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“FRINGING” CURRENT INFLUENCE ON RESULTS OF MEASURING CROSS-SECTION AREA OF LIQUID FLOW BY A CONDUCTIVE SENSOR

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Abstract: The work presents the results of theoretical research and simulation of “fringing” current distribution and its influence on the output signal of a conductive sensor which is used as a measuring device for determining a cross-sectional area of liquid flow (in particular, milk flow) and consists of electrodes placed on the walls of the dielectric tube with a rectangular cross-section.

As a result, an influence coefficient of fringing current on measurement results has been obtained, which determines the deviation of the total current of the sensor from the current of the same sensor without taking into account the fringing current.

It has been determined the cross-sectional area of the current flow where fringing current significantly influences the value of the sensor output signal. This allows determining the minimum length of the conductive sensor. The results of research are presented in graphical and numerical forms.

Key words: conductive sensor, fringing current, cross-section area, liquid flow.

1. Introduction

The principle of conductivity measurement is widely applied to conductive liquids. An immersed measuring probe detects the resistance of the medium with small currents, which is processed by an integrated electronic device and is converted into a measured value. Typical applications are overflow protection or protection from the lack of liquid, pump control. Currently, there is an actual problem of calculating the liquid flows and controlling their properties and parameters.

These problems are the subject of many theoretical and practical works. New measurement methods for corrosive liquid flows were developed, e. g. in [1] developed contactless experimental methods of flow measurement for aggressive conductive liquids based on electromagnetic forces were shown. By measuring the Lorentz force, we can calculate the average velocity of the liquid flow. An issue of the day is the calibration of measuring devices taking into account the influence of external electromagnetic fields and temperature fluctuations on the liquid properties as well as design features of conductive sensors. Improving the accuracy of measurements of liquid flows’ parameters was discussed in the article [2], where the measurement of the electrical conductivity of aqueous solutions was considered, which gave necessary information about solution chemistry. The authors [2] remarked that the understanding of these changes allowed the user to obtain a tool to achieve greater accuracy and repeatability.

For measurement of liquid expenditure and flow speed a variety of sensors is used.

To determine the cross-section area of liquid flow, conductive sensors can be used, whose operation is based on measuring the electrical resistance between sensor electrodes of a transducer, located on the walls of the channel.

A number of works were devoted to this problem [3–6]. So, in the works [4, 5] a technique of liquid expenditure measurement was substantiated, that uses data received from an electrochemical transducer of velocity and a conductive transducer of cross-sectional liquid flow. In the work [6], the design features of a sensor implementing the above method were documented.

2. Statement of the problem

The purpose of this research is to determine the impact of fringing current on the output value of a conductive sensor signal.

The construction of the transducer of cross-sectional liquid flow is shown in Fig. 1.

The transducer consists of the tube 1 made of a dielectric material, the electrodes 2, 3, and the information conversion unit (ICU), which ensures sensor operation and the conversion of the sensor output signal into the value of the cross-sectional flow.

The electrodes are placed on the opposite walls of the tube and have the following dimensions: the area of the tube cross-section is of 121 mm^2 and the electrode’s length in the flow direction is of 5 mm.

Besides the current whose cross section coincides with the area of the electrodes, i.e. mainstream current, there is also a current between the electrodes that flows outside of this zone, i.e. fringing current.

To determine the structural parameters of the transducer it is necessary to find the relation between the fringing current and the measurement error of the sensor and to determine the zone of concentration of current density.

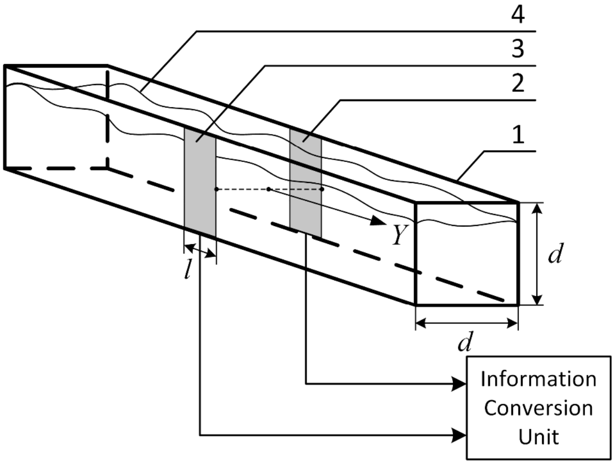

Fig. 1. Construction of the transducer of cross-sectional liquid flow (1 – tube; 2, 3 – electrodes; 4 – liquid flow).

3. Determination of the impact of fringing current on the output value of conductive sensor signal

To solve this problem it is necessary to simulate the current flow in the transducer of cross-sectional liquid flow in two cases: firstly, under condition that the current flows only in the area of electrodes (i.e. total current is equal to mainstream current) and, secondly, providing free current flow for different values of electrodes' length.

