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Analysis of the error of influencing factors on the result of measuring the moisture content of grain and grain products

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Abstract. The potential to utilize an ultrahigh-frequency method to regulate the humidity of grain and the products of their industrial processing, allowing one to use this method to regulate technological processes in the production environments of grain-processing industries by controlling the material under examination in free space and converting the measured parameters of the electromagnetic wave passed through the material into an electrical signal. The developed functional scheme of the experimental setup based on the ultrahigh-frequency method of dependence of attenuation and phase shift of electromagnetic wave on the volumetric density of wheat grain at different mass fraction of humidity is discussed, it is shown that with increasing volumetric density at a constant value of the mass fraction of moisture decreases the error of grain moisture measurement with increasing volumetric density, where the main component of the total error of the ultrahigh frequency method (amplitude and phase) is associated with the influence of interfering factors and depends mainly on the variable thickness and density of the controlled material. In order to reduce the components of measurement error brought on by various non-informative (interfering factors) parameters on the outcome of measuring the mass moisture ratio of grain and grain products, the method of moisture measurement in both discrete and inline manufacturing is investigated.

1. Introduction

The mass ratio of moisture is one of the indicators of grain quality. This indication is determined using the thermal gravimetric method and the drying method. To determine the moisture content of grain and products of their industrial processing various express instruments are used. The most important metrological characteristic of measuring instruments is their accuracy, which can be quantitatively characterized by the inverse of the module of relative error. More widespread is the notion of accuracy for the general qualitative characteristic of measurements - closeness from the results to the true value of the measured quantity.

Intensification and automation of production processes, the desire to optimize their technical indicators have increased the requirements for the accuracy of technical means of obtaining information, especially those that are used for economic calculations between different branches of the economy or in the foreign market. Suffice it to say that the error for effective management of technological processes is permissible higher errors of moisture measuring instruments of agro-industrial complex materials. In most processes of agro-industrial complex technological charts and other regulatory documents allow the value of error not more than 0.5% abs.



It is known that increasing the accuracy of measuring instruments, as a rule, entails an increase in its cost, and the price per measurement increases approximately exponentially as a function of measurement accuracy.

Microwave methods allow measuring humidity in a wide range from 0 to 100% with higher accuracy. A distinction is made between amplitude and phase methods of moisture measurement. The purpose of this research is to evaluate the effect of grain inhomogeneity in density on the mass moisture ratio in grain moisture measurements using the microwave method.

2. Materials and methods

For the practical implementation of the ultrahigh-frequency (UHF) method considered in our studies, the optimal choice of the number of measured parameters of the object of research, providing maximum accuracy of determination of the desired value is important. In this case, for the materials under research as, grains and grain materials is the mass ratio of moisture. The UHF method is based on the interaction of the electromagnetic field with the volume of the moist material and the amplitude of the passing (attenuation) and phase shift of the electromagnetic wave [1] Analysis of a number of scientific sources in the field of moisture control of the materials in question [2] confirms that the main informative parameter of grain moisture mass ratio is the attenuation value of electromagnetic wave [3, 4]. Fig.1 shows a scheme of electromagnetic wave attenuation.

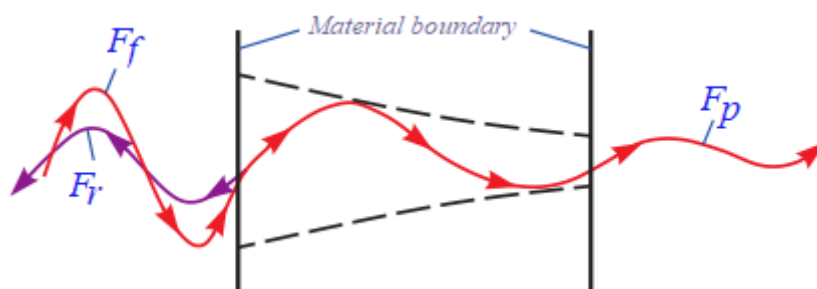


Figure 1. Diagram of the interaction of the microwave energy flow with wet material

The attenuation, which characterizes the UHF power loss, will be a function of the electromagnetic properties of the material, determining the values of its complex propagation constant

$$\gamma = \alpha + j\beta$$

Where α - attenuation coefficient, β - phase constant.

