

## **Synthesis of test actions for capacitive moisture meter that is invariant to change of substance type**

*Ekaterina Golub<sup>1, 2</sup>, Aleksandr Zabolotnyj<sup>1</sup>, Nikolaj Koshevoj<sup>1</sup>, Irina Kirichenko<sup>3</sup>*

<sup>1</sup>National Aerospace University "KhAI", 17, Chkalova St., Kharkov, 61070, Ukraine,  
e-mail: golub-ekaterina@bk.ru

<sup>2</sup>PRE «HARTRON-ARKOS», 1, Akademika Proskury` St., Kharkov, 61070, P.O.Box 9971, Ukraine

<sup>3</sup>Volodymyr Dahl East-Ukrainian National University,  
Molodizhny bl., 20a, Lugansk, 91034, Ukraine

Received May 13.2014: accepted June 05.2014

**S u m m a r y .** In the article the research of various test actions to ensure invariance of capacitive moisture meters to change of substance type is carried out. The analysis of ways to reduce uncertainty of substance type is carried out. The most perspective direction of researches – test methods is chosen. The algorithm of a test method and the block diagram of measuring system for additive and multiplicative tests are chosen. During calculations the expression for determination of substance moisture content that is invariant to change of dielectric permeability is obtained. For the purpose of approbation of this expression the results of check of dependence of moisture content from dielectric permeability are received. Pearson criterion is applied for determination of results consistency. It is determined that these results rather well compensate the uncertainty of substance type.

**Key words.** Capacitive moisture meter, uncertainty of substance type, test method, additive test, multiplicative test.

### **INTRODUCTION**

One of the most widespread product-quality indexes is moisture [5]. Moisture is an important factor at control of parameters and control of technological processes in industry and in production of various materials [3, 14, 19]. For many types of agricultural production (grain and fodders) moisture is the factor that

shows a share of nutrients in production and duration of its storage [12, 13, 16, 18].

In industry it is often necessary to analyze moisture of petroleum products, bulks, building materials and other substances directly in technological process without using bulky samplers. For the solution of an objective and some other tasks the capacitive method for moisture measurement has gained the most widespread.

Advantages of capacitive moisture meters are first of all the possibility to control moisture in wide range with high accuracy, efficiency of measurements and no damages on the measured sample [1]. The main disadvantage is presence so-called uncertainty of substance type associated with the fact that the values of dielectric permeability significantly differ not only for various substances but also for various brands of the same substance [21].

Thus the most important direction of researches in the field of capacitive moisture meters is reduction of substance type uncertainty that will allow using these moisture meters for measuring of substances moisture content because they have a number of advantages.

## ANALYSIS OF PUBLICATIONS

Today there are some ways to solve the uncertainty of substance type for measuring of moisture of substances using capacitive moisture meters [4, 17, 20]. One of such ways is input of calibration curves in memory of moisture meters. These curves have information about dielectric permeability of substances that can be used in the measurement process. However it is obvious that the amount of substances and types of these substances is so great that to consider all possible dielectric permeabilities isn't possible.

Another way is providing of moisture meters with a calibration tables (moisture meters of Kett, IVZ-M1, IVZ-M1T, WILE-55, Sinar AP 6060, Kaplya, Grain Master, VSN-100, VSP-6P, Multi Grain, FAUNA, Farmpoint, GAC500, HE-50, Superpoint types) [11]. These tables are created on the basis of experimental data about dielectric characteristics of moisture containing materials. Use of these data requires some caution as the results of measurements that have been carried out in different conditions and with different methods don't coincide and sometimes contradict each other [1].

One of the ways is carrying out of moisture meters calibration for the specified structure of substance. Thus the moisture meter ceases to be universal as the measurements of moisture are possible only for that structure of substance for which a calibration was carried out. Moreover the most important is the fact that accuracy of analytical methods of moisture meters calibration in many cases not more than accuracy of calibrated device [1]. The shortcomings given above and also bulkiness and labor input of the calculations connected with the use of calibration don't allow the use this method to solve the uncertainty of substance type.

One of the perspective directions is use so-called "test methods" that allow to reduce influence of substance type on the moisture content value [2, 15]. The essence of these methods consists in generation of test actions by means of injection a known amount of water or dielectric substance with the set

dielectric permeability in initial substance. Thus the result of measurement is determined by change of dielectric permeability of initial sample after test actions with use of test methods.

