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# AN ANALYSIS OF THE EFFECT OF INTERFERING FACTORS ON THE RESULTS OF MEASUREMENTS OF THE MOISTURE CONTENT OF A MATERIAL AT HIGH FREQUENCIES

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*The action of interfering factors on the results of measurements of the moisture content of liquid, paste-like and friable materials is analyzed. Recommendations are made on the construction of an electrical model of a primary measuring transducer.*
***Keywords:*** *measuring transducer, high-frequency method, moisture content monitoring, interfering factors.*

The control of technological processes and objects in the form of an automatic regulating action is only possible with a measuring transducer and when data on the required informative parameter, characterizing the course of the technological process or the state of the object being investigated, are obtained. Measurements and instruments for controlling technological processes are used in different areas of the national economy. The design of measuring instruments forming part of automatic systems for controlling technological processes plays a major role when constructing automatic regulation systems, and also when monitoring the course of technological processes in industry, where measuring information in a form convenient for further processing is required.

When using direct measurements of moisture content, a predominant role is played by the measurement of the mass fraction of moisture by a thermogravimetric method, which is basic for estimating the errors of indirect methods. The basic principle of the method consists of isolating the moisture from the material by drying in special apparatus to a certain mass. This method has been investigated thoroughly and analyzed by the majority of investigators, concerned with problems of monitoring moisture content, and is highly accurate, which explains its use as a laboratory and standard method [1]. However, it is complicated, requires a long measurement time, and the apparatus employed has large dimensions.

High-frequency technology (the high-frequency method) of measuring the mass fraction of moisture in different materials has some of the advantages of indirect methods of measurement [2]. High-frequency moisture measuring systems are widely used in a number of areas of industry. This is due to the fact that one can judge the content of moisture in materials being investigated from their permittivity. However, no product can be regarded as the ideal dielectric, since the electrical energy applied to the capacitive converter filled with the product, is consumed not only in recharging the capacitor, but is also dissipated in the form of thermal losses in the dielectric. Hence, in practice one does not measure the true capacitance but the apparent capacitance, which depends considerably on parasitic losses. If the product being monitored is regarded as a dielectric, filling the transducer, the equivalent circuit of the transducer can be represented in the form of a circuit.

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We will now consider the processes by which the electrophysical characteristics of liquid and friable materials are converted from the point of view of the problems of increasing the accuracy and speed of response of such instruments and ensuring reliability of the primary quantitative and qualitative measuring data.

Several quantities $X_1, X_2, ..., X_n$ are applied to the input of the measuring transducer, and the output quantity $Y = f(X_1, X_2, ..., X_n)$ is determined. For this scheme, the apparent capacitance is expressed by the formula [2]:

$$C_a = C[(1 + r_s/r_m)^2 + (\omega^2 r_m C^2)^{-1}], \tag{1}$$

where $C$ is the true capacitance of the transducer, $r_s$ is the equivalent resistance of the surroundings, $r_m$ is the equivalent resistance of the material conduction loss, and $\omega$ is the angular frequency.

It follows from (1) that the measured apparent capacitance $C_a$ for the same moisture-content in fact depends on the changes in the conduction of the material, characterized by $r_m$. This can lead to considerable errors when determining the moisture content unless special measures are taken to compensate for the effect of the resistive losses. The number of interfering factors includes the chemical and granular composition of the sample, the quality of the material, its specific surface, the density, temperature, content of electrolytes, etc.

Measurements using a high-frequency method based on the dependence of the permittivity $\varepsilon$ on the mass fraction of water are distinguished by a considerable reduction in the error compared with the error of the method based on a measurement of the electrical conduction of the material, for which the presence of ions of salts, intermediate resistance on the electrodes and other factors to a considerable extent distort the results of the analysis.

When designing and choosing a method of measurement, it is first necessary to take into account the form of the bond between the water molecules and the material, due to the structure of the materials being investigated. Such complex multicomponent and structurally inhomogeneous materials, for example, margarine, belong to the class of heterogeneous systems and, when describing their electrical properties, in addition to the methods of the modern physics of dielectrics, it is also necessary to take into account the particular features of heterogeneous mixtures.

When using the high-frequency method, the optimum choice of the variable from the number of measured parameters of the object being investigated is important, in order to ensure the greatest accuracy of the quantity being determined. In this case, the main criterion of optimality is minimization of the number of parameters, most sensitive to the measured quantity. In general, the capacitance of the primary transducer, filled with the monitored material, and also its resistance, is a function of many parameters:

$$C = f(W, m, t, x, k, \gamma...),$$

where $W$ is the mass fraction of moisture in the material, $m$ is the mass, $t$ is the temperature, $x$ is the form of the moisture distribution, $k$ is the electrolyte concentration, and $\gamma$ is the electrochemical criterion of the electrode-material interface.

