MICROWAVE FOOD FAT METER

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Abstract

The paper considers the possibility of measuring the fat content of food products by estimating the level of reflected microwave radiation from the product. The functional scheme of the device is offered, the algorithm of its work and process of measurement of parameter of fat content is described.

It is shown that with the use of the described measurement algorithm the influence on the measurement result of the parameters of the measuring path elements is significantly reduced. This, in turn, increases the accuracy of measurements from 0.05% to 0.2% when changing the fat content of products in the range up to 12%.

Keywords: food product, fat content, microwave radiation, electromagnetic waves.

INTRODUCTION

In the production of food products based on milk, sauces, nutrient mixtures and other products, it is often necessary to assess the fat content in them [1]. For this purpose, laboratory analysis devices are used, such as the device for determining the fat content SER 148, automatic fat content meters ANKOM XT15 and XT10, infrared analyzer Inframatic 9500 and others [2]. They provide high measurement accuracy, but can only be used in the laboratory and involve sampling the mixture and placing it in the cell of the instrument. However, food production processes are for the most part continuous and require real-time results. In addition, intervention in the process chain and sampling is not always possible and appropriate.

PROBLEM STATEMENT

In such conditions, the use of microwave methods for determining the fat content in food is promising. These methods are non-contact and do not require intervention in the technological process. The fundamental possibility of using electromagnetic radiation (EMR) of the microwave range to measure fat content is based on a significant difference in the dielectric constant of fats and water that are part of the product. Thus, the dielectric constant of fats is in the range of 1,2…2 units, and water - 75…78 depending on the selected frequency range. The relationship between the dielectric constant of a mixture and the percentage of its components is described by known relations, for example, the Odelevsky formula [3].

Thus, the dielectric properties of the food mixture are determined by the ratio of fat and water. Increasing the amount of fat in the food mixture from 0.1% to 10% changes the dielectric constant of the mixture, reducing it to 55…60 units.

When probing microwave radiation of food product, which is on the conveyor belt or in the dielectric product line, at the boundary of its distribution is reflected. This is due to the difference between the dielectric constant of air and the test product. The highest level of reflection is observed in the absence of fat in the product. Increasing the amount of fat in the product reduces the level of the reflected signal due to changes in dielectric constant. This allows you to determine the fat content of food by measuring the reflection coefficient of EMR from the test product.

A similar method is used in the fat meter described in [4]. The meter consists of a microwave generator, an adjustable attenuator, two directional couplers, a comparison unit and a primary converter. The primary transducer is a waveguide tee, one arm of which is insulated with a Teflon cap. The liquid test product is passed through the other two arms. The measurement compares the signals taken from the directional couplers using ultra-high frequency (microwave) detectors. One channel in which the adjustable attenuator is installed is used as a model. The second, connected to the waveguide tee, is a measuring one. The difference signal from the comparison unit is amplified and sent to the meter. The problems with the use of such a meter are due to the fact that the studied product is in contact with the elements of the waveguide path. In addition, the need for adjustment in the measurement process of the two attenuators significantly complicates the measurement process, and the instability of the characteristics of microwave detectors causes significant errors.

These shortcomings are partially eliminated in the fat meter proposed in [5]. According to the structure of construction, this meter is single-channel. It includes a microwave generator, an adjustable attenuator and a double waveguide bridge. A transceiver antenna, a microwave detector and a recording device are connected to one of the arms of the bridge. A feature of the meter is the reciprocating movement of the antenna, formed by the crank mechanism. Due to the periodic movement of the antenna relative to the product line from the detector removes the voltage modulated by the frequency of movement of the antenna. The depth of voltage modulation is inversely proportional to the fat content of the product. The disadvantages of this device include the low accuracy of measurement due to the nonlinearity of the static characteristic, which is especially evident at low values of fat content. In addition, the presence of mechanical elements in the design of the fat meter significantly reduces its reliability.

The authors propose a food fat meter, which eliminates the shortcomings inherent in the above meters.

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In fig. 1 shows a functional diagram of the device developed by the authors, which improves the accuracy of measuring the fat content of food products.

