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The Study Of The Transformation Functions Of Capacitive Level Gauges In The Construction Of Mathematical Models.

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ABSTRACT

The article presents the results of studying methods for measuring the electrical capacitance of primary converters. A developed capacitive level sensor of a coaxial type for non-conducting liquids is proposed. Recommendations are given for the practical implementation of methods for measuring electrical capacity by the parameters of transient processes.

Keywords: capacitive sensor, liquid level, transients

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INTRODUCTION

The operation of capacitive converters of non-electrical quantities to electrical is based on the principle of the operation of an electric capacitor. An electric capacitor is a system consisting of two conductors separated by a dielectric layer [1, p. 56]. It is known that the value of the capacitor C's electrical capacitance for a plane-parallel arrangement of electrodes (without taking into account the edge effect) is determined by the following expression:

$$C = \varepsilon_0 \varepsilon \frac{S}{d}; \qquad (1)$$

where ε_0 - a dielectric constant numerically equal to 8,854187817·10^{-12} F/m;

ε – relative permittivity of the medium filling the interelectrode space;

S - capacitor electrode area;

d - distance (gap) between the electrodes of the capacitor.

It can be seen from expression (1.1) that the capacitance of the capacitor sensors having a plane-parallel electrode system depends on the change in one of the three variables of the electrode area S of the capacitor, the distance between the electrodes d and the relative permittivity ε of the medium located between the electrodes, or from combination of all parameters simultaneously [2, p. 183; 3, p. 70].

A controlled non-electrical quantity usually affects one of these parameters, thereby changing the capacity of the CD. Thus, the principle of operation of capacitive sensors (pressure sensors, sensors for angular and linear movements, humidity, level sensors for liquid and bulk materials, etc.) is determined by the type of the measured quantity and the way it affects the capacitance of the sensor.

The measurement of the level of liquids by capacitive sensors is based on a change in the permittivity ε of the medium filling the interelectrode space. It is seen from expression (1.1) that the capacity of the capacitor is proportional to the relative permittivity ε of the substance filling the interelectrode space [4, p. 53]. The dielectric constant ε_{air} air is practically equal to 1, and for different liquids the values ε_l are in the range from 2 to 80.

A feature of the application of EC in control and monitoring systems is a small initial capacitance of sensors, which in most cases lies in the range of 10 to 10^3 pF. This circumstance leads to the need to use high frequency voltage from 1×10^3 to $(1\div2)\times10^8$ Hz for the operation of sensors. When using low frequencies, for example the industrial frequency of 50 Hz, capacitive level sensors (and other types of capacitive sensors) have a large reactive resistance, which limits their use in measuring circuits [5, p. 6-7].

The use of a high-frequency signal leads to the need for additional analog and digital conversion, in order to obtain unified signals (current, frequency or voltage) that are convenient for remote transmission over distances and subsequent use in control and monitoring systems [5, p. 7-9; 6. with. 62].

Another important parameter affecting the accuracy of measuring the level of capacitive sensors is the active leakage resistance of the R_{leak} of the primary converter. The value of this resistance depends on the quality of the insulating materials used in the design of the capacitive sensor, on the leakage resistance of the connecting cable, and also on the conductive films that can form on the surface of the insulators. In the event that the quality of the insulator is not satisfactory, the active conductivity of the sensor can be commensurate with the capacitive. This will lead to a significant increase in the measurement error, and in some cases to a malfunction of the sensor - the lack of the ability to perform measurements [6, p. 62].

Therefore, ideally capacitive methods are inherently designed to work with dielectric liquids, which have a sufficiently high specific electric resistance. In the case of an electrically conductive medium, as noted above, a complex of problems arises immediately, due to the need to eliminate the influence of "parasitic" conductivity [6, p. 62].

In addition, even with good dielectrics (mineral oils, oil products, etc.), it is necessary to apply additional measures to eliminate the effect on the metrological characteristics of the change ε_l. These changes can be caused by fluctuations in both temperature and the change in composition or type of liquid.

