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R. RADEV**

MODELING AND CONTROL OF POWER SYSTEMS

ADVANCED MEASUREMENT APPLICATION 2

CONTROL THEORY

Research and Analysis of the Method for Measuring the Moisture Content of Cottonmaterials at Ultrahigh Frequencies

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Abstract – **The article provides a theoretical analysis of the ultrahigh frequency (microwave) method of humidity measurement, discusses the problems of instrumentation of the method in question, and proposes a scheme of an experimental installation. Bulk cotton materials were selected as the objects of research. The electromagnetic wave radiation is analyzed during measurement and the evaluation of electrophysical characteristics requires the study of the functional dependence of the amplitude and phase shift on the mass ratio of humidity, mathematical models for various bulk cotton materials describing the joint effect of humidity, material density on the attenuation and phase shift of the passing wave are obtained.**

Keywords – automation, control, humidity, ultra-high-frequency method, air-material, passing, reflected, wave, attenuation, phase shift.

I. INTRODUCTION

In theoretical and experimental studies of the physical properties of materials, heterogeneous media are most often encountered. These are cotton materials (raw cotton, cotton seeds) consisting of cellulose, water and air containing seeds and impurities of organic and inorganic origin [1].

In accordance with the theory of dielectrics, the studied materials in the electromagnetic field, including raw cotton, do not detect temperature and temperature anomalies in the dehydrated state. Therefore, it can be considered that the observed anomalous dependencies in raw cotton are inherent in water, which is one of the main components of this type of raw material in its natural state. An electromagnetic wave that acts reciprocally with water molecules, changes its electrical characteristics, depending on the state of aggregation. This change, which characterizes the mass ratio of moisture, is the basis of all developed methods of measurement at ultrahigh frequencies [2].

II. MATERIAL AND METHODS

Studies and analysis of modern physical methods for measuring the moisture content of various materials of the agro-industrial complex have led to the conclusion that for these materials the most promising is the diesel method based on the measurement of moisture at ultrahigh frequencies.

In the microwave range, primary measuring transducers are electromagnetic systems with distributed parameters, the functioning of microwave moisture meters is based on the dielcometric method [3]. Studies of the electrical properties of bulk materials such as raw cotton, cotton seeds, grain-wheat, grains of mass significantly expands the existing understanding of the factors affecting its electrical properties They allow you to implement scientifically based methods for calculating the parameters of primary converters and measuring circuits of humidity control devices based on the microwave method [4].

III. RESULTS AND DISCUSSIONS

Let us consider the influence of the physical and mechanical properties of raw cotton on the intensity of the passage of an electromagnetic wave from the material understudy.

Suppose that a flat electromagnetic wave falls on a sample of the material under study with conductivity $\sigma \neq 0$ perpendicular to its surface. When itpasses through the studied sample, there is also a loss of energy, which is characterized by dielectric losses caused by thermal the motion of particles under the action of an applied electromagnetic field, dispersion on inhomogeneities, as well as the phenomenon associated with the simultaneous existence in a homogeneous medium of several oscillations obeying the principle of superposition. Let us confine

ourselves to the case when there are no magnetic losses $\mu = 1$. Then the plane wave equation of the form [5] is valid

$$E = E_0 \cdot e^{-\alpha z} \cdot e^{-\beta z} \qquad (1)$$

Turning to instantaneous values, considering the scattering coefficient, equation (1) can be represented as

$$E = E_0 \cdot e^{-\alpha z} \cdot \cos(\omega t - \beta z) \cdot F. \qquad (2)$$

where:

E −electric field strength at the output of the sample;

E_0- electric field strength at the sample inlet;

α- attenuation coefficient;

β- phase coefficient;

z is the thickness of the specimen.

The first factor of the wave equation (2) characterizes the attenuation of the electromagnetic wave, and the second - the phase velocity of propagation along z and the loss of phase.

Cotton materials have elastic properties, so as long as the pore size of the dry material is small compared to the wavelength and evenly distributed in the sample volume, the scattering and interference of the electromagnetic wave on inhomogeneities can be neglected. In this case, neglecting the second and third factors in equation (2), we determine the attenuation and energy loss coefficient α per unit length dz.

To do this, considering that the power p is proportional to the square of the amplitude of the electric field strength E, and the change in power along the sample under study per unit length is, we write equation (2) in the following formdz Δp

$$p = p_o \cdot e^{-2\alpha z} \qquad (3)$$

where:

p- power at the output of the sample;

p_o- power at the input of the sample.

Differentiating (3) with respect to z, we get

$$\alpha = \frac{\left|\frac{dp}{dz}\right|}{2p} = \omega \sqrt{\frac{E_a}{2}} \left(\sqrt{1 + \mathrm{tg}^2\delta} - 1 \right), \qquad (4)$$

where:

α- attenuation coefficient;

$\frac{dp}{dz}$-power loss per unit length;

E_a- absolute value of the dielectric constant;

tg δ- dielectric losses.

