РАДІОЕЛЕКТРОНІКА
ТА ТЕЛЕКОМУНІКАЦІЇ

РАДИОЭЛЕКТРОНИКА
И ТЕЛЕКОММУНИКАЦИИ

RADIO ELECTRONICS
AND TELECOMMUNICATIONS

PROXIMATE TESTING METHOD OF MOISTURE MEASUREMENT FOR SUBSTANCES OF DIELECTRIC NATURE

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ABSTRACT

Contest. Variable chemical composition of the materials under research is a reason for so-called "type uncertainty" appearance, because the result of moisture measurement strongly depends from initial dielectric permittivity (type) of a material, and dielectric permittivity can be significantly different not only for different materials, but for different varieties of the same material. Development of new and modification of existing moisture measurement methods and development of new instrumental and secondary transducers is a problem of current importance for increasing the accuracy of moisture measurement.

Objective. The purpose of this work is reduction the error of moisture measurement for bulk and liquid materials by new methods and means of moisture measurement development.

Methods. A new method of moisture measurement had been developed with two additive, two multiplicative and two complementary testing influences on the sample under research. It foresees getting seven readings of a capacitance that should be plugged into the formula of a testing algorithm to get the moisture value. The method allowed to reduce material's type influence on the result of moisture measurement and to increase accuracy of measurements. To make a new method of moisture measurement proximate, special instrument transducer had been developed. It allows simulation of additive testing influences on the material by using flat conductive plates of a certain thickness, introduced directly into a space between the electrodes.

Results. The main purpose of experiments was to prove the capability of the new method of moisture measurement to work with experimental values of capacitances. New instrument and secondary transducers had been developed for that purposes. Obtained results helped to see that new testing algorithm has good conditionality when working with real values of capacitances with natural random variation.

Conclusions. As a result we could see that maximal absolute error does not overcome 1.3 % of moisture content. It shows that substitution the direct adding of water with metallic plates does not decrease conditionality of calculated moisture value results, obtained using the new method of moisture measurement.

KEYWORDS: moisture content control, capacitance moisture meter, dielectric permittivity, test methods, testing algorithms, conditionality.

NOMENCLATURE

δ_m – "type uncertainty" relative error;

ε_1 – dielectric permittivity of water;

ε_2 – dielectric permittivity of a material;

$\Delta\varepsilon_2$ – dielectric permittivity variation depending from material's type;

ε_m – dielectric permittivity of a dry material;

C_1 – first reading from the capacitance initial transducer;

C_2 – second reading from the capacitance initial transducer;

C_3 – third reading from the capacitance initial transducer;

C_4 – fourth reading from the initial transducer;

$C_2^{/}$ – fifth reading from the initial transducer;

$C_3^{/}$ – six reading from the initial transducer;

$C_4^{/}$ – seventh reading from the initial transducer;

W – nominal value of moisture;

W_{calc} – calculated value of moisture;

ΔW – quantity of water that should be added into the sample under research to get first additive test;

$\Delta W^{/}$ – quantity of water that should be added into the sample under research to get second additive test.

INTRODUCTION

Grain farming is a strategic and most effective branch of Ukrainian economy. In the Law of Ukraine "About Grain and Grain Market" much attention is paid to state control of grain quality and its storage conditions. Modern grain quality ratings are regulated with national standard [1], and in accordance with it moisture content should be not more than 14.5…15.5%.

Ukrainian grain farming produces 2.5 million tons of grain, and the quality of approximately 1.5 million tons is necessary to be increased. One of the popular ways to increase grain quality ratings is one- or two times processing by moistening with further conditioning up to 12…13% of moisture level, that allows increasing baking properties significantly.

According to the regulations "Approval of Energetic Strategy of Ukraine up to 2035 year", where it was told about introduction of power efficient technologies of oil fuels usage, we can remember the usage of oil-water slurries, that allow to provide fuel economy and reduce emissions in atmosphere. Amount of water in such a slurries can be up to 40 % and is the object of strict control.

For all these examples moisture control with high accuracy is really indispensable.

The object of study is the process of moisture measurement of bulk and liquid materials of dielectric nature.

The work is dedicated to the problem of different materials moisture measurement accuracy increase in a way of new methods of moisture measurement development, new testing algorithms synthesis to calculate the quantity of moisture, conditionality examination for the solutions, received with a help of new testing algorithms, and new initial and secondary transducers of moisture measurement development.

The subject of study is the methods and technical means of accuracy increase for dielcometer moisture meters.

Subject of the research are methods, mathematical models and technical means of capacitance moisture meters for dry and liquid materials accuracy increase. The analysis of modern moisture measurement principles for dry and liquid materials with capacitance moisture meters had been carried out. As a result the dielcometer principle of measurement had been taken for the research. Inside the dielcometer principle several perspective methods of moisture measurement had been found, but all of them have to be improved. Accordingly, modern initial and secondary transducers of moisture quantity have to be improved too, and it was confirmed by the results of modern moisture meters analysis.

The purpose of the work is reduction the error of moisture measurement for bulk and liquid materials by new methods and means of moisture measurement development.