MATERIALS AND METHODS

The basis for obtaining primary information about technological parameters are primary converters of various non-electrical quantities, which are called sensors. It is from the metrological characteristics of the primary measuring transducers and the methods of processing the measuring signals that the efficiency of the entire measuring system will depend.

In the works [7, p. 1; 8 p. 1; 9 p. 69], various functional structures of capacitive level gauges have been studied that have different metrological characteristics. Primary converters are made in the form of a set of rods, cylinders or plates of arbitrary shape. As the second electrode, the metal walls of a reservoir with a controlled liquid are often used. To increase the initial capacity of the sensors, and accordingly, to increase the sensitivity of the device, the sensor is assembled from several concentrically arranged tubes forming parallel capacitors [7, p. 1; 8 p. 1].

One of the most common structures of capacitive level sensors are coaxial sensors, the electrodes of which are made in the form of cylinders. One of the electrodes (cylinders) is located in the inner cavity of the other. The plates of the coaxial sensor are the surfaces of the cylinders facing each other [10 p. 1].

The wide distribution of capacitive sensors of the coaxial type is due to a simple design (for manufacturing), high noise immunity, rigidity of the design of the primary converter. In addition, capacitive sensors of the coaxial type are included in the range of level measuring instruments of the "State system of industrial instruments and automation equipment" (GSP).

RESULTS AND DISCUSSION

A capacitive level sensor of a coaxial type for non-conductive liquids is shown in Fig. 1. The sensor consists of two coaxially located electrodes 1 and 2 made in the form of tubes of circular section placed vertically in a tank 3 with a dielectric liquid whose level is to be measured. The free ends of the sensor are connected to the measuring instrument.

For each value of the liquid level in the tank, the capacitance of the sensor is defined as the capacitance of two parallel capacitors C_1 and C_2 (Figure 1), one of which is formed by a part of the sensor electrodes and the liquid (part of the sensor immersed in the liquid) whose level is to be measured, the rest of the converter electrodes and the air or vapor of the liquid (part of the sensor not submerged in the liquid).

In general, when the level of the monitored liquid is between the extremes of the sensor, the value of the electrical capacitance of the coaxial sensor is determined by the following expression:

$$C_{sen} = C_1 + C_2 + C_0, \qquad (2)$$

where C_1 - capacity of the liquid-filled part of the condenser level sensor;
C_2 - capacity of the immersed part in the liquid of this sensor;
C_0 - capacity of bushing and connecting cable.

The values of C_1 and C_2 vary with the change in the level of the liquid in the tank, and accordingly, the total capacitance of the sensor changes. In this case, the capacitance C_1 depends on the length of the unloaded part of the capacitor level sensor of the liquid level and, correspondingly, on the specific capacity of the empty sensor. The relative dielectric permeability of air or the gaseous medium to a change in capacitance C_1 will not affect, since the dielectric constant of air and various gaseous media ε_g is approximately equal to unity and can be regarded as a constant. The value of C_2 depends on the length of the immersed part of the sensor and is determined by the relative permittivity of the controlled liquid ε_l.

