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Design Of Devices For Monitoring The Humidity Of Materials Based On Capacitive Converters

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Abstract: The issues of designing a high-frequency device for monitoring the moisture content of grain and grain mass and products of their industrial processing in industrial conditions are considered. A tactical analysis of previously performed studies on the choice of operating frequency and calculation of the capacity of primary converters is carried out and the optimal option for choosing the operating frequency and capacity of humidity measuring converters is proposed.
The features of granular materials are shown, where it is necessary to take into account when mathematically describing the dielectric properties of the materials under study from their humidity, that the dielectric properties of wet materials are described by mixture formulas that are sufficiently accurate for moisture-containing liquids (including grain mass).
The Wiener formulas describing mathematical models of wet materials, the dependencies connecting the permittivity of an n-phase mixture with the permittivity and volume concentrations of individual components are described. The scientific and practical value of the article is presented, it is shown where grain moisture is one of the most important technological parameters, which requires the development of humidity control devices and monitoring humidity at all stages of grain and granular materials production.

Keywords: measurement, operating frequency, capacitance, generator circuit, grain, grain mass, high-frequency device, primary converter.

1. INTRODUCTION

It is known that humidity monitoring devices are based on the principle of the presence of a dependence between the dielectric constant of the controlled material and its humidity [1].
To measure humidity, medium-and short-wave ranges (from 0.1 to 50 MHz) of high frequencies are most often used [2]. In the specified range, primary capacitive converters of dielkometric monitoring devices can be considered as systems with concentrated parameters [3].

The controlled material is placed in a capacitive primary converter, and the object of measurement is not the permittivity, but the capacitance of the converter. As for the permittivity, its calculation from the data of such measurements is a difficult task.
The capacity of the primary converter filled with the controlled material (as well as its resistance) is a function of many parameters.
Where: *W* - humidity, *T* - temperature, *G* - granulometric and chemical composition of the controlled material; *X*- electrochemical criterion of the electrode-material boundary.
A large number of works have been devoted to the research of capacitive primary converters [4, 5, 6]. The analysis of these works allows us to formulate a requirement for the design forms of converters [4, 7].

1. Ensuring the stability of the conversion function in time, i.e. the mechanical and temperature stability of its own capacity;
2. Small dimensions and weight;
3. Resistance to corrosion;
4. Mechanical strength;
5. Adaptability.

2. MATERIALS AND METHODS

In the technological process of processing granular materials, one of the main factors affecting the qualitative and quantitative indicators is humidity. A change in humidity by 0.1% from the optimal value reduces the yield by the order of 0.8 to 1.0%, which leads to income losses. Each percentage of the humidity measurement error can lead to a distortion of the data on the accounting quantity of the product produced. For example, if there is a systematic error in measuring grain moisture by only 0.1%, there is uncertainty in determining its actual quantity with a gross volume of 100 million tons the tn will be 100 thousand tons [8].

Analyzing our studies of the high-frequency (HF) method and devices based on this method for various properties of materials of similar grain mass, they have a number of significant advantages and disadvantages over others.

For the design of an RF humidity control device, it is extremely important to choose a measuring converter, its operating principles,and design. The study of humidity and frequency-humidity characteristics makes it possible to determine the conversion functions of the circuit of a high-frequency humidity-monitoring device, i.e. the conversion of "humidity-dielectric properties" of materials in the frequency range under study, the choice of the optimal operating frequency for the design and development of the measuring conversion.

Critically assessing the presence of shortcomings in the design of primary converters, it should be noted that developers and designers do not have a single approach to the choice of the operating frequency, the converter and the control method. In the works of a number of authors, there are significant differences in the frequency range of measurements. Such a spread in the values of experimental studies and the frequency range indicates an insufficient study of this issue and a lack of methodological solutions for conducting research.

The first thing that catches the eye when analyzing [8, 13] is a significant discrepancy and contradictions in the technical data of the devices under consideration. For example, operating frequencies from 7 to 100 pF are recommended, as for the proposed measurement methods, there is also a significant discrepancy: Z-meters, F - meters and bridges with close inductive coupling and parameter modulation are used.

