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HIGH FREQUENCY METHOD AND DIGITAL TOOL FOR MEASUREMENT OF HUMIDITY OF HETEROGENEOUS DISPERSIVE DIELECTRICS

Method and tool for digital measurement of humidity of heterogeneous dispersive dielectrics, based on phase-shift of measuring signal relatively reference signal have been developed. Strip-line wave-guide is suggested as the sensor. The investigated sample is located on the surface of waveguide.

Key words: *humidity, phase-shift, strip-line asymmetric waveguide, statistic characteristic.*

Introduction

Increase of accuracy and rate of measurement of finished products humidity in processing branch of agro-industrial complex is one of the promising directions of products quality increase [1]. This problem is very actual in the sphere of dairy industry, particularly, in production of butter, the express-control at the stage of its production is complicated as result of the lack of primary measuring converters, having high operation rate, accuracy and reliability [2].

Taking into account the above-mentioned, the search of new methods of indirect measurement of butter humidity, having, as it was shown in [2], higher operation rate, as compared with direct methods, is promising direction of scientific research, and their successful implementation is promising direction of up-grading the equipment of dairy industry enterprises.

Problem set-up

As it follows from the analysis, performed in [2] the most promising from the point of view of express-measurement of humidity, are methods, connected with passing or reflection from controlled object electromagnetic radiation, with further measurement of phase-shift and attenuation of information wave as compared with reference wave. Simplification of the construction of primary converter is also an important problem. The converter, having the above-mentioned properties of sensors, based on electromagnetic radiation, should be invariant to the impact of non-informative parameters of the environment [3]. As while usage of asymmetric line wave- guide external environment is hardly overlapped by information wave [4], providing the possibility to neglect the influence of its parameters, then the application of such constructions is useful for creation of measuring converters of humidity. Proceeding from construction reasons, the most expedient is the usage of the given construction in the device, as information wave of metric wave band, that allows to neglect the influence of internal inductance of zig-zag like system of waveguide [5].

Taking into account the above-mentioned, it becomes obvious, that it is necessary to study in details the peculiarities of interaction of electromagnetic radiation of metric wave band with water and humid substances, that allows to use the obtained results for construction of humidity sensor. That is why, proceeding from the above-mentioned, carrying out of experimental research aimed at studying the impact of humidity on the parameters of electromagnetic radiation of 250 – 400 MHz frequency range and development of the structure of primary measuring converter, that would be able to use the peculiarities of this influence for obtaining reliable information, regarding the humidity of the controlled sample is very actual problem its results are of scientific and applied character

Analysis of the ways of problem solution

According to classical approach, transmission line with lumped parameters, which is strip line waveguide, used for construction of the above- mentioned sensor, can be presented in the form of simplified electric circuit, shown in Fig. 1 [6]

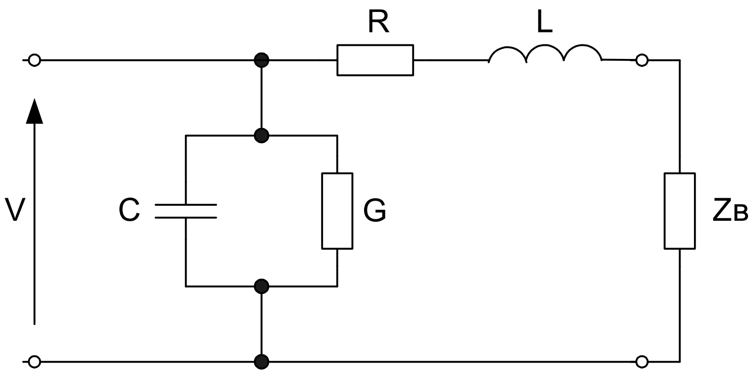

Fig. 1. Electric equivalent circuit of the waveguide

As it is shown in [6], values of P and L characterize losses and energy accumulation in metal conductor, G and C – are losses and energy accumulation in the material of dielectric.