We will consider a general structural circuit, representing a measuring transducer based on the electrophysical (including the dielectric) method of measuring the moisture content and consisting of three series-connected sections. We know from [3] that the first section corresponds to the conversion of the measured quantity – the moisture content $W$ – into a physical quantity $\varepsilon$ (in this case an electrical quantity), i.e., it represents the dependence of the properties of the material used in this method (the temperature $t$, the density $\rho$, the pressure $p$, the chemical composition and other quantities, which affect the dielectric characteristics of the object being investigated) on the moisture content. The second section is the sensor of the measuring transducer, which converts $\varepsilon$ into an output signal (capacitance, impedance or one of its components), convenient for further processing. Here the action of the form and mass of the material, the frequency of the electric current, etc., which affect the characteristics of the measuring device, are taken into account. An analog or digital signal $Y$ is obtained at the output of the third section.

In an alternating electric field, the main process which determines the properties of the actual dielectric is the polarization [4]. In products such as cotton-seed oil and margarine, all the well-known forms of polarization are observed, but inertial forms of the polarization, such as dipole-relaxation and structural, predominate in the high-frequency band. If the material being monitored is considered as a dielectric filling the transducer, its equivalent circuit can be represented in general form by an electrical equivalent circuit [5].

To determine the effect of processing the results of a direct measurement and a calculation of the errors, we use the equation obtained by $n$ direct measurements $X_1, X_2, ..., X_n$:

$$\overline{X} = \frac{1}{n}\sum_{i=1}^{n} x_i.$$

In general form, the measurement error can be represented by the equation

$$\delta = \left[\left(\frac{\partial f}{\partial x_1}\Delta x_1\right)^2 + \left(\frac{\partial f}{\partial x_2}\Delta x_2\right)^2 + ... + \left(\frac{\partial f}{\partial x_n}\Delta x_n\right)^2\right]^{1/2},$$

where $x_1, x_2, ..., x_n$ are the values of the quantities obtained by direct measurements.

For indirect measurements, it is necessary to choose correctly the accuracy of the measurement of the individual components, on which the measured quantity depends:

$$\delta_{\text{tot}} \approx \left[\sum_{i=1}^{n} \delta_i^2\right]^{1/2},$$

where $\delta_i$ are the errors due to all forms of interfering factors.

The relative errors of these factors (the inaccuracy of the measurements, the sample, the calibration, the weighting, the nonuniformity, the temperature and the electrolyte concentration) affect the systematic and instrumental errors and also the errors of the method, employed when calibrating the measuring transducer. Optimization requires the best selection of the useful signal from its mixture. The components of the error of the mean square deviation and the errors due to nonuniformity of the material being analyzed, of the calibration, etc., are taken account of at the stage when the monitoring instruments are being designed and, consequently, their effect can and must be reduced to a minimum. The errors due to nonuniformity and the temperature of the material being analyzed, and also due to a number of unknown factors, which affect the informative indicator of the mass fraction of the moisture, require additional theoretical and experimental investigations. The errors due to the concentration of electrolytes need not be taken into account when estimating the total error of a measurement of the mass ratio of the moisture, since their effect is small. To choose the range of measurement, it is necessary to solve two problems simultaneously: the determination of the instrumental and systematic errors.

When estimating the reliability of the result of a measurement, equal to the mean value $\overline{X}$, an accuracy indicator is employed, which, according to the theory of errors, is $n^{1/2}$ times less than the estimate of the mean square deviation of the result of an individual measurement. The parameter characterizing the random error enables the error of each measurement, carried out using the same instrument or measuring equipment and under the same conditions, to be estimated.

Hence, for a mathematical description of the dependence of the dielectric properties of the materials investigated on the moisture content, it is necessary to bear in mind the particular features of the materials. For an experimental investigation of the dielectric properties of such materials as cotton-seed oil, margarine and friable products in a high-frequency field, the following problems, which have only been investigated to a small extent, need to be solved:

1) the determination and analysis of the conversion functions of the primary high-frequency measuring transducer (for this it is necessary to investigate experimentally how the dielectric properties of the products depend on the moisture content when they are acted upon by significant influencing factors);

2) the construction, using experimental data, of an electrical model of the primary measuring transducer, with the optimum approximation of the actual characteristics of the materials being investigated; and

3) the development of high-frequency instruments for monitoring moisture content for liquids, paste-like and friable products and test them under laboratory and production conditions.

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