1 PROBLEM STATEMENT

To collect information about the most popular moisture measurement principles the modern market of moisture meters for bulk materials and oil products had been analyzed. Generally 358 models of moisture meters for bulk materials and 64 models of moisture meters for oil products had been detected. In accordance with reference we can see that capacitance principle of measurement prevails the others (approximately 33% of moisture meters for bulk materials and 63% of moisture meters for oil products).
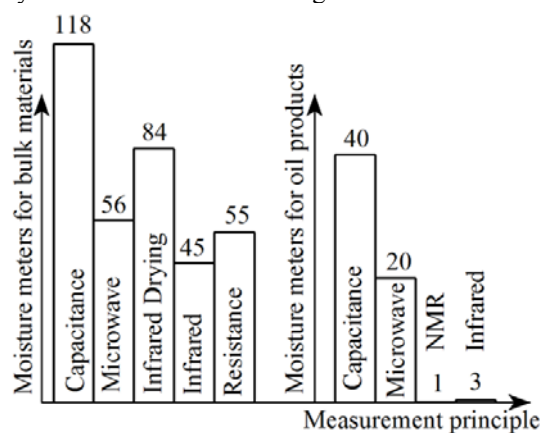
Analysis results are shown on Fig. 1.

Figure 1 – Parts of the market for moisture meters

Figure 1 forces us to pay attention on the capacitance (dielcometer) principle of moisture measurement. It is based on material's dielectric properties measurement with a help of capacitance initial transducer. A lot of researches and developers choose capacitance principle of measurement because of its relative simplicity and possibility to define moisture content as a difference of water and researched material dielectric permittivity [2–5].

But the problem is a significant dielectric permittivity variation of medium, that contains water, because it makes strong influence on the result of moisture measurement [6]. An error, created by dielectric permittivity variation, especially when measuring small moisture values (for example in a range from 0 to 1 %), can overcome the range of measurement for more than 5 times. The value of this error decreases if we increase the range of measurement, but remains significant.

When we have practical measurements, change of dielectric permittivity for different materials under research causes methodical "type uncertainty" error if we have a scale of a meter, graduated only for one dielectric permittivity value. Its value can be estimated in such a way:

$$\delta_m = \frac{\Delta\varepsilon_2}{\varepsilon_2}\left(1 - \frac{3\varepsilon_1\varepsilon_2}{(\varepsilon_1 + 2\varepsilon_2)(\varepsilon_1 - \varepsilon_2)}\right) \approx \frac{\Delta\varepsilon_2}{\varepsilon_2}.$$

2 REVIEW OF THE LITERATURE

A decision had been made to fulfill the methods of moisture measurement analysis inside the capacitance principle to detect methods, which allow effective "type uncertainty" methodical error compensation.

Methods, taken for the analysis, should provide express measurements for technological process conditions and provide high accuracy due to the effective "type uncertainty" compensation [7, 8]. As a result, methods of moisture measurement for bulk, solid, paste-like and liquid dielectric materials had been taken into account. Approximately 300 patents of USA, Japan, China, Europe, Ukraine and Russia starting from 1994 and up to 2017 had been analyzed during the research [9–16]. All detected methods were classified using some number of common features and divided into 15 groups. The most popular ways to compensate "type uncertainty" error are measuring capacitance on two or more frequencies, preliminary graduating characteristics receiving or standard samples preparation, measuring some number of complementary parameters, application of special testing influences on the material under research, measuring the capacitance of initial and dehydrated sample etc. Big manufacturers of modern moisture meters, such as Agra-Tronix, Dickey John (USA), A-Grain, Panomex (India), ASONIC, Draminski (Poland), Farmcorp (Finland), Isoelectric (Italy), Kett (Japan), Pfeuffer (Germany), Sinar (GB) etc. provide their devices with some number (from 3 to 400) of calibrating characteristics for certain materials.

It would be more rational for a moisture meter to be universal for the wide range of materials without calibrating characteristics application, and it is possible to reduce the influence of "type uncertainty" error significantly directly in a capacitance instrument transducer due to the application of a new testing method of moisture measurement.

3 MATERIALS AND METHODS

One of the perspective directions had been detected for that purpose. The idea was to use special test methods that allow increase the accuracy of measurements. Essentiality of these methods consists in determining the parameters of a static function for the transducer with a help of additional tests, functionally connected with an object under control. For the moisture control purposes test actions should be formed as a number of water injections into the substance under consideration. Using the values of dielectric permittivity after each of test actions it is possible to calculate the initial moisture of the material [17]. Different testing algorithms had been explored after what a perspective combination, consisting of two additive and two multiplicative tests was formed.

The idea of the method can be described in such a way. At first we take a sample of a material under research and get a first reading from the capacitance initial transducer C_1. After that some quantity of water should be added into that sample (during the experiments $\Delta W = 10$ % of water had been taken) to create first addi-

tive test and get a second reading from the initial transducer C_2. At the third step value of C_1 capacitance should be increased two times to get the first multiplicative test and a third reading from the initial transducer C_3. Next step foresees adding double amount of water $\Delta W^{/} = 20$ % into initial sample under research to form second additive test and reading number four $C_2^{/}$. And, at last, value of C_1 capacitance should be increased four times to get the second multiplicative test and a fifth reading from the initial transducer $C_3^{/}$.

