Chemical Technology, Control and Management

Volume 2018
Issue 3 *SPECIAL ISSUE 4-5*

Article 46

10-19-2018

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Recommended Citation

Usmanova, Kh.A and Turgunbaev, A. (2018) "Developing a multi-purpose moisture meter on ultra high frequency.," *Chemical Technology, Control and Management*: Vol. 2018 : Iss. 3 , Article 46.
DOI: https://doi.org/10.34920/2018.4-5.202-206
Available at: https://uzjournals.edu.uz/ijctcm/vol2018/iss3/46

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Cover Page Footnote

Tashkent State Technical University, SSC «UZSTROYMATERIALY», SSC «UZKIMYOSANOAT», JV «SOVPLASTITAL», Agency on Intellectual Property of the Republic of Uzbekistan

This article is available in Chemical Technology, Control and Management: https://uzjournals.edu.uz/ijctcm/vol2018/iss3/46

ISSN 1815-4840
CHEMICAL TECHNOLOGY.
CONTROL AND MANAGEMENT
2018, Special issue №4-5 (82-83) pp.202-206. https://doi.org/10.34920/2018.4-5.202-206
International scientific and technical journal
journal homepage: https://uzjournals.edu.uz/ijctcm
Since 2005

DEVELOPING A MULTI-PURPOSE MOISTURE METER ON ULTRA HIGH FREQUENCY

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Abstract: *The article deals with the problems of optimizing the design and structure of the moisture meter, which generally reduces to minimizing measurement errors by selecting the type of sample former and its basic parameters. The constructive, structural and algorithmic optimization methods proposed in the article allow to create a single unified complex of means for controlling the moisture content of fibrous and solid bulk materials that were used in the development of a multi-purpose microwave moisture meter for fibrous materials and granular products of the agro-industrial complex.*

Key words: *super high frequency moisture measurement, design optimization, minimization of error, moisture converters, fibrous, solid, bulk and liquid materials.*

In recent years, ultra-high frequency (microwave) moisture metering has received rapid development. Its theoretical foundations have been deeply developed, and a whole range of microwave moisture meters for fibrous, solid bulk and liquid materials has been created. The interest of developers in the field of moisture measurement to the microwave method is explained by its advantages such as the possibility of contactless measurements of integral humidity, the possession of a significantly higher sensitivity to free water in the material than to its other components, as well as physicochemical properties and structure. However, an equally important advantage of the microwave method, to which so far little attention has been paid, is universality. The moisture meters developed to date are highly specialized and in each specific case the developers are oriented towards a specific material. At the same time, optimization of the design and structure of the moisture meter as a whole reduces to minimizing measurement errors by selecting the type of sample former and its main parameters.

Our work on finding optimal solutions for creating widely used moisture meters showed the promise of developing a unified series of microwave moisture meters that can cover almost the entire range of moisture metering tasks for fibrous, solid, solid bulk and liquid materials [1]. At the same time, as practice shows, moisture meters can have a single measuring circuit and several types of primary transducers (sample formers). The economic feasibility of this approach is obvious, since for hundreds of varieties, for example, bulk materials, it is necessary to develop only one type of moisture meter. The main task of optimization in the development of such a moisture meter is also reduced to minimizing the error, but for a wider range of composition and properties of controlled materials and in a wider range of measurements. Therefore, here it is necessary to consider the possibilities of constructive, structural and algorithmic optimization methods in the complex.

Exploring the microwave method to different materials, we concluded that, given the structural structure and physical properties of controlled substances, the problem of moisture measurement can be solved using four types of moisture converters: for fibrous, solid, solid bulk and liquid (pasty) materials. However, due to the physicomechanical properties of the large variety of materials of the same type, the task of unifying the primary transducer is much more complicated. The main requirement in the choice of the geometric dimensions of the transducer is to ensure the required sensitivity and a specified measurement range. This requirement is contradictory, since increasing the sensitivity decreases the dynamic range of the conversion. In addition, an additional requirement is imposed on the converter - a combination of statistical characteristics for various materials.

The latter task is practically impossible to solve with constructive methods, therefore its solution is shifted to algorithmic methods, which will be discussed below. As for the geometric dimensions of the converter, for amplitude and phase moisture meters, they are defined as follows. The first is determined by the thickness of the standard of the controlled material from the relations:

$$S \geq \frac{3R_u}{\delta} 8{,}68 \cdot \alpha_{max} \cdot l \leq A_{max} \qquad (1)$$

where S- is the sensitivity of the method dB /% or rad /%; R_u - is the resolution of the measuring circuit,%; a $_{max}$ - is the attenuation coefficient of microwave energy in a material at its maximum humidity. dB / m;

l- sample layer thickness, m; A_{max} - maximum attenuation at which the signal passed through the material is sufficient to measure its parameters, dB.

