INOVATION IN POLYMER NANOCOMPOSITES

Dielectric spectroscopy of bio-based nanocomposites dielectric materials (Event–Public)

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New methods for estimating the moisture content of the solid component of power transformers

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1. Introduction

Cellulose impregnated with insulating oil has been the dominant insulating material for power transformers for about a hundred years.

Immediately after transformer manufacture, the water content of cellulose does not exceed, as a rule, 0.8 % by weight.

During many years of operation, the moisture content gradually increases. Once the critical value of the moisture level of about 5 % by weight is exceeded, transformer failure can occur.

One of the causes of transformer failure can be the so-called "bubble effect" causing rapid evaporation of water and dissolved gases, thus leading to rising pressure in the transformer vat.

This means that, especially in older transformer units, the moisture content of the cellulose insulation should be carefully estimated.

2. Cellulose-Oil Insulation

The basis for diagnostics of transformer insulation by the *Frequency Domain Spectroscopy method* (FDS method), including estimation of the water content of the solid component, is the tangent of the loss angle. For a system with homogeneous insulation, it is described by the formula:

$$tg\delta = \frac{1}{\omega R_p C_p}$$

The transformer isolation system is a complex series-parallel cylindrical capacitor. CIGRE has replaced this arrangement with a flat capacitor model in which the dividers, oil channel and barriers are in series-parallel connection.

2. Cellulose-Oil Insulation

XY CIGRE Model:

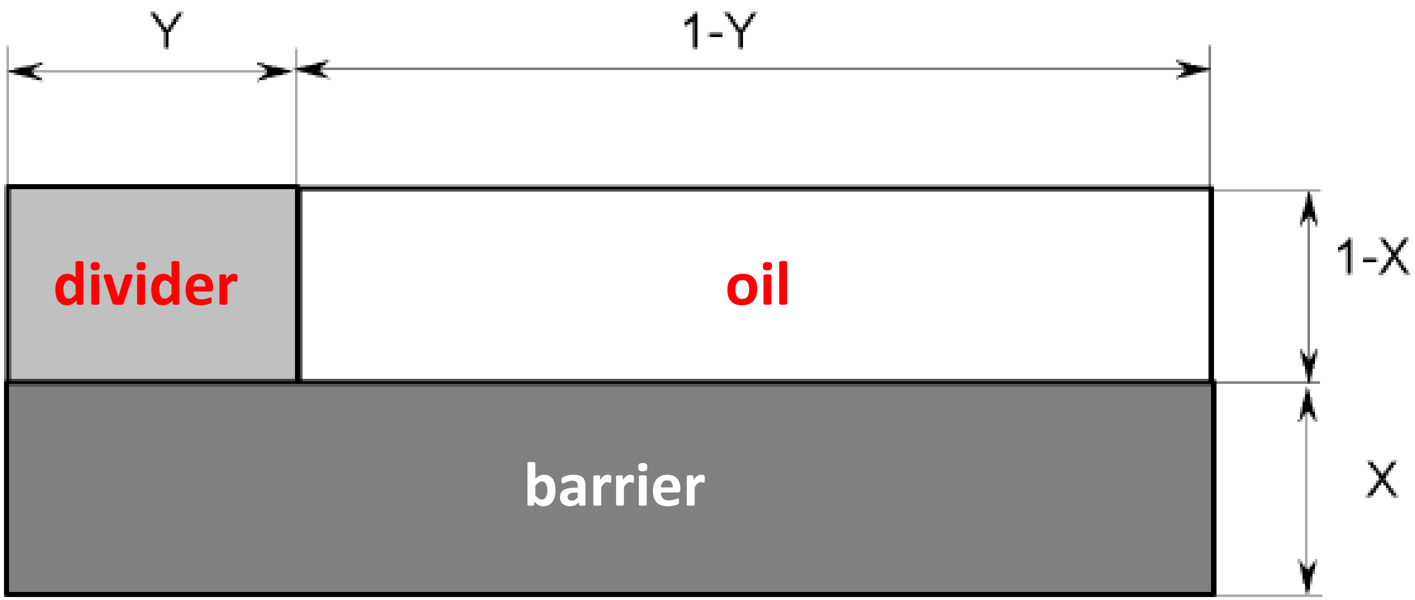


Fig. 2. Paper-oil insulation of the transformer – XY CIGRE model

2. Cellulose-Oil Insulation

The **resistances** and **capacitances** of the **barriers and dividers** are functions of the XY parameters of the CIGRE model and the conductivity and permittivity of the impregnated electrotechnical pressboard.

$$R_B = f(\sigma_p, X, Y)$$
$$C_B = f(\varepsilon_p, X, Y)$$

The **resistance** and **capacitance** of the **oil channel** are functions of the XY parameters of the CIGRE model and the conductivity and permittivity of the oil.

$$R_K = f(\sigma_o, X, Y)$$
$$C_K = f(\varepsilon_o, X, Y)$$

It follows that the tangent of the loss angle of transformer insulation is a function of **six variables** – the conductivity of the pressboard and oil, the permittivity of the pressboard and oil, and the XY parameters.