To get the moisture value for the material under research all five readings of a capacitance should be substituted into the formula:

$$W = \left(\frac{\Delta W^{/}\left(C_3^{/} - C_1\right)}{\left(k^{/} - 1\right)\left(C_2^{/} - C_1\right)} + \frac{\Delta W\left(C_3 - C_1\right)}{\left(k - 1\right)\left(C_2 - C_1\right)} \right) \Bigg/$$
$$\Bigg/ \left[\left(\frac{\Delta W^{/}\left(C_3^{/} - C_1\right)}{\left(k^{/} - 1\right)\left(C_2^{/} - C_1\right)} - \frac{\Delta W\left(C_3 - C_1\right)}{\left(k - 1\right)\left(C_2 - C_1\right)} \right) \times \right.$$
$$\times \left. \left(1 + 0.0029 C_1\right) \right].$$

To calculate moisture four materials with different values of dielectric permittivity (2; 2.5; 3 and 3.5) had been chosen. Calculations for moisture control points 0, 10, 20, 30 and 40 % are given in tabler 1.

Table 1 – Calculated values of moisture

W	ε_m			
	2	2.5	3	3.5
	W_{calc}	W_{calc}	W_{calc}	W_{calc}
0.0	0.014	0.014	0.002	0
0.1	0.115	0.104	0.111	0.094
0.2	0.205	0.206	0.202	0.199
0.3	0.305	0.3	0.297	0.293
0.4	0.396	0.394	0.391	0.389

Calculated results can be called acceptable, if we have the same values of moisture for the materials with different physical and chemical structure (different values of dielectric permittivity ε_m) for a certain moisture value W.

We can say that material's type influence on the result of moisture measurement is rather strong. Maximal moisture variation for different materials is 1.5%, but calculated values of moisture are close to nominal and provide static characteristic of a transducer, close to linear. Graphical illustration to the calculations in table 1 is given on Fig. 2.

To reduce "type influence" for the method, mentioned before, it was suggested to add two more complementary tests into the process of measurement. Description of a new modified method is given below. Again we take a sample of a material under research and get a first reading from the capacitance initial transducer C_1. Then we add
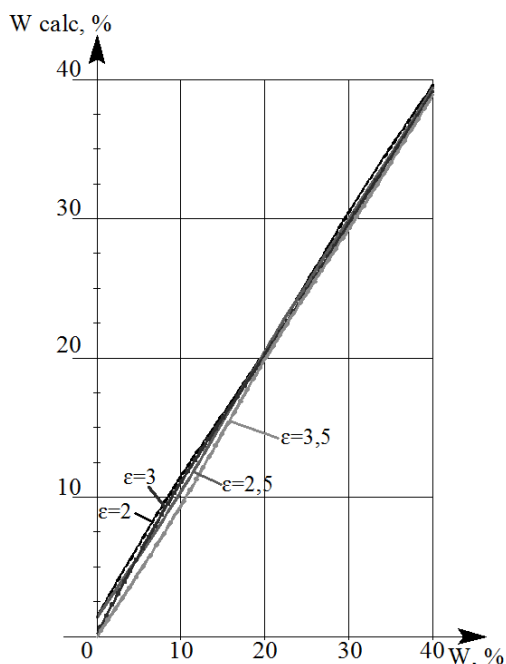
Figure 2 – Variation of calculated moisture values

Table 2 – New calculated values of moisture

W	ε_m			
	2	2.5	3	3.5
	W_{calc}	W_{calc}	W_{calc}	W_{calc}
0.0	0.132	0.647	0.002	0.275
0.1	10.425	9.922	10.333	10.010
0.2	19.687	20.280	20.431	20.637
0.3	29.689	29.785	29.998	30.094
0.4	38.835	39.154	39.335	39.499

10 % of water into that sample to create first additive test and get a second reading from the initial transducer C_2. Third step will be the same as before: value of capacitance C_1 is increased two times to create the first multiplicative test and get a third reading from the initial transducer C_3. Step number four needs the value of a capacitance C_2, received after a second step, to be multiplied on two. We will get reading number four C_4. Then it is necessary to add double amount of water $\Delta W^{/} = 20\%$ into initial sample to form second additive test and fifth reading $C_2^{/}$. Step number six means four times increasing the capacitance of the first reading C_1 to get reading number six $C_3^{/}$ as a second multiplicative test. To get the last reading $C_4^{/}$ (number seven) it is necessary to make four times increasing the capacitance of the fifth reading $C_2^{/}$.

Moisture value for the material can be calculated using seven readings of a capacitance using the formula:

$$W = \left(\frac{\left(C_3^{/} - C_1 \right) \Delta W^{/}}{\left(C_4^{/} - C_2^{/} \right) - \left(C_3^{/} - C_1 \right)} + \frac{\left(C_3 - C_1 \right) \Delta W}{\left(C_4 - C_2 \right) - \left(C_3 - C_1 \right)} \right) \Big/$$
$$\Big/ \left(\frac{\left(C_3^{/} - C_1 \right) \Delta W^{/}}{\left(C_4^{/} - C_2^{/} \right) - \left(C_3^{/} - C_1 \right)} + \frac{\left(C_3 - C_1 \right) \Delta W}{\left(C_4 - C_2 \right) - \left(C_3 - C_1 \right)} \right) \times$$
$$\times \left(1 + 0,0045 C_1 \right).$$

New calculations of moisture values are given in table 2.