Main feature of asymmetric strip line waveguide is that in case of correct choice of its parameters, only transversal magnetic waves can propogate in it, electromagnetic field structure of these waves is similar to the structure of the field of transversal electromagnetic wave [4]. Since part of electromagnetic field is propagated outside the limits of dielectric, located between the central conductor and the ground, then the conclusion can be drawn that parameters C and G will greatly depend on the structure of the substance, located on external surface of the central conductor. Proceeding form the above –mentioned, since characteristic feature of water is rather high refractive index, it would be logically to assume, that phase parameters of such wave will greatly depend on the humidity of the sample, located on the surface of such waveguide.

In this case, phase shift of initial wave can be determined with rather high accuracy, proceeding from the relation [6]:

$$\Delta\varphi = \omega (LC)^{1/2} \Delta x, \tag{1}$$

where ω – is angular frequency of wave, propagating in the waveguide; Δx – is the length of the waveguide.

Analyzing the expression (1) the conclusion can be drawn, that values ω, $L\ and\ \Delta x$ for the considered case are constant, and, hence, the given expression is the function of $\Delta\varphi = f(C)$ type. To confirm the hypothesis regarding considerable influence of sample humidity on the parameters of electromagnetic wave, experimental installation is suggested, its structural diagram is shown in Fig. 2.

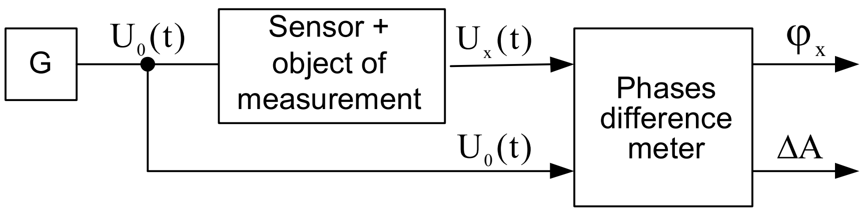

Fig. 2. Structural diagram of experimental installation

Measuring converter is asymmetric strip line waveguide, geometrical dimensions of the converter are shown in Fig. 3. Dielectric plate is made of glass-cloth-base laminate (electromagnetic permeability $\varepsilon = 5$, glass-cloth-base laminate thickness $h = 2\,mm$)

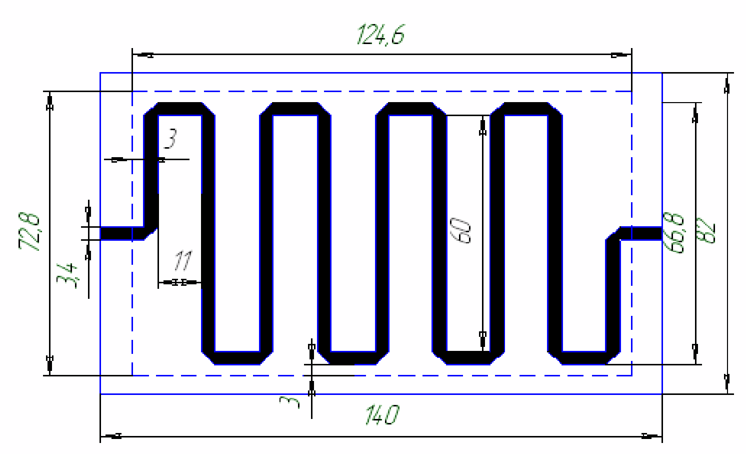

Fig. 3. Diagram of the waveguide

Correspondingly, total resistance of the waveguide by (1) [4] is:

$$Z_0 = \frac{120\pi}{\sqrt{\varepsilon}\cdot\frac{L}{h}\cdot\left(1+\frac{1{,}735}{\varepsilon^{0{,}0724}\left(\frac{L}{h}\right)^{0{,}836}}\right)} = 50\ (Ohm), \qquad (2)$$

where L – is the width of the waveguide (3,4 mm).

While studying the intensity of the attenuation and phase shift the following devices are used: phase difference meter «ФК2 – 12» and high-frequency signal generator «Г4 – 107» (initial voltage of the generator was recorded at the level $U_0(t) = 0{,}7(B)$)

The experiment was carried out in two stages within the range of electromagnetic waves frequency change 250 – 400 MHz.

