Information-measurement system for determining moisture content of dry and liquid agricultural produce

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Abstract. The article presents a functional diagram of the proposed information-measuring system, based on the developed method for determining the moisture content of dry and liquid agricultural produce. Additionally we present the measurement algorithm.

1. Introduction

Today, the existence of agriculture is inextricably linked with the assessment of the quality of solid and liquid products, such as cereals, dry and liquid yeast, vegetable oil, milk and other products of manufacture, storage and processing. One of the most important indicators of product quality is moisture content, which has a significant impact on its cost, technical and nutritional values, the availability of useful consumer properties, etc. Moisture plays a great role for treatment of crop seeds, because it gives information about ripeness, methods and time of harvesting, operating modes of harvesting, grain cleaning and drying equipment, safe storage conditions, etc. Therefore, an accurate and prompt determination of this value is the critical task of modern science and technology, as confirmed by active study of this problem in the scientific community [1-3].

The most common method for determining the moisture content of agricultural products is the dielectric method, which is based on the use of capacitive parametric sensors. Structurally, such sensors are a capacitor, the dielectric of which is the product under investigation, placed between its plates. As a rule, such sensors are included in the circuits of monitoring and control systems, which are commonly called information-measuring systems or complexes operating in real time. To ensure their operation, high speed and accuracy of the sensor parameters conversion into electrical signals are required, depending on the way they are received.

In most cases, the methods of obtaining electrical signals are reduced to the study of informative parameters (through active resistance, geometric capacitance, active relaxation resistance, etc.) of sensor equivalent circuits, which by their nature are bipoles, including three, four, five or more elements [4-7]. A significant contribution to the theory and practice development of methods for determining the informative parameters of multi-element bipoles was made by well-known researchers: Mashoshin P.V., Sarvarov L.V., Martyashin A.I., Safarov M.R., Fayans A.M.and others [8-13], who identified two main approaches of problem solution.

The first approach is to apply active sinusoidal effects on the bipole and study the received response signals from the object under study. Here, bridge, resonant, cumulative and test conversion methods are used, which are distinguished by high functional and technical capabilities, but with low
speed and complexity in implementation [14]. The second approach is to obtain the necessary information through the study of transient processes in the measuring circuit that occur when applying to bipole impulse effects of various forms [15]. This approach is highly accurate and versatile, but it has a significant disadvantage associated with the need to take four or more measurements during the transient process, the duration of which is tenths, hundredths, and sometimes billionths of a second, depending on the number of bipolar elements. The implementation of this approach is quite complex and requires expensive components with high speed, large memory capacity, significant computational power.

2. Materials and methods
This disadvantage caused the search for methods to reduce the number and time of measurements, as a result of which an information-measuring system was developed, based on the original method for determining the moisture content of dry and liquid agricultural products, a functional diagram of which is shown in Figure 1.

![Functional diagram of the information-measuring system](image)

**Figure 1.** Functional diagram of the information-measuring system.

Functional diagram of the information-measuring system contains the reference voltage source $E_0$; microcontroller MC, providing control and management of the system; analog-to-digital converter ADC, converting analog signals into digital signals; contact groups K1-K5, performing circuit switching elements; a multi-element bipole BP, which is an equivalent circuit of the primary measuring converter PMC (i.e., a capacitive sensor); model elements ME1, ME2, including the reference resistor $R_0$ and the capacitor $C_0$; active element AE in the form of an operational amplifier OA; control buses CB and data buses DB.

The principle of the information-measuring system operation is based on the successive conduct of four measurement cycles at the control points of the measuring circuit, carried out in steady-state and transient modes when a constant voltage jump $E_0$ is applied to the input of the circuit under study. Let us consider in more detail the process of conducting each measurement.

At the first measurement, the microprocessor MC via the control buses CB delivers a control signal to the contact groups K3 - K5, which occupy position 3 for contact groups K3 - K4 and position 1 for contact group K5. After that, a voltage surge is applied to a model element ME1, which is a reference
resistor $R_0$, and through a group of contacts K3 to a bipole BP connected to ground through a group of contacts K4. The voltage $U_1$ in analog form through a group of contacts K5 goes to the analog-to-digital converter ADC and transmitted via the data bus DB to the microcontroller MC, which processes the received digital value and calculates on the basis of the known data ($E_0, R_0$), the value of the equivalent circuit element $R_1$ – through active resistance according to the formula:

$$R_1 = \frac{U_1 R_0}{E_0 - U_1}$$

(1)

where $R_1$ is the through active resistance, Ohm; $U_1$ is the measured voltage of the first study, V; $R_0$ is the reference resistance, Ohm; $E_0$ is the power supply voltage, V.