Having these results we can say, that "type uncertainty" reduced to the value 1.16% in comparison with 1.5% for the previous testing algorithm. And if we take a range of measurement from 0 to 30%, maximal variation of moisture values will not overcome 0.647%, and this is the best result we managed to get.

Graphical illustration to the table 2 is given on Fig. 3.

Next step of the research was to check the ability of the last testing algorithm to retain stability when working with experimental results that have natural random variation. A need for such a research is conditioned with a fact that values of electric capacitances taken from instrument transducer will not be ideal deterministic values, but will be the results of measurements that always have some random variation.

Level of random variation (capacitance measurement uncertainty) will directly influence the calculated moisture values conditionality: measurement uncertainty growth will decrease the calculated moisture values conditionality up to the moment when testing algorithm becomes irrelevant [18].

After conditionality inspection in a special way described in [18], it had been occurred that both testing algorithms have similar problems with conditionality of calculated moisture values for the points 0 % and 10 % of moisture. That circumstance forced us to study denominators of both testing algorithms, described before, and to synthesize a new testing algorithm as their average:

$$W = \left| \frac{\left(C_3^{/} - C_1 \right) \Delta W^{/}}{\left(C_4^{/} - C_2^{/} \right) - \left(C_3^{/} - C_1 \right)} - \right.$$
$$\left. - \frac{\left(C_3 - C_1 \right) \Delta W}{\left(C_4 - C_2 \right) - \left(C_3 - C_1 \right)} + 0.033 \right| \cdot 833 +$$
$$+ \left| \frac{\Delta W^{/} \left(C_3^{/} - C_1 \right)}{\left(k^{/} - 1 \right) \left(C_2^{/} - C_1 \right)} - \frac{\Delta W \left(C_3 - C_1 \right)}{\left(k - 1 \right) \left(C_2 - C_1 \right)} - 0.033 \right| \cdot 800.$$

So, the method of moisture measurement, suggested in the article, still consists of seven steps with implementing of two additive, two multiplicative and two complementary tests, and to calculate moisture it's necessary to use formula, described in a previous abstract.
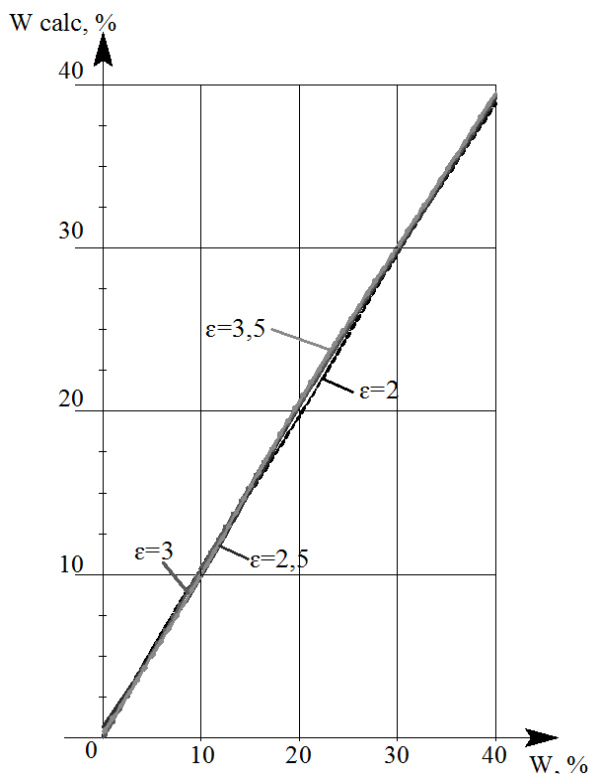
Figure 3 – Variation of calculated moisture values

4 EXPERIMENTS

The main purpose of experiments was to prove the capability of the last form three testing algorithms to work with experimental values of capacitances, taken directly from the transducer, and to give adequate values of moisture, independent from the type of material under research. To fulfill experimental researches it was necessary to create material-water samples with 0%, 10%, 20% and 30% of water. To prepare such samples it was necessary to fulfill preliminary drying for maximal extraction of water from the sample. Air-oven reference method had been used for that purpose. Taking into account big size of used initial transducer, mass of a sample for drying should be approximately 600 g. To dehydrate such a big sample 30 standard aluminum weighting bottles with 20 g probes had been used. Empty aluminum bottles should be weighed on the scales with ± 0.01 g accuracy [19]. Process of weighting is demonstrated on Fig. 4, and, in accordance with [19], weighting bottles should be kept in desiccator with a dehumidifier.

Figure 4 – Aluminum bottles weighting process

Seeds of a pearl-barley, poppy, millet, pea and wheat had been chosen as materials for experimental researches. Each of 30 weighting bottles was filled with a 20 g sample of a certain seed and prepared for drying (Fig. 5).

Figure 5 – Weighting of a poppy seed samples

After that weighting bottles with opened lids should be placed into a drying oven to be dried on 130 °C temperature during 120 minutes (Fig. 5). Then it's necessary to put weighting bottles with dry samples into the desiccators to provide their cooling to the temperature of laboratory conditions. After that process a sample can be called dry and used to prepare probes with a certain percent of moisture.