Let us decompose (4) according to the degree $\mathrm{tg}^2\delta$ and neglecting the values of the higher order, since for dry raw cotton tg $\delta \ll 1$, we then get

$$\alpha = \omega \sqrt{\frac{E_a}{2}} \left(1 + \frac{1}{2}tg^2\delta - \frac{1}{2\cdot4}tg^4\delta + \cdots - 1 \right) =$$
$$= \frac{\omega}{2}\sqrt{E_a tg^2\delta} = \frac{\sigma}{2}\sqrt{\frac{1}{E_a}}. \qquad (5)$$

Equation (5) shows that attenuation α in an isotropic medium with conductivity $\sigma \cong 0$ does not depend on frequency and has practically no effect on energy loss.

Conductivity, σ according to [20] is determined by the magnitude of losses $tg\delta$ and dielectric constant ε, i.e.

$$\sigma = \omega\varepsilon_a tg\delta \qquad (6)$$

Then, using Maxwell's equation, the dp/dz power loss per unit length dz, given (6), can be represented by

$$\frac{dp}{dz} = \omega\sqrt{\varepsilon_a}tg\delta|\varepsilon|^2 dv \qquad (7)$$

where v is the volume of cotton material occupied.

Equation (7) characterizes the power losses in a dielectric with conductivity, $\sigma \neq 0$ which are associated with the orientation of the dipoles of water molecules under the action of the applied electric field E, or in other words, with the tangent of the angle of relaxation dielectric losses.

As the mass ratio of the moisture content of the component σ и $tg\delta$ increases, increasing the power p. From this it follows that with a low moisture content in raw cotton, all water molecules are in a bound state. Water loses mobility and, as a result, the dielectric constant decreases ε. The weakening of microwave energy practically does not occur. With an increase in moisture content in raw cotton, moisture begins to predominate with physical forms of communication. In our research, we are dealing with a loosely bound form of moisture.

In the meantime, it plays an important role in the ultra-high frequency control method of heterogeneous wet systems. For water in a free state at room temperature, in the frequency range of the dielectric constant, Hz values are taken [6]. $10^5 \leq f \leq 10^8$

$$\varepsilon \approx 81.$$

According to experimental data [2], the wavelength corresponding to the critical frequency at a temperature is equal to. The value is considered to be equal to 5.5, although, according to some researchers, the values of 4.5 or 4.9 are more accurate. $t = 20^o C$ $\lambda_0 = 1,74см$ ε_∞

At this stage of the study, a single-parameter measurement method was studied, and a frequency of 9.3 GHz was adopted for its implementation. The mass sample weight was 800 g, the bulk density was 116 $\frac{\text{kg}}{\text{m}^3}$.

The main informative parameter is the attenuation and phase change.

$$A = f(W, \rho)$$
$$\varphi = f(W, \rho)$$

where:

A-attenuation of microwave energy;

φ- phase shift of microwave energy.

W is the mass attitude in the mess;

ρ- bulk density of raw cotton.

When measuring the moisture content of materials in an alternating flow, the main task is to determine the degree of influence of the inconstancy of the mass of the controlled material on the informative parameter of the microwave field to select the method that provides the greatest accuracy. The paper investigates the amplitude and phase methods of a passing wave in free space [7].

The inconstancy of the mass of the material leads to the inconstancy of its thickness or density, depending on the design of the transport. In both cases, the change in mass

leads to a change in the informative parameter - weakening or phase shift, and therefore to an error in measuring the humidity of the microwave moisture meter. The thickness of the material has a direct effect on attenuation and phase shift, and the density through the dielectric constant [8].

Without considering the influence of other material parameters (temperature, pubescence, etc.) on the measurement result, the conversion equations for the amplitude and phase measuring device can be written in the form

$$A = f_1(W, m)$$
$$\varphi = f_2(W, m)$$

where m is the mass of the material in the control zone.

The influence W of and m on A и φ is expressed from the following ratios

$$dA = \frac{\partial A}{\partial W} dW + \frac{\partial A}{\partial m} dm$$
$$d\varphi = \frac{\partial \varphi}{\partial W} dW + \frac{\partial \varphi}{\partial m} dm .$$

Let's express

$$\frac{\partial A}{\partial W} = S_{AW} \quad \frac{\partial \varphi}{\partial W} = S_{\varphi W}$$

$$\frac{\partial A}{\partial m} = S_{Am} \quad \frac{\partial \varphi}{\partial m} = S_{\varphi m}$$

where and S_{AW} $S_{\varphi A}$, accordingly, the sensitivity of the amplitude and phase methods to moisture.

S_{Am} and, accordingly, the sensitivity of the $S_{\varphi m}$ amplitude and phase methods to the mass of materials.