Based on the analysis [4,7] of the development of RF humidity monitoring devices, it is necessary to proceed from the methods given in the works [9]. Where it is shown that preference should be given to F-meters (frequency), which have a sufficiently high and constant sensitivity with a Q-factor of the circuit, and have significant technological advantages over bridges with a close inductive connection, since they do not require complex work on winding and fitting inductors for bridges.

When choosing the operating frequency and capacitance of the primary converter, many developers completely miss the question of the need to solve this problem taking into account the parameters and characteristics of the circuit of the working generator. It is known that the physico-chemical composition of the aggregate of the granular material under consideration, the presence of macro-and micropores in them, various in shape and size, as well as electrolytes, determines a wide, almost continuous spectrum of relaxation time.

3. RESULTS

As for the moisture content of grain, the international standards for wheat set restrictive humidity standards for harvested and supplied wheat. When processing for varietal grinding, the moisture content of wheat supplied to industrial enterprises should be no more than 13.5%, wheat with a moisture content of no more than 15% is used for wallpaper grinding, and when processing into cereals - no more than 14.5 %.

The inertial component of the permittivity depends on the relaxation time, frequency and electrical conductivity. As the humidity increases, successive filling of pores of ever larger sizes occurs, films and extended closed water inclusions are formed, which determine the increase in the dipole moment and the value of the dielectric constant. With a further increase in humidity, the increase in the dielectric constant depends mainly on an increase in the content of water components with a large value of the dielectric constant [10].

With increasing frequency, the implementation of the mechanisms of relative lower-frequency types of polarization gradually and smoothly ceases, which is accompanied by a decrease in the dielectric constant. The obtained series of frequency-humidity characteristics for granular materials show that there is a regular dependence between the permittivity and humidity, the nature of which is influenced by the frequency. With increasing frequency, the sensitivity to humidity decreases [6]. 10

With increasing humidity, moisture is distributed not in the form of separate isolated inclusions, but in the form of continuous films, bridges, etc. This leads to a wide, practical continuous spectrum of relaxation time, covering the range from 10^{-8} to 10^{-3} s [3, 11].

The above-mentioned features of agro-industrial complex materials must be taken into account when mathematically describing the dielectric properties of the materials under study from their humidity.

As is known, the dielectric properties of wet materials are described by the formulas of the mixture, which are quite accurate for moisture-containing liquids (including grain mass).

Let us turn to Wiener's formulas describing mathematical models of wet materials, i.e. the dependencies connecting the permittivity of an n-phase mixture with the permittivity and volume concentrations of individual components.

Formulas of Wiener, Lorenz-Lorentz, Clausius-Mossotti:

$$\varepsilon = \varepsilon_0 \left(1 + \frac{3\delta}{\frac{\varepsilon_в + \varepsilon_0}{\varepsilon_в - \varepsilon_0} - \delta}\right).$$

Wiener proposed to take into account the location of the particles of the dispersed medium relative to the direction of the electric field by the "mixture coefficient" n $(0 \le n \le \infty)$. The Wiener equation, applied to the complex permittivity, has the following form:

$$\frac{\varepsilon-1}{\varepsilon+n}=\delta\frac{\varepsilon_{в}-1}{\varepsilon_{в}+n}+(1-\delta)\frac{\varepsilon_0-1}{\varepsilon_0+n}$$

The experimental values are:

a) The maximum at, corresponding to the location ofdispersed particles with a large axis parallel to the direction of the field. In this case $\varepsilon_{макс}=\delta\varepsilon_{в}+(1+\delta)\varepsilon_0$

b) The minimum at $n = 0$ for particles with a large axis perpendicular to the direction of the field:

$$\frac{1}{\varepsilon_{мин}}=\delta\frac{1}{\varepsilon_{в}}+(1-\delta)\frac{1}{\varepsilon_0}.$$

For intermediate values of n corresponding to any arrangement of particles between the specified extreme values, the permittivity of the mixture will take the value $\varepsilon_{мин}<\varepsilon<\varepsilon_{макс.}$

The most complete reliable information about the humidity frequency characteristics of grain materials and their processed products can be obtained as a result of their comprehensive experimental studies.