As a first moisture sample (with 0% of moisture) we can use any dry material, prepared before. Second moisture sample can be received by adding 60 g of water (10% from total volume) into the first sample. To get third moisture sample we should add 120 g of water (20%), fourth – 200 g of water (30%). After that each moisture sample should be carefully mixed to provide moisture distribution uniformity.

Figure 6 – Drying of a pearl-barley sample

When working with seed its necessary to take into account that presence of water activates physiological, physical and chemical processes: absorption of water, swelling, sprouting etc. That's why free water in seed is usually absent. To simulate real conditions it was necessary to cover just prepared moisture samples with lids and leave them in such a state for an hour (seed will soak free water) [20].

To make test influences on the material fast and simple, a new instrument transducer had been developed (Fig. 7).

Instrument transducer consists of a system of flat electrodes 1, created by V-type plates. System of flat electrodes is held out on the inside surface of two dielectric
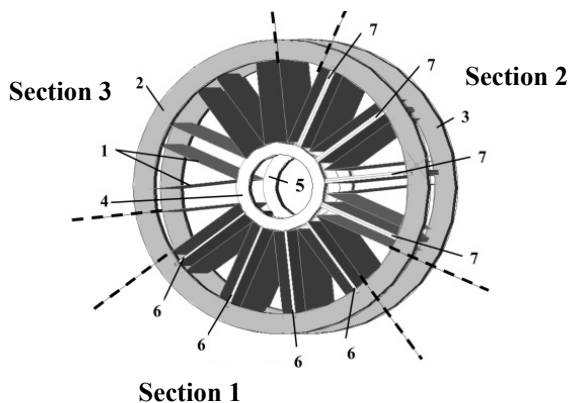
Figure 7 – Modified instrument transducer

rings 2 and 3. To simulate direct test influences on the material with adding some portions of water, metallic flat plates of different thickness 6 and 7 had been introduced into the space between electrodes. Internal rings 4 and 5 are necessary to fix all the plates [21].

Such a transducer allows simulation of two additive test influences on the material under research. Let's imagine, that it is necessary to create two additive test influences like adding 10% and 20% of water. To fulfill this task initial transducer was conventionally divided into three measuring sections (Fig. 6). Certain number of metallic plates 6 should be introduced into the space between electrodes of section 1. It was calculated, that simulation of 10 % water content in the material needs 27.64% increasing initial transducer's dielectric permittivity or electric capacitance. It helped to calculate necessary thickness of one plate 6.

Second section was needed to create second additive test influence on the material. For that purpose electric capacitance of that section should be increased on 59.74 % or 1.5974 times. As a result, it would be possible to get three values of electric capacitances: capacitance C_1 as a first reading from the initial transducer (we can get it from section 3); capacitance C_2 as a second reading from the initial transducer (section 1); and capacitance $C_2^/$ of a second additive test and fifth reading form the transducer. Values for the rest of capacitances, necessary to get moisture content W, can be simply calculated as described before.So, having an experimental sample of instrument transducer (Fig. 8), it would be possible to check how the last testing algorithm will work with capacitance values, obtained in experimental way.
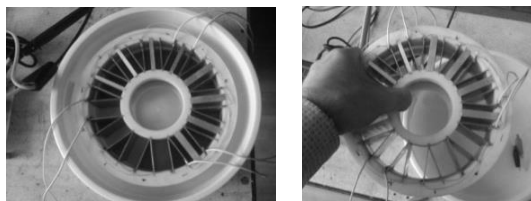

Figure 8 – Instrument transducer experimental sample

Experimental setup for moisture measurement consists of instrument and secondary transducers, oscilloscope Tektronix 2213A to control the form and duration of pulses, digital multimeter UTM18803 to measure voltage from the secondary transducer's output, variable air capacitor to substitute instrument transducer and digital RLC-meter UTM 1612 used as capacitometer of a variable air capacitor. Process of moisture measurement consisted of several steps.

At the first step instrument transducer filled with a prepared sample was connected to the secondary transducer with it's section 3, free from metallic plates. The task of a digital multimeter was to measure output d. c. voltage of the secondary transducer, which is a function of moisture content. D. c. voltage value was fixed by the operator. At the second step instrument transducer with a sample was disconnected from the circuit and replaced by variable air capacitor able to change its capacitance in a range of 5…760 pF (Fig. 9).
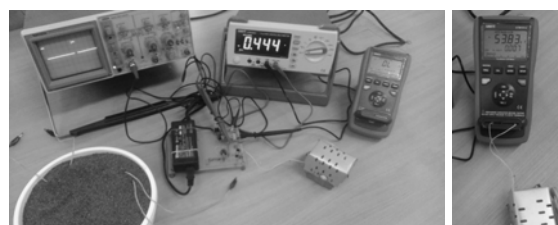

Figure 9 – Moisture measurement of a poppy seed

Then air capacitor was disconnected from the circuit and its capacitance was measured with high resolution by RLC-meter. Electric capacitances of 1 and 2 instrument transducer's sections were measured in the same way.

Each capacitance was measured for ten times and averages were used in a suggested method of moisture measurement (table 3).

Mentioned above capacitance-voltage transducer is based on two 555 or 777 timers (Fig. 10), where the left one is connected as a multivibrator circuit and generates meander pulses on its output.