With a research objective of this direction in early works [6, 21, 22] synthesis and tests of effective ways of test algorithms formation were carried out. These test algorithms would allow the compensating of substance type uncertainty of studied substances in conditions close to real polarizing processes in dielectrics and with a minimum of restrictions. Thus in [22] it is presented a method for formation and research of invariant test algorithm with the use of least-squares method (LSM), and in [6] – with the use of an interpolation Lagrange's polynomial. The researches conducted in these works showed that compensation of change of dielectric permeability of dehydrated substances is carried out in insufficient degree. Thus application of test methods for the solution of objectives requires more careful research.

## PURPOSE OF RESEARCH

Objective of this research is check of possibility of test methods using for solving the uncertainty of substance type problem for capacitive moisture meters.

## RESULTS OF RESEARCH

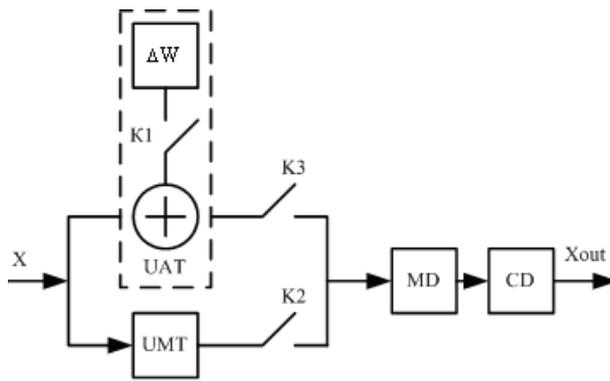
Generally at test methods the measuring process consists of several steps. In the first step (the main) the measured value is defined and in others steps an additional tests are carried out each of which is some function of the measured value [2].

So let we have the substance that dielectric permeability is unknown. For an exception of this value at determination of moisture content it is necessary to carry out some additional tests. In the previous works [6, 21, 22] such tests were formed by addition of some in advance known amount of water in studied substance. Thus dielectric permeability of initial sample of substance was equalled  $\varepsilon_1$ .

In the first test dielectric permeability of the same sample after addition of a known amount of water was received ( $\epsilon_2$ ). The second test was formed by adding to the sample of the first test still the same amount of water. However as the results of calculations showed such approach didn't allow to get rid completely of the problem of substance type uncertainty.

For the solution of objective the various test algorithms are analysed by authors. As a perspective the algorithm consisting in carrying out of independent additive and multiplicative tests is chosen.

There are some ways of measuring systems (MS) construction for realization of chosen algorithm. Block diagrams of MS for additive and multiplicative tests with three keys is presented in Fig. 1.



**Fig. 1.** Block diagram of measuring system for additive and multiplicative tests with three keys: UAT – unit of additive test; UMT – unit of multiplicative test; MD – measuring device; CD – computing device; K – key

For this diagram process of measurement consists of three steps. In the first step keys K1 and K2 are disconnected, and key K3 is closed and on input of measuring device (MD) measured value – moisture is directly supplied. In the second step K1 is closed and on input of MD additive test is supplied. In the third step K3 is disconnected, and K2 is closed connecting output value  $k \cdot W$  of unit of multiplicative test (UMD) on input of MD.

Results of transformations are transferred from output of MD in computing device (CD).

Thus independent additive tests can be presented in the form of the sum:

$$W_{ad} = W + \Delta W, \quad (1)$$

where:  $W_{ad}$  – value of substance moisture content received after carrying out of additive test,  $W$  – measured value of moisture content,  $\Delta W$  – constant component of additive test which is uniform and independent value from  $W$ , and is a water addition.

Independent multiplicative tests can be presented in the form of product:

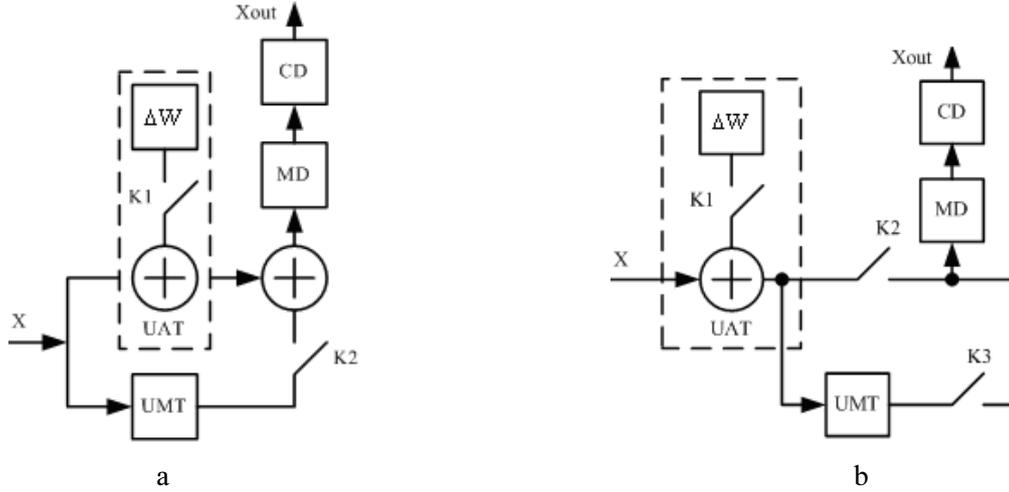
$$W_{mult} = k \cdot W, \quad (2)$$

where:  $W_{mult}$  – value of substance moisture content received after carrying out of multiplicative test,  $k$  – coefficient of transformation which is independent from  $W$  and represent a certain multiplier.

The block diagram of MS differing by presence of the adder and the block diagram without influence of conversion coefficient are presented in Fig. 2.

The diagram with two keys and adder (Fig. 2, a) is used in case it is impossible to include a key K3 in a chain of the measured value. Thus the additive test will be the same as in the first case:  $W_{ad} = W + \Delta W$ . The result of multiplicative test can be presented as a sum:  $W_{mult} = k \cdot W + W$ .

The advantage of the block diagram presented in Fig. 2, b is the possibility of an exception of influence of transformation coefficient of UMT on the result of measurement. In this case process of measurement consists of four steps: measurement of moisture content value  $W$ , additive test  $W_{ad} = W + \Delta W$ , multiplicative test  $W_{mult} = k \cdot W$  and  $k \cdot W + k \cdot \Delta W$  test type.



**Fig. 2.** Block diagram of measuring system for additive and multiplicative tests: a – with two keys and adder, b – without influence of conversion coefficient

For realization of the test method chosen by authors the most suitable diagram is the block diagram presented in Fig. 1 as it allows to receive a necessary number of tests of a certain type.

For the purpose of implementation of possibility of application of test method for capacitive moisture meters at this stage we will consider tests creation for liquid dielectrics (for example petroleum) [9].

Taking into account that test conditions have to be at least two during researches we will receive: capacity of primary measuring transducer (PMT) with initial sample of substance ( $C_1$ ), capacity of PMT with the same sample after addition of the set amount of water ( $C_2$ ) (additive test) and capacity of PMT with initial sample of substance at carrying out of measurements  $k$  times ( $C_3$ ) (multiplicative test). This is sufficient for the formation of a system with three equations solving which we will receive expression for determination of substance moisture content.

Thus using a linear dependence given in [21] we will receive:

$$\begin{cases} C_1 = \varepsilon(1+3W)g, \\ C_2 = \varepsilon(1+3(W+\Delta W))g, \\ C_3 = k \cdot \varepsilon(1+3W)g, \end{cases} \quad (3)$$

where:  $\varepsilon$  – dielectric permeability of studied substance;  $g$  – spatial characteristic of

electric field of the gap created by a form of electrodes chosen by PMT, equal 10 m;  $\Delta W$  – addition of water for additive test, equal 0,1 (10 %);  $k$  – coefficient for multiplicative test, equal 2.

For the solution of Eq. 3 the differential method offered in [8] is used:

$$\begin{aligned} C_2 - C_1 &= 3\varepsilon g \Delta W, \\ C_3 - C_1 &= \varepsilon g (k-1)(1+3W), \\ \frac{C_3 - C_1}{C_2 - C_1} &= \frac{(k-1)(1+3W)}{3\Delta W}, \end{aligned}$$

from which:

$$W_{calc1} = \frac{\Delta W (C_3 - C_1)}{(k-1)(C_2 - C_1)} - \frac{1}{3}, \quad (4)$$

Thus from Eq. 4 it is visible that moisture content of substance doesn't depend on dielectric permeability at using the offered test algorithm.

Check of Eq. 4 on invariance is carried out with the use of formulas:

$$C_1 = g \cdot \varepsilon_1, \quad (5)$$

$$C_2 = g \cdot \varepsilon_2, \quad (6)$$

$$C_3 = g \cdot \varepsilon_1 \cdot k, \quad (7)$$

where:  $\varepsilon_1$  – dielectric permeability of initial substance;  $\varepsilon_2$  – dielectric permeability

of substance with addition of water  $\Delta W$ , equal 0,1 (10 %).