The scientific novelty of our research, unlike all previous works on measuring the humidity of products such as grain-wheat and grain mass, is that when designing it is necessary to apply a systematic scientific approach to choosing the operating frequency that is within the method based on the physics of properties in high-frequency electromagnetic fields, is equal to the frequency range from 5.10^3 to 5.10^7 Hz,and the capacitance of the primary converter circuit to solve the problem as a whole, in which the sensor is installed is $C=250\ pF$. Resolution $\Delta C=10^{-2}$pF. The sensitivity is of the order of $S\approx 2$.

Based on the above, it can be argued that the grain mass (our controlled material) is an emulsion of the w/o type (water in oil), i.e. an emulsion in which the conducting phase (water) is dissolved in oil [12]. For an w/o type emulsion, the continuous phase is a good dielectric, and the internal phase (water, depending on the salinity and frequency) is either conductive or dielectric. Similar results were obtained in [13].

4. DISCUSSION

Taking into account that the designed devices must be universal, that is, according to all the technical conditions of the industry, it is required to measure humidity both during storage in flour mills and in the field during their assembly, i.e. discrete measurement [14].

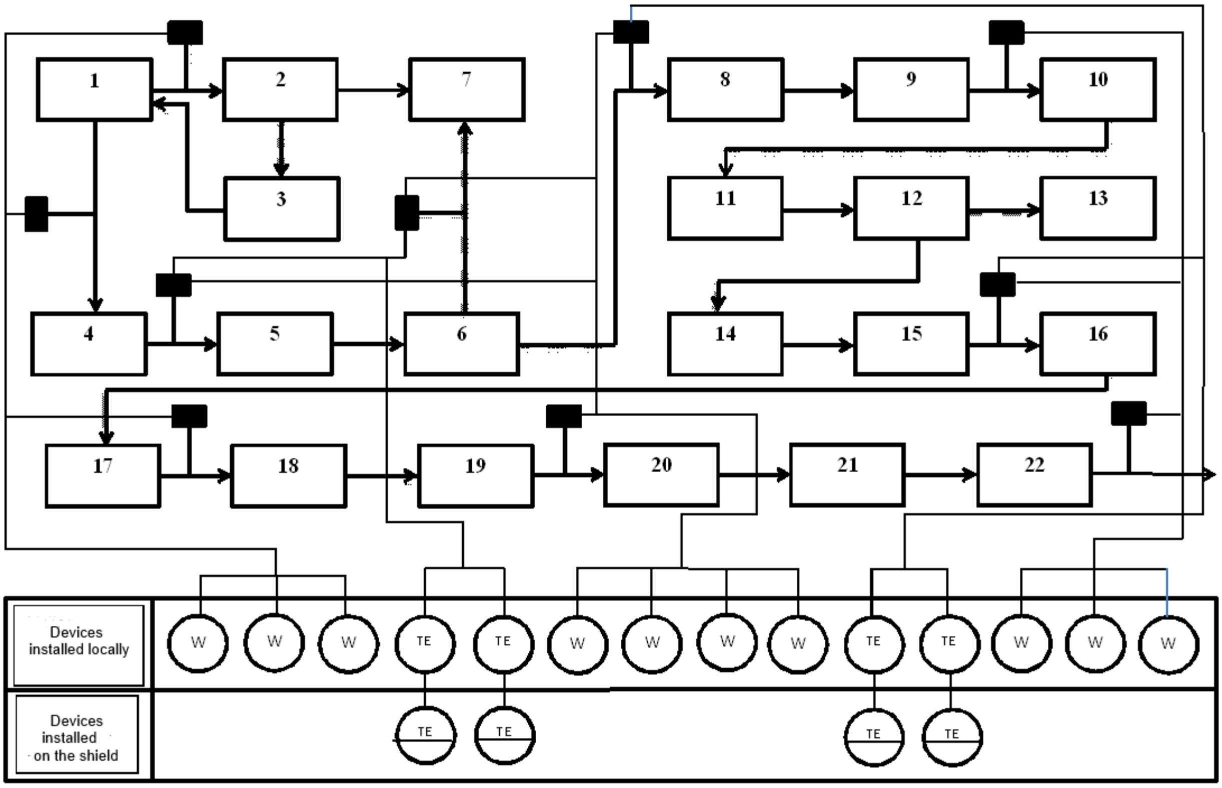

Figure 1. General technological scheme for monitoring the moisture content of grain and grain products

Where: 1-field; 2-preparation place; 3-harvesting machine; 4-filling place; 5-grain dryers; 6-storage place for dry grain; 7-grain storage containers; 8-elevator; 9-container for raw grain; 10-dispenser; 11-grain heater; 12-grain cleaning from foreign objects; 13-grain output; 14-grain washing; 15-dryer; 16-first humidification; 17-first wet storage place; 18-second humidification; 20-final grain cleaning; 21-additional soaking; 22-the first wet storage before grinding;■ -control of humidity in places.

For these purposes, the optimal design will be one that will ensure maximum technological simplicity of the measurement operation itself. These conditions will be best met by ring-type converters [15].

To control the moisture content of the grain mass (in the liquid state) then these conditions are more fully satisfied by the flow converters. An important factor to consider when choosing capacitive converters is the possibility of using them without first measuring or weighing the controlled product that the converter fills with. Meeting this condition requires excessive loading of the converter so that the controlled material fills not only the interelectrode space, but also a significant volume above the working part of the converter, and this additional volume should be 2-3 times greater than the working volume [16].

