A HIGH SENSITIVE MICROWAVE MEASURING DEVICE OF THE MOISTURE CONTENT IN THE NON-POLAR DIELECTRIC LIQUIDS BASED ON AN INHOMOGENEOUS STEP COAXIAL RESONATOR

Introduction. Measuring the moisture content of the nonpolar liquid dielectrics is important for many practical applications, such as: electrical engineering, chemical industry, food industry, in the military and aviation equipment. So, for the electrical equipment is important to determine the moisture content of transformer oil, chemical and food industry – determination of moisture content in a variety of mineral oils, for the military and aviation equipment – determination of moisture content in diesel, aviation fuel. In most of the areas studied fluid (transformer and sunflower oils, diesel and jet fuel, etc.) are nonpolar liquid dielectrics.

It should be noted that the lower limit of the moisture content measurements in all of these applications is very low: the minimum value of the measured volumetric water content is not more than 10^{-3} \% which creates difficulties for conventional measurements of these known methods. Traditional methods such as Karl-Fischer method and liquid-chromatographic method requires special equipment rather expensive consumables and quite a long time.

The goal of the work is development of a meter moisture content in non-polar liquid dielectrics with a lower limit of volumetric water content not more than 10^{-3} \% allowing to quickly perform measurements with a minimum of material and time costs.

Substantiation of ways to solve the defined problem. To solve this problem dielectric method of measuring the moisture content was chosen based on the moisture content depending on the dielectric constant study watered nonpolar liquid dielectrics [1]. The measured dielectric constant which is proportional to moisture content, characterizes the water content value itself.

To the improvement of this method in [2] a simplified model of the emulsion «water – non-polar dielectric» is proposed that allowed simply to determine...
the amount of volumetric water content in the mixture $W$ as a function of dielectric permittivity $\varepsilon_2$ mixture and dehydrated nonpolar liquid $\varepsilon_1$ in the following form:

$$W = \frac{\varepsilon_2 - \varepsilon_1}{3 \cdot \varepsilon_1}. \quad (1)$$

In [3] it is proposed the use of the resistance method for determining dielectric permittivities $\varepsilon_1$ and $\varepsilon_2$ implemented for the measuring transducer (MT) of the capacitive type, to be filled successively and dehydrated liquid test mixture (emulsion). Thus MT connected to the capacitive measuring generator (MG) contains the amplification circuit and the feedback coil [3]. Unknown values $\varepsilon_1$ and $\varepsilon_2$ are expressed in four frequency values MG generation (frequency of MG with disconnected MT, frequency of MG with MT filled with air, frequency of the MG with MT filled with dehydrated test liquid, and frequency of the MG with MT filled with test mixture), and the values of design parameters of MT. This approach allowed in the MG frequency range from 100 kHz to 2 MHz practically solve the problem of determining the moisture content of the non-polar dielectrics in the range of 0.1% $\leq W \leq$ 10%. However, using at this approach of MG and MT systems in the form of lumped elements (a coil for the IG and a measuring capacitor for MT) which had the parasitic parameters are not allowed to fully realize the potential of the resonance dielectricometry to measure extremely low levels of moisture content [3].

The analysis shows that the main directions of improving the sensitivity of the proposed in [3] dielectricometry resonance method are as follows: increase in operating frequency of measurement, minimizing the parasitic capacitance of the inductive element of the MG and MT, increased frequency stability of MG generation in all four modes, the maximum reduction in the number of measured frequencies.

For the implementation of indicated directions by the authors MT with distributed parameters has been proposed as a step inhomogeneous coaxial resonator (SICR) [4]. Here, SICR resonance spectra were investigated in the frequency range up to 1.8 GHz. As a result of investigations carried out in [4] significant advantages of MT performed as SICR have revealed as compared to a MT with lumped parameter and compared with known MT of microwave range as quarter-wave homogeneous resonators.

Further development of the theory of SICR application in resonant dielectricity of nonpolar liquid media was developed in [5] which held as a mathematical analysis of electromagnetic processes in SICR and their simulation in Micro Cap environment. The result of these studies was to optimize for SICR for dielectric goals and the definition of its metrological characteristics. Based on the above, the following methodology for the design of the meter was adopted:

1. The moisture content of the mixture is determined by the difference of the dielectric permittivities of the dehydrated liquid and mixture.

2. To determine the dielectric permittivities IT as SICR is connected to and alternately filled by dehydrated liquid and mixture.

3. The operating frequency of MG is selected as maximal possible taking into account the frequency dispersion of the dielectric permittivity of water.

4. SICR and MG have minimum values of parasitic parameters, which reduces the number of frequency measurements from four to two and reduce the experimental time by 2 times.

5. In order to improve the stability of the frequency generated by the MG, the MT is designed as a system with distributed parameters: SICR which has a substantially higher $Q$ than the lumped system «MT – MG».

Description of the meter. A flowchart of the meter is shown in Fig. 1. Used MT converter, in the form of SICR, is connected to the MG. The MG frequency generation is measured by a frequency meter $F$, and the temperature of the MT – by an electronic thermometer $T$.

![Fig. 1. Flowchart of the meter](image)

Schematic diagram of the meter (MT together with MG) is shown in Fig. 2. Its MT transducer as SICR formed as two coaxial lines $Z_1$ and $Z_2$ of equal length with different wave impedances $Z_1 = 77.61 \, \Omega$, $Z_2 = 4.09 \, \Omega$. Using inductive loop of communication $A$ transmitter is connected to the MG on the transistors Q1, Q2 which are collected by the scheme «common base» (at the MG output) – «common collector» (at the MG input).