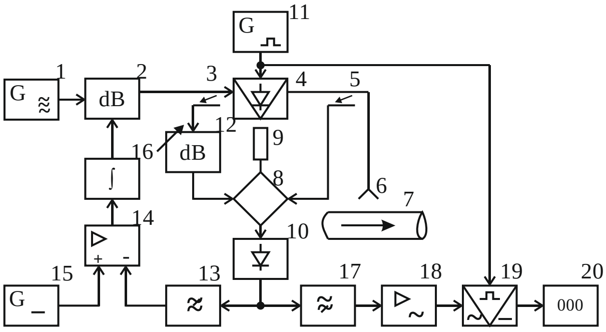

Fig 1. *Functional diagram of the food fat meter.*

Designations on the functional scheme of the meter of fat content of foodstuff: 1 - microwave generator; 2 - attenuator with adjustable gear ratio; 3, 5 - directional couplers; 4 - microwave switch; 6 - transceiver antenna; 7 - product pipeline; 8 - double waveguide bridge; 9 - agreed load; 10 - microwave detector; 11 - generator of rectangular pulses; - 12 adjustable attenuator; 13 low pass filter; 14 - differential amplifier; 15 - reference voltage source; 16 - integrator; 17 - high-pass filter; 18 - amplifier; 19 - synchronous detector; 20 - measuring device.

The food fat meter works as follows. The ultra-high frequency signal from the generator 1 through a series-connected adjustable microwave attenuator 2, a directional coupler 3, a public microwave switch 4 and a directional coupler 5 are fed to the transceiver antenna 6. The microwave oscillations emitted by the antenna are partially absorbed through the product. product line 7, and partially reflected from it. The reflected microwave oscillations are received by the antenna 7 and through the directional coupler 5 are fed to one of the inputs of the double waveguide bridge 8. Part of the oscillations is absorbed by the agreed load 9, and part is fed to the microwave detector 10.

The output voltage of the detector 10 can be represented as

$$U_1 = S_{10} K_2 K_5 K_8 \left(\rho_0 - \Delta\rho \right) P_0 , \qquad (1)$$

where: P_0- microwave power of the generator 1;

ρ_0- reflection coefficient from the defatted product;

$\Delta\rho$- change in the reflection coefficient, proportional to the amount of fat in the product;

K_2- transmission ratio of the adjustable attenuator 2;

K_5- the transmission factor of the directional coupler 5;

K_8- the transmission factor of the double waveguide bridge 8;

S_{10}- the sensitivity of the microwave detector 10.

The operation of the microwave key 4, made, for example, on the pin diode, is controlled by the rectangular voltage of the generator 11. Positive and negative pulses of the alternating voltage of the generator 11 open or close the pin diode of the microwave key 4. When the microwave diode is open When the microwave diode is closed, the oscillations are completely reflected from it and through the directional coupler 3 enter the adjustable microwave attenuator 12 and then fall on the other input of the double waveguide bridge 8.

The output voltage of the microwave detector 10 thus takes the value

$$U_2 = S_{10} K_8 K_{12} K_3 K_2 P_0 , \qquad (2)$$

where: K_{12} - the transfer factor of the adjustable microwave attenuator 12;

K_3- the transfer factor of the directional coupler 3.

When periodically opening and closing the key 4 with a low frequency at the output of the microwave detector 10, a sequence of video pulses with amplitudes U_1 and U_2 is formed. The constant component of the sequence of video pulses is described by the expression:

$$\begin{aligned} U_3 &= \frac{U_1 + U_2}{2} = \\ &= \frac{1}{2} S_{10} K_2 K_8 \left[K_5 \left(\rho_0 - \Delta\rho \right) + K_{12} K_3 \right] \end{aligned} . \qquad (3)$$

The generated voltage (3) is released by the low-pass filter 13 and is fed to one of the inputs of the differential amplifier 14. The other input of the differential amplifier receives the reference voltage from the source 15. The differential voltage of the differential amplifier 14 charges the integrator 16. The process of automatic adjustment of the transmission factor K_2 continues until the voltages at the inputs of the differential amplifier are equalized. In the established mode

$$U_3 = \frac{1}{2} S_{10} K_2 K_8 K_{13} \left[K_5 \left(\rho_0 - \Delta\rho \right) + K_{12} K_3 \right] = U_0 , \qquad (4)$$

where: U_0- DC voltage of the reference voltage source 15;

K_{13}- the transfer factor of the filter 13 low frequencies.

