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INVARIANT TRANSDUCERS OF CAPACITIVE SENSOR PARAMETERS INTO VOLTAGE

M. R. Herasym
Postgraduate*
E-mail: marta88leskiv@gmail.com
Y. V. Pokhodylo
Doctor of engineering, Professor*
E-mail: evgenp@meta.ua
*Department of Metrology, Standardization and Certification
National University "Lviv Polytechnic"
Bandera str., 12, Lviv, Ukraine, 79013

Проаналізовано варіанти побудови вимірювальних перетворювачів «імпеданс-напруга» на основі пасивних та активних перетворювачів з контактними чотириелектродними сенсорами, які забезпечують режим заданого струму або режим заданої напруги. Наведено електричну схему заміщення чотириелектродного первинного перетворювача, яка враховує приелектродний імпеданс та імпеданс контрольованого об’єкта між всіма електродами, а також відповідна математична модель

Ключові слова: ємнісний сенсор, перетворювач, електрична модель, ємність подвійного шару, неінформативний імпеданс

Проанализированы варианты построения измерительных преобразователей «импеданс - напряжение» на основе пассивных и активных преобразователей с контактными четырехэлектродной сенсорами, которые обеспечивают режим заданного тока или режим заданного напряжения. Приведена электрическая схема замещения четырехэлектродного первичного преобразователя, которая учитывает приэлектродном импеданс и импеданс контролируемого объекта между всеми электродами, а также соответствующая математическая модель

Ключевые слова: емкостной сенсор, преобразователь, электрическая модель, емкость двойного слоя, неинформативен импеданс

1. Introduction

Electrophysical parameters monitoring of nonelectric products (granular materials, liquids) by means of primary capacitive transducers is much extended today. The reason is realization measuring procedure efficiency, simplicity and providing of high metrological specification. Nowadays, there are many various conductometric cells based on capacitive sensors of different engineering design for monitoring the parameters regarding electric conductivity [1]. There are mainly two-electrode and four-electrode capacitive sensors with the fixed constant of cell. They are used with appropriate measuring devices (conductometers) as well as with traditional meters of impedance and admittance parameters [2]. As an informative parameter of these sensors is the impedance of a cell with the monitored object, there is a problem of near-electrode effects. The measured parameters that specify electroconductivity of these sensors with the monitored object make it possible to detect changes in its internal structure, identify various examples of production, monitor their quality, meanwhile using for comparing the basic models with known metrics of analogical parameters.

2. Analysis of the data literature and problem formulation

One of the problems of electrophysical parameters measuring by means of contact primary transducers is dependence of a measuring result on near-electrode impedance [3]. The result depends on electrodes material, level of their contaminant and oxidation before measurement, test signal amplitude and frequency, concentration and mobility of ions, temperature of the monitored object etc. [4, 5]. The main influential factor in the process of polar objects parameters monitoring is near-electrode capacity, which is created on the boundary "electrode-monitored object" [3]. This influence is absent in the case of monitoring the nonpolar objects parameters.

For decreasing of double layer capacity influence in conductometers with two-electrode sensors we use a high-frequency signal. However this method cannot be used anytime and besides that high-frequency measurement creates new problems. The use of four-electrode sensors that have current and potential electrodes enables eliminating the near-electrode impedance effect at all without linking to signal frequency. Efficiency of employing such four-electrode sensors depends on measuring means of their parameters [6].

Another problem in many cases beside uninformative impedance influence is providing an appropriate measurement mode during a measuring experiment, such as mode of given current or that of preset voltage. Not constantly we can get it using traditional meters or we don't pay attention to it. Simultaneously some objects parameters depend exactly on the given mode of measurement.

The main objective of the research is providing of result invariance to near-electrode impedance as uninformative parameter.

To achieve the main objective, it is necessary to build transducers of „impedance-voltage-with four-electrode sensors, that will provide a result invariance of the measurement to the near-electrode capacity and to the change of signal parameters.

3. Electric models of capacitive sensors at alternating current

Electric model of a two-element sensor at alternative current is demonstrated on Fig. 1.

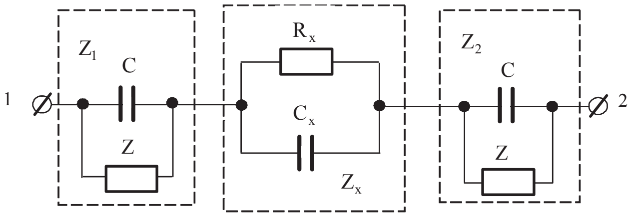

Fig. 1. Electric model of two-element sensor

Impedances Z_1, Z_2 are created by double layer capacities C of electrodes 1 and 2, impedance Z which includes Warburg impedance and impedance characterizing electrochemical reaction [7, 8]. Impedance Z_x – impedance of the monitored object.