The right one, where instrument transducer with moisture sample C_{x1} is connected, works as a one-shot multivibrator and pulses duration on its output is in straight proportion with a capacitance of the instrument transducer. Low-pass filter R_4C_4 works as pulse duration into d. c. voltage transducer in a range 0.000…2.000 volts.

5 RESULTS

According to the method only C_1, C_2 and $C_2^/$ capacitances, that corresponds sections 3, 1 and 2 of an instrument transducer must be measured directly. Rest of the capacitances can be easily calculated. We can see the results of direct measurements for the materials under research with 30 % of moisture content in tabler 3 as an example.
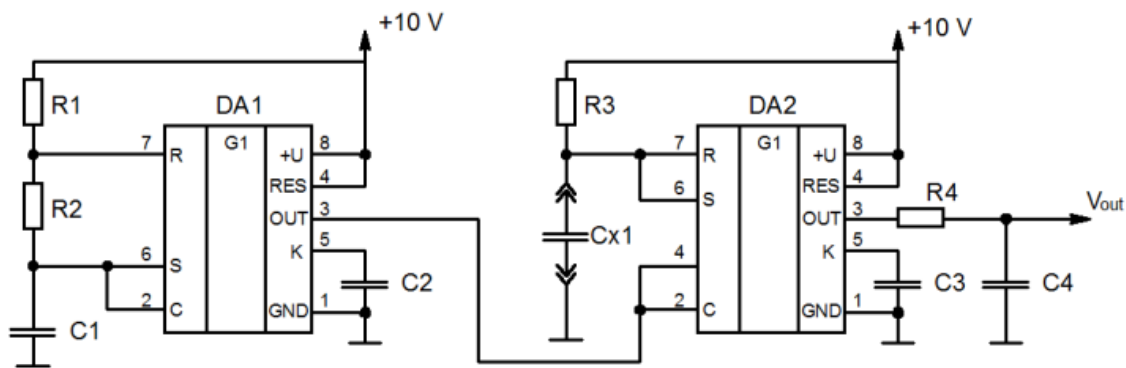
Figure 10 – Capacitance – d.c. voltage transducer

Table 3 – Results of direct multiple measurements for samples with 30 % of moisture content

№ of experiment	1	2	3	4	5	6	7	8	9	10	$\overline{C}$
Pearl-barley											
C_1, pF	117,91	117,63	117,54	117,72	117,84	117,91	117,69	117,82	117,55	117,76	117,73
C_2, pF	138,81	138,45	138,51	138,49	138,76	138,99	138,46	138,51	138,85	138,49	138,61
$C_2^{/}$, pF	164,21	164,65	164,48	164,39	164,53	164,29	164,38	164,45	164,71	164,19	164,42
№ of experiment	1	2	3	4	5	6	7	8	9	10	$\overline{C}$
Poppy											
C_1, pF	111,64	111,32	111,48	111,59	111,19	111,28	111,54	111,63	111,71	111,59	111,50
C_2, pF	131,64	131,85	131,94	131,52	131,46	131,51	131,39	131,68	131,71	131,49	131,62
$C_2^{/}$, pF	155,94	155,81	155,64	155,71	155,49	155,58	155,72	155,81	155,58	155,73	155,70
Millet											
C_1, pF	100,71	100,60	100,94	100,85	100,49	100,73	100,68	100,82	100,66	100,59	100,71
C_2, pF	119,14	118,91	118,69	118,72	118,89	118,61	118,92	118,74	118,79	118,85	118,82
$C_2^{/}$, pF	140,32	140,61	140,86	140,60	140,49	140,72	140,73	140,48	140,54	140,66	140,61
Pea											
C_1, pF	94,98	95,29	95,26	95,31	95,16	95,01	95,39	95,41	95,03	94,96	95,18
C_2, pF	111,94	112,11	112,43	112,52	112,31	112,22	112,38	112,30	112,05	112,49	112,28
$C_2^{/}$, pF	132,85	132,99	132,21	133,30	133,05	133,12	133,19	132,89	132,92	133,10	133,06
Wheat											
C_1, pF	82,54	82,33	82,64	82,51	82,71	82,30	82,41	82,56	82,68	82,46	82,51
C_2, pF	97,54	97,78	97,41	97,55	97,62	97,66	97,33	97,51	97,71	97,44	97,56
$C_2^{/}$, pF	115,62	115,31	115,22	115,34	115,56	115,42	115,60	115,31	115,28	115,19	115,42

All the results of moisture content, obtained with the help of suggested method of measurement for five samples of different bulk materials taken as an object of research, can be seen in table 4.