At the first stage the characteristics of attenuation and phase shift were obtained for samples with the humidity of 100% and 50% (50% - distilled water, 50% - glycerin) and sample thickness 10 mm. As a result of the research the following results were obtained. They are shown in Fig. 4 and Fig. 5.

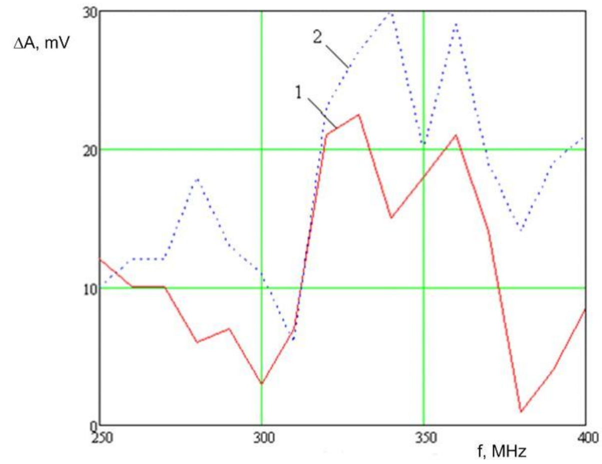

Fig. 4. Dependence of attenuation intensity of electromagnetic wave on the frequency:
1 – sample with 100% humidity;
2 –sample with 50% humidity (50% –distilled water, 50% – glycerin)

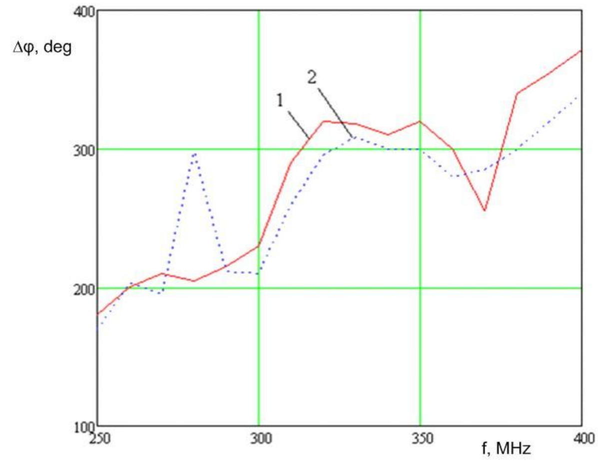

Fig. 5. Dependence of phase shift of electromagnetic wave on the frequency:
1 – sample with 100% humidity;
2 – sample with 50% humidity (50% –distilled water, 50% – glycerin)

At the second stage characteristics of attenuation and phase shift were obtained for the samples with $\approx 0\%$ (dried butter), 16,04%, 19,66%, 24,86%, 26,92% humidity. The thickness of the layer of each of the samples is 10 mm. As a result of the study, the results, shown in Fig. 6 and 7 were obtained.

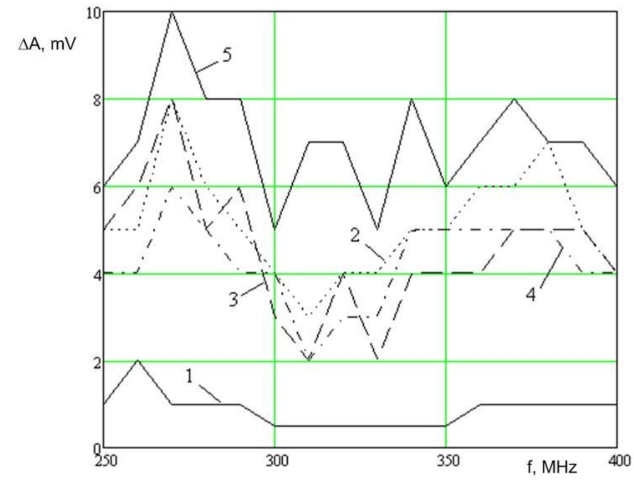

Fig. 6. Dependence of attenuation intensity of electromagnetic wave on the frequency:
1 – sample with 0% humidity;
2 – sample with 16,04% humidity;
3 – sample with 19,66% humidity;
4 – sample with 24,82% humidity;
5 – sample with 26,92% humidity