This circuit solution of MG is selected to minimize the effect of parasitic MG parameters on the parameters of MT (cascade with «common base» has a maximum output impedance and cascade with «common collector» has maximum input impedance). The signal from the emitter follower transistor Q2 is input (emitter) of the amplifying stage transistor Q1 on, the output of which is connected to the MT communication via an inductive loop $A$. The output of the MG through «isolation» amplifier transistor Q3 is input to a digital frequency divider U3, which is included under the scheme divider into 80. The output of the frequency divider through a «decoupling» emitter follower transistor Q4 signal is fed to a frequency. For maximum stability, it MG frequency generating stages (Q1 – Q3) and digital stages (U3, Q4) are fed from different linear regulators U1 (9) and U2 (5 V) voltage, respectively.
Structurally, MT together with MG is a collapsible system, the bottom of which is MT and at the top – MG. In the lower part of the MT test liquid is supplied which after filling its entire volume goes to the drain. General view and the view with the cover removed measuring moisture content is shown in Fig. 3. In this constructive execution of MT and MG the MT operation is possible both in stationary mode and a test liquid flow mode. Furthermore, this design provides the IG minimize the effects of parasitic resonance frequency parameters to MT (which is determined by the geometrical dimensions of the lines Z1 and Z2 and the magnitude of test liquid dielectric constant) due to the following factors:

1. The values of the coupling coefficient of the equivalent oscillating circuit formed by lines Z1 (inductive element) and Z2 (capacitive element) with MT does not exceed 0.08. Therefore, the parasitic parameters of the IG, the MG which are introduced in the loop, do not exceed in magnitude \((0,08)^2 = 0.0064\). In combination with high input impedance values (for Q2) and output (for Q1) is part of an IG ensures high quality of the oscillatory system and a small influence on the frequency of the MG meter generation.

2. Place of the connection of inductive loops A, as close as possible to the point of the oscillating system, which has zero potential. This fact provides a minimum distortion of the longitudinal electric field in SICR.

3. Mechanical fixation of the central electrode line Z1, the value of parasitic capacitance provides MT is almost zero, which also helps improve the accuracy of the proposed measuring moisture content.

The described meter has the following main characteristics:

1. The frequency generation of MG with MT filled with air, about 158 MHz.
2. The frequency generation of MG with MT filled with transformer oil, about 104 MHz.
3. The sensitivity of the meter – no worse than 1 cm³/m³.
Results of experimental investigations. To confirm the correctness of the chosen design and technical solutions of the MG and MT pilot studies were carried out in two stages.

In the first stage using the meter amplitude-frequency characteristics (AFC) of the type X1 – 42 studied the resonance characteristics of IT filled with air, and IT filled with dehydrated transformer oil.

The block diagram on which the moisture meter investigated to determine the AFC is shown in Fig. 4.

Fig. 4 shows: 1 – 42 meter AFC X1 (at the top – measuring part; at the bottom – generating part); 2 – IT; 3 – Inductive loop; 4 – the medium under study; 5 – high-resistance (external) input X1 – 42; 6 – output X1 – 42 (50 Ω).

Here, for removing reaction the meter X1 – 42 in the AFC output X1 SP – 42 was agreed by 50 Ω resistor, and to increase the input impedance a series with the input the 100 kΩ – 0.5 pF chain was included.

Results of IT investigations as MT AFC are shown in Fig. 5-8. The resulting AFC have been deciphered for the purpose of determining the value of the loaded Q of the measuring transducer. Loaded Q (MT is loaded on 50 Ω) is determined using 2ΔF value (AFC width at 3dB) and F (central resonance frequency).

As the results of processing with accuracy up to 5% loaded Q value of MT with air (Q₁, F₁) and with transformer oil (Q₂, F₂) are practically the same indicating a weak influence of oil on Q of MT:

\[ Q_1 = \frac{F_1}{2\Delta F_1} = \frac{160 \cdot 10^6}{2 \cdot 10^5} = 80; \]
In the second stage of the experimental studies were identified value of volumetric moisture content of the prepared mixtures «transformer oil – water» in the moisture content range \((10 – 10^5) \text{ cm}^3/\text{m}^3\). In the course of experiments with micro-stamps «Hamilton» in pre-dehydrated oil of volume \((500 \pm 0.6) \text{ cm}^3\) was injected the required amount of water. Thereafter, the homogeneous emulsion was prepared with the desired moisture content.

Thus, when the concentration of moisture in the prepared emulsion \(W_0 = 10 \text{ cm}^3/\text{m}^3\) the measured value of the moisture content is \(W = 9.51 \text{ cm}^3/\text{m}^3\) and the value of \(\Delta W = 0.5 \text{ cm}^3/\text{m}^3\) that enables measurement of moisture content in the range \(10^{-3} \% < W < 0.1 \%\) with a relative error (defined as the difference in moisture content of the emulsion prepared and measured divided by the moisture content of the cooked) is not more than 5.2%.

Analysis of the experimental results shows that the created meter is characterized at determining the moisture content by a relative error less than 6.7% in the range \(10 \text{ cm}^3/\text{m}^3 < W < 10^2 \text{ cm}^3/\text{m}^3\).

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