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Erratum

The structure has been changed

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CAPACITY TRANSFORMER OF COAXIAL AND CYLINDRICAL FORM OF HUMIDITY METER

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Abstract: *The question of development and calculation of construction of a coaxial and cylindrical form of the capacity transformer of a humidity meter is considered. As basic data, the sizes and the materials ditches allowing to measure the humidity of different volumes of bulks from 5 to 50 gr are selected. As materials of a ditch, plastic are selected, and as tanks, the magnetizing materials are selected. It is briefly cited the advantages and disadvantages of ways to measure humidity and the basic dielectric characteristics of capacitive converters. The electrical replacement scheme of the proposed capacitive converter was provided and the geometric capacity of the cylindrical capacity transformer and its tangent of the dielectric loss angle was calculated.*
Keywords: *humidity, bulk, grain, millet, capacity, dielectric permittivity, tangent of dielectric loss angle.*

Аннотация: *Намлик ўлчагичнинг коаксиал-цилиндрик шаклдаги сиғимли ўзгарткичи конструкциясини яратиш ва ҳисоблаш масаласи кўриб чиқилган. Дастлабки маълумотлар сифатида 5 дан 50 гр. гача бўлган турли ҳажмдаги, намликни ўлчашга имкон берадиган материаллар ва кюветнинг ўлчамлари танланган. Кюветни ташкил этувчи материаллар сифатида пластмасса, сиғим сифатида эса магнитланмайдиган материаллар танланган. Намликни ўлчаш усуллари, уларнинг афзаллик ва камчиликлари тавсифланган ҳамда сиғимли ўзгарткични асосий диэлектрик тавсифлари келтирилган. Таклиф этилган сиғимли ўзгарткични геометрик сиғими ҳамда унинг диэлектрик йўқотиш бурчагининг тангенси ҳисобланган.*
Таянч сўзлар: *намлик, сочилувчан материал, буғдой, тариқ, сиғим, диэлектрик ўтказувчанлик, диэлектрик йўқотиш бурчагининг тангенси.*

Аннотация: *Рассмотрен вопрос разработки и расчёта конструкции преобразователя коаксиально-цилиндрической формы ёмкостного измерителя влажности. В качестве исходных данных выбраны размеры и материалы кюветы, позволяющие измерять влажность различных объемов сыпучих материалов (от 5 до 50 г). В качестве материалов кюветы выбрана пластмасса, а в качестве емкостей выбраны ненамагничивающие материалы. Описаны достоинство и недостатки способов измерения влажности и приведены основные диэлектрические характеристики емкостного преобразователи. Приведена электрическая схема замещения предложенного емкостного преобразователя и осуществлен расчет геометрической емкости цилиндрического емкостного преобразователя.*
Ключевые слова: *влажность, сыпучий материал, зерно, пшено, ёмкость, диэлектрическая проницаемость, тангенс угла диэлектрических потерь.*

Introduction

One of the most important figures of merit of loose substances is the humidity. In the national economy and industrial productions, more than 1000 different substances [1,2,3,4,5,7,8,9] are required to define humidity, for example; grain, fertilizers (saltpeter), millet, sunflower seeds, etc. The humidity indicator directly influences the storage period of materials and further processing. The analysis of humidity of bulks carries out not only during acceptance it on storage, but also during the entire period of its storage to final processing and application.

Research Methods and the Received Results

Methods of determination of humidity divide into two groups: direct and indirect. Indirect methods use in the express analysis of humidity of bulks by means of different hygrometers and analyzers of humidity. However, data of these methods are considered insufficiently exact.

For more exact determination of moisture content in bulks and products of its processing use the direct methods based on removal from a moisture sample by its drying in the cabinet dryer. The air and thermal method belongs to such methods.

This method of determination of humidity is the only standardized laboratory method. The technique of implementation of this method in the territory of Russia and the CIS countries is regulated by state standard specifications (GOST 13586.5-93, GOST 13496.3-92, (ISO 6496-83), GOST 26312.7-88, GOST 9404-88, GOST 10856-96). According to them, determination of humidity of bulks, for example, more than 17% carry out grains and grain of products with humidity with preliminary dehumidification. In that case, if the humidity of grain less than 17% carries out determination of humidity without preliminary dehumidification.