As change of dielectric permeabilities  $\varepsilon_1$  and  $\varepsilon_2$  in range of humidity from 0 % to 15 % is nonlinear as mathematical dependence we use Winer's formula allowing rather adequately to describe polarizing processes for a wide class of binary dielectric systems [10].

$$\varepsilon_1 = \varepsilon \left( 1 + \frac{3W}{\frac{\varepsilon_w + 2\varepsilon}{\varepsilon_w - \varepsilon} - W} \right), \quad (8)$$

$$\varepsilon_2 = \varepsilon \left( 1 + \frac{3(W + \Delta W)}{\frac{\varepsilon_w + 2\varepsilon}{\varepsilon_w - \varepsilon} - (W + \Delta W)} \right), \quad (9)$$

where:  $\varepsilon_w$  – dielectric permeability of water, equal 80.

So let dielectric permeabilities of some virtual group of substances equal 2,0; 2,5; 3,0 and 3,5. We will change moisture of these substances by addition of water into them from 0 (0 %) to 0,3 (30 %) with a step of 0,1 (10 %). The calculated values of dielectric permeabilities are given in Table 1.

**Table 1.** Calculated values of dielectric permeabilities

Moisture content ( $W$ )	Dielectric permeability ( $\varepsilon$ )			
	for $\varepsilon = 2$	for $\varepsilon = 2,5$	for $\varepsilon = 3$	for $\varepsilon = 3,5$
0	2,0	2,5	3,0	3,5
0,1	2,614	3,252	3,385	4,512
0,2	3,368	4,173	4,963	5,741
0,3	4,317	5,324	6,305	7,262
0,4	5,545	6,806	8,022	9,197

Having substituted in equations (5), (6), (7) known values we will receive capacities  $C_1$ ,  $C_2$ ,  $C_3$  of PMT which are necessary for determination of calculated value of moisture content according to the Eq. 4. Results of calculations of substance moisture content are given in Table 2.

Obvious is that fact that with the increase of substance moisture content  $W$  the calculated value of moisture content  $W_{calc}$  also has to increase. As evident from results

presented in the Table 2 the monotonous increase of values of moisture content is missing and invariance to change of  $\varepsilon$  isn't present.

**Table 2.** Results of calculations of substance moisture content

Moisture content ( $W$ )	Calculated value of moisture content ( $W_{calc}$ )			
	for $\varepsilon = 2$	for $\varepsilon = 2,5$	for $\varepsilon = 3$	for $\varepsilon = 3,5$
0	-0,0076	-0,0009	0,0057	0,013
0,1	0,013	0,02	0,027	0,034
0,2	0,022	0,029	0,036	0,044
0,3	0,018	0,026	0,034	0,042

Thus there is a need for creation of one more test with greater addition of water. In this case Eq. 3 will be:

$$\begin{cases} C_1 = \varepsilon(1 + 3W)g, \\ C_2' = \varepsilon(1 + 3(W + \Delta W))g, \\ C_3' = k' \cdot \varepsilon(1 + 3W)g, \end{cases} \quad (10)$$

where:  $C_1$ ,  $C_2'$ ,  $C_3'$  – capacity of PMT with initial sample of substance and at creating of additive and multiplicative tests respectively, pF  $\Delta W'$  – addition of water for additive test, equal 0,2 (20 %);  $k'$  – coefficient for multiplicative test, equal 4.

As well as in the first case the system of Eq. 10 is solved using differential method. The calculated value of moisture content can be determined by a formula:

$$W_{calc2} = \frac{\Delta W'(C_3' - C_1)}{(k' - 1)(C_2' - C_1)} - \frac{1}{3}. \quad (11)$$

Capacities of primary transducer can be determined by formulas:

$$C_1 = g \cdot \varepsilon_1, \quad (12)$$

$$C_2' = g \cdot \varepsilon_2', \quad (13)$$

$$C_3' = g \cdot \varepsilon_1 \cdot k', \quad (14)$$

where:  $\varepsilon_2'$  – dielectric permeability of substance with addition of water  $\Delta W'$ , equal 0,2 (20 %).

Check on invariance the various combinations of two test expressions: Eq. 4 and Eq. 11. The most obvious combination is the ratio:

$$\frac{W_{calc2}}{W_{calc1}} = \frac{\Delta W'(C_3' - C_1)}{(k' - 1)(C_2' - C_1)} \cdot \frac{\Delta W(C_3 - C_1)}{(k - 1)(C_2 - C_1)}. \quad (15)$$

Results of calculations of substance moisture content for Eq. 15 are given in Table 3.