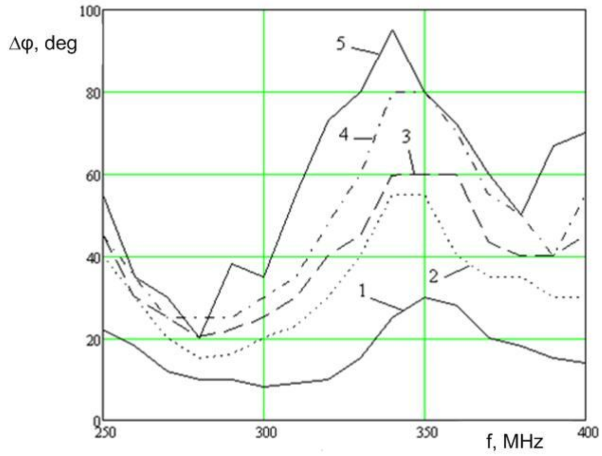

Fig. 7. Dependence of phase shift of electromagnetic wave on the frequency:
1 – зразка з 0% humidity;
2 – sample with 16,04% humidity;
3 – sample with 19,66% humidity;
4 – sample with 24,82% humidity;
5 – sample with 26,92% humidity

It follows, from the experimental results obtained, that usage of phase shifts provides the possibility to construct measuring converter, usage of wave attenuation parameter being not expedient, due to low sensitivity.

From the analysis of data, obtained while measuring of phase shifts for samples with various humidity (Fig. 6.), we can note distinctly expressed non-linearity of the function of sensor conversion. Since high sensitivity is observed not for all investigated frequencies, the most promising for the construction of the humidity sensor, are frequencies 290, 300, 310, 320, 330 and 340 MHz.

While approximation of the obtained data, applying the method of least squares, the following results are obtained by the polynomials of the first ($y = a[0] + a[1] \cdot x$) and the second ($y = a[0] + a[1] \cdot x + a[2] \cdot x^2$) orders for the above-mentioned frequencies. The results are presented in Table 1.

Table 1

Results of experimental data approximation

Frequency of information wave, MHz	Polynomial of the first order	Sum of the squares of polynomial of the fist order deviation	Polynomial of the second order	Sum of the squares of polynomial of the second order deviation
290	$a[0] = 7{,}167$ $a[1] = 0{,}86$	108,29	$a[0] = 10{,}128$ $a[1] = -0{,}489$ $a[2] = 0{,}052$	38,54
300	$a[0] = 6{,}874$ $a[1] = 0{,}956$	12,67	$a[0] = 8{,}011$ $a[1] = 0{,}439$ $a[2] = 0{,}02$	2,39
310	$a[0] = 5{,}443$ $a[1] = 1{,}427$	211,82	$a[0] = 9{,}273$ $a[1] = -0{,}317$ $a[2] = 0{,}067$	95,17
320	$a[0] = 5{,}289$	338,13	$a[0] = 10{,}318$	137,02

	$a[1]=1{,}996$		$a[1]=-0{,}294$ $a[2]=0{,}088$	
330	$a[0]=10{,}672$ $a[1]=2{,}135$	255,3	$a[0]=15{,}386$ $a[1]=-0{,}012$ $a[2]=0{,}083$	78,54
340	$a[0]=20{,}906$ $a[1]=2{,}407$	191,7	$a[0]=25{,}31$ $a[1]=0{,}402$ $a[2]=0{,}077$	37,47

Statistic characteristics of the converter for each of the mentioned frequencies are given in Fig. 8 and Fig. 9.

