EFFECT OF SHF WAVES REFLECTED FROM A MEDIA BOUNDARY ON EVALUATION OF THE MOISTURE CONTENT OF RAW COTTON

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An analysis is made of the feasibility of improving the accuracy of measurement of the moisture content of raw cotton as a result of additional measurement of an electromagnetic wave reflected from the media boundary. Results of a study are presented.

It is known that the following condition must be satisfied [1] in order for Brewster's angle to exist in the normal polarization of a wave when it passes entirely into a second medium

$$0 < \frac{1 - \mu_1\varepsilon_2/\mu_2\varepsilon_1}{1 - (\mu_1/\mu_2)^2} < 1. \tag{1}$$

Raw cotton is a dielectric, the permeability of which is nearly equal to the permeability of air $\mu_c = \mu_a = 1$. Inserting μ into (1), we see that the condition is not satisfied. Thus, a normally polarized wave at the media boundary between air and cotton will be reflected at any angle of incidence. Also considering that raw cotton is a disperse medium with a distinct nonuniformity with regard to density, moisture content, and other parameters which affect the electrical characteristics of an electromagnetic wave, it can be assumed that, depending on the aggregate state of the medium, the amount of reflected energy does not remain constant but is instead a function of the above-mentioned factors. This fact ultimately leads to a complex relation describing the change in the reflection coefficient R.

To reduce energy loss due to reflection, which affects the moisture-content measurement error, it is necessary to match the wave impedance of the media. The matching is done by means of a dielectric of $\lambda/4$ thickness closely adjoining a sample. The permittivity ε of such a layer should be equal to the geometric-mean permittivities of cotton ε_c and air ε_a. However, since ε_c varies broadly from 2.6 to 23 in the 5-40% moisture-content range, then all measures taken to match the wave impedances of the media will be ineffective. Thus, having taken the attenuation A as the main index of moisture content W, it is useful to additionally measure the reflection coefficient R so that it can serve as a correction for A.

The following relation exists between the attenuation A and the moisture content of raw cotton W [2]:

$$W = 6.53\cdot10^{-4}A^3 - 3.74\cdot10^{-2}A^2 + 1.06A + 3.67.$$

TABLE 1. Comparison of Experimental Results and Standard

Mean value of the moisture content W of the material determined		Random component of the measurement error σ_W	
in the Uz-7-m dryer	on the exptl. shf unit	with allowance for R	without allowance for R
7,1	7,5	2,2	2,2
9,2	8,8	2,0	1,9
10,1	9,7	1,6	1,4
10 6	10,8	1,6	1,7
15,5	15,8	1,2	1,3
21,2	21,3	2,7	3,3
22,8	23,6	2,1	2,3
32,0	31,3	1,1	1,3
41,1	39,3	2,3	2,8

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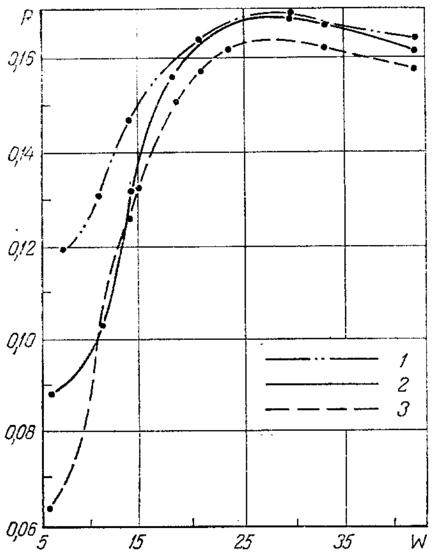

Fig. 1. Experimental dependence of the reflection coefficient on the mass ratio of the moisture content of raw cotton with different values of the volume density of the sample: 1) ρ = 87 kg/m^3; 2) 116; 3) 145.