Modelling of these processed may be done through the calculation of current distribution in the system of conductors.

As a component of an electric circuit, the liquid between the electrodes of the conductive sensor can be represented by a simplified equivalent circuit shown in Fig. 2. Here the total sensor current flows between the electrodes $E1$ and $E2$, and electrical resistance of the liquid between the electrodes that corresponds to mainstream current flow is equal to $R0$. Other resistances form a conducting system for spreading of fringing current flowing outside of the cross-sectional area that coincides with the area of the electrodes.

Obviously, the farther the circuit sections are placed from $R0$, the smaller the value of fringing current flowing in them is and the less impact it has on the measurement results of the sensor.

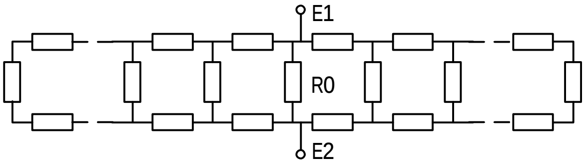

Fig. 2. Simplified equivalent circuit of the liquid between the conductive sensor's electrodes.

Thus, the current in the circuit sections that are far enough from $R0$ causes insignificant change in the total sensor current and its influence on the result is within the measurement error.

In physical meaning, fringing current that flows through the liquid at a sufficient distance from the cross-sectional area that coincides with the area of the electrodes does not have a significant impact on the measurement result. Therefore, to determine the minimum length of the sensor the distance from the edge of the cross-sectional area to the point where fringing current effect is still noticeable must be defined.

The rectangular cross-sectional area of liquid flow enables avoiding distortions caused by different distances between opposing electrodes and simplifies the calculation of electrical resistance between them.

Ideally, when there is no fringing current and the current flow is homogenous, the current density is the same at all points of the conductor formed by electrodes and liquid between them, and its resistance $R0$ is calculated by the expression for the resistance of the conductor with the constant cross-section.

In practice, the impact of fringing current results in the appearance of concentration gradient of current density within the entire sensor. The heterogeneity of current density and its concentration in different parts of the sensor can be determined when a model with heterogeneous parameters is developed.

Taking into account the fact that current density does not change along the immersed height of the electrode, i.e. the vector of current density does not have z-component. it is reasonable to develop a two-dimensional model. Such problem can be described by Poisson's equation for scalar electric potential U in the form of current continuity equation:

$$\partial/\partial x\left(1/r \cdot \partial U/\partial x\right)+\partial/\partial y\left(1/r \cdot \partial U/\partial y\right)=0\,, \qquad (1)$$

where r is liquid resistivity.

Here the vector of current density is determined by the expression $\vec{j}=-r^{-1}\,\mathrm{grad}\,U$.

Boundary conditions for the problem are the Dirichlet conditions, which determine the known values of potential on the electrodes' surfaces and Neumann conditions at the rest of the boundary the current does not flow through.

The numerical simulation of the two-dimensional field has been carried out by finite element method using the software ELCUT (QuickField in English) [7]. Entry data of the problem: the voltage between the electrodes is of 2 V; the tube width (the length of the vertical side of the rectangular area shown in Fig, 3a) and the tube height are of d=11 mm each; the effective tube length (the length of the horizontal side of the rectangular area shown in Fig. 3a) is of 205 mm; the electrode's length is of l=5 mm. The denotations d and l are shown in Fig.1.

The results of simulation of current density distribution in the conductive transducer of cross-sectional liquid flow, in case of taking and in case of not taking into account the fringing current, are shown in Fig. 3. It can be seen that consideration of the fringing current (Fig. 3a) significantly changes the structure of the electric field as opposed to the case without fringing current (Fig. 3b).

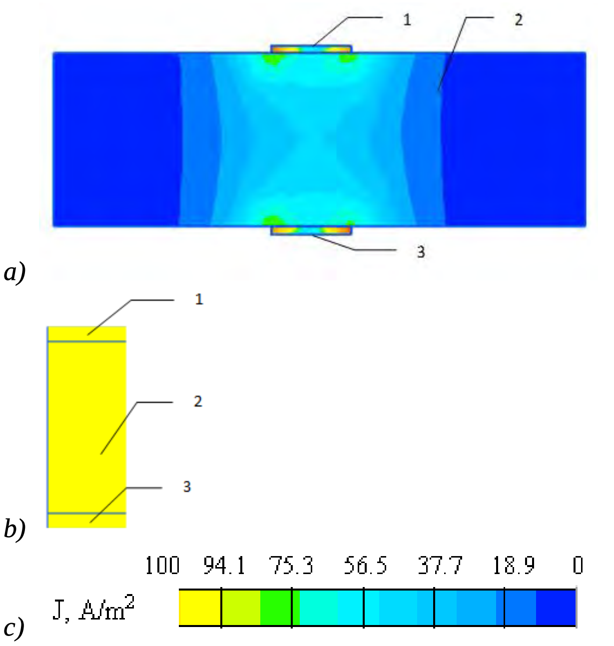

Fig. 3. Graphical representation of current density distribution in the conductive transducer of cross-sectional liquid flow (1 - anode; 2 - fluid; 3 - cathode): a) with fringing current; b) without fringing current; c) the scale of current density.