The sensitivity S in the expression (1) for the amplitude and phase methods is determined respectively:

$$S_A = 8{,}68 \cdot \frac{d\alpha}{dw} \cdot l, \qquad (2)$$

$$S_u = \frac{d\beta}{dw} \cdot l, \qquad (3)$$

where is the β - phase coefficient, rad /%; W - is the moisture content of the material.

The height and width of the sample material in the primary transducer are determined from the condition of sufficient representativeness of the sample, which does not present any particular difficulties. When choosing a single sample thickness for various materials, conditions (1) are written in the form:

$$\{Si\}\ min \geq \frac{3R_u}{\alpha_i} 8{,}68 \cdot \{\alpha_k\}_{max} \cdot l \leq A_{max}, \quad (4)$$

where $\{S\}min$ - is the minimum sensitivity determined by (2) from a number of considered materials;

$\{a_k\}max$ - the maximum coefficient of attenuation of the material.

In general, conditions (4) are more stringent than (2), since not necessarily i=K. To ensure that conditions (4) are met, it is necessary to use in addition to constructive, structural, and algorithmic optimization methods. With the help of the latter, it is necessary to achieve an increase in resolution, a decrease in measurement error, and an increase in the range of measurable attenuation, which makes condition (4) less stringent.

To improve the efficiency of the converter, we have proposed the following

constructive ways:

- compaction of the sample in the measuring chamber (for fibrous materials), which allows to bring together the dielectric characteristics of various materials, because $\beta = \beta(p) -$ and where is p - the density;

- sample rotation with constant mixing under its own weight (for bulk materials) and multiple measurements.

Our experimental studies have shown that the use of these constructive methods allows us to create optimal transducers for a large group of similar materials. For example, one primary transducer with rotation of a pre-compacted sample is applicable to such fibrous materials as raw cotton, cotton fiber, cotton seeds, kenaf, hay, viscose fiber, tobacco, etc. almost a wide range of solid bulk materials.

To optimize the measuring circuit of moisture meters, the direct report, differential, and compensation schemes were analyzed. For a more complete and accurate analysis of the effectiveness of microwave moisture meters, in addition to metrological characteristics, information characteristics were considered - a set of indicators expressed by an information efficiency factor that also takes into account the degree of universality of the moisture meter. As a result of the analysis, a compensation circuit with a semiconductor balancing element was chosen as the basic measuring circuit.

To implement algorithmic methods to increase the efficiency of the moisture meter, we have developed an embedded microcontroller based on a microprocessor. It is entrusted with the functions of a secondary measuring transducer - processing the results of multiple measurements, selecting the calibration characteristic appropriate to the material being monitored and the humidity of the sample determined from it, taking into account the temperature of the material and the environment.

A method has been developed that makes it possible to reduce the measurement error due to the influence on the informative parameter of the prehistory of the moisture state of the material. The method is based on that. that the dispersion of the results of repeated measurements depends on the history of the moisture state of the material before the measurement (time elapsed after wetting or drying).

According to the results of multiple measurements, the variance and the expectation of the informative parameter are determined and the microcontroller determines the correction value of the measurement result by this parameter using a special algorithm.

There are non-trivial problems in moisture measurement, the solution of which requires a special approach. This measurement is directly in the process stream, where the volume, material and its density in the control zone can continuously change, measurements in large volumes and in the region of low moisture content.

To solve these problems we have proposed the following methods:

1. Constructive methods. To stabilize the flux density, three types of auger shapers in the measurement zone with loading, unloading and two augers have been developed.

A discretely continuous humidity sensor with a branching flow for measurements intended for raw cotton and cotton materials has been developed.

2. Structural methods. To control the moisture of the material directly on the transport belt, a two-parameter method has been developed, which allows to take into account the thickness of the material in the control zone. One informative parameter (humidity) is the amplitude. passing through the wave material; and the second is the phase of the wave, reflected from the material boundary, which provides correction from changes in material thickness.

Experimental studies have shown that the component error due to a change in the thickness of the material within $\lambda / 2$ when measuring the phase of the reflected wave and the amplitude of the transmitted waves does not exceed 0.1% (abs).

For measurement in the low humidity range, a method has been developed in which a sample of a material is formed in two steps. The height of the steps and the intensity of the electromagnetic wave flux incident on them are chosen so that at the maximum material humidity the fluxes passing through the steps are the same and their phases are opposite [2]. The flows passing through the stages are summed up taking into account their phases, and the humidity is judged by the magnitude of the amplitude of the total flow. The method allows to increase the sensitivity of measurements on average by 5-10 times. In the development of this method, a converter design is proposed, in which one of the steps is replaced with a wet material simulator, and the electromagnetic wave flows are divided into two channels, in one of which a controlled sample is placed, and in the other - a simulator [3].

Developed constructive, structural and algorithmic optimization methods allow you to create a single unified set of means for controlling the moisture content of fibrous and solid bulk materials. The complex is based on a basic measuring device with a microcontroller that mates with a primary transducer of a given type, depending on the type of material being monitored and the measurement conditions.