Thus, when we refine A by additionally measuring R, we increase in the accuracy of the determination of W. The value of the attenuation A_0 of an electromagnetic wave reflected from a media boundary is expressed by the formula [3]

$$-10\lg\frac{|\dot{U}_p|^2-|\dot{U}_0|^2}{|\dot{U}_p|^2}=1-|R|^2. \quad (2)$$

The attenuation A_n of an electromagnetic wave which has passed through the test material is expressed by the formula [3]

$$-10\lg\frac{|\dot{U}_p|^2}{|\dot{U}_p|^2}. \quad (3)$$

Then the total attenuation A_m of the electromagnetic wave will be

$$A_m=10\lg\frac{|\dot{U}_p|^2\left(1-\frac{|\dot{U}_0|^2}{|\dot{U}_p|^2}\right)}{|\dot{U}_i|^2}. \quad (4)$$

In shf moisture meters, the values of $\dot{U}_i$, $\dot{U}_0$, and $\dot{U}_p$ are measured at the output of the detector. Under the condition that the characteristic of this detector is close to quadratic, the attenuation A introduced by the material can, with allowance for R, be determined from the formula

$$A_m=10\lg\frac{U_p\left(1-\frac{U_0}{U_p}\right)}{U_i}. \quad (5)$$

Equation (5) does not consider the effect of the reflected wave from the rear boundary between the media on the value of A_m. Thus, the equation is valid in the case when the depth of penetration of the electromagnetic wave Δ is less than the doubled thickness d of the test sample:

$$\Delta=\frac{1}{\omega\sqrt{\frac{\varepsilon_a}{2}\sqrt{1+\mathrm{tg}^2\delta}}}<2d.$$

Figure 1 shows the dependence of the reflection coefficient R on the moisture content W of the material obtained experimentally for three values of volume density ρ = (145, 116, 87) kg/m^3.

The graph confirms the complex functional relationship between the parameter R and the moisture content of the material W.

Beginning with 22% and more, the reflection coefficient becomes insensitive to the moisture content of the material. This can be explained by a change in the elastic properties of the cotton. Under the influence of moisture it loses its elastic properties and takes the form of small lumps. As a result, with the volume and mass of the sample remaining constant inside the measurement chamber, cavities commensurate with the wavelength are formed and cause wave interference. The interference pattern remains the same on the average with a further increase in moisture content (to more than 22%), and the path of the curve in the figure is shallow in character.

Table 1 presents results of calculation of the moisture content measurement error. It can be seen that the random component σ_W of the error obtained with allowance for the parameter R is tenths of a percent lower than without allowance for it, and the effect of the reflected wave on the error increases with an increase in moisture content.

For a specific material (raw cotton), the error of the method used in a serially produced moisture meter in a single measurement of an object is 10% (rel.) [4], and the use of additional information on reflection has a positive effect only when the methodological error is no more than 1-5% (rel.) over the entire measurement range. Thus, it is best to use the additional information on reflection in the repeated measurement of an object, when the measurement error σ_W can be reduced to the required level and the speed of the moisture meter will not be the dominant factor.

In the present case, this was achieved by folding the sample ten times. The measurement time here was 10 min. However, there is a method of evaluating moisture content which makes it possible to perform up to 100 measurements a second [5].

Rotating the specimen in an electromagnetic field after it has been compacted to 300-400 kg/m^3 produces the same effect as multiple folding, but the analysis is much quicker in this instance.

NOTATION

ε, permittivity of the medium; μ, permeability of the medium; U_p, normalized amplitude of the wave incident on the sample, equal to $|\dot{U}_p|^2/2$; U_0, normalized amplitude of the wave reflected from the forward boundary of the media, equal to $|\dot{U}_0|^2/2$; U_i, normalized amplitude of a wave passed through the material, equal to $|\dot{U}_i|^2/2$; A_0, attentuation of shf energy due to reflection; A_n, attenuation of shf energy absorbed in the load; A_m, attenuation of shf energy absorbed by the material; σ_W, measurement error; t, Student's coefficient; n, number of measurements; R, modulus of reflection coefficient.

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