From the obtained equation (4) it follows that the transmission coefficient of the microwave attenuator 2 takes the value

$$K_3 = \frac{2U_0}{S_{10} K_9 K_{13} \left[K_5 \left(\upsilon_0 - \Delta\rho \right) - K_{12} K_3 \right]} . \qquad (5)$$

The variable component of the sequence of video pulses is described by the expression:

$$\begin{aligned} U_4 &= \frac{U_1 - U_2}{2} = \\ &= \frac{1}{2} S_{10} K_2 \left[K_5 \left(\rho_0 - \Delta\rho \right) - K_{12} K_3 \right] \end{aligned} . \qquad (6)$$

The generated voltage (6) is emitted by the high-pass filter 17, amplified by the amplifier 18 and rectified by a synchronous detector 19, controlled by the rectangular pulses of the generator 11. As a result, we obtain:

$$U_5 = K_{17} K_{18} U_4 , \qquad (7)$$

where: K_{17}- the transmission factor of the filter 17 lower frequencies;

K_{18}- the gain of the low frequency amplifier 18.

The variable component (7) U_4 taking into account the value of the transmission factor of the microwave attenuator 2 takes the form

$$\begin{aligned} U_4 &= \frac{2S_{10}K_8\left[K_5\left(\rho_0-\Delta\rho\right)-K_{12}K_3\right]U_0}{2S_{10}K_8\left[K_5\left(\rho_0-\Delta\rho\right)+K_{12}K_3\right]} = \\ &= \frac{K_5\left(\rho_0-\Delta\rho\right)-K_{12}K_3}{K_5\left(\rho_0-\Delta\rho\right)+K_{12}K_3}\frac{U_0}{K_{13}} \end{aligned}. \quad (8)$$

The scheme of the fat meter uses the same type of directional couplers of reflected oscillations 3 and 5. Therefore, we can assume that. The transmission $K_3 = K_5$ rate of the microwave attenuator 12 is set in the process of calibration for the defatted product and the absence of a variable component ($U_4 = 0$). This corresponds to the ratio $K_{12} = \rho_0$.

Given the latter, the voltage measured

$$U_5 = K_{17}K_{18}\frac{\Delta\rho}{2\left(\rho_0-\Delta\rho\right)}\frac{U_0}{K_{13}}. \quad (9)$$

If you choose filters 13 and 17 with the same transfer coefficients ($K_{13} = K_{17}$), then when the fat content of the product, for example, milk up to 10...12%, you can write:

$$U_5 = -K_{17}\frac{\Delta\rho}{\rho_0}\frac{U_0}{2}. \quad (10)$$

Thus, the output voltage (10) U_5 registered by the device 20 is proportional to the relative change of the reflection coefficient $\Delta\rho$ of microwave oscillations from the milk line. The registered voltage:

- does not depend on the level of microwave power generated (P_0), the sensitivity of the microwave detector (S_{11}) and the parameters of the measuring circuit (K_2, K_3, K_5, K_8);

- the effect of the thickness of the walls of the product line ρ_0 is taken into account when calibrating the meter with a corresponding change in the transmission rate of the microwave attenuator 12;

- the measurement result is determined not by the absolute change of the reflection coefficient ρ, but by its relative value, $\Delta\rho/\rho_0$ therefore the influence of temperature changes and other factors on the measurement results is significantly reduced.

CONCLUSION

1. The fat content of a product is estimated by the ratio of the amount of fat to the volume of the product and is a relative value. Therefore, the relative change in the reflection coefficient $\Delta\rho/\rho_0$ is associated with a linear relationship with the fat content of the product as a relative value. The zero readings of the measuring device correspond to the zero fat content of the product.

2. Experimental studies conducted with foods of different fat content (0,1...12%) at a microwave frequency of 10 GHz and a switching frequency of 1 kHz showed the following:

- linear dependence occurs in the range from 0,1 to 3% fat with an absolute measurement error of not more than 0,05%;
- in the range of 3...6% the error becomes slightly increased but does not exceed 0,1%;
- in the range of 6 ... 12% the methodical error from influence $\Delta\rho$ on ρ_0 in a denominator of expression (10) for tension U_5 the error increases to 0,2% is shown.

Changing the measurement limits in the considered scheme when measuring the fat content of other types of products is carried out by changing the gain K_{17} of the amplifier 17 without changing the main elements of the scheme.

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