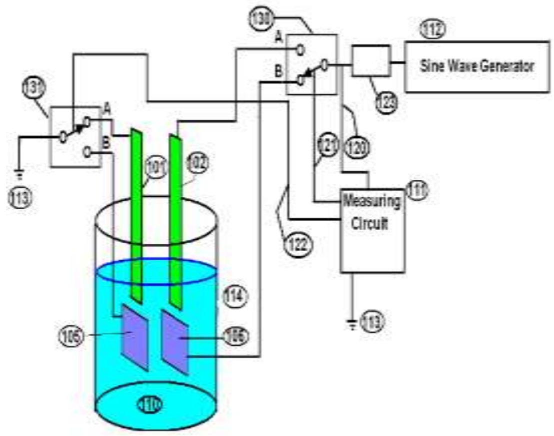

Figure 2. Second arrangement of electrodes in the invention

The third arrangement: in this case, three electrodes with different lengths or cross sections are used. The first, second and third electrodes are placed in the liquid in order of length, and the lower part of the smaller electrode is always in the liquid. Therefore, the electrical connection between the electrodes is established through liquid (Figure 3). The electronic circuit can measure the value of resistance or capacitor between each pairs of electrodes. This measurement has been done either by using a reference impedance and divider between each pair of electrodes according to the method described in the first and second arrangement, or by using direct measurement of the RMS value of voltage or current applied to the pair of electrodes. The resistance or capacitance between both pairs of electrodes depends on the electrical conductivity and the surface of the electrode that is placed inside the liquid. So, the equation of resistance or capacitance includes two

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surface parameters of the conductor that is in the liquid and electrical conductivity. Therefore, there are two independent equations between the resistance of both pairs of electrodes and the depth of the liquid and their electrical conductivity. It is better to measure the resistance or capacitance between the first and second electrodes and the third electrode, which is smaller than the others. If these two resistors are called R23 and R13. The equations will be R13 = f(H,S) and R23 = g(H,S), where H is the liquid depth and S is the liquid conductivity. Therefore, by simultaneously solving the two equations f and g, the values of depth and conductivity are derived.
In the invention introduced in the previous paragraphs, a sinusoidal oscillator is used as an alternating signal source. But any other method can be used for this purpose, including the use of digital to analog converters with the ability to create any type of waveform and any frequency. The signals of resistive or capacitive dividers between the electrodes or the electrode and the reference impedance pass through a band pass filter at the frequency of the alternating signal source to eliminate the noise caused by the electromagnetic interference on the electrodes, which can be caused by the 50 or 60 Hz power lines located near the electrode.

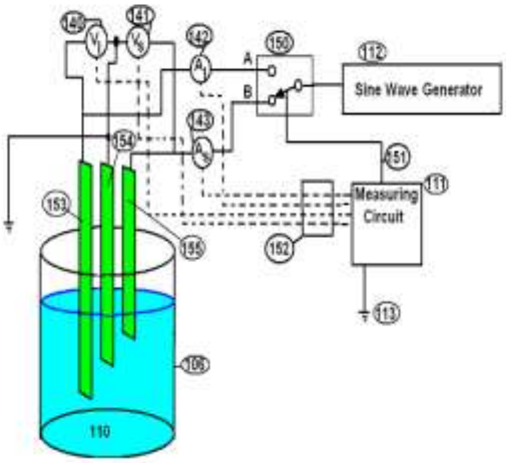

Figure 3. Third arrangement of electrodes in the invention

To measure the RMS voltage of the alternating signal, RMS-to-DC converters, which are provided as integrated circuits (such as AD736 as shown in Figure 4), have been used. Then, using the analog to digital converter, the obtained values are given to a microcontroller. The microcontroller sets the desired arrangement by connecting and disconnecting the relays placed in the circuit and calculates the values of the liquid depth and electrical conductivity based on the data obtained from the ADC and based on the relevant calculations.

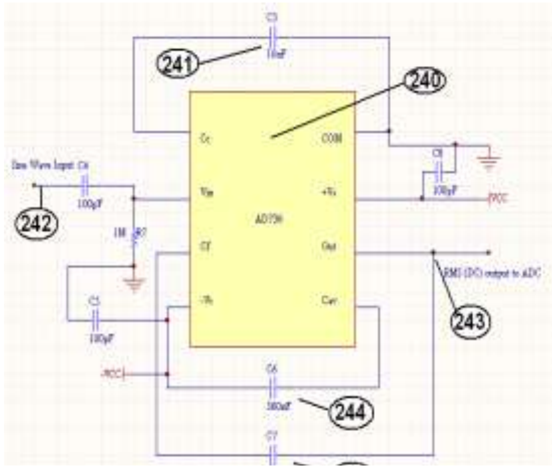

Figure 4. True RMS to DC converter used in the invention embodiment

The block diagram of the measuring electronic circuit used in this invention is shown in Figure 5. The microcontroller is responsible for setting the functional characteristics of the circuit blocks or the position of the relays for different arrangement, analysing the data and calculating the height and conductivity values of the liquid.

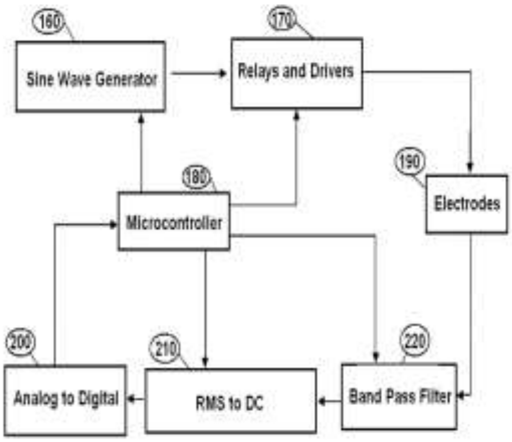

Figure 5. Block diagram of the electronic circuit of the invention

The shape, material and cross section of the electrodes have an important impact on the measurement quality. The type of electrodes is selected from steel or copper any other type of electrode that is resistant to corrosion caused by liquid. In the first and second arrangement, PCB printed circuit manufacturing techniques have been used to make the electrodes. The sets of electrodes in the first and second arrangements is implemented inside a cylinder, which makes it easy to install. In the third arrangement, it's possible to use three conductive steel cylinders that are inside each other. Any combination of these three arrangements can be used according to the requirements of a desired application.

In the case that PCB printed circuit manufacturing techniques are used, pattern is very important in the measurement accuracy and performance of the invention. Figures 6 show two examples of electrode patterns. It should be noted that there is no mechanical connection between two pairs of short and long electrodes, and the electrical connection between the electrodes is established according to the stated arrangements.

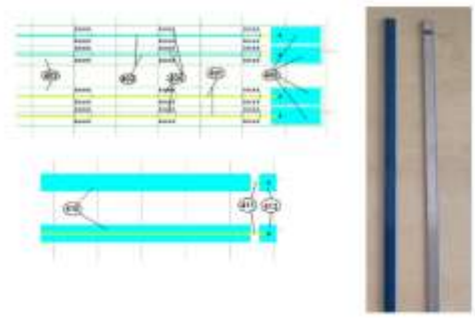

Figure 6. Two examples of electrodes pattern

III. CONCLUSION

Present paper has described a novel method and device in the field of level measurement. This invention has made by researchers and has tested on various occasions (Figure 7). The results show reliable and effective operation and thus can measure level and electric conductivity in harsh environment. The invention has filed for Iran patent application and has won an IFIA supported international Gold Medal at iCAN 2019 (Figure 8).

Figure 7. The invention test and validation

Figure 8. Gold Medal for the invention, iCAN2019, Toronto, Canada

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