The exact determination of the moisture content of bulk materials is carried out mainly by drying the sample, which takes 8-10 hours of time and requires large expenditures of electricity and human labor. A drying cabinet marked SESH-3M is used to measure grain moisture [10]. As a result of the analysis of the drying process and determination of the moisture content of the grain (sample) by the help of drying oven, the following shortcomings were revealed:

1. It takes more than 45-50 minutes to complete the measurement of grain moisture;
2. Large electrical energy is expended (for the preparation of heating the SESH-3M and drying the sample);
3. The sample is underdried, this measurement is offset by a large defect.

A Nuclear Magnetic Resonance instrument is promising for measuring moisture and other parameters of plant seeds. However, the high cost of this device (more than US $ 27,000), as well as the danger of the device working on human health, limits its usage. These factors determine the relevance of this work.

It should be noted that at present, at the Department of Information Processing and Controlling Systems, groups of employees, undergraduates, and bachelors have developed and implemented various versions of moisture meters designed to control the moisture content of raw cotton seeds, bulk materials, and powder. At the same time, each device is designed to measure the humidity of individual crops. In this regard, we were tasked to develop a combined device for the express method of measuring the moisture content of bulk materials, in this case, to control the moisture content of grain and fertilizers.

The main characteristic of the device as well as other devices is the accuracy, reliability, range of humidity measurement, working temperature, etc.

Accuracy of humidity monitoring depends on the construction ditches, which is a component of the capacity transformer. For ensuring precision characteristics of capacity transformers, it is necessary to carry out material selection, to carry out the calculation of its parameters, and to consider them during the assessment of humidity of the studied test. This work is devoted to studying and calculation of the main dielectric characteristics of the capacity transformer.

According to [1, 2, 3, 6], the main dielectric characteristics of the capacity transformer are:

1. The relative dielectric permittivity (DP) of insulating material is ε-the relation of capacitor capacity C_x in which the space between electrodes and about them is entirely filled with the considered

insulating material, to the capacity C_p (operating capacity) of electrodes of the same configuration in a vacuum:

$$\varepsilon = \frac{C_x}{C_p}. \quad (1)$$

Capacity $C_p = C_0 + C_\kappa$, where C_0 and C_κ – geometric and edge tanks.

2. The absolute DP of the insulating material ε_a is the product ε of the dielectric constant ε_0 (absolute DP of the vacuum): $\varepsilon_a = \varepsilon_0 \cdot \varepsilon$, $\varepsilon_0 = 8{,}85 \cdot 10^{-12}$ F/ m;

3. The complex dielectric constant $\tilde{\varepsilon}$ is determined by the DP ε' and the coefficient of dielectric loss ε'':

$$\tilde{\varepsilon} = \varepsilon' - j\varepsilon'' \quad (2),$$

where ε' – the active component of the dielectric constant; $j = \sqrt{-1}$.

4. The dielectric loss angle δ of the insulating material is the angle that complements the phase angle of the applied voltage and the resulting current strength to $\pi/2$ rad, provided that the capacitor dielectric is perfect;

5. Dielectric loss tangent angle of insulating material $tg\delta = \varepsilon''/\varepsilon'$;

6. Dielectric loss coefficient of insulating material $\varepsilon'' = \varepsilon' tg\delta$.

The simplest electrical analog of a system consisting of electrodes and an imperfect dielectric located between them is a parallel connection of conductivity and capacitance (Fig. 1). If a voltage that varies in time according to a sinusoidal law is applied to parallel conductivity G_p and capacitance C_p, then current will flow through the system

$$I = \left(G_p + j\omega C_p\right)U_0 e^{j\omega\tau}, \quad (3)$$

where G_p – medium conductivity, *Cm*; C_p – cell capacity with substance (without edge tanks), *F*; $U_0 e^{j\omega\tau}$ – the brought Voltage, *V*; I – full current strength in the considered system, A.

