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Development of Correction Schemes of Temperature Errors in the Moisture Meter Transformer with Cylindrical Electrodes

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Abstract: The aim of carried out investigations is the analysis of different correction errors circuits of temperature in the moisture transformer with a cylindrical electrode in point of view increasing the measurements accuracy of grain and grain products moisture. Improving the measurement accuracy in the moisture transformer using functionality, constructive manufacturability and linearity of static characteristics ensure methods is realized. At the same time, a multiplier correction circuit, a circuit with a high degree of correction, and an additive logo metric circuit, which can also be used in other capacitive transformers, have been considered. The dependence of the reactive resistance of cylindrical transformer on the bulk materials capacity has been obtained experimentally. It has been shown that the reactive resistance is decreased sharply when the bulk materials capacity reaches the value 2 *pF*. Further, it is decreasing slowly on the capacity that demonstrates the change of the transformer sensitivity too. The functional dependence of capacity moisture transformer with cylindrical electrode sensitivity on the reactive resistance has been studied. It has been revealed that when the reactive resistance of the cylindrical transformer is growing then its sensitivity is decreasing. The maximal cylindrical transformer sensitivity reaches when the reactive resistance equals to r_m=0.5·10^4 *Ohm* which corresponds to maximal change of the bulk materials capacity. The dependence of the cylindrical transformer reliability for bulk materials on the middle working time without failure has been studied. The carried out analysis showed that the reliability of cylindrical transformer is decreasing on the using time and in the initial working exploitation stage of the transformer essential interaction of heating and electric effects in the device leads to decreasing the reliability down to value 0.3.

Keywords: Temperature Errors, Moisture Capacity Transformer, Cylindrical Electrode, Sensitivity

1. Introduction

It is known that accuracy of the moisture meter with cylindrical electrode depends on the constructive technological features its structure elements, possibilities their effective using and linearity degree of static characteristics. Increasing the accuracy of the moisture meter transformer by methods of ensure of functionality, constructive manufacturability and linearity of static characteristics is realized.

In recent paper the moisture censor had been developed where powder aluminum oxide obtained through anodization of pure aluminum sheet for moisture meter transformer had been used [1]. The sensitivity of this censor by controlling pores nanostructured thin Al_2O_3 films had been optimized and from 180 up to 1000 ppm had been reached.

It should be noted paper, in which characteristics of response of capacitive sensors based on the fullerene loaded with metal nanoparticles had been investigated and had been shown that the sensors moisture sensitivity is getting better after loaded of nanoparticles [2]. However, presented in this paper results showed that for developing moisture sensors with different characteristics depending on the using requirements we must choose nanoparticles of different metals that complicates versatility of the proposed there device.

In paper the modified variant of the dielectric moisture meter had been described which with minimal quantity of structure elements has enough good metrological characteristics conditioned by using definition method of capacitive component of the sensitive element current [3].

It should be noted that the essence of the constructive technological method for measurement accuracy growing thing is in that the main transformer elements is improving, in particularly, the flow formation, sensitive element and all measurement elements stages [4].

The statistical errors minimization of the moisture meter transformer with cylindrical electrode is characterized by that in this case the output transformer signals is processing with high effective modern methods, that is random errors dealing with input signal correlation is decreased down to very little value. As to the functional minimization of measurement errors, it by input method to the measuring circuit of errors correlation elements is realized. The experiences results showed that the measurement media and change in one temperature lead to essential decreasing the measurement accuracy. Reasons for the change of temperature are change of product for which is required to measure moisture and transformer geometrical sizes, its structure and characteristics. This which is typical for all measuring, in particularly, capacitive transformers, they leads to the essential measurement errors. However, it should be noted that the capacitive transformer can work in the enough wide temperature range [5].

We must remember that by high temperatures the geometrical sizes of moisture transformer with cylindrical electrode are being changed and this situation leads to essential errors. In order to correction of ones to measuring circuit introduces depending on the temperature capacitor C_t. Therefore for moisture transformer with cylindrical electrode there is a need develop correlation circuits on the temperature change.

In paper the mathematical models of dielectric permeability for heterogenic wet systems and credibility and accuracy of results of dielectric process controlling materials moisture methods had been analyzed [6]. The projecting questions of high frequency system and controlling moisture based on the capacitive measuring transformers devices had been considered. The grain dielectric resolution model which takes into account the material temperature allows estimate the degree and character affecting polarization factor to general measurement error of grain moisture and, consequently, can be used for introducing required corrections to measurement results.