The simulation has been carried out for a liquid with conductivity 0.6 S/m, which corresponds to average value of electrical conductivity of milk.

A diagram that shows the dependence of the current I_1 between the conductive transducer electrodes that is confined to some width counted along the axial line of the liquid flow on the distance Y that is equal to half the difference between the width and the electrodes' length is shown in Fig. 4.

The following symbols are used in this diagram: I_0 is the mainstream current between the electrodes of the conductive transducer; I_p is current value that is close to the total current and includes the significant part of fringing current that substantially influences the output signal of the conductive transducer; Y_p is a distance counted along the axial line of liquid flow to which the above-mentioned significant part of fringing current is confined.

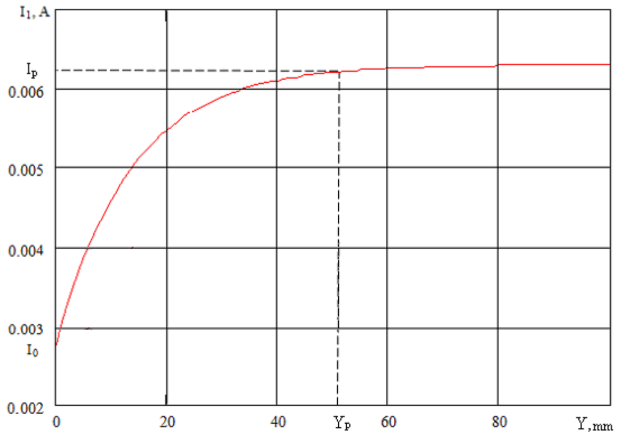

Fig. 4. The dependence of the current (confined to some width counted along the axial line) on the width parameter.

The current I_1 through the surface s_1 it is confined to is determined by the equation

$$I_1 = \int j_n ds_1 , \tag{2}$$

where j_n is the normal current density obtained from the simulation, s_1 is the surface area. If the surface coincides with the axial cross-section of the tube, $s_1 = h \cdot (2Y + l)$, where h =1 mm is the height unit of the immersed electrode part, l is the electrode's length.

As it is shown in Fig. 4, the mainstream current between the electrodes in the conductive transducer of cross-sectional liquid flow I_0 is of 2.76·10^{-3} A, and the dependence of fringing current ($I_1 - I_0$) on the distance is of exponential nature.

The most significant part of the fringing current is confined to the distance of 50 mm. Beyond this distance fringing currents have negligible effect on the total current value.

The sum of the mainstream current I_0 and the most significant part of the fringing current is of 6.3·10^{-3} A, which is 2.3 times more than I_0.

4. Conclusion

Analysing the obtained results, we can draw the following conclusion.

The impact on the output value of transducer signal is caused by fringing currents confined to the area of

50 mm counted along the axial tube line outside the mainstream current flow.

The total current between the electrodes of cross-sectional liquid flow transducer that includes fringing current (confined to the distance of 50 mm) differs from the mainstream current (without fringing current) by a coefficient equal to 2.3.

The obtained results of this research can be used to increase the accuracy of the output signal of a conductive sensor with a given geometry. This sensor is used as a measuring device for determining the cross-sectional area of liquid flow.

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ВПЛИВ СТРУМІВ РОЗСІЮВАННЯ НА РЕЗУЛЬТАТИ ВИМІРЮВАННЯ ПЛОЩІ ПОПЕРЕЧНОГО ПЕРЕРІЗУ ПОТОКУ РІДИНИ КОНДУКТИВНИМ СЕНСОРОМ

Володимир Войтюк, Дмитро Трушаков,
Сергій Рендзіняк

Наведено результати теоретичних досліджень та моделювання ступеня впливу струмів розсіювання на вихідний сигнал кондуктивного сенсору, що складаються з електродів, розташованих на стінках діелектричної труби прямокутного перерізу, який використовується як вимірювач площі поперечного перерізу потоку рідини (молока). У результаті отримано значення коефіцієнта впливу струмів розсіювання на результати вимірювання, який визначає відхилення величини загального струму сенсора порівняно з величиною струму, що протікає по поперечному перерізу, який збігається з поверхнею електродів, тобто основного струму. Загальний струм сенсора визначається як сума основного струму та струму розсіювання. Визначено відстань, що відлічується по осьовій лінії труби від границі протікання основного струму, від краю електродів сенсора, на якій струми розтікання спричиняють відчутний вплив на величину вихідного струму сенсора, що дає змогу визначити мінімальну довжину сенсора. Результати дослідження подано в графічній та числовій формі.

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