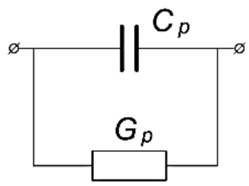


Fig. 1. ***The idealized electric equivalent circuit of substitution of a capacity cell with substance to a fixed frequency.***

For a cell with cylindrical electrodes (fig. 2):

$$C_0 = \frac{2\pi\varepsilon_0 l}{\ln\left(\frac{D}{d}\right)}, \quad (4)$$

$$k = \frac{2\pi l}{\ln\left(\frac{D}{d}\right)}, \quad (5)$$

where, *D* – internal diameter of an outer electrode; *d* – external diameter of an inner electrode.

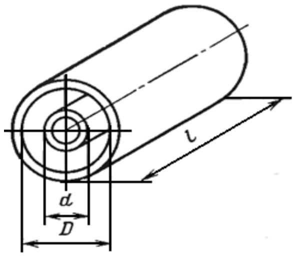
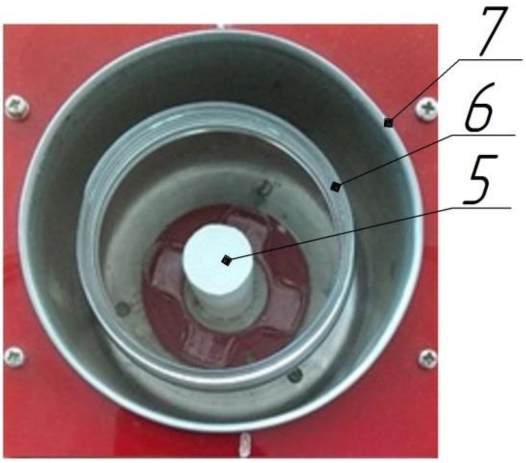


Fig. 2. ***A general view of the capacitive transducer with cylindrical electrodes.***

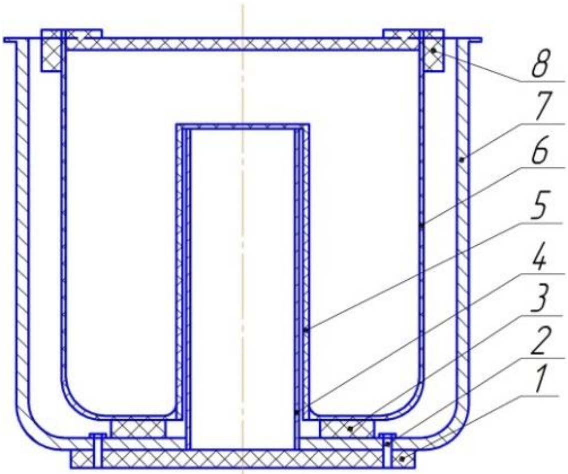
Ratios (4) are fair on condition of uniformity of electric field in a working cavity of a cell.

The construction, the capacity transformer of a cylindrical form based on the coaxial core developed by us is given below. In fig.3. *a*, general view of the capacity transformer of a cylindrical form is given, in fig.3. *b*, its construction is given in a cut set.

In real conditions, the electric field at the ends of the electrodes is inhomogeneous, and this leads to the appearance of unaccounted edge capacitances. The equivalent circuit of a cell with a substance corresponding to the frequency interval is more complicated than the equivalent circuit in Fig. 1, since and are frequency-dependent quantities. In addition, at the alternating current in the material of the electrodes and at the electrode-substance interface, physical phenomena that depend on the frequency occur, these phenomena must also be taken into account when analyzing the results of measuring the dielectric properties of bulk materials.



a) general view of the capacity transformer



b) construction of the capacity transformer

Fig.3. ***Capacity transformer of a cylindrical form:***
1 - washer (lower holder); all washers are executed on base organic glass, the case of a container is executed on the basis of the metalized polyethylene tube; 2 - (little) screw; 3 - washer (holder); 4 – screw; 5 - coaxial core; 6 - polyethylene ditch; 7 - case of a container; 8 - polyethylene cover.

Really, the availability of moisture has a great influence on the polarization of heterogeneous dielectrics of complex structure what wet materials are. Generally, as well as other capillary-porous materials, bulks are complex dielectric. In bulks, the following main types of polarization can take place: electronic, ionic, dipolar, structural, and interlayer. Depending on the features of bulks (empty, the different sizes, etc.) different types of polarization can have a bigger or smaller specific weight, and some of them can be absent at all. The total polarization of bulks represents the sum of all available polarization states. Leakage losses are only one component of the total losses in an alternating field; different types of polarization can cause additional losses.