In the recent years a number of works on the mathematical description for creating capacitive moisture sensors had been devoted. For example in paper two physical models of capacitive transformers as the most effective for moisture controlling of grain and grain products had been proposed [7]. Besides the algorithm for numerical analysis of mathematical model functioning of the investigating device providing obtain the maximum permissible instrumental errors values, on which the total device working authenticity is realized, had been developed [8].

In paper an analysis of conversion equations and equations of errors of the generalized block diagram of the iteratively integrating measuring converter which uses iterative integrating conversion method had been considered [9]. An analysis for the simplest case of combinations of input and output values, namely when all input values X, Z1 and Z2, as well as the output value Y are constant values had been carried out. Here considered situation when the additive errors of all blocks change continuously in time. Authors approved they can formulate the requirements for the errors of blocks of the measuring converter. For example, the results of the analysis of the generalized block diagram of the measuring transducer can be used to create specific outlines of iteratively integrating converters can be formulated.

Sandomirski proposed a model of the correlation field between the parameter true values and the results of its measurement with a given reduced error δ, where the merits and legitimacy of using the model for estimation of the achievable correlation coefficient $R_{\max}$ had been substantiated [10]. Analysis of influence of δ parameter measurement in different ranges d of its change on $R_{\max}$ had been carried out. It had been established in this work that the coefficient $R_{\max}$ calculated for the reduced measurement error is always smaller than $R_{\max}$ calculated himself for the relative measurement error.

In paper the process of gas flow around temperature sensors with paired thermocouples in the cavities of a multi-camera experimental device had been investigated [11]. The strength calculations of thermocouples had been carried out and the rational values of the deepening of the temperature sensors there in the pipe to ensure had been defined the required accuracy of the measurement of the temperature of the working fluid.

In paper the basic errors of coaxial cylindrical sensors of capacitance levelmeaters had been investigated and simplified expressions for their calculations had been obtained and also the table for practical errors estimation had been presented [12].

In paper the issues of the use of linear measuring devices for measuring temperature had been considered, where a method for measuring temperature by resistive temperature sensors based on a modification of the zero method had been described [13]. This modification ensures the invariance of the meter to changes in the gain of the measuring path. The errors of temperature measurements by the modified zero method had been considered. The calibration of the manufactured digital thermometer with a miniature resistive temperature sensor made of platinum had been described.

In previous our paper the mathematical model of high frequency moisture meter for cottonseeds had been proposed where we showed that the simplest two element RC equivalent circuit corresponds to the closest real description of a measuring object in frequencies range of $10^5 \div 10^8$ Hertz [14].

As the logical continuing this type investigations in the present paper we discuss the analysis of results carrying out experiments in growing the measurement accuracy of grain moisture using capacitive transformer with cylindrical electrode.

2. Theoretical Part

Correction of the temperature change in the developed ourselves capacitive transformer realizes using multiplicative correlation in which it is carried out using the decreasing method of transformer function deviation.

In case of the multiplicative correlational method the interior and bearing capacitors consequently to measurement transformer are connected and then set voltage via the feedback circuit of operational amplifier are controlling [15].

The multiplicative correlation circuit of errors for temperature change of the moisture transformer with cylindrical electrode has been presented in Figure 1.

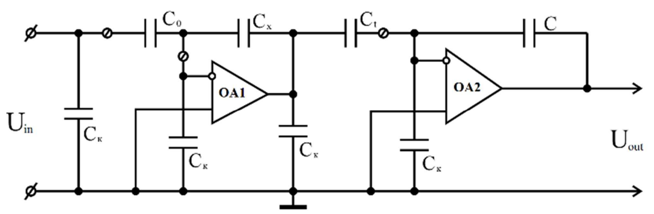

Figure 1. *The multiplicative correlation scheme of errors for moisture transformer with cylindrical electrodes temperature changes.*

Here OA1 and OA2 are the operation amplifiers working in the middle quadratic measurement results calculation regime; C_0 is the initial value for working capacity of parametric transformer sensor, C_x is the capacity taking into account the distance shift between capacitive transformer plates by changing the sensor temperature, C_c is the capacity of connecting cables. Capacities C_0, C_x, C_t and C_c create the phase shift of signal and provide the stable work of correction circuit because of consequently connected differentiator OA1 and integrator OA2. U_{in} and U_{out} are the voltages at the device entrance and exit, correspondingly.