Transducer of such sensor parameters into voltage which provides the mode of given current is shown in Fig. 2.

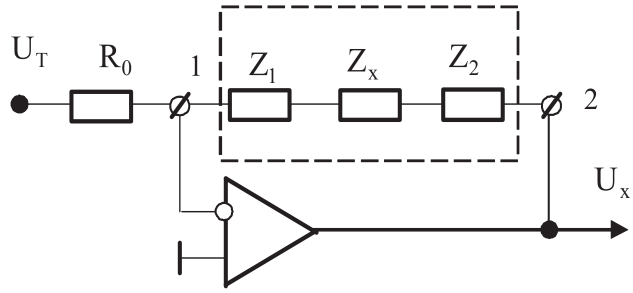

Fig. 2. Transducer of two-electrode sensor parameters with mode of given current

Current passing through the sensor is given by the resistance R_0 and voltage at the output of this transducer

$$U_x = U_T \frac{Z_x}{R_0}\left(1+\frac{Z_1}{Z_x}+\frac{Z_2}{Z_x}\right), \tag{1}$$

if Z_x is defining only by active resistance R_x, impedances Z_1, Z_2 – only by double layer capacitances C_1 and C_2, then

$$U_x = U_T \frac{R_x}{R_0}\left(1+\frac{1}{\omega C_1 R_x}+\frac{1}{\omega C_2 R_x}\right) \tag{2}$$

and if $\frac{1}{\omega C_1 R_x} << 1$ or $\frac{1}{\omega C_2 R_x} << 1$ we get

$$U_x = U_T \frac{R_x}{R_0}. \tag{3}$$

As was mentioned above, one of the variant of providing the result invariance to uninformative impedance is frequency enhancement of a test signal when indexes of double sphere capacity and measuring resistance are constant. In this case the measurement error is supposed to be defined by relation of uninformative impedance to informative parameter at the selected frequency of measuring.

The most prevailing construction of a contact four-electrode sensor is that demonstrated in the Fig. 3.

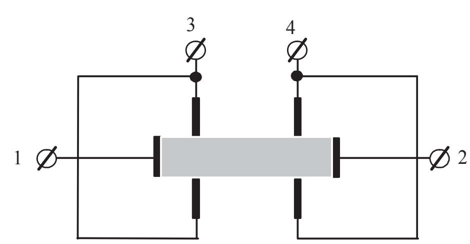

Fig. 3. Scheme of four-electrode contact capacitive sensor

Electrodes 1, 2 (Fig. 3) are electrodes through which the electric signal of the specified level and frequency is supplying to the monitored object, and electrodes 3, 4 are used to create a voltage drop at the part of the monitored object that corresponds to the distance between them.

Accordingly to such constructive design of a contact sensor, the electrical scheme of substitution (model) will have the following shape demonstrated in the Fig. 4.

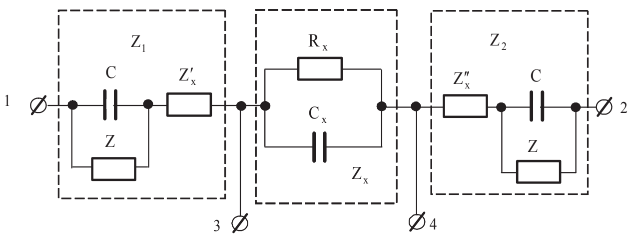

Fig. 4. Scheme of four-electrode sensor substitution

In this case the scheme of four-electrode capacitive sensor substitution also includes impedances Z'_x and Z''_x. These last impedances are the impedances of the monitored product that is located between electrodes 1 – 3 and 2 – 4.

Z_x is measuring impedance of the monitored object that is located between electrodes 3 and 4. These mention impedances depend on geometric size of electrodes and distance between them.

Putting into operation of two potential electrodes 3 and 4 results in creating of double sphere capacities, but significant decrease of their effect in comparison with other uninformative parameters can be attained by means of reducing the area of appropriate electrodes. All indicated impedances of this demonstrated scheme are uninformative except impedance Z_x.

Result invariance of measurement to uninformative parameters is providing by the voltage measurement U_x on the potential electrodes 3 and 4 with the given current I_x through the monitored object between electrodes 1 and 2. Accordingly to results of voltage measurement for given current, we get impedance $Z_x = \frac{U_x}{I_x}$. To wit, the result measured voltage will be proportional to impedance of the monitored object: $U_x = I_x Z_x$ [6]. We can realize this by means of connecting the sensor X with the monitored object to the current source CS and voltage measurement by voltmeter V [7] (Fig. 5).