The equivalent scheme of the dielectric under consideration contains a geometric capacitance (a capacitance corresponding to the field of electrodes in a vacuum) and the sum of capacitances due to different types of polarization. The last capacitances (except the electron polarization capacitance) in the equivalent circuit have successive resistances that take into account losses due to these types of polarization. In addition, the circuit has an active resistance R, the value of which depends on the through current of conductivity between the electrodes. The complete equivalent scheme of a polarized dielectric with a cylindrical capacitive transducer corresponding to Fig. 3 is shown in Fig. 4.

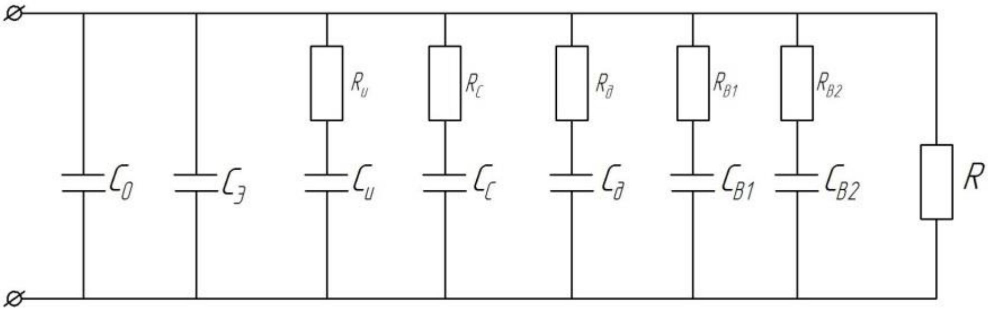


Fig. 4. ***The equivalent scheme of the complex polarized dielectric:***
C_0 – capacity in a vacuum; $C_э$ – capacity of electronic polarization; C_u – capacity of ionic polarization; C_c – capacity of structural polarization; C_∂ – capacity of dipolar polarization; C_{B1} – capacity the first interlayer polarization; C_{B2} – capacity of the second interlayer polarization; R_u, R_c, R_∂, R_{B1}, R_{B2} – equivalent resistances of losses at different types of polarization; R – resistance to through current.

Thus, polarization of the moisture containing material has difficult character, and in all cases, the total resistance of the sensor with the material is complex value.

By the constructive sizes of the capacity transformer of a cylindrical form (fig. 3. b), it is possible to calculate its main parameters. The constructive sizes of the capacity transformer of a cylindrical form have the following data: internal diameter of an outer electrode is *D=75 mm*; external diameter of an inner electrode of *d=13 mm*; length of an inner electrode of *l=55 mm*. Then, according to [2, 3, 4] geometrical constant of the capacity transformer of a cylindrical form (4) is equal to the following:

$$k = \frac{2\pi l}{\ln\left(\frac{D}{d}\right)} = \frac{2 \cdot 3{,}14 \cdot 0{,}055}{\ln\left(\frac{0{,}075}{0{,}013}\right)} = 0{,}197 .$$

To calculate the dielectric loss and permittivity of complex insulation, an equivalent scheme is used for both individual components and the entire inhomogeneous dielectric [2, 3, 4]. Possible variants of the ordered arrangement of components can be represented in the form of their parallel and sequential inclusion.

When the components are connected in series, their separation plane is perpendicular to the electric field vector (Fig. 5).

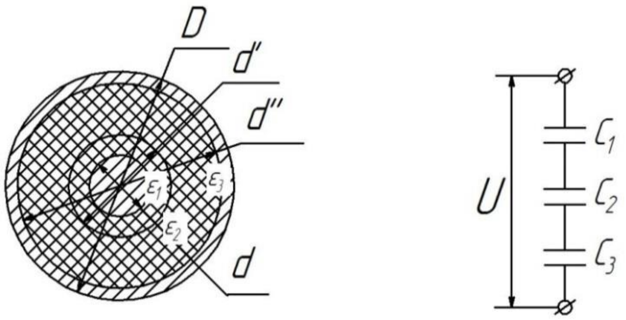


Fig. 5. ***The cylindrical condenser with two consistently connected dielectrics:***

The external diameter of the outer dielectric insulating material is $D = 75\,mm$; the internal diameter of the dielectric insulating material is $d'' = 71\,mm$; the external diameter of the inner electrode is $d' = 20\,mm$; the internal diameter of the inner electrode is $d = 13\,mm$.