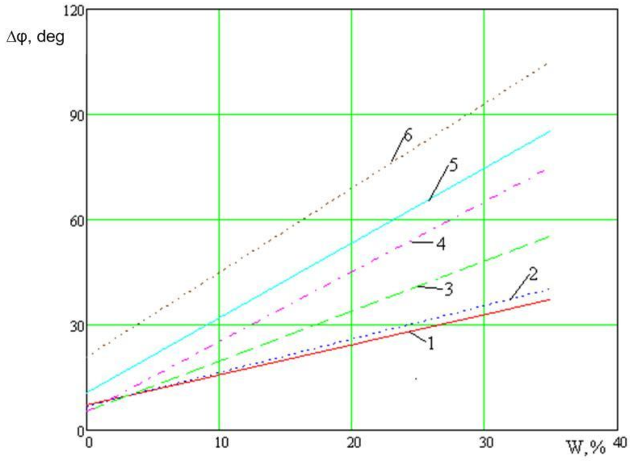

Fig. 8. Static characteristics of the sensor at approximation of the results by polynomial of the first order:
1 – for the frequency of information wave 290 MHz;
2 – for the frequency of information wave 300 MHz;
3 – for the frequency of information wave 310 MHz;
4 – for the frequency of information wave 320 MHz;
5 – for the frequency of information wave 330 MHz;
6 – for the frequency of information wave 340 MHz

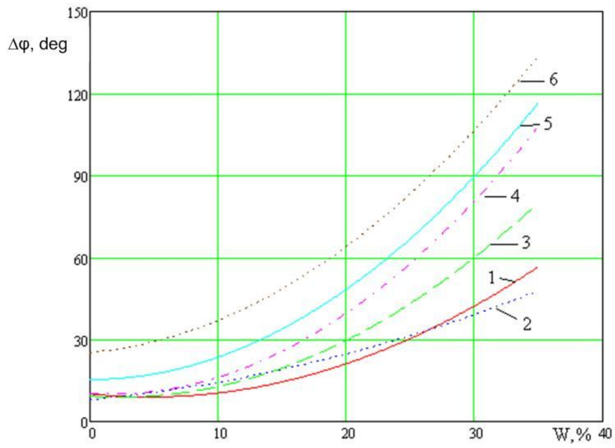

Fig. 9. Static characteristics of the sensor at approximation of the results by polynomial of the second order:
1 – – for the frequency of information wave 290 MHz;
2 – for the frequency of information wave 300 MHz;
3 – for the frequency of information wave 310 MHz;
4 – for the frequency of information wave 320 MHz;
5 – for the frequency of information wave 330 MHz;
6 – for the frequency of information wave 340 MHz

Correspondingly , analyzing the obtained sums of deviation squares, the conclusion can be drawn, that the most promising in the given range is the wave frequency of 300 MHz. But the drawback of its usage is that it is impossible to measure phase shift, using standard digital channel of phase difference, due to withdrawal of the given frequency, and signal quantizing signal over the upper limit of bandwidth of existing digital circuits.

Proceeding from this, it is expedient to apply special high frequency digital channels, providing the possibility to measure phase difference of metric waves with rather high accuracy. As a result of combination of such channel with the developed sensor, the time of measurement equals approximately double duration of input wave, and the error at the frequency of input wave from 5 to $5{*}10^8$ does not exceed:

$$\Delta \le (0{,}1 + 10^{-7} f)^0, \qquad (3)$$

where f – is the frequency of input wave.

On the basis of the above-mentioned, strip line meter of humidity was developed, its structural diagram is shown in Fig. 10.