**Table 3.** Results of calculations of substance moisture content

Moisture content ( $W$ )	Calculated value of moisture content ( $W_{calc}$ )			
	for $\varepsilon = 2$	for $\varepsilon = 2,5$	for $\varepsilon = 3$	for $\varepsilon = 3,5$
0	0,898	0,899	0,902	0,903
0,1	0,885	0,889	0,891	0,894
0,2	0,872	0,874	0,877	0,88
0,3	0,852	0,857	0,861	0,865

As evident from results of calculations the invariance of moisture content  $W_{calc}$  to change of substance dielectric permeability still isn't present. Monotonous increase is present along with low sensitivity of PMT to change of moisture content.

Next, check on an invariance a combination of ratio of square of moisture content calculated value for test with an addition of water equal 20 % to a calculated value of moisture content of test with an addition of water equal 10 %.

$$\frac{W_{calc2}^2}{W_{calc1}} = \frac{\left( \frac{\Delta W'(C_3' - C_1)}{(k' - 1)(C_2' - C_1)} \right)^2}{\frac{\Delta W(C_3 - C_1)}{(k - 1)(C_2 - C_1)}}, \quad (16)$$

Results of calculations of substance moisture content are given in Table 4.

By the results of calculations of Table 4 it is visible that monotonous increase of values of moisture content is missing.

**Table 4.** Results of calculations of substance moisture content

Moisture content ( $W$ )	Calculated value of moisture content ( $W_{calc}$ )			
	for $\varepsilon = 2$	for $\varepsilon = 2,5$	for $\varepsilon = 3$	for $\varepsilon = 3,5$
0	0,262	0,269	0,276	0,282
0,1	0,272	0,279	0,286	0,293
0,2	0,27	0,277	0,285	0,292
0,3	0,255	0,264	0,272	0,281

Check the combination on invariance:

$$\frac{W_{calc2} + W_{calc1}}{W_{calc2} - W_{calc1}} = \frac{\Delta W'(C_3' - C_1)}{(k' - 1)(C_2' - C_1)} + \frac{\Delta W(C_3 - C_1)}{(k - 1)(C_2 - C_1)}, \quad (17)$$

$$= \frac{\Delta W'(C_3' - C_1)}{(k' - 1)(C_2' - C_1)} - \frac{\Delta W(C_3 - C_1)}{(k - 1)(C_2 - C_1)}$$

Results of calculations of substance moisture content are given in Table 5.

**Table 5.** Results of calculations of substance moisture content

Moisture content ( $W$ )	Calculated value of moisture content ( $W_{calc}$ )			
	for $\varepsilon = 2$	for $\varepsilon = 2,5$	for $\varepsilon = 3$	for $\varepsilon = 3,5$
0	-18,543	-18,799	-19,342	-19,654
0,1	-16,467	-17,017	-17,338	-17,836
0,2	-14,606	-14,909	-15,315	-15,696
0,3	-12,504	-12,952	-13,353	-13,772

From the Table 4 it is visible that value  $W$  increases with increase of  $\varepsilon$ , therefore it is necessary to make a correction in a denominator of Eq. 17 for its more intensive increase with increase of  $\varepsilon$ .

Thus taking into account correction of the denominator we will receive:

$$\frac{W_{calc2} + W_{calc1}}{(W_{calc2} - W_{calc1}) \cdot (1 + 0,011 \cdot C_1)}. \quad (18)$$

Results of calculations of substance moisture content are given in Table 6.

Apparently from results of calculations the deviation of moisture content calculated values still is significant.

**Table 6.** Results of calculations of substance moisture content

Moisture content ( $W$ )	Calculated value of moisture content ( $W_{calc}$ )			
	for $\varepsilon = 2$	for $\varepsilon = 2,5$	for $\varepsilon = 3$	for $\varepsilon = 3,5$
0	-15,199	-14,744	-14,543	-14,191
0,1	-12,789	-12,534	-12,147	-11,92
0,2	-10,657	-10,219	-9,906	-9,62
0,3	-8,478	-8,168	-7,884	-7,656

Further for the purpose of receiving an optimum denominator we will change the multiplier of  $C_1$  in Eq. 18 with some chosen step  $h$ . As a result of the analysis of received new combinations the expression for which the deviation of moisture content calculated values is minimum is determined. At the further change of the coefficient with specified step the deviation is increased. This expression is:

$$\frac{W_{calc2} + W_{calc1}}{(W_{calc2} - W_{calc1}) \cdot (1 + 0,0029 \cdot C_1)}. \quad (19)$$

Results of calculations of substance moisture content are given in Table 7.