Geometrical capacity of the capacity transformer (fig. 3.b) can be calculated by the made formula:

$$C_0 = \frac{C_1 C_2 C_3}{C_1 C_2 + C_1 C_3 + C_2 C_3} = \varepsilon_0 \varepsilon_э k, \tag{6}$$

$$\varepsilon_э = \frac{\varepsilon_1 \varepsilon_2 \varepsilon_3}{\theta_1 \varepsilon_2 \varepsilon_3 + \theta_2 \varepsilon_1 \varepsilon_3 + \theta_3 \varepsilon_1 \varepsilon_2}, \tag{7}$$

where, $\varepsilon_э$ – effective dielectric permittivity; ε_1 – dielectric permittivity of insulating material (polyethylene), $\varepsilon_1 = 2{,}3$; ε_2 – dielectric permittivity of air, $\varepsilon_2 = 1$; ε_3 – dielectric permittivity of insulating material (plastic), $\varepsilon_3 = 2$; θ_1, θ_2, θ_3 – volume concentrations of components.

According to [2, 3, 5], the volume concentration of the components will be proportional to the diameters of the cylindrical capacitor:

$$\theta_1 = \frac{V_1}{V} = \frac{\pi\left(\frac{d}{2}\right)^2 l}{\pi\left(\frac{D}{2}\right)^2 l} = \left(\frac{d}{D}\right)^2 = \left(\frac{13}{75}\right)^2 = 0{,}030; \tag{8}$$

$$\theta_2 = \frac{V_2}{V} = \frac{\pi\left(\frac{d'}{2}\right)^2 l}{\pi\left(\frac{D}{2}\right)^2 l} = \left(\frac{d'}{D}\right)^2 = \left(\frac{20}{75}\right)^2 = 0{,}071; \tag{9}$$

$$\theta_3 = \frac{V_3}{V} = \frac{\pi\left(\frac{d''}{2}\right)^2 l}{\pi\left(\frac{D}{2}\right)^2 l} = \left(\frac{d''}{D}\right)^2 = \left(\frac{71}{75}\right)^2 = 0{,}896 \cdot \tag{10}$$

where, d' – internal diameter of dielectric insulation material, $d' = 20\,mm$.

$$\varepsilon_э = \frac{\varepsilon_1 \varepsilon_2 \varepsilon_3}{\theta_1 \varepsilon_2 \varepsilon_3 + \theta_2 \varepsilon_1 \varepsilon_3 + \theta_3 \varepsilon_1 \varepsilon_2} = \frac{2{,}3 \cdot 1 \cdot 2}{0{,}030 \cdot 1 \cdot 2 + 0{,}071 \cdot 2{,}3 \cdot 2 + 0{,}896 \cdot 2{,}3 \cdot 1} = \frac{4{,}6}{2{,}4474} \approx 1{,}87 \;\; F/m.$$

Substituting the calculated data θ_1, θ_2, θ_3, ε_1, ε_2, ε_3 in (4) we determine the following value:

$$C_0 = \varepsilon_0 \varepsilon_э k = 8{,}85 \cdot 10^{-12} \cdot 1{,}87 \cdot 0{,}197 = 3{,}28 \cdot 10^{-12} F \approx 3 \;\; pF.$$

The following important parameter of any capacity transformer are dielectric losses $tg\delta$. Dielectric losses in multi-layer heterogeneous dielectric consist of losses in each of consistently connected dielectric components according to the equation [2,3,4,5,10]:

$$P = P_1 + P_2 + P_3 = U^2 \omega C_0 tg\delta = U_1^2 \omega C_1 tg\delta_1 + U_2^2 \omega C_2 tg\delta_2 + U_3^2 \omega C_3 tg\delta_3 \tag{11}$$

where, U_1, U_2 and U_3 – voltage drops on condensers, C_1, C_2 and C_3 respectively (Fig. 5.b); $tg\delta_1$ – tangent of dielectric loss angle of insulating material (polyethylene), $tg\delta_1 = 2 \cdot 10^{-4}$ (at 20^0 C, 0,1 MPa and low frequency); $tg\delta_2$ – air tangent of dielectric loss angle, $tg\delta_2 = 10^{-8}$; $tg\delta_3$ – tangent of dielectric loss angle of insulating material (plastic), $tg\delta_3 = 10^{-4}$ (at 20^0 C, 0,1 MPa and low frequency) [2,4,6].