Table 4 – Results of moisture measurement

Material	Moisture content W . %			
	0	10	20	30
Pearl-barley	0.503	10.882	20.487	29.818
Poppy	0.445	10.204	19.066	30.963
Millet	0.622	9.758	19.914	30.705
Pea	0.701	10.843	20.678	30.94
Wheat	0.001	10.396	19.405	28.692

If we compare these results with data from table 2, it is hard to see the progress. That's why it was necessary to estimate the accuracy level for the claimed method of moisture measurement. The method of mathematical programming was used for that purpose. If function $f(x)$ is continuous it is possible to get it's maximal and minimal values inside the range of limiting error for the argument x. In this case estimated value of an absolute error can be calculated as a half-difference:

$$\Delta f = \left(f_{\max}(x) - f_{\min}(x)\right)/2.$$

Upper limit of moisture will be received in a case:

$$W = \left| \frac{\left(C'_{3\max} - C_{1\min}\right)\Delta W'}{\left(C'_{4\min} - C'_{2\max}\right) - \left(C'_{3\max} - C_{1\min}\right)} - \right.$$

$$\left. - \frac{\left(C_{3\max} - C_{1\min}\right)\Delta W}{\left(C_{4\min} - C_{2\max}\right) - \left(C_{3\max} - C_{1\min}\right)} + 0.033 \right| \cdot 833 +$$

$$+ \left| \frac{\Delta W'\left(C'_{3\max} - C_{1\min}\right)}{\left(k' - 1\right)\left(C'_{2\min} - C_{1\max}\right)} - \right.$$

$$\left. - \frac{\Delta W\left(C_{3\max} - C_{1\min}\right)}{\left(k - 1\right)\left(C_{2\min} - C_{1\max}\right)} - 0.033 \right| \cdot 800.$$

Lower limit of moisture will be received in a case:

$$W = \left| \frac{\left(C'_{3\min} - C_{1\max}\right)\Delta W'}{\left(C'_{4\max} - C'_{2\min}\right) - \left(C'_{3\min} - C_{1\max}\right)} - \right.$$

$$\left. - \frac{\left(C_{3\min} - C_{1\max}\right)\Delta W}{\left(C_{4\max} - C_{2\min}\right) - \left(C_{3\min} - C_{1\max}\right)} + 0.033 \right| \cdot 833 +$$

$$+ \left| \frac{\Delta W'\left(C'_{3\min} - C_{1\max}\right)}{\left(k' - 1\right)\left(C'_{2\max} - C_{1\min}\right)} - \right.$$

$$\left. - \frac{\Delta W\left(C_{3\min} - C_{1\max}\right)}{\left(k - 1\right)\left(C_{2\max} - C_{1\min}\right)} \right| \cdot 800.$$

Maximal and minimal values of corresponding electric capacitances were taken from the results of ten measurements of pearl-barley seed with 30 % moisture content (table 5). After we substitute these values into the formulas for maximal and minimal moisture levels calculation we will get:

$$W_{\max} = 31.007 \%, \ W_{\min} = 29.799 \%,$$
$$\Delta(W) = (W_{\max} - W_{\min})/2 = 0.604 \%.$$

It's necessary to emphasize that ΔW represents random part of the error, calculated for the results of indirect multiple measurements. The method error was calculated as a square root from RMS error:

$$\Delta_m(W) = \sqrt{\frac{\sum\sum\left(W_{ij} - W_{sj}\right)^2}{n}} = 0.64 \%.$$

In this formula:

W_{ij} – twenty calculated values of moisture, taken from the table 4; W_{sj} – standard moisture values: 0, 10, 20 and 30 %; n – number of calculated moisture values, $n = 20$.

Total error can be calculated as an arithmetic sum of random and method error:

$$\Delta_{\sum}(W) = \Delta(W) + \Delta_m(W) = 0.604 + 0.64 = 1.24 \%.$$

6 DISCUSSION

Experimental check of the material's type influence on the moisture measurement result, defined using the new testing algorithm, had been carried out. Two situations were compared, when to create additive testing influences certain amounts of water had been directly introduced into the material under research and when presence of water had been simulated in the instrument transducer by using metallic flat plates of different thickness in the space between electrodes (last one described in the article). For both cases maximal absolute error does not overcome 1.3% of moisture content. It shows us that substitution the direct adding of water with metallic plates does not decrease conditionality of calculated moisture value results, obtained using the last testing algorithm.

CONCLUSIONS

The problem of methodical "type uncertainty" error reduction for moisture measurement with a capacitance moisture meters is solved to increase the accuracy of measurements.

The scientific novelty of this work is a new method of moisture measurement, where sample of a material is taken to get the first reading form the instrument transducer's output, then certain amount of water should be added to the sample what allows to get second reading from the instrument transducer's output. At a third step capacitance value of the first reading should be twice increased to get the third reading form the instrument transducer's output. Reading number four is a twice increased capacitance of a second reading. To get reading number five we add double amount of water to the sample, and for the reading number six and seven capacitance values of the first and fifth reading should be increased four times.

As a result we have a method of moisture measurement with two additive, two multiplicative and two complementary testing influences on the sample under research, what allowed to reduce material's type influence on the result of moisture measurement and to increase accuracy of measurements.

The practical significance of obtained results is that to make a new method of moisture measurement

Table 5 – Maximal and minimal values of electric capacitances

Pearl-barley		Values of electric capacitances. pF						
		C_1	C_2	C_3	C_4	C'_2	C'_3	C'_4
$W = 30$ %	max	117.91	138.99	235.82	277.98	164.71	471.64	658.84
	min	117.54	138.45	235.08	276.9	164.19	470.16	656.76

proximate, special instrument transducer had been developed. It allows simulation of additive testing influences on the material by using flat conductive plates of a certain thickness, introduced directly into a space between the electrodes. The practical novelty connected with the development of instrument and secondary transducers to fulfill the process of moisture measurement.

Prospects for further research are to study the proposed method of moisture measurement for a possibility to provide better conditionality.