The multiplicative correlation circuit begins work in case of exceeding value 30°C of the medium temperature. In turn, the exit voltage of capacitive transformer with cylindrical electrode depends on the optimal values of parameters C_0, C_x, C_t and C_c via representation

$$U_{\text{out}} = U_{\text{in}} \frac{C_0}{C_x}\left(1+\frac{1}{1+k\mu_1}\right)\cdot\frac{C_t}{C}\left(1-\frac{1}{1+k\mu_2}\right),$$

where k is the amplifier coefficient for operation amplifier; μ_1 and μ_2 are the coifficients of negative feedback of operation amplifiers OA1 and OA2, correspondingly. Their values are defined by

$$\mu_1 = \frac{C_x}{C_x + C_c + C_0};\ \ \mu_2 = \frac{C_x}{C_t + C_c + C}.$$

The correlation variant for temperature changing of capacitive transformer with cylindrical electrode, which differs from multiplicative correlation circuit with high correlation degree, is presented in Figure 2.

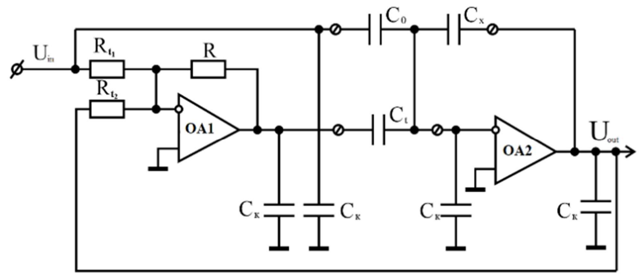

Figure 2. *The additive logo metric correlation scheme of errors for moisture transformer with cylindrical electrodes temperature changes.*

In this correlation circuit we must define the errors measurement dependence of parameters C_0 and C_x and also depending on temperature of capacitor C_t on the transformer temperature. Wherein we measure the correlated values of parameters C_0 and C_t. The correlated signal in exit by this circuit is defined by

$$U_{\text{out}} = U_{\text{in}} \frac{C_0 - C_t \dfrac{R}{R_{t_1}}}{C_x - C_t \dfrac{R}{R_{t_2}}}$$

and the setting of the errors additive correlation is realized changing resistances of resistors R_{t_1} and R_{t_2}. In the presented correlation circuit the entrance resistances of both operational amplifiers are shunted by cabled capacities C_k.

Change of capacities values of capacitors C_0, C_x, C_t and C_c leads to the signal phase shift and this situation provides continuous work of the integrator correlation circuit containing consequently connected to the differentiator circuit of operational amplifiers OA1 and OA2. In this developed circuit the common mode component emerging almost simultaneously together with measuring signal decreases little the voltage correlation degree, however in order to remove the unstable influence of this component we must increase entrance differentiator and integrator resistances. Besides, if to capacitor C_k we connect a resistor then in the resulting RC_k filter the common mode voltage is absorbed and its unstable influence fades.

The additive logo metric circuit of correlation change for transformer temperature of moisture with cylindrical electrode is presented in Figure 3. On this figure the element of additive logo metric correlation of temperature errors, C_t, connected to the entrance circuit of operational amplifier OA2 gives the middle quadratic value of correlating in ones signal.

The errors value of operational amplifier OA1 is defined by values of its main parameters and resistors

$$R,\ R_{t_1} \text{ and } R_{t_2},$$

because of after setting they are being constant and in turn the possibility for errors correction signals summation is created. The negative feedback coefficient of the operational amplifier OA2 is defined by

$$\beta = \frac{C_x}{C_x + C_0 + C_t + C_c}$$

and no phase shift for negative feedback to exit voltage of measuring circuit and thus the output voltage is being constant.

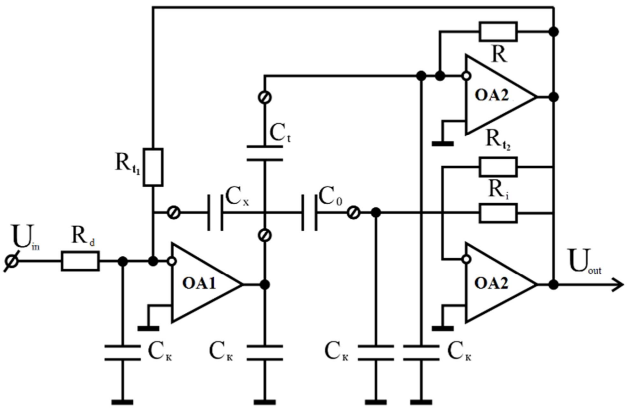

Figure 3. The additive logo metric scheme combining the errors correction of temperature and changes.