Given that

$$C_0 = \frac{C_1 C_2 C_3}{C_1 C_2 + C_1 C_3 + C_2 C_3};$$

can write:

$$\frac{U_1}{U} = \frac{C_0}{C_1}; \quad \frac{U_2}{U} = \frac{C_0}{C_2}; \quad \frac{U_3}{U} = \frac{C_0}{C_3} \tag{12}$$

After some transformations, equation (11) can be written in the following form:

$$tg\delta = \frac{C_2 C_3 tg\delta_1 + C_1 C_3 tg\delta_2 + C_1 C_2 tg\delta_3}{C_1 C_2 + C_1 C_3 + C_2 C_3}$$

$$C_1 = \frac{2\pi\varepsilon_0\varepsilon_1 l}{\ln\left(\frac{d'}{d}\right)} = \frac{2\cdot 3{,}14\cdot 8{,}85\cdot 10^{-12}\cdot 2{,}3\cdot 0{,}055}{\ln\left(\frac{0{,}020}{0{,}013}\right)} = \frac{7{,}031\cdot 10^{-12}}{0{,}431} \approx 16{,}3\cdot 10^{-12}\,\Phi \approx 16{,}3\ \text{pF};$$

$$C_2 = \frac{2\pi\varepsilon_0\varepsilon_2 l}{\ln\left(\frac{d''}{d'}\right)} = \frac{2\cdot 3{,}14\cdot 8{,}85\cdot 10^{-12}\cdot 1\cdot 0{,}055}{\ln\left(\frac{0{,}071}{0{,}020}\right)} = \frac{3{,}057\cdot 10^{-12}}{1{,}267} \approx 2{,}4\cdot 10^{-12}\,\Phi \approx 2{,}4\ \text{pF};$$

$$C_3 = \frac{2\pi\varepsilon_0\varepsilon_3 l}{\ln\left(\frac{D}{d''}\right)} = \frac{2\cdot 3{,}14\cdot 8{,}85\cdot 10^{-12}\cdot 2\cdot 0{,}055}{\ln\left(\frac{0{,}075}{0{,}071}\right)} \approx \frac{6{,}114\cdot 10^{-12}}{0{,}055} \approx 111{,}2\cdot 10^{-12}\,\Phi \approx 111{,}2\ \text{pF}\cdot$$

In the final form, the dielectric loss tangent of a cylindrical capacitive transducer can be calculated using the following formula:

$$tg\delta = \frac{C_2 C_3 tg\delta_1 + C_1 C_3 tg\delta_2 + C_1 C_2 tg\delta_3}{C_1 C_2 + C_1 C_3 + C_2 C_3} = \frac{2{,}4\cdot 111{,}2\cdot 2\cdot 10^{-4} + 16{,}3\cdot 111{,}2\cdot 10^{-8} + 16{,}3\cdot 2{,}4\cdot 10^{-4}}{16{,}3\cdot 2{,}4 + 16{,}3\cdot 111{,}2 + 2{,}4\cdot 111{,}2} =$$
$$= \frac{(533{,}76 + 0{,}18 + 39{,}12)\cdot 10^{-4}}{39{,}12 + 1812{,}56 + 266{,}88} = \frac{573{,}06}{2118{,}56} = 0{,}27\cdot 10^{-4} \tag{13}$$

Conclusion

Accounting of complex dielectric characteristics of capacity transformers in further calculations gives the chance to define and consider the pacing factors that influencing the accuracy of assessment of bulk humidity. The developed construction of the capacity transformer is the humidity of bulks of different volume, simple and convenient for measurement, at their corresponding calibration.

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