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ЕКСПРЕСНИЙ ТЕСТОВИЙ МЕТОД ВИМІРЮВАННЯ ВМІСТУ ВОЛОГИ ДЛЯ РЕЧОВИН ДІЕЛЕКТРИЧНОЇ ПРИРОДИ

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АНОТАЦІЯ

Актуальність. Змінний хімічний склад матеріалів, що підлягають дослідженню, є причиною появи так званої «сортової невизначеності», через те, що результат вимірювання вмісту вологи суттєво залежить від початкової діелектричної проникності (типу) речовини, а діелектрична проникність може істотно відрізнятись не тільки для різних речовин, але й для різновидів однієї речовини. Розроблення нових і удосконалення наявних методів вимірювання вмісту вологи, а також розроблення нових первинних і вторинних вимірювачів вмісту вологи є важливою проблемою для підвищення точності вимірювань. Метою роботи є зменшення похибки вимірювання вмісту вологи для сипких і рідинних речовин шляхом розроблення нових методів і засобів вимірювання.

Метод. Розроблено новий метод вимірювання вмісту вологи з використанням двох адитивних, двох мультиплікативних та двох додаткових тестових впливів на досліджуваний зразок. Він передбачає отримання семи відліків електричної ємності, що мають бути підставлені у формулу тестового алгоритму для обчислення вмісту вологи. Метод дозволяє зменшити вплив типу речовини на результат вимірювання вмісту вологи і підвищити точність вимірювань. Для забезпечення експресності вимірювань було розроблено спеціальний первинний вимірювальний перетворювач. Він забезпечує імітацію адитивних тестових впливів на речовину завдяки використанню пластин із струмопровідного матеріалу певної товщини, що розміщені безпосередньо у міжелектродному просторі перетворювача.

Результати. Головною метою експериментів було довести здатність нового методу вимірювання вмісту вологи зберігати працездатність під час роботи з експериментальними значеннями електричних ємностей. Для цього було розроблено нові первинний і вторинний вимірювальні перетворювачі. Отримані результати допомогли пересвідчитись, що новий тестовий алгоритм має хорошу обумовленість під час роботи з реальними значеннями електричних ємностей, що мають природну варіацію.

Висновки. В результаті було визначено, що максимальна абсолютна похибка вимірювання не перевищує 1,3 % вмісту вологи. Це доводить, що заміна безпосередніх добавок води металевими пластинами не погіршує обумовленості обчислених значень вмісту вологи, отриманих з використанням нового методу вимірювання.

КЛЮЧОВІ СЛОВА: вимірювання вмісту вологи, ємнісний вимірювач вологи, діелектрична проникність, тестові методи, тестові алгоритми, обумовленість.

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ЭКСПРЕССНЫЙ ТЕСТОВЫЙ МЕТОД ИЗМЕРЕНИЯ ВЛАГОСОДЕРЖАНИЯ ДЛЯ ВЕЩЕСТВ ДИЭЛЕКТРИЧЕСКОЙ ПРИРОДЫ

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АННОТАЦИЯ

Актуальность. Переменный химический состав исследуемых материалов является причиной возникновения так называемой «сортовой неопределенности» по причине того, что результат измерения влагосодержания существенно зависит от начальной диэлектрической проницаемости (типа) вещества, а диэлектрическая проницаемость может существенно варьироваться не только для разных веществ, но и для разновидностей одного вещества. Разработка новых и усовершенствование существующих методов измерения влагосодержания, а также разработка новых первичных и вторичных преобразователей влажности является важной проблемой для повышения точности измерений. Целью этой работы является уменьшение погрешности измерения влагосодержания для сыпучих и жидких веществ путем разработки новых методов и средств измерений.

Метод. Разработан новый метод измерения влагосодержания с использованием двух аддитивных, двух мультипликативных и двух дополнительных тестовых воздействий на исследуемый образец. Он предусматривает получение семи отсчетов электрической емкости, которые должны быть подставлен в формулу тестового алгоритма для вычисления влагосодержания. Метод позволяет уменьшить влияние типа вещества на результат измерения влагосодержания и повысить точность измерений. Для обеспечения экспрессности измерений был разработан специальный первичный измерительный преобразователь. Он обеспечивает имитацию аддитивных тестовых воздействий на вещество благодаря использованию пластин из токопроводящего материала определенной толщины, размещенных непосредственно в межэлектродном пространстве преобразователя.

Результаты. Главной целью экспериментов было доказать способность нового метода измерения влагосодержания сохранять работоспособность при работе с экспериментальными значениями электрических емкостей. Для этого были разработаны новые первичный и вторичный измерительные преобразователи. Полученные результаты помогли убедиться, что новый тестовый алгоритм имеет хорошую обусловленность во время работы с реальными значениями электрических емкостей, которые имеют природную вариацию.

Выводы. В результате было установлено, что максимальная абсолютная погрешность измерения не превышает 1,3 % влагосодержания. Это доказывает, что замена непосредственных добавок воды металлическими пластинами не ухудшает обусловленности рассчитанных значений влагосодержания, полученных с использованием нового метода измерений.

КЛЮЧЕВЫЕ СЛОВА: измерение влагосодержания, емкостный измеритель влажности, диэлектрическая проницаемость, тестовые методы, тестовые алгоритмы, обусловленность.

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