As in case of multiplicative errors correlation of temperature transformer of moisture with cylindrical electrode in additive logo metric correction too, the model based on parameters C_x and C_0 must have a linear dependence on temperature, that is

$$C_x(t) = C_{x0}(1 + \alpha_x t) \text{ and } C_0(t) = C_{00}(1 + \alpha_0 t),$$

where α_x and α_0 are the temperature coefficients of parameters C_x and C_0, C_{x0} and C_{00} are the capacities values on 0°C temperature.

The mathematical expression of model having a multiplicative temperature correction and depending on temperature of the measuring circuit on high (≥100°C) temperatures has form

$$C_t(t) = C_{t0}(1 + \alpha_t t)$$

where α_t is the temperature coifficient of capacitor C_t, C_{t0} is the capacity value on 0°C temperature.

As the sample of practical application of the circuit we putted to the device the additive logo metric circuit of temperature changing correction (see, Figure 3) based on the capacitive method of moisture measure of grain and grain products. It should be noted that the considered temperature correction circuits could be used also in other capacitive transformers.

3. Sensitivity and Authenticity of the Moisture Meter Transformer with Cylindrical Electrode

Creation automatized controlling systems, which are used widely in complex automatize of the production processes and computer science, requires often using measure transformers in different quantity on physical characteristics and working principles. Therefore, the demands for subject to credibility of the measurement system and its elements are growing.

The advantages of the cylindrical transformers include, in particularly, the high authenticity, sensitivity and low consumption of electrical energy.

Application of integrated electronics provides increase the information systems authenticity. As the same time the task of growing authenticity is being actual because of the technical progress rate increasing incessantly too.

As the experimental tests of the constructive and main characteristics of moisture transformers with cylindrical electrode showed, the sensitivity and authenticity criteria affecting essentially to measurement accuracy of transformer and nonlinearity of statistical characteristics play an important role.

The polarization effects appearing in the cylindrical transformer working processes that is displacement of electric charges between electrodes leads to reduction of measurement range and essential decreasing sensitivity of bulk materials moisture especially when we measure small moisture values.

The sensitivity, accuracy and zero drifting of the measurement device depend on frequency of the high frequency sinusoidal generator and frequency stability of variable voltage source. As to the sensitivity, accuracy, transformer function linearity, they depend directly on flow changes and transformer constructive elements.

As the measuring object of the capacitive transformer, we study the absolute and relative sensitivities. The absolute sensitivity by relation of output signal increment of the transformer to its input signal increment is defined

$$S_1 = \frac{\Delta U}{\Delta U_0}.$$

As to the relative sensitivity, it using the following expressions can be calculated:

1) by relation of transformer output signal increment to relative input signal increment

$$S_2 = \frac{\Delta U}{\Delta U_0 / U_0};$$

2) by relation of relative increment of transformer output signal to input signal relative signal increment

$$S_3 = \frac{\Delta U}{U} / \frac{\Delta U_0}{U_0}.$$

The experimental tests showed that only using the last expression from mentioned above ones is possible to analyze comprehensively the change sensitivity of the cylindrical transformer output signal.

Let us consider the measuring circuit containing two parallel-connected capacitors and a high frequency pulse (quaziresonator) generator. Transformer capacity in the output circuit C_n by sensitivity S to equivalent capacity C_{ak} is replaced and is defined by

$$C_{ak} = C_n + C_0;$$

$$S = \frac{\partial U}{\partial U_0} \cdot \frac{U_0}{U}, \qquad (1)$$

here C_0 is the ballast capacity.

The complex resistant in cylindrical capacitive transformer output is defined by

$$Z_{ak} = \frac{R_m r_m^2}{R_m^2 + r_m^2} - j\frac{R_m^2(r_m - r_u) - r_m^2 r_u}{R_m^2 + r_m^2}, \qquad (2)$$

here R_m and r_m are the material active and capacitive (reactive) resistances, correspondingly, r_u is the capacitive resistant of isolation surface.