The structural and algorithmic methods considered above were used by us in developing the structure of microwave moisture meters for fibrous materials and bulk solids of the agro-industrial complex.

The block diagram of the moisture meter is shown in Figure 1: The moisture meter contains microwave modules M1 (transmitting), M2 (receiving), a cylindrical cell CC for placing the sample under study, temperature sensors TS and pressure P. transceiver antennas A, motor M with control unit CU, commutator of channels CC, analog digital converter ADC, microprocessor unit with memory MUM, low frequency tracking system LTFS, indicator I nd and the control panel CP.

In the permanent memory device MUM, the control programs for measuring the processing of results are recorded. To select the coefficients of the regression equation for a particular type of material, the corresponding code of the initial address of the program is typed on the control panel. At the “start” command, the MUM turns off the engine M, which rotates the measuring chamber at a constant speed of 2 rpm.

The material is irradiated with microwave energy. The low-frequency tracking system monitors the level of the signal transmitted through the material, which is functionally related to the humidity of the material. Information on humidity, temperature and mass of the material is fed to the input of the ADC and then to the MUM. Information about the humidity is removed many times during one revolution of the cuvette.

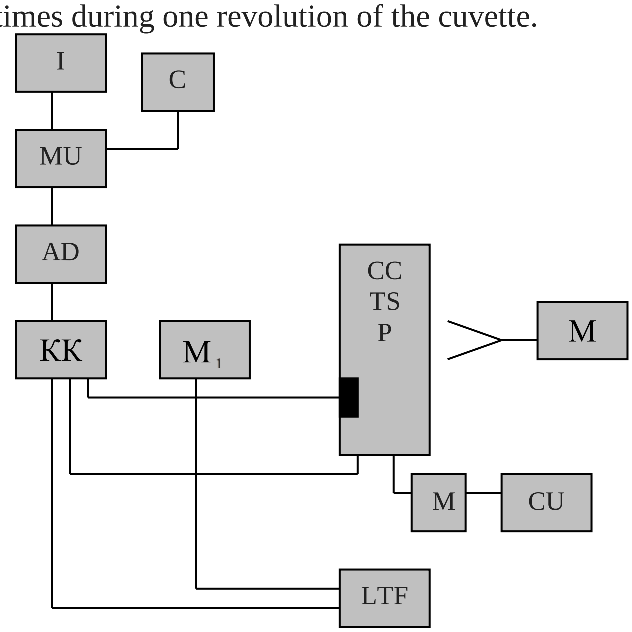

Fig. 1. ***Block diagram of the microwave humidity converter***

where is the W - humidity value corrected by temperature and mass of materials; K_2 - constant coefficient; $P_{()}$., P - respectively, the pressure sensor reading in the calibration and measurement.

The regression equation for the materials in question is

$$W_N = a_1 N_2 + a_1 N + a_3, \qquad (5)$$

where is W_N - the moisture content of the material in%; N - is the average value of the informative signal, mA; a_1, a_2, a_3 - constant coefficients.

Correction of the result of measuring humidity by temperature is made according to the equation:

$$W_{nt} = W_N + K_1 W_N (T - T_0), \quad (6)$$

where is the W_{NT} - moisture value corrected by the temperature of the material; K_1 - temperature coefficient; T_0,T - respectively, the temperature of the material during calibration and measurement.

Correction of the result of measuring the moisture content of a material by mass is carried out according to the formula:

$$W = W_{NT} + K_2 (P - P) W_{NT}, \qquad (7)$$

Due to the introduction of mass correction, the test sample is filled in a cuvette to a constant volume without prior weighing. The moisture meter for fibrous materials is provided with a compacting device that provides the optimum density for each specific material. After compaction, a sample of the material rotates along an axis perpendicular to the direction of propagation of electromagnetic waves and multiple measurements are taken in one revolution of the transducer. The measurement results are processed according to the calibration characteristic set for this material, taking into account the material temperature. The moisture meter allows you to control the moisture content of fibrous materials in the range of 5-30% with an accuracy of 0,8-1%.

The moisture meter for bulk materials differs in the design of the primary converter. The primary transducer with the material rotates along an axis parallel to the direction of propagation of electromagnetic waves. Measuring circuits and antenna-feeder devices of moisture meters are identical. The moisture meter allows you to control the moisture content of bulk materials (grains, its products, oilseeds) in the range of 5-30% with an accuracy of 0,5%.

Moisture meters have been tested on various materials of the agro-industrial complex and have been successfully exploited at a number of enterprises of the republic; for moisture control of cotton meal (Karshi, Kattakurgan), oilseeds (Tashkent), grain and grain products (Tashkent, Asaka, Andijan region), peanuts (Halkabad city, Tashkent region). During the period of operation, moisture meters showed good metrological, operational and reliable characteristics.

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