The obtained value of $R_1$ is stored in the memory of the microprocessor MC for further calculations and is transmitted via the usb-interface to the personal computer PC.

The second measurement is carried out at the following positions of contact groups: K1, K2, K5 are position 1; K3 is position 2; K4 is position 3. After that, as in the first measurement, a voltage jump $E_0$ is applied to the model element ME2, which includes the reference capacitor $C_0$, and through the contact group K3 to the bipole BP connected to ground through the contact group K4. Thus, the voltage $U_2$ with subsequent processing and calculation of the total capacitance of the equivalent circuit elements – capacitors $C_1$ and $C_2$, is measured by the formula:

$$C_1 + C_2 = C_0 \frac{E_0 - U_2}{U_2}$$

(2)

where $C_i$ is the instantaneous polarization capacity, F; $C_2$ is the capacity of relaxation polarization, F; $C_0$ is the reference capacitance, F; $U_2$ is the measured voltage of the second study, V.

As in the first measurement, the microcontroller MC stores the calculated values in memory and transfers them for processing to a personal computer PC.

The first and second measurements are carried out in steady state when a constant voltage is applied, which leads to saturation (charging) of capacitors in the measuring circuit. To discharge the capacitors, there is a discharge resistor $R_{\text{discharge}}$, installed in the 4th position of the K3 contact group. After discharge of the capacitors, the measuring system proceeds to the third and fourth measurements, which are performed at fixed points in time $t_1$ and $t_2$ for a time that does not exceed the duration of the developing transient process (Figure 2).

For this, the microcontroller MC by means of control signals transfers the contact groups K1, K2, K5 to position 2, and the contact groups K3 and K4 to position 1. Then through the contact group K3, voltage surge $E_0$ is applied to the multi-element bipole BP and the active element AE, which is operational amplifier OA in the feedback of which the model element ME2 is included, i.e. capacitor

![Figure 2. Graph of the Transient Process.](image-url)
In this case, the output voltage at the operational amplifier OA will change according to the law of the transient process:

\[
u_{\text{output}}(t) = -\frac{E_0 C_1}{C_0} \frac{E_0 C_2}{C_0} \frac{E_0 t}{C_0 R_1} \frac{-t}{\tau} e^{rac{-t}{\tau}}
\]

(3)

where \(u_{\text{output}}(t)\) is the magnitude of the output voltage, \(V\); \(t\) is the time, \(s\); \(\tau\) is the time constant, \(s\).

Based on this, the output voltage of the operational amplifier for fixed points in time \(t_1\) and \(t_2\) can be written in the form:

\[
u_{\text{output}}(t_1) = -\frac{E_0 C_1}{C_0} \frac{E_0 C_2}{C_0} \frac{E_0 t_1}{C_0 R_1} \frac{-t_1}{\tau} e^{rac{-t_1}{\tau}}
\]

(4)

\[
u_{\text{output}}(t_2) = -\frac{E_0 C_1}{C_0} \frac{E_0 C_2}{C_0} \frac{E_0 t_2}{C_0 R_1} \frac{-t_2}{\tau} e^{rac{-t_2}{\tau}}
\]

(5)

Imagine these expressions in the form of a difference:

\[
u(t_2) - u(t_1) = -\frac{E_0 C_1}{C_0 R_1} \frac{E_0 C_2}{C_0} \frac{-t_1}{\tau} + \frac{E_0 C_2}{C_0} \frac{-t_1}{\tau} - \frac{t_2}{\tau} e^{rac{-t_2}{\tau!}} - \frac{t_1}{\tau} e^{rac{-t_1}{\tau}}
\]

(6)

Let us transform the above expression, taking into account the fact that the difference between the times \(t_1\) and \(t_2\) can be written as \(\Delta t\):

\[
u(t_1) - u(t_2) = -\frac{E_0}{C_0 R_1} \frac{C_1 C_2}{C_0} \frac{-t_1 + \Delta t}{\tau} + \frac{E_0 C_2}{C_0} \frac{-t_1}{\tau} - \frac{t_2}{\tau} e^{rac{-t_2}{\tau}} - \frac{t_1}{\tau} e^{rac{-t_1}{\tau}}
\]