Let us analyze the sensitivity of considering cylindrical capacitive transformer. According to Expr. (1) the differential sensitivity of the connected to capacitive transformer equivalent circuit we can express by

$$S_{R_m} = \left[\frac{\partial Z_{ak}}{\partial R_m}\frac{R_m}{Z_{ak}}\right] \to \min, \quad S_{r_m} = \left[\frac{\partial Z_{ak}}{\partial r_m}\frac{r_m}{Z_{ak}}\right] \to \max \cdot$$

From Expr. (2) we can obtain representation for complex resistance

$$Z_{ak} = \sqrt{\frac{R_m^2(r_m + r_u) + r_m^2 r_u^2}{r_m^2 + r_u^2}}. \qquad (3)$$

In order to find the cylindrical capacitive transformer sensitivity we differentiate Expr. (3) on R_m

$$\frac{\partial Z_{ak}}{\partial R_m} = \frac{R_m r_m^2 (r_m^2 + 2r_m r_u)}{\sqrt{\left[R_m^2(r_m + r_u)^2 + r_m^2 r_u^2\right](R_m^2 + r_u^2)}}.$$

Thus, for the cylindrical capacitive transformer sensitivity we obtain

$$S_R = \frac{\partial Z_{ak}}{\partial R_m}\frac{R_m}{Z_{ak}} = \frac{R_m^2 r_m^2 (r_m^2 + 2r_m r_u)}{\left[R_m^2(r_m + r_u)^2 + r_m^2 r_u^2\right](R_m^2 + R_u^2)}. \qquad (4)$$

As seen from Expr. (4), the transformer sensitivity is function of three variables which complicates the calculations. Therefore, we introduce relative quantities

$$\eta = r_u / r_m \text{ и } \beta_m = \vartheta_m / g_m = R_m / r_m = \omega C_m R_m, \qquad (5)$$

here ϑ_m is the material reactive conductivity.

After replacement representation (5) Expr. (4) takes form

$$S_R = \frac{\beta_m^2(1+2\eta)}{\left[\beta_m^2(1+\eta)^2 + \eta^2(1+\beta_m{}^2)\right]}, \qquad (6)$$

here β_m is the material corpulence, η is the constructive quantity characterized eccentities of bulk materials moisture in the cylindrical capacitive transformer.

As seen from Expr. (6), the transformer capacitive sensitivity depends, basically, on parameters β and η. The carried out observations and calculations showed that when parameter η, which depends on the bulk materials reactive resistance and isolated surface, is growing then transformer sensitivity is decreasing essentially. In physical point of view, this situation corresponds that the bulk materials interact with electric flow in the cylindrical capacitive transformer and therefore the reactive resistance and corpulence are changing essentially.

We can see from Expr. (6), that if the material corpulence is growing then the cylindrical transformer sensitivity is increasing. If we take into account the measuring system for this process then transformer sensitivity depends directly on the oscillatory circuit corpulence of the measuring generator, which is common for all capacitive measuring transformers.

4. Analysis of Results

We have obtained the dependence of the reactive resistance for cylindrical transformer on the bulk materials capacity (see, Figure 4). It is seen from one that the reactive resistance is decreases sharply when bulk materials capacity reaches value 2 *pF*. Further, it is decreasing slowly in dependence of capacity that demonstrates transformer sensitivity change too.

The functional dependence of quantity S_m on reactive resistance r_m has been presented in Figure 5. We can see from the Figure that when the cylindrical transformer reactive resistance is growing then its sensitivity is decreasing. The experimental data analysis showed that the cylindrical transformer maximal sensitivity reaches when the parameter r_m value equals to $0.5 \cdot 10^4$ *Ohm*, which corresponds maximal change for bulk materials capacity.

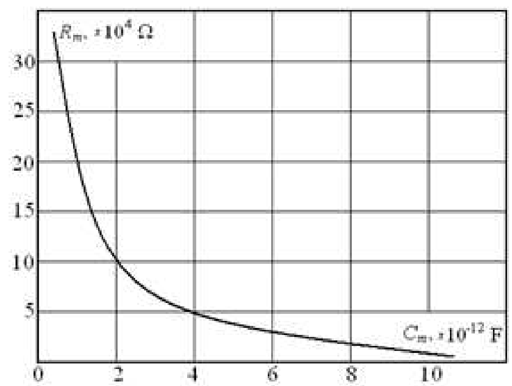

Figure 4. *The dependence of reactive resistance of cylindrical transformer on the bulk materials capacity.*

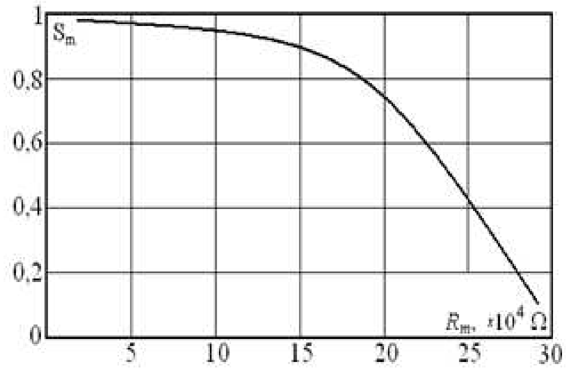

Figure 5. *The dependence of functional characteristics of sensitivity S_m on resistance r_m.*