The components of the propagation constant are related to the electromagnetic properties of materials by known relations:

$$\alpha = \frac{2\pi}{\lambda} \sqrt{\frac{\epsilon' \mu}{2} (\sqrt{1 + \operatorname{tg}^2 \delta} - 1)}$$

$$\beta = \frac{2\pi}{\lambda} \sqrt{\frac{\epsilon' \mu}{2} (\sqrt{1 + \operatorname{tg}^2 \delta} + 1)}$$

Where $\operatorname{tg} \delta = \epsilon'' / \epsilon'$ - the tangent of the angle of dielectric losses.

ϵ' , ϵ'' - active and reactive components of dielectric permittivity.

μ - magnetic permeability of the material.

When analyzing the error of the UHF method, we will proceed from the above considerations.

The main criterion of optimality is: minimizing the number of parameters, the most sensitive to the measured value, and the technical level of development of modern electronic base, on the basis of which it is possible to implement the UHF-method.

The output signal of the microwave transducer depends not only on moisture, but also on other factors affecting various quantities [5, 6].

In the general case, the magnitude of the attenuation A of the UHF energy in the grain can be represented by a family of characteristics:

$$A = f(W, m, l, t, x, h, k \dots)$$

Where: W - mass ratio of grain moisture; m - mass, l - thickness, t - temperature, x - moisture distribution pattern, h - unevenness in densities, k - electrolyte concentration.

The effect on the attenuation A and on the phase shift φ of the listed factors will be

$$dA = \frac{dA}{dW} dW + \frac{dA}{dm} dm + \frac{dA}{dt} dt + \frac{dA}{dx} dx + \frac{dA}{dh} dh + \frac{dA}{dk} dk \quad (1)$$

$$d\varphi = \frac{dA}{dW} dW + \frac{dA}{dm} dm + \frac{dA}{dt} dt + \frac{dA}{dx} dx + \frac{dA}{dh} dh + \frac{dA}{dk} dk \quad (2)$$

The first summand of these expressions determines the sensitivity of the measured parameters to moisture, and the remaining summands the errors caused by changing factors.

From equations (1) and (2) it follows that to eliminate systematic errors, calibration of measuring instruments should be performed at average values of influencing quantities.

However, in measurements, the values of these quantities may fluctuate within some limits relative to the average. In this case, the effect on the UHF wave parameters will be determined by the result of the impact of random independent variables.

The cumulative effect of this effect on attenuation and phase shift is determined by the following equation

$$\delta_A = K \sqrt{\sum_{i=1}^n \delta_{Ai}^2} \quad (3)$$

$$\delta_\varphi = K \sqrt{\sum_{i=1}^n \delta_{\varphi i}^2} \quad (4)$$

Where n is the number of influencing quantities δ_{Ai} , $\delta_{\varphi i}$ - respectively, changes in attenuation and phase shift due to the influence of each factor. The value of the coefficient K is taken equal to 1.1 for the confidence probability $P=0.95$.

In the practice of processing analytical results, direct measurements are usually substituted into formulas containing several unknowns. Hence, the measurement is indirect [7]. The measurement error δ of which in general form can be represented by the equation

$$\delta = \sqrt{\left(\frac{df}{dx_1} \delta x_1\right)^2 + \left(\frac{df}{dx_2} \delta x_2\right)^2 + \dots + \left(\frac{df}{dx_n} \delta x_n\right)^2} \quad (5)$$

Due to the fact that this formula sums up the squares of values, the result will be determined by the largest terms of this expression if there is a noticeable difference in values. Therefore, in indirect measurements it is necessary to choose the correct accuracy of measurements of individual components, on which the measured quantity depends. The easiest way to do this is with the help of errors

$$\delta = \sqrt{\delta_o^2 + \delta_B^2 + \delta_r^2 + \delta_m^2 + \delta_l^2 + \delta_t^2 + \delta_x^2 + \delta_h^2 + \delta_k^2} \quad (6)$$

Where δ_o - error caused by inaccuracy of attenuation measurement, δ_B - sampling error, δ_r - calibration error, $\delta_m \div \delta_k$ - errors caused by the factors listed above.