**Table 7.** Results of calculations of substance moisture content

Moisture content ( $W$ )	Calculated value of moisture content ( $W_{calc}$ )			
	for $\varepsilon = 2$	for $\varepsilon = 2,5$	for $\varepsilon = 3$	for $\varepsilon = 3,5$
0	-17,526	-17,528	-17,794	-17,843
0,1	-15,306	-15,551	-15,582	-15,772
0,2	-13,306	-13,3	-13,388	-13,455
0,3	-11,112	-11,219	-11,288	-11,376

The results of calculations received for Eq. 19 have a minimum deviation and are monotonously increasing.

The values of moisture content received in Table 7 are nonnormalized. Normalization of values includes the following stages:

a) transformation of  $W_{calc}$  to positive values range:

$$W_{positive} = |W_{calc\ max}| + W_{calc}, \quad (20)$$

where:  $|W_{calc\ max}|$  – maximum modulo value of moisture content for Table 7, equal 17,843,

b) combination of ranges:

$$W_{norm} = \frac{W_{positive}}{x}, \quad (21)$$

$$\text{where: } x = \frac{6,624}{0,3} = 22,08.$$

The normalized values are given in Table 8.

**Table 8.** Normalized values of calculations results of substance moisture content

Moisture content ( $W$ )	Normalized values of calculations results of substance moisture content ( $W_{norm}$ )			
	for $\varepsilon = 2$	for $\varepsilon = 2,5$	for $\varepsilon = 3$	for $\varepsilon = 3,5$
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

In order to compare the results of calculations given in Table 8 for Eq. 19 with the results obtained in early works [6, 21, 22] in this direction of research, we will apply Pearson's criterion of consent ( $\chi^2$ ) [7]. This criterion allows accepting or rejecting of hypothesis about conformity of samples.

This criterion allows us to estimate degree of deviation of the calculated data from the ideal values of moisture content.

In [22] the least-squares method (LSM) was applied for creation of test influences system. Expression for determination of substance moisture content in this case is:

$$W_{calc} = \frac{100(0,17\varepsilon_1 + 0,17\varepsilon_3 - 0,33\varepsilon_2)}{\varepsilon_3 - 0,013\varepsilon_3^2}, \quad (22)$$

where:  $\varepsilon_1$  – dielectric permeability of initial sample of substance,  $\varepsilon_2$  – dielectric permeability of substance sample after addition of a known amount of water (the first test influence),  $\varepsilon_3$  – dielectric permeability obtained after addition to the second test still of the same amount of water (the second test influence).

Results of check of this expression are given in Table 9.

**Table 9.** Results of calculations of substance moisture content with application of LSM

Moisture content ( $W$ )	Normalized values of calculations results of substance moisture content ( $W_{norm}$ )			
	for $\varepsilon = 2$	for $\varepsilon = 2,5$	for $\varepsilon = 3$	for $\varepsilon = 3,5$
0	0,008	0,009	0,000	0,001
0,1	0,097	0,088	0,090	0,085
0,2	0,218	0,222	0,222	0,223
0,3	0,419	0,415	0,354	0,417

In [6] Lagrange's interpolation polynomial of the second order was applied for obtaining value of moisture content. This polynomial is an interpolation dependence of moisture content of substance from its dielectric permeability.

The expression obtained with the use of second order polynomial is:

$$W_{calc} = 59,2 - \frac{10 \cdot \frac{\varepsilon_3 - \varepsilon_2}{\varepsilon_1 - \varepsilon_2} + 20 \cdot \frac{\varepsilon_3 - \varepsilon_1}{\varepsilon_2 - \varepsilon_1}}{100 - 90 \frac{\varepsilon_3 - \varepsilon_2}{\varepsilon_1 - \varepsilon_2} - 70 \frac{\varepsilon_3 - \varepsilon_1}{\varepsilon_2 - \varepsilon_1}}, \quad (23)$$

where:  $\varepsilon_1$  – dielectric permeability of initial sample of substance;  $\varepsilon_2$  – dielectric permeability of substance sample after addition of a known amount of water (the first test influence),  $\varepsilon_3$  – dielectric permeability obtained after addition to the second test still of the same amount of water (the second test influence).

Results of check of this expression are given in Table 10.

**Table 10.** Results of calculations of substance moisture content with application of Lagrange's polynomial of the second order

Moisture content ( $W$ )	Normalized values of calculations results of substance moisture content ( $W_{norm}$ )			
	for $\varepsilon = 2$	for $\varepsilon = 2,5$	for $\varepsilon = 3$	for $\varepsilon = 3,5$
0	0,0	0,0	0,0	0,0
0,1	0,08	0,08	0,08	0,08
0,2	0,16	0,16	0,16	0,16
0,3	0,32	0,24	0,24	0,24

Checking the results of calculations on conformity by Pearson's criterion is carried out as follows.