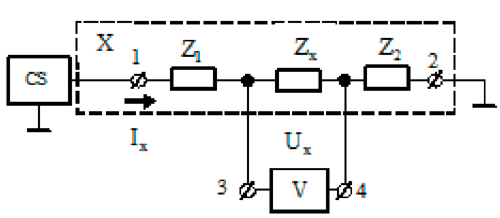

Fig. 5. Transducer of four-contact sensor parameters into voltage

In accordance with the mentioned above for realization of given current mood we need the current source CS of a sine signal and voltage meter of alternating current B. At the same time for ensuring of result invariance to effect of a voltage meter the last must have high input resistance at the frequencies of the selected bandwidth.

Accounting mentioned above the result of impedance measuring will depend on stability of current through the object but it's not simply realized within wide bandwidth.

Let consider the variants of construction of the transducer "impedance-voltage" with four-electrode sensors that provide the result invariance both to uninformative impedances and to signal source parameters.

4. Invariant transducers "impedance-voltage"

Let consider the variants of construction of a transducer with four-electrode sensors that realize the method of direct transformation "impedance-voltage" [9, 10] on the basis of passive and active transducers.

Passive transducer differs from active one by the fact that its measuring object and standard element are not feedbacks' components of active elements (operative amplifiers OA) but connected to the circuit of signal source SS [11, 12].

For the purpose of providing result invariance of measuring to the change in signal parameters, a standard element is switching on consistently with the sensor with further measuring the voltage on it.

This method scheme on the basis of a passive transducer is described in the Fig. 6.

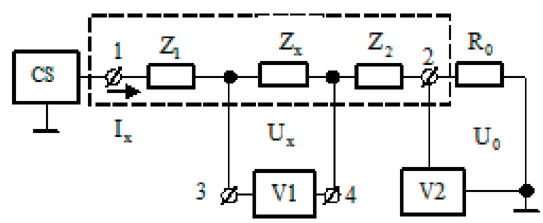

Fig. 6. Passive transducer with mode of given current

The relation of voltages $U_x = I_x Z_x$ and $U_0 = I_x R_0$ that are measured by voltmeters B1 and B2 gives proportional relation of impedance of the monitored object to active resistance (capacitor can be used as standard element):

$$\frac{U_x}{U_0} = \frac{Z_x}{R_0}, \tag{4}$$

in the Fig. 7 there is a scheme of providing the given current mode with using the active transducer and voltage source U_T.

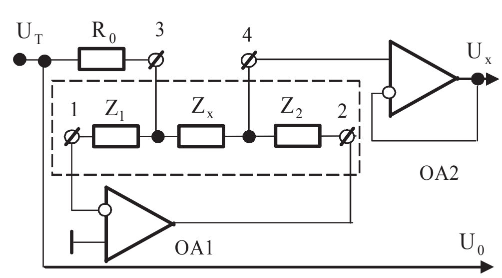

Fig. 7. Active transducer with mode of given current

The mode of given current is providing by the resistor R_0. Result invariance of uninformative impedance is providing in this case excluding the uninformative impedances

Z_1 and Z_2 from the feedback circuit OA1, and elements of negative feedback OA1 are only Z_x and R_0. Impedance Z_1 does not impact practically on the result because potentials of electrodes 1 and 2 under such switching are virtually identical.

Impedance Z_2 is not included in negative feedback circuit OA1 but added to output resistance OA1. High-resistance input is provided by means of a follower on OA2 which is connected to transducer output.

Taking into account mentioned above information we will get:

$$U_x = U_0 \frac{Z_x}{R_0}. \qquad (5)$$

These transducers help to provide the mode of given current via sensor. Mode of given current is mainly used for measuring the electrophysical parameters of low-resistance objects (water and water solution, dairy products and acids etc.).

A lot of objects of electrical and nonelectrical nature require also mode of preset voltage which as mentioned above can impact on parameters of object in many cases. This mode is also used for measuring the parameters of high-resistance objects (petrol, lubricants, oils etc.).

In the Fig. 8 is shown the scheme of a transducer which is providing the mode of preset voltage on the sensor with using a passive transducer.