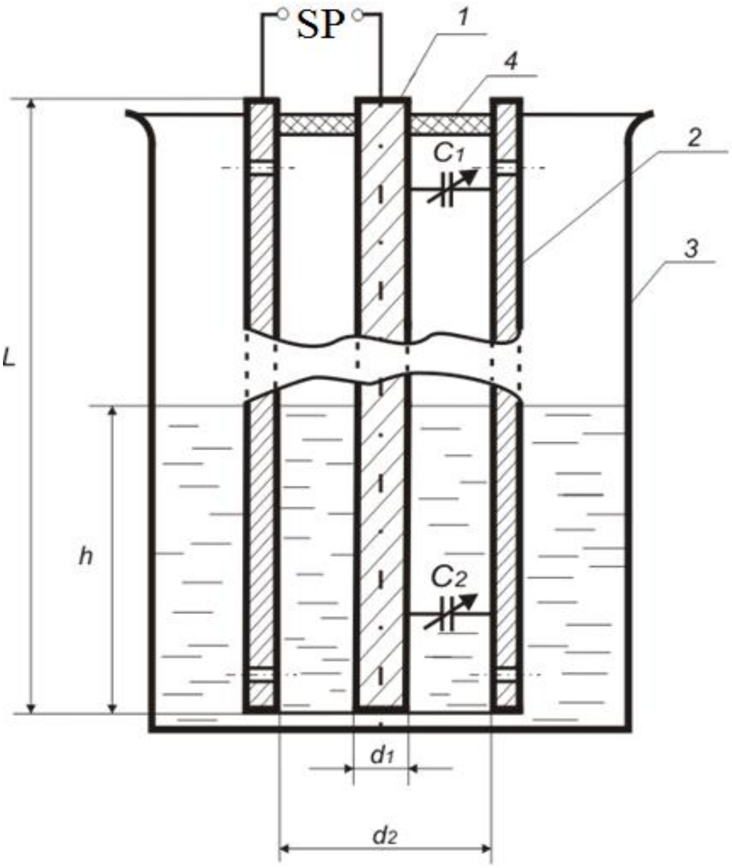

Figure 1: Scheme of a capacitive coaxial sensor for measuring the level of non-conductive liquids

Capacity C_0 does not depend on the change in the level of the liquid in the tank, but is determined only by the properties of the insulating material. In this case, the sensor's impedance is determined by the value of capacitance C_0 and its active leakage resistance R_{leak}, which is due to the conductivity of the insulating material.

In general, the capacitance of the coaxial level sensor is determined by the expression:

$$C = \frac{2\pi\varepsilon\,\varepsilon_0 L}{\ln(\frac{d_2}{d_1})}, \qquad (3)$$

where L – length of probe electrodes;
d_1 – outer diameter of internal electrode (cylinder);
d_2 – inner diameter of external electrode.
Hence it is not difficult to write down the expressions for determining C_1 and C_2:

$$C_1 = \frac{2\pi\varepsilon_0\varepsilon_g(L-h)}{\ln(\frac{d_2}{d_1})};\quad C_2 = \frac{2\pi\varepsilon_0\varepsilon_l h}{\ln(\frac{d_2}{d_1})}; \qquad (4)$$

where ε_g – relative permittivity of air or vapor-air medium located above the surface of the monitored liquid ($\varepsilon_g \approx 1$);
ε_l - relative permittivity of the controlled fluid;
h – liquid level.
Then expression (2) takes the form:

$$C_{sen} = C_0 + \frac{2\pi\varepsilon_0\varepsilon_g(L-h)}{\ln(\frac{d_2}{d_1})} + \frac{2\pi\varepsilon_0\varepsilon_l h}{\ln(\frac{d_2}{d_1})}; \qquad (5)$$

Expression (1.5) is a simplified function of the transformation of a coaxial capacitive level sensor for non-conducting liquids. Principal differences in the design of capacitive sensors are determined by the electrical characteristics of the liquid, the level of which is to be measured, or more precisely the degree of electrical conductivity of the controlled medium. Depending on the electrical properties of the liquid, the capacitive level sensors are divided into sensors for measuring the level of conductive and non-conductive fluids. It is known that liquids having specific resistivity $\rho > 10^7 \div 10^8$ Om×m and the relative permittivity $\varepsilon_l \leq 5 \div 6$, belong to the group of non-conductive, and liquids having $\rho \leq 10^5 \div 10^6$ Om×m and $\varepsilon_l \geq 7 \div 10$, belong to the group of electrically conductive.

The difference is that when measuring the level of electrically conductive liquids, one of the sensor electrodes is covered with an insulating material (in most cases it is a potential electrode), in the case of measuring the level of non-conductive liquids, the electrodes are not insulated. In the case of measuring the level of conductive fluids, the expressions for determining C_1 and C_2 will take a different form.

CONCLUSION

The measurement of the electrical capacitance of primary converters is carried out by methods and instruments that are different in principle [11 p. 62-63]. For the practical implementation of methods for measuring the electrical capacity by the parameters of transient processes and methods for measuring the level from the value of the electrical capacity of primary liquid level converters, a device described in [12, p. 10-12].

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