Empirical value of Pearson's criterion can be determined by a formula:

$$\chi^2_{emp} = \sum_{i=1}^m \frac{(W_{norm} - W)^2}{W}, \quad (24)$$

where:  $W_{norm}$  – normalized value of moisture content (it is used as empirical value)  $W$  – specified moisture content of substance (it is used as theoretical).

So we will calculate empirical value of Pearson's criterion for results of Table 8. When true value of moisture content equals 0 it is visible that at various dielectric permittivities we will receive empirical values of moisture content 0,014; 0,014; 0,002 and 0 respectively; for 0,1 we will receive values of 0,115; 0,104 ; 0,111; 0,094, etc. Apparently not all results of calculations coincide with true values i.e. there are deviations. Taking into account all possible deviations for Table 8 we will receive:

$$\begin{aligned} \chi^2_{emp} &= \frac{(0,014-0)^2}{0,014} + \frac{(0,014-0)^2}{0,014} + \\ &+ \frac{(0,002-0)^2}{0,014} + \frac{(0-0)^2}{0,014} + \\ &+ \frac{(0,115-0,1)^2}{0,1} + \frac{(0,104-0,1)^2}{0,1} + \\ &+ \frac{(0,111-0,1)^2}{0,1} + \frac{(0,094-0,1)^2}{0,1} + \dots + \\ &+ \frac{(0,305-0,3)^2}{0,3} + \frac{(0,3-0,3)^2}{0,3} + \\ &+ \frac{(0,297-0,3)^2}{0,3} + \frac{(0,293-0,3)^2}{0,3} = 0,028. \end{aligned} \quad (25)$$

Empirical values of Pearson's criterion for results of calculations with the use of LSM and Lagrange's polynomial of the second order are defined similarly.

Results of calculations of Pearson's criterion are given in Table 12.

**Table 12.** Results of calculations of Pearson's criterion for table 8, LSM and with application of Lagrange's polynomial of the second order

Indexes	$\chi^2_{emp}$
For Table 8	0,033
For LSM	0,171
For Lagrange's polynomial of the second order	0,085

## CONCLUSIONS

1. Attempt to use test methods for solving the uncertainty of substance type problem for capacitive moistures have been carried out.

2. As a result of application of test approach the Eq.4 allowing to define substance moisture without dielectric permeability (i.e. substance type) has been received.

3. For minimization of deviations of calculated values which are received with use of test method from the set values the Eq. 19 is defined.

4. Apparently from results of Table 8 for Eq. 19 the calculated values of moisture content along with high sensitivity to change of moisture content are adequately invariant to change of substance dielectric permeability.

5. During check of the results received in article on coherence by Pearson's criterion it was determined that these values have the smallest divergences (are conformed) in comparison with the results received in the previous works on this direction.

6. Thus the Eq. 19 can be used at measurement of moisture content of the substance that dielectric permeability is unknown.

Influence of moisture content on the mechanical properties and grinding energy requirements of dried quince (*Cydonia Oblonga* Miller), TEKA Commission of Motorization and Energetics in Agriculture, Vol. 12, No 2, Lubline, 35-39.

4. **Gehrid R., 2011.:** Device and method for determining a dielectric property of a capacitor arrangement, Pat. EP2347249 A1, 6.
5. **Gert J.W. Visscher, 1985.:** Moisture and humidity measurement, CRC Press LLC, Washington, 14.
6. **Golub K., Zabolotny`j A., Koshevoj N., 2013.:** Providing the invariance to the change of material type for dielcometer humidity meters with the use of Lagrange polynomials, National Technical University of Ukraine "Kyiv Polytechnic Institute", Instrument-making: collection of scientific works, No 45, 116-122. (in Russian).
7. **Greenwood P., Nikulin M., 1996.:** A Guide to Chi-Squared Testing, John Wiley & Sons, Inc., New York.
8. **Gusef`nikov V., Borisenko E., 2011.:** To a question of application of test methods at level measurement by ultrasonic method, "Bulletin of NTU "KhPI" Automatics and instrument making", No 11, 7-13. (in Russian).
9. **Kirichenko I., Koshevoj N., Kostenko E., Rozhnova V. 2013.:** Application of optimal planning methodologies for investigation of echnological processes, devices and systems, TEKA Commission of Motorization and Energetics in Agriculture, Vol. 13, No 3, Lubline, 90-97.
10. **Krichevskij E., Benzar` V., Venediktov M., 1980.:** Theory and practice of bulks moisture express control, E`nergiya, Moskov, 240. (in Russian).
11. **Krushevskij Yu., Borodaj Ya. 2007.:** Influence of water mass exchange on accuracy of measurement of moisture of grain, Scientific works of Vinnitsa national technical university, No 1, 20-26. (in Russian).
12. **Krzykowski A., Dziki D., Polak R., Rudy S., 2012.:** Influence of heating plates temperature on freeze drying energy requirements and quality of dried vegetables, TEKA Commission of Motorization and Energetics in Agriculture, Vol. 12, No 2, Lubline, 129-132
13. **Mashoshin P., 2003.:** Trandusers of parameters of capacitive sensors for moisture measurement of bulks, Synopsis of a thesis, 05.11.01, Penza, 258. (in Russian).