The calibration measured by amplitude and phase moisture meters is determined from the ratio

$$W_A = A/S_{AW}; \quad W_\varphi = \varphi/S_{\varphi W} .$$

When the mass of the controlled material deviates from the value at which the calibration was performed, the attenuation and phase shift change accordingly.

$$dA = S_{AW} dm; \quad d\varphi = S_{\varphi W} dm .$$

This is perceived as a change in humidity measured by moisture meters

$$dW_A = \frac{dA}{S_{AW}}; \quad dW_\varphi = \frac{d\varphi}{S_{\varphi W}}$$

or

$$dW_A = \frac{S_{Am}}{S_{AW}} dm; \quad dW_\varphi = \frac{S_{\varphi m}}{S_{\varphi W}} dm .$$

That is, the errors in measuring humidity by amplitude and phase moisture meters and due to fluctuations in the mass of the controlled material depend on the ratio of the sensitivity of these methods to mass and humidity [9].

In order to determine what information, the electromagnetic wave carries and how it can be used to study and evaluate the electrical characteristics of the material under study, it is necessary to investigate the functional dependence of attenuation on the mass ratio of humidity in the real range of the mass ratio of humidity.

When conducting research and solving problems of measuring the parameters of materials such as raw cotton,

cotton seeds, grain and grain products, it is necessary to solve the following little-studied problems [10]:

- the choice of the primary measuring transducer, and the study of influencing factors on the measurement result.
- analysis of existing methods for measuring electrophysical parameters of granular materials of plant origin and the choice of rational ways of their instrument and hardware implementation.
- investigation of metrological and accuracy characteristics of a series of developed measuring transducers of electrophysical parameters of grain products of agricultural production and their testing in production conditions.

To implement this problem, we have developed an experimental setup based on the microwave method [11]. The functional diagram of the experimental setup is shown in figure 1.
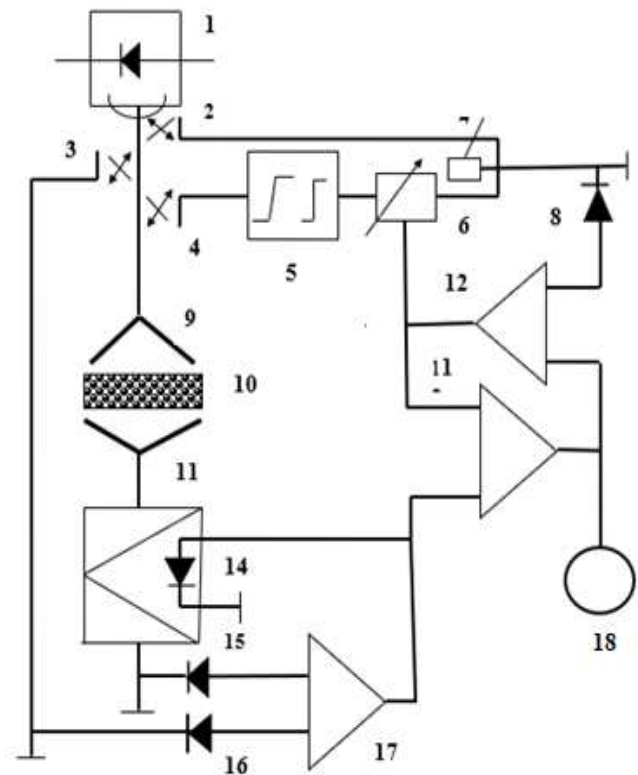

Fig. 1. Block diagram of an experimental microwave installation for measuring the moisture content of materials in a technological process

The controlled process of passing a microwave wave through an experimental setup ensures the accuracy of measuring the humidity value in an automated microwave moisture meter.

The installation makes it possible to measure in a wide range with sufficient accuracy the attenuation and phase shift introduced by the material, located in the free space between the transmitting and receiving antennas.

In order to determine what information, the electromagnetic wave carries and how it can be used to study and evaluate electrical characteristics, it is necessary to investigate the functional dependence of the attenuation of the electromagnetic wave on the humidity of the materials under study.

Processing of the results of the experiments showed that the humiditycharacteristics are adequately described by polynomials of the 2nd degree

$$A = 0,55W^2 - 0,116W + 1,742$$

$$\varphi = 06425W^2 + 3,127W + 255,7.$$

Based on theoretical studies, it was concluded that the study of the electrical properties of the grain mass significantly expands the existing understanding of the influence of factors on its electrical properties and allows us to implement scientifically sound methods for calculating the parameters of primary converters and their measuring circuits of measuring devices.

IV. FINDINGS

Based on the analysis, the following can be stated:

1. A pilot plant has been developed, equipped with modern metrological certification measuring equipment., which allows to study the electrophysical properties of grain products and reveal multifactorial functional dependencies that are necessary to determine the composition and properties of bulk materials.

2. Experimental studies on the installation for measuring both informative parameters of attenuation and phase shift made it possible to determine and describe mathematically the $A(W)$ moisture characteristics $\varphi(W)$ for various bulk materials of the agro-industrial complex.

3. As a result of a complete factorial experiment, with the improvement of the experiment planning methodology, mathematical models for various loose cotton materials were obtained, describing the combined effect of moisture, density of the material on the attenuation and phase shift of the passing wave.

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