(7)

Since the values of \(R_1\) and \(C_1+C_2\) are known from the first and second dimensions, expression (7) can be converted as follows:

\[
U_{1\text{rated}} = u(t_1) + \frac{E_0}{C_0 R_1} \frac{(C_1 + C_2)}{C_0} + \frac{E_0}{C_0 R_1} \frac{C_1}{C_0} \frac{-t_1}{\tau} e^{rac{-t_1}{\tau}}
\]

(8)

where \(U_{1\text{rated}}\) is the rated voltage, \(V\).

Dividing the right sides of equations (7) and (8) into each other, we get:

\[
\frac{\Delta U_{1\text{rated}}}{U_{1\text{rated}}} = e^{rac{-\Delta t}{\tau}} - 1
\]

(9)

where \(\Delta U_{1\text{rated}}\) is the difference between the rated voltage at fixed intervals, \(V\).

During the transient process in the measuring circuit, the instantaneous voltage values \(u(t_1)\) and \(u(t_2)\) are determined, which are transmitted through a group of contacts K5 to the analog-to-digital converter ADC. After converting the analog signal to digital, the measured values are transferred to the microcontroller MC for further processing and calculations. Based on the obtained data and the above algorithm, the microcontroller MC calculates the final value of \(C_2\):
\[ C_2 = \frac{U_{\text{rated}} C_0}{E_0 t} \]  

(10)

The value of \( R_2 \) is calculated by the following formula:

\[ R_2 = \frac{\tau}{C_2} \]  

(11)

where \( \tau \) is the time constant, which is determined by the expression:

\[ \tau = -\frac{\Delta t}{\ln\left(\frac{\Delta U_{\text{rated}}}{U_{\text{rated}}} + 1\right)} \]  

(12)

3. Results and discussion

Thus, the information-measuring system determines four main parameters of the equivalent circuit of the measuring circuit, characterizing the object under study: \( R_1 \) is the through active resistance, characterizing the through active conductivity of the medium; \( C_1 \) is the capacitance, characterizing the instantaneous polarization depending on the electrophysical and natural properties of the medium; \( R_2 \) is the active relaxation resistance, which characterizes the relaxation conductivity of the medium, depending on the salt content and the presence of impurities in the medium; \( C_2 \) is the capacity that characterizes relaxation polarization and the main informative parameter for the system, since it has a direct dependence on the number of water particles and their sizes, i.e. from moisture of controlled medium.

4. Conclusions

1. The proposed information-measuring system provides the ability to determine not only the moisture content of the studied dry or liquid products, but also the presence of organic, mineral and impurities, which is of great importance in determining the quality class, grade and type of the object under study.

2. The system allows to determine specific characteristics of agricultural products according to the electrophysical properties, such as density, vitreousness, viability, consistency, chemical composition, etc.

3. The practical significance of the proposed measuring technique is to reduce the measurement time during the transient process in the measuring circuit. This is especially important for portable measuring devices that have small dimensions of measuring containers, and consequently, small ranges of measured capacities, about a dozen picofarads, which significantly limits the measurement time and the duration of the transient process.

5. Field of application

The developed information-measuring system has wide potential for use in various industries, agriculture and construction, since the determining of moisture content of materials is the main production task affecting product quality, reducing energy consumption during its storage and processing, as well as its cost, technical and nutritional value, the presence of useful consumer properties, etc. The use of the proposed information-measuring system will allow determining the moisture content of more than 1000 different substances and materials, such as seeds of grain crops (wheat, rye, rice, oats, barley, corn, sorghum, millet, chumiza, mogar, payza, dagussa, etc.), dairy products (milk, cottage cheese, kefir, sour cream, whey, etc.), vegetable oils (sunflower, corn, olive, linseed oils, etc.), dry and liquid yeast (wine, dairy, baking, brewer’s yeast, etc.) and many other products. The presented system will be used in farms and agricultural enterprises, enterprises of the bread industry (bakery plants, bakery-houses, mills, bakery productions, etc.), agro-industrial...
companies and agricultural holdings, dairy productions, etc. The information-measuring system can have, as a stationary performance, implemented on production lines, conveyors, technological pipelines, etc., and portable, embodied in portable moisture meters, mobile measuring stations, etc.

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