## REFERENCES

1. **Berliner M., 1973.:** Moisture measurements, E`nergiya, Moskov, 400. (in Russian).
2. **Bromberg E`., Kulikovskij K., 1978.:** Test methods of increase of measurements accuracy, E`nergiya, Moskov, 176. (in Russian).
3. **Dziki D., TomiŁoa J., RozyŁo R., Laskowski J., Gawlik-Dziki U., 2012.:**

14. **Mitin D., Ozericzkiy I., 2006.:** Monitoring of water presence in petroleum and lubricating oils is a protection of your investments, *Territoriya Neftegaz*, No 2, 5-10. (in Russian).
15. **RMG 64-2003 GSI, 2004.:** State system for ensuring the uniformity of measurements. Ensuring the effect of measurements by the control of technological processes. Methods and ways of the measuring accuracy rise, Entered 01.01.1997, IPK Izd-vo standartov, Moskov, 13. (in Russian).
16. **Semyonova T., 2003.:** Development of electrodynamic method of SHF moisture measurements of grain in a flow, Synopsis of a thesis, 05.18.12, Moskov, 130. (in Russian).
17. **Schröder D., 2008.:** Measuring apparatus and method for determining a dielectric property, in particular moisture and/or density, in a product, Pat. US 2008/0164887 A1, Int. Cl.<sup>6</sup> G01N 27/22, U.S. Cl. 324/668, 12.
18. **Soltani M.; Alimardani R., 2011.:** Prediction of corn and lentil moisture content using dielectric properties, *International Journal of Agricultural Technology*, Vol. 7, No 5, 1223-1232.
19. **United States. National Bureau of Standards, 1965.:** Humidity and Moisture: Measurement and Control in Science and Industry. Reinhold Publishing Corporation, United States, Vol. 2, 634.
20. **Wakino K., Yukawa K., Imagawa S. all of Kyoto, 1995.:** Method of measuring dielectric constant of powder, Pat. 5,451,882 US, Int. Cl.<sup>6</sup> G01N 27/22, U.S. Cl. 324/663, 361/281, 6.
21. **Zabolotny`j A., 2012.:** Compensation nuances of the "material type" uncertainty in the test formation for adaptive moisture meters, *East European magazine of advanced technologies*, No 2/9 (56), 47-50. (in Russian).
22. **Zabolotny`j A., 2012.:** Providing satisfactory level of invariance of adaptive moisture meters with use of least-squares method, *Bulletin of Cherkassy state technological University*, No 4, 13-17. (in Russian).

СИНТЕЗ ТЕСТОВЫХ ВОЗДЕЙСТВИЙ ДЛЯ  
ДИЭЛЬКОМЕТРИЧЕСКОГО ВЛАГОМЕРА,  
ИНВАРИАНТНЫХ К ИЗМЕНЕНИЮ СОРТА  
ВЕЩЕСТВА

*Екатерина Голуб, Александр Заболотный,  
Николай Кошевой, Ирина Кириченко*

**А н н о т а ц и я .** В статье проводится исследование различных тестовых воздействий с целью обеспечения инвариантности диэлькометрических влагомеров к изменению сорта вещества. Проведён анализ способов уменьшения сортовой неопределённости. Выделено наиболее перспективное направление исследований – тестовые методы. Выбран алгоритм тестового метода и структурная схема измерительной системы для аддитивного и мультипликативного тестов. В ходе расчётов получено выражение для определения влагосодержания вещества, инвариантное к изменению диэлектрической проницаемости. С целью апробации данного выражения получены результаты проверки зависимости влагосодержания от диэлектрической проницаемости. Для определения согласованности результатов применён критерий Пирсона. Установлено, что данные результаты достаточно хорошо компенсируют "сортовую неопределённость".

**К л ю ч е в ы е с л о в а :** диэлькометрический влагомер, сортовая неопределённость, тестовый метод, аддитивный тест, мультипликативный тест.