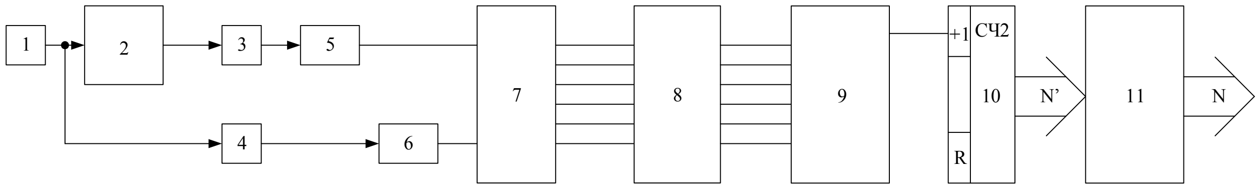

Fig. 10. Structural diagram of strip line meter of humidity

The given device comprises: 1 – 300 MHz generator of electromagnetic waves, the output of the generator is connected with the input of primary measuring converter 2 and the second shaper 4; 2 – the above-described sensor, output of which is connected with the input of the fist shaper 3; 3, 4 – first and second shapers, outputs of which are connected with inputs the first 5 and second 6 pulse filters, correspondingly; 5, 6 – are the first and the second pulse filters, outputs of these filters are connected with the first and the second inputs of phase intervals shapers 7; 7 – is the shaper of phase intervals outputs of which are connected with the inputs of quantization unit 8; 8 – is quantization unit, output of which are connected with the inputs of the element of dynamic summation 9; 9 – is the element of dynamic summation, output of which is connected with the input of binary counter 10; 10- is binary counter, outputs of which are connected with the inputs of numerical converter 11; 11 – is numeric converter.

Principle of operation of humidity meter is the following: signal of 300 MHz frequency is sent from the generator 1 to the input of primary measuring converter 2 and the second shaper Passing across measuring converter 2, information parameter $U_1(t)$, depending on the humidity, is shifted by phase relatively reference signal $\mathrm{U}_0(\mathrm{t})$ on phase difference:

$$\Delta\varphi = \varphi_0 - \varphi_1 = a_1 + a_2 \cdot W + a_3 \cdot W^2,$$

where W – is humidity of the sample; φ_1 – is the phase of information wave ; φ_0 – – is the phase of reference wave; a_1, a_2, a_3 – are constant coefficients.

From output 2 the signal is sent to the input of the first shaper 3.

At the output 3 and 4 rectangular pulses are formed, front and cut of these pulses are bound to zero –transitions of input signals, from the output of shapers 3 and 4 arrive at the first 5 and 6 second pulse filters, by means of which exclusion of error, caused by the transition across zero-level of signal voltage at the input of the shaper at the moment of time, that corresponds to zero transitions of input signal, is realized. The reason of this error is bandwidth noise in the input signal and generation of additional bandwidth noise in the input stage s of shapers.

Filtered signals from the output of pulse filters 5 and 6 are sent to the inputs of phase intervals shaper 7, intended for formation of four phase intervals, representing pulses of positive polarity, duration of which is proportional to phase shift, being measured, and frequency equals half of the frequency of the input signal.

Besides, two correction intervals are formed in 7,they are pulses of positive polarity, their duration is proportional to delay time of signals in 5 and 6, frequency equals double frequency of the signal.

Four phase intervals and two correction intervals are sent from the outputs 7 to the input of quantizing unit 8, where they are filled with quantizing pulses, i.e., six pulse sequences and correcting intervals are formed.

Total number of pulses of all sequences, arriving at the inputs of the element of dynamic summation 9 during measuring cycle equals proportional phase shift between information and reference signals, i.e., it is described by the following transformation equation: $N = S_\varphi \cdot \Delta\varphi$.

In the element of dynamic summation 9 combining of six pulse sequences of phase and correcting intervals in one pulse sequence is performed, the total number of pulses remains the same.

From the output of dynamic summation element 9, the signal is sent to binary counter 10, where consecutive counting of signals during one measurement is carried out. After that, the obtained binary code from counter 10 output arrives at the input of numerical converter 11, where, applying transformation equation $N = S_{\varphi} \cdot (a_1 + a_2 \cdot W + a_3 \cdot W^2)$, we obtain measured value of the humidity.

Conclusions

1. It was established experimentally, that construction of measuring converters in frequency range of 250 – 400 MHz is possible only on the basis of conversion of humidity in phases difference, because the conversion of the humidity into voltage is characterized by non-admissible law sensitivity for its practical realization.

2. It is shown, that dependence of phase difference on the humidity has monotonously growing non-linear character.

3. It has been proved, that for the construction of primary measuring converter it is necessary to choose the frequency of information wave 300 MHz, as at the given frequency we observe not only monotonous growth of phase difference at the growth of sample humidity, but minimum sum of squares of experimental values deviations from polynomial of the second order, determined by applying the method of least squares takes place.

4. As one of the examples of practical realization of humidity measurement device, the basis of which is the method of humidity conversion into phase difference of electromagnetic wave, digital strip line meter is suggested.

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