As is known from carried out investigations that the probability distribution of sudden failure usually expressed by an exponential law. The probability density is expressed by sudden failure intensity according [16]

$$f(t) = \lambda e^{-\lambda t}.$$

Here parameter λ is the sudden failure quantity, which as parameter of elements authenticity is considered. Other authenticity parameters by following representations are defined:

1) average device life

$$\overline{T} = \int_0^\infty t\lambda e^{-\lambda t} dt = 1/\lambda ;$$

2) average frequency for sudden failure

$$\overline{f}(t) = 1/t \int_0^\infty t\lambda e^{-\lambda t} dt = 1/t(1-e^{-\lambda t}).$$

If $\lambda t \le 1$, $e^{-\lambda t} \approx 1-\lambda t$, then $\overline{f}(t) \approx \lambda$.

Thus, in period of beginning initial working process up to start of physical destruction the middle sudden failure frequency equals practically to the sudden failure intensity.

The dependence of cylindrical transformer authenticity for bulk materials on the middle sudden failure has been presented on Figure 6. We can see from the Figure that over time of user cylindrical transformer its authenticity is decreasing. The characteristic of this dependence thing is in the beginning transformer working exploitation stage the essential interaction of heating and electrical effects leads to decreasing the authenticity down to 0.3 value.

From the qualitative analysis of results carried out ourselves investigations in comparison with the different known variants for controlling moisture of grain and grain products [17] we can conclude that:

1) for controlling moisture of grain and grain products in the technological processes the radioactive, conductometrical, high frequency and capacitance methods are using;
2) the measuring accuracy and reliability on radioactive, conductometrical and high frequency methods are camparatible low (1 ÷ 2.5 % and 0.8 ÷ 0.85, correspondingly);
3) realization the radioactive method requires a lot of effort, the cost is expensive and devices with radioactive elements are using.

As to the capacitance method, it is simpler in point of view the device construction and has comparable low costs in which the measuring accuracy and reliability take values 0.2÷0.6 % and 0.95, correspondingly.

It follows from mentioned above conclusions that using the capacitance method of moisture measuring of grain and grain products on the dynamical processes is the actual task. The results of carried out investigations will being used, certainly, by construction the measuring device, which will control the grain and grain products moisture on the dynamical regime of industrial equipment.

We can obtain this device after solving the following problems:

1) investigation the main characteristics of first capacitance transformer of the grain and grain products moisture based on the many electrodes system;
2) study and choice of capacity measuring principles in the first capacitance transformers;
3) finding the functional dependence of transformer capacity on the investigating substance moisture;
4) development the accuracy calibration methods for measuring and controlling grain and grain products device.

5. Conclusion

Thus, the main parameters of moisture cylindrical transformer for bulk materials by sensitivity and its elements authenticity criteria are defined. The time characteristics of cylindrical transformers for bulk materials are developed. These characteristics by influencing heating and electrical effects over time lead to aging transformer elements. As our calculation showed the cylindrical moisture transformer authenticity equals to 0.95. The cylindrical transformer sensitivity depends, basically, on the bulk materials corpulence and transformer constructive factors. All these we must take into account by projecting the cylindrical transformer main elements.

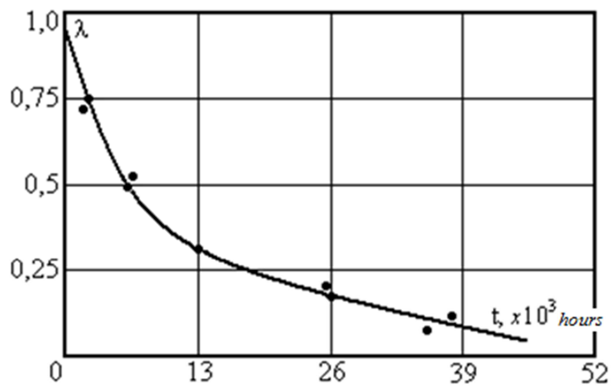

Figure 6. *The dependence of reliability of cylindrical transformer for bulk materials on the middle working time without failure.*

6. Recommendations

The results of this paper for construction of moisture meter device based on the capacitance transformer with cylindrical electrodes can be used.

Acknowledgements

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