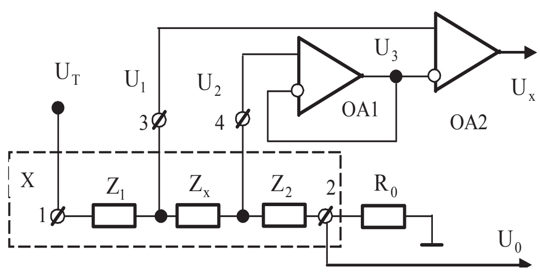

Fig. 8. Passive transducer with mode of preset voltage

Consecutive connection of sensor X and standard resistor R_0 is connected to voltage source of level U_T. Reference voltage U_0 of such transducer is voltage on the resistance R_0 which we can describe by next formula:

$$U_0 = U_T \frac{R_0}{Z_1 + Z_2 + Z_x + R_0}, \qquad (6)$$

informative voltage is creating as result of voltages subtraction

$$U_1 = U_T \frac{Z_x + Z_2 + R_0}{Z_1 + Z_2 + Z_x + R_0} \qquad (7)$$

and

$$U_2 = U_T \frac{Z_2 + R_0}{Z_1 + Z_2 + Z_x + R_0}, \qquad (8)$$

so informative voltage

$$U_x = U_T \frac{Z_x}{Z_1 + Z_2 + Z_x + R_0}. \qquad (9)$$

Dividing voltage (9) by voltage (6) gives deduction (4) which is providing result invariance to the voltage source and uninformative parameters.

If we use current source instead of voltage source (scheme in the Fig. 7) we get a transducer providing the given mode of current.

In the Fig. 9 passive transducer is shown which is providing voltage regime directly on the divider that contains measuring impedance and standard resistance.

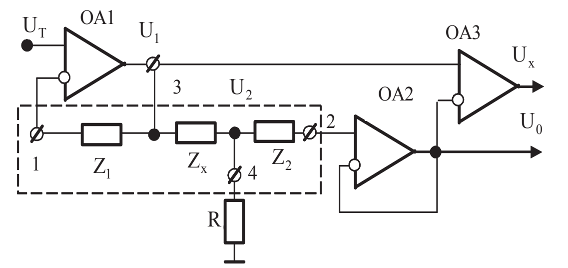

Fig. 9. Passive transducer with mode of preset voltage

Voltage U_1 on the divider by means of a follower on OA1 repeats voltage of a voltage source (by this way we can remove effect of impedance Z_1, and effect of impedance Z_2 is removed by his switching on consistently with high-resistance input of a follower on OA3).

Reference voltage of such follower is voltage on resistance

$$U_0 = U_T \frac{R_0}{Z_x + R_0}. \qquad (10)$$

Informative voltage is creating as result of subtraction of voltages U_1 and U_0 by a differential amplifier on OA3. In this case we get:

$$U_x = U_T \frac{Z_x}{Z_x + R_0}. \qquad (11)$$

Division of voltages (11) by (10) gives us again next formula (4), proving the result invariance to voltage source and uninformative parameters.

Advantage of such passive transducers over the transducer shown in the Fig. 6 is that voltages have common point.

The scheme of an active transducer providing the mode of preset voltage directly on the measured impedance Z_x is shown in the Fig. 10.

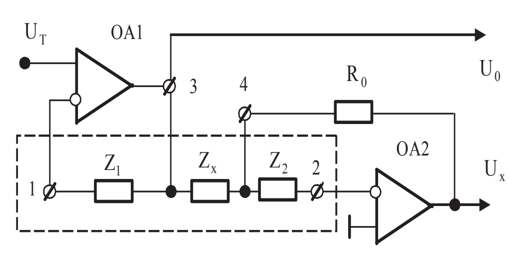

Fig. 10. Active transducer with mode of preset voltage

Uninformative impedance Z_1 effect is eliminated by the voltage follower on OA1, and impedance Z_2 effect – by means of bringing it out of feedback circuit OA2. In this case we get

$$U_x = -U_0 \frac{R_0}{Z_x} = -U_0 R_0 Y_x . \qquad (12)$$

As reference voltage we use voltage on the output of a follower that is the source voltage.

5. Conclusions

Different variants of transducers, that provide result invariance to uninformative impedance, particularly to the capacity of a double layer, created in the case of measuring the polar liquids, or to the remains of the product of previous measuring in the case of measuring the nonpolar liquids are constructed.

Transducers of "impedance-voltage" of nonelectrical nature objects can be used for designing the devices of monitoring the parameters of liquids quality by reactive and active components of complex conductivity within the audio-frequency range simultaneously providing the mode of preset voltage and given current. The most effective way to remove the effects of uninformative impedance is the use of four-electrode scheme.

As you can see a given current mode is mainly used to measure the electrophysical parameters of low-resistance objects (water and aqueous solutions, acids, etc.), and in case, for measuring parameters of high- resistance objects use the a preset voltage mode.

Simultaneously transducers provide result invariance to parameters of a test signal.

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