Metrological and information optimization of any measuring device requires the best possible separation of the useful signal from its mixture. Consequently, in order not to complicate the measuring

device and not to make unnecessary accurate measurements, it is necessary to determine the number of measured parameters and permissible accuracy of measurement of components, at which the resulting error will not exceed the specified value.

Based on the above and the analysis of errors we come to the following conclusion:

- components of errors related to sampling, calibration, weighing, attenuation can be considered at the design stage of measuring devices and, therefore, their impact can be minimized;
- error components with unknown perturbations affecting the informative index of mass moisture ratio, which require a combined theoretical and experimental research;
- values of component errors the determination of which is inexpedient due to the smallness of values, or impossible for reasons that do not allow to establish the nature of the influence of interfering factors on the informative indicator of moisture mass ratio, cannot be considered in the evaluation of the total error of measurement.

3. Results and discussion

We must first determine the extent of change in the influencing elements under certain measurement settings in order to compute the errors of measurement of moisture content by the amplitude and phase approach. Processing of experimental results showed that the moisture characteristics of grain are adequately described by polynomials of degree 2

$$A = 0,55W^2 - 0,116W + 1,742 \text{ dB}$$

$$\varphi = 0,425W^2 + 3,127W + 255,7 \text{ deg}$$

Experiments to identify errors from influencing values were carried out in the conditions of JSC "Galla-Alteg" Republic of Uzbekistan [3, 8]. Samples were taken in screw compactors, samplers, weight batchers and on conveyor belts. The density of the controlled materials varies in this case within $\pm 2\div 5\%$ due to variable granulometric composition of the grade. Calculation of the change in attenuation and phase shift with $+5\%$ change in density and 10% grain moisture showed that the value of $\delta_{A\rho}$ and $\delta_{\varphi\rho}$ at a confidence level of 0.95 does not exceed 0.4 dB and 18.0 deg, respectively.

With the currently adopted open method of grain storage in grain processing industries, their temperature fluctuations are determined by air temperature fluctuations and do not exceed $\pm 5^\circ\text{C}$ per day [9]. At grain humidity of 10% and temperature variations by $\pm 5^\circ\text{C}$, the value of δ_{At} and $\delta_{\varphi t}$ did not exceed 0.3 dB and 5.7 deg.

Determination of influence of non-uniformity of moisture distribution on forms of connection was carried out by statistical processing of results according to the corresponding equation, that the error caused by this factor was in limits $\delta_{Ac}=0.5\text{dB}$, and $\delta_{\varphi c}= 5.2 \text{ deg}$.

The total influence of the considered factors on the measurement result of attenuation and phase shift in the grain with 10% moisture content is $\delta_A = \pm 0.8\text{dB}$, and $\delta_\varphi = \pm 20.1 \text{ deg}$, or in recalculation according to calibration dependences, the mean square deviation of measurement results at 10% grain average moisture content was $\pm 0,8\%$ (abs.) by amplitude method and $\pm 1,2\%$ (abs.) by phase shift.

Fig. 2 shows the functional diagram of the experimental setup to measure the moisture content of grain in the technological process - automated UHF moisture meter.