2. Cellulose-Oil Insulation

Based on the world literature and our research, it can be concluded that the presence of an oil channel significantly degrades the quality of moisture content determination.

The negative effects of the inclusion of the oil channel may be related to the difference between the actual activation energy of the conductivity of the insulating oil and the energy value assumed in the software of Dirana analizer.

2. Cellulose-Oil Insulation

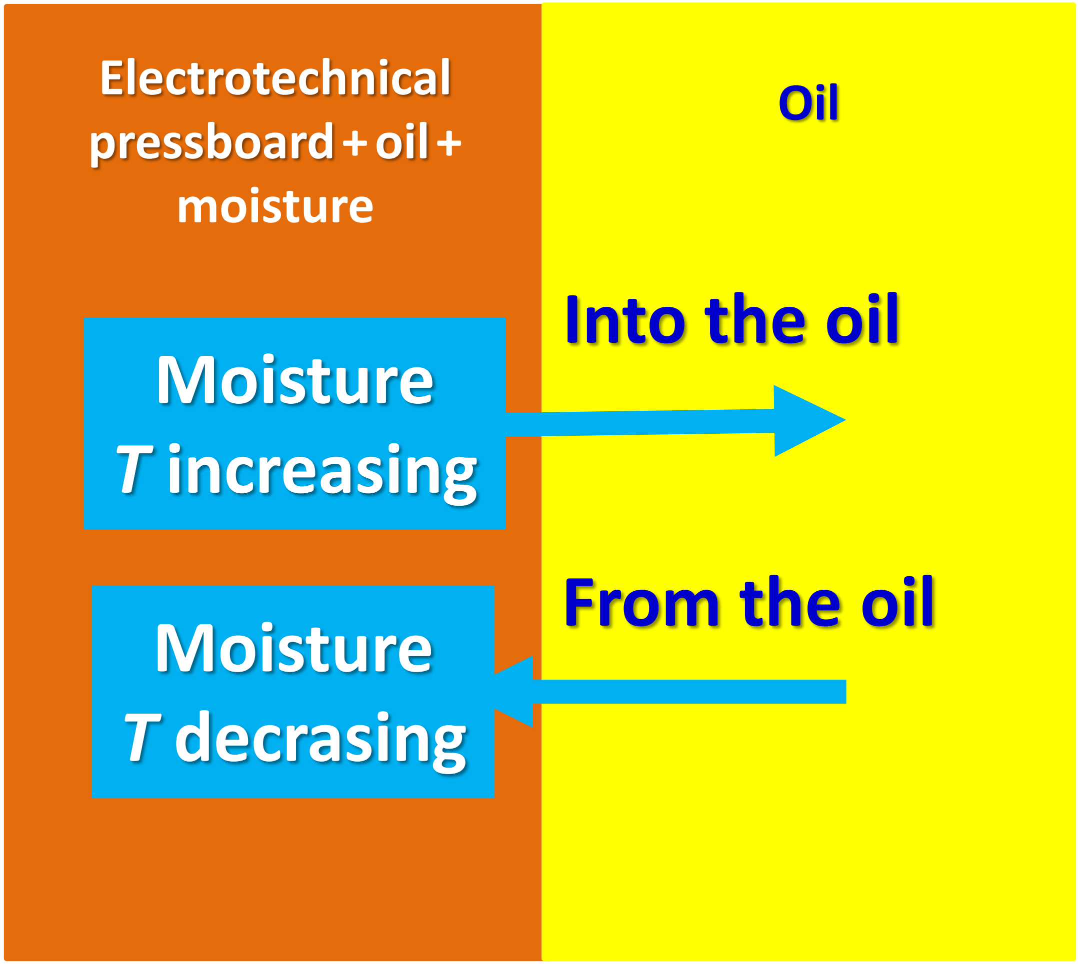


Fig. 4. Moisture exchange between the electrotechnical pressboard and oil with temperature of insulation changes

2. Cellulose-Oil Insulation

Therefore, change of the temperature changes the oil's resistivity in two ways.

1. Normal temperature change in resistivity of insulating materials:

$$\rho = \rho_0 \exp\left(\frac{\Delta W}{kT}\right)$$

2. Migration of water from the pressboard to the oil when the temperature increases, and the migration of water from the oil to the pressboard when the temperature decreases (*T.V. Oommen's rule*).

3. Sensor and method for determining moisture in the solid component of cellulose-oil insulation of a power transformer

How to get rid of the negative effect of the oil channel on the accuracy of moisture determination using Dirana software?

3. Sensor and method of determining moisture content

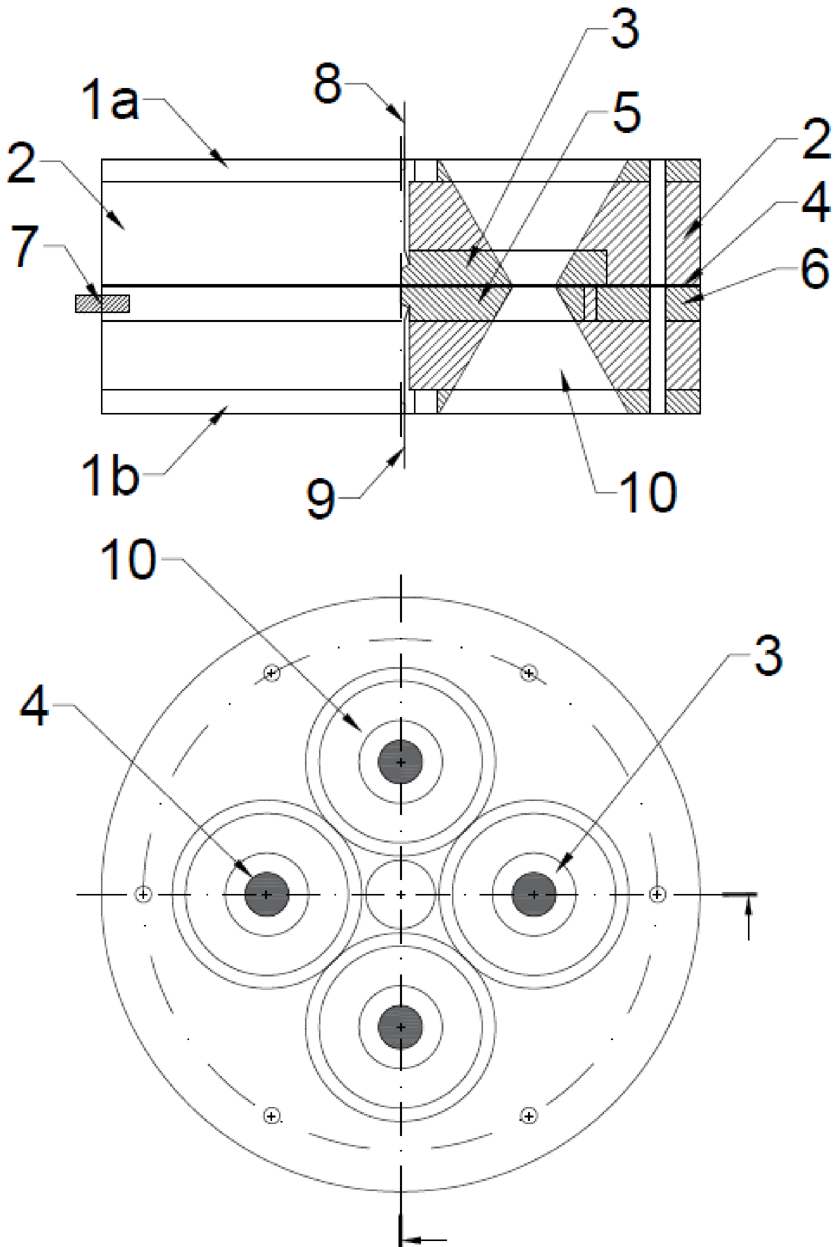


Fig. 5. Cross-section of the electrotechnical pressboard moisture sensor:

1a – upper couver

1b – bottom couver

2 – insulator

3 – voltage electrode

4 – electrotechnical pressboard plate

5 – measuring electrode

6 – protective electrode

7 – temperature sensor

8 – voltage wire (cable)

9 – measuring wire (cable)

10 – holes

3. Sensor and method of determining moisture content

In order to accurately determine the moisture content of impregnated pressboard and diagnose transformer insulation, a number of different electrical parameters should be used and analysed. These include:

- ***Impedance*** and ***phase shift angle***
- ***DC*** *and* ***AC conductivities*** and associated ***lossiness***
- ***Permittivity***
- ***Tangent of the loss angle***

3. Sensor and method of determining moisture content

An increase in resolution to 6 points in the range of 100 µHz to 1 mHz and to 10 points per decade in the range of 1 mHz to 5 kHz was used to precisely determine the frequency-temperature **reference characteristics**.

Measurements were made at 6 measurement temperatures from the transformer's operating temperature range.

For the AC parameters, the frequency for which there are significant changes in the parameter depending on the moisture content was selected from the frequency dependence obtained for different temperatures.

On this basis, 7 patent applications have been filed with the Polish Patent Office under the title "*Sensor and method for determining moisture content in the solid component of cellulose-oil insulation of a power transformer".*

In each of the patent applications, a histogram is presented, including the dependence of one of the above-mentioned DC and AC parameters on moisture content and insulation temperature.

3.1. DC resistance

Read from the sensor

$R_{DC}=4\times10^{10}\ \Omega$

$T=50°C$

Moisture content read from the relationship

1.5 % by weight