The fulfillment of this requirement for flat and coking capacitors leads to an exorbitant increase in their dimensions, necessary for the installation of all kinds of protective rings [17], etc. To a large extent, capacitive scattered field converters are free from this disadvantage [18]. The peculiarity of such converters is that the field in them actually exists only relatively thin at the electrode region, which frees the measurement results from the influence of the completeness of the fill and, accordingly, neither the volume nor the weight of the filled sample does not affect the measurement result [19].

The final stage of the study of the high-frequency method is the construction of a mathematical model of an RF humidity control device, which allows us to obtain a fairly accurate mathematical ratio of its conversion function and the function of influencing uninformative parameters. Synthesizing an electric capacitive model of a primary measuring converter that provides an acceptable approximation of real frequency-humidity characteristics in the high frequency range, using a two-element parallel substitution scheme [20].

5. CONCLUSION

The main meaning of the results regarding the goal is as follows: we have studied the high-frequency method for a number of similar products of the agro-industrial sector, such as: grain, seeds, rice, corn, barley, etc.The results obtained on the basis of the RF method, humidity control devices were built and passed both laboratory and production tests in factory conditions.

The relevance of the study is due to the fact that the moisture control of grain and granular materials must be carried out starting from harvesting in the field, transportation, as well as storage and processing in industrial conditions. For these purposes, universal portable humidity monitoring devices are required at all stages of their industrial processing.In this regard, this article is aimed at identifying and disclosing the principles when designing similar express devices for the materials under consideration. The leading method for studying this problem is the choice of a high-frequency method on the basis of which it will be necessary to synthesize a device that allows to comprehensively measure the moisture content of grain and grain materials at all stages of their humidity control.

In the article, the presented materials will allow for engineering calculation and selection of the operating frequency and capacitance of the measuring parameters of the primary capacitive type converter and synthesize an express humidity control device for the materials under consideration. The materials of the article are of practical value for flour milling industries where grain moisture is one of the most important technological parameters, which requires monitoring at all stages of grain and granular materials production.

6. REFERENCES

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