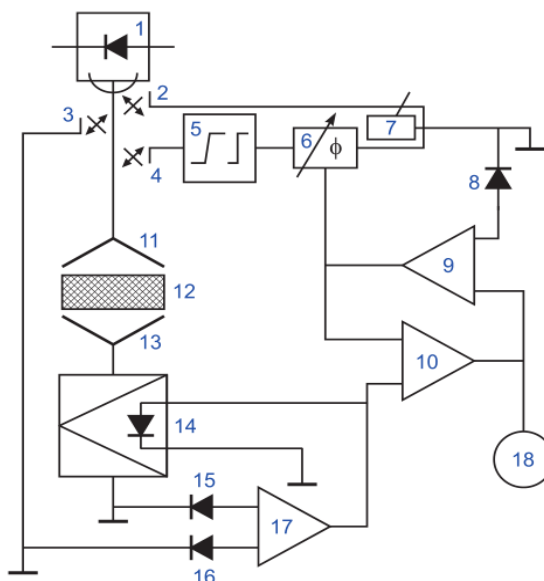


Figure 2. Functional diagram of the experimental installation for measuring grain moisture in the technological process:

1 – generator; 2–4 – guide couplers; 5 – ferrite valve; 6 – phase shifter; 7 – double waveguide bridge; 8, 15, 16 – detectors; 9, 10, 17 – selective amplifiers; 11, 13 – transmitting and receiving antennas, respectively; 12 – controlled material; 14 – compensating attenuator; 18 – indicator.

The analysis of the components of the total errors shows that the most significant contribution in amplitude measurements is made by non-uniformity of moisture distribution by bond forms and inhomogeneity of the sample by density, and in phase measurements - by changes in the density of the sample. To eliminate the influence of various non-informative parameters, it is more appropriate to measure two electromagnetic wave parameters related to the mass ratio of moisture and bulk density of grain: attenuation by amplitude A and phase shift ϕ . For a grain moisture meter, the highest useful signal extraction $\partial A/\partial W$ with maximum suppression of the interfering factors $\partial A/\partial \rho$ is required. This confirms the theoretical conclusions [10].

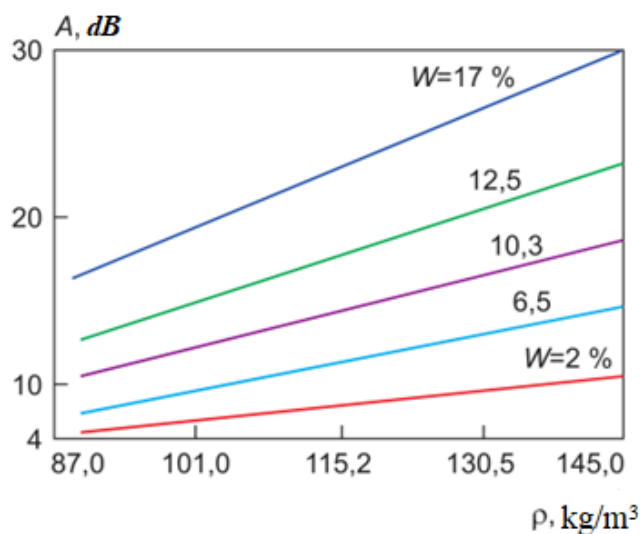


Figure 3. Graph of the dependence of the attenuation of the electromagnetic wave on the bulk density of grain-wheat at different mass fraction of moisture

4. Conclusions

The results of the investigation show that the changeable thickness and density of the controlled material, as well as other influencing characteristics, are the primary causes of the overall inaccuracy of UHF methods (amplitude and phase). Correcting a temperature miscalculation is not that difficult. It is required to create new variations of UHF-methods that are free from the aforementioned limitations in order to guarantee the necessary accuracy of moisture control of agricultural products.

Measuring the mass ratio of moisture on the basis of the two mentioned parameters will allow considering the influence of interfering factors and increase the accuracy of measurement by 2 % relative to the accuracy of the single-parameter method.

In order to solve these problems, it is necessary to conduct a complete factor experiment with the improvement of the methodology of planning the experiment, as well as the development of mathematical modeling of grain describing the joint effect of humidity, density and other interfering factors on the attenuation and phase shift of the transmitted UHF wave.

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