Improving the algorithms for measuring sensor parameters to determine the moisture content of dry and liquid agricultural products

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Abstract. The article describes the result of algorithms studies for measuring sensor parameters to determine the moisture content of dry and liquid agricultural products. Measuring circuits are given and an algorithm for determining the moisture and impurities of agricultural products based on measuring the parameters of multi-element two-terminal devices in steady and transient modes is described in detail.

1. Introduction
The quality of dry and liquid agricultural products directly depends on their moisture content. This indicator has a significant impact on their cost, technological and nutritional values, the availability of useful consumer properties, the ability to safely store and process, a predisposition to the development of negative physical and chemical processes, etc. Therefore, monitoring and determining the moisture content of agricultural products is becoming the main scientific and technical problem that can be solved by the development and improvement of methods for its determination, increasing their accuracy and speed.

When determining the moisture content of agricultural products, primary measuring transducers (PMT) are used, which are capacitive sensors and described by two-, three- and four-element equivalent circuits. In turn, to improve the accuracy and more correct presentation, such equivalent circuits of the sensor with the substance are considered in the form of multi-element two-terminal devices (MTD).

For many years, domestic and foreign scientists Stuart O. Nelson, Mashoshin P.V., Ivanov V.I., Sarvarov L.V., Petrov A.S., Martyashin A.I., Safarov M.R., Titov V.S., Faience A.M. et al. [1-6], which outlined two main approaches to its solution. The first approach is to study the response signals from the studied object, subject to active sinusoidal or pulsed action. The conversion methods used here have low speed and are difficult to implement [7]. The second approach is based on the study of transients in the measuring circuit that occur when applying pulse forms of various shapes to a two-terminal device [8]. The versatility and accuracy of this approach hide a significant weakness associated with the need to conduct four or more measurements during the transition process, the duration of which is very short.

The identified problem served as the reason for the search and development of a more advanced algorithm for determining the parameters of multi-element two-terminal devices [9], which combined the existing approaches to solving the problem of prompt and accurate data on the moisture content of the studied object.
2. Materials and methods
The developed algorithm for determining the MTD parameters is subdivided into three measurement cycles. When performing the first measurement cycle, the resistor $R_0$ is used as a reference element, the resistance value of which is selected in the range from 100 to 500 kΩ ± 1%. By measuring the value of voltage $U_1$ at the control point, one of the equivalent circuit elements is determined - the through resistance $R_1$ according to the formula:

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

(1)

As a reference element for the second measurement cycle, the capacitor $C_{01}$ is used, the capacitance of which is taken in the range from 50 to 1000 pF ± 0.25%. By analogy with the first measurement cycle, the voltage $U_2$ is determined, which, based on the already known values of $E_0$ and $C_{01}$, allows you to get the total value of the capacitance of the equivalent circuit elements - capacitors $C_1$ and $C_2$ according to the following formula:

$$C_1 + C_2 = C_{01} \frac{E_0 - U_2}{U_2}.$$  

(2)

The measuring circuit for the first and second measurement cycle is shown in Figure 1.

![Figure 1. Measuring circuit of the first and second measurement cycle](image)

The next measurement cycle is performed using a reference capacitor $C_{02}$, the capacitance of which is also known. For this, the voltage jump $E_0$ is again applied to the measuring circuit shown in Figure 2, but the voltage is measured at fixed points in time $t_1$ and $t_2$ over a period of time not exceeding the duration of the developing transient process.
The voltage at the output of the operational amplifier when applying a voltage surge $E_0$ to the input of the measuring circuit changes according to the law of the transient process, based on which the output voltage of the operational amplifier for fixed times $t_1$ and $t_2$ can be represented as:

$$u_{\text{output}}(t_1) = \frac{E_0C_1}{C_0} - \frac{E_0C_2}{C_0} - \frac{E_0}{C_0R_1} + \frac{E_0}{C_0} - \frac{t_1}{\tau} e^{-t_1/\tau}; \quad (3)$$

$$u_{\text{output}}(t_2) = \frac{E_0C_1}{C_0} - \frac{E_0C_2}{C_0} - \frac{E_0}{C_0R_1} + \frac{E_0}{C_0} - \frac{t_2}{\tau} e^{-t_2/\tau}. \quad (4)$$

Using simple mathematical transformations, based on the known values of $C_1 + C_2$ and $R_1$, one more element of the equivalent circuit can be determined - capacity $C_2$, which characterizes relaxation polarization and is an indicator of the moisture content of the studied product:

$$C_2 = \frac{U_{\text{1rated}} C_0}{E_0} \frac{1}{\tau} \quad (5)$$

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

The value of $R_2$ is calculated by the following formula:

$$R_2 = \frac{\tau}{C_2} \quad (6)$$

where $\tau$ is the time constant, s.

The performance of the proposed algorithm was tested by comparing the accuracy of the measurement results with the known methods for measuring the parameters of multi-element two-terminal devices using the installation shown in Figure 2, which is based on the ATmega 8-16PI type AVR microcontroller currently manufactured by Microchip Technology Inc.

As an operational amplifier, a measuring (instrument) amplifier type 2 INA128P manufactured by Texas Instruments is installed. The measurement results were displayed using an LCD display 3 type WH 1602B YHI EM manufactured by Winstar Display Co. Ltd. As the switching device of the measurement circuits, switch 5 is installed.
3. Results and discussion

The advantage in the measurement results accuracy of the proposed algorithm for determining the MTD parameters for the given characteristics of the studied object is confirmed by the measurements results carried out and statistically processed, presented in Table 1.

| Indicator | Value          | Known method | Proposed method |
|-----------|----------------|--------------|-----------------|
|           | R<sub>1</sub>, kΩ | C<sub>1</sub>, pF | R<sub>2</sub>, kΩ | C<sub>2</sub>, pF | R<sub>1</sub>, kΩ | C<sub>1</sub>, pF | R<sub>2</sub>, kΩ | C<sub>2</sub>, pF |
| Actual    | 960.02         | 91.05        | 100.22          | 1000.63         | 960.02         | 91.05         | 100.22          | 1000.63         |
|           | ±9.6           | ±1           | ±1              | ±10             | ±9.6           | ±1           | ±1              | ±10             |
| Measured  | 963.26         | 90.68        | 100.43          | 996.82          | 961.01         | 90.87         | 100.14          | 998.92          |
|           | ±0.35          | ±0.25        | ±0.35           | ±0.25           | ±0.15          | ±0.1         | ±0.15           | ±0.1            |
| Relative error δ, % | +0.33 | -0.41 | +0.21 | -0.38 | +0.1 | -0.19 | +0.08 | -0.17 |
4. Conclusion

1. The proposed algorithm for determining the parameters of multi-element two-terminal devices allows one with high accuracy, in comparison with known methods, to determine not only the moisture content of dry and liquid agricultural products, but also their electrophysical properties, such as density, vitreous, vitality, consistency, etc., and also to identify the presence of organic, mineral and extraneous impurities, which is of great importance in establishing the class of quality, grade and type of the studied object.

2. The proposed algorithm can significantly reduce the measurement time during the transient in the measuring circuit, which is especially important for portable measuring devices [10], since such devices have small PMT sizes, and, therefore, small ranges of measured capacities, which in turn reduces measurement time and transition time.

3. The implementation ease of the proposed algorithm in the information-measuring systems based on microprocessor technology opens up unlimited possibilities for expanding their functional properties, increasing speed and accuracy of measurements, which in turn will significantly reduce losses of agricultural production when determining the moisture content of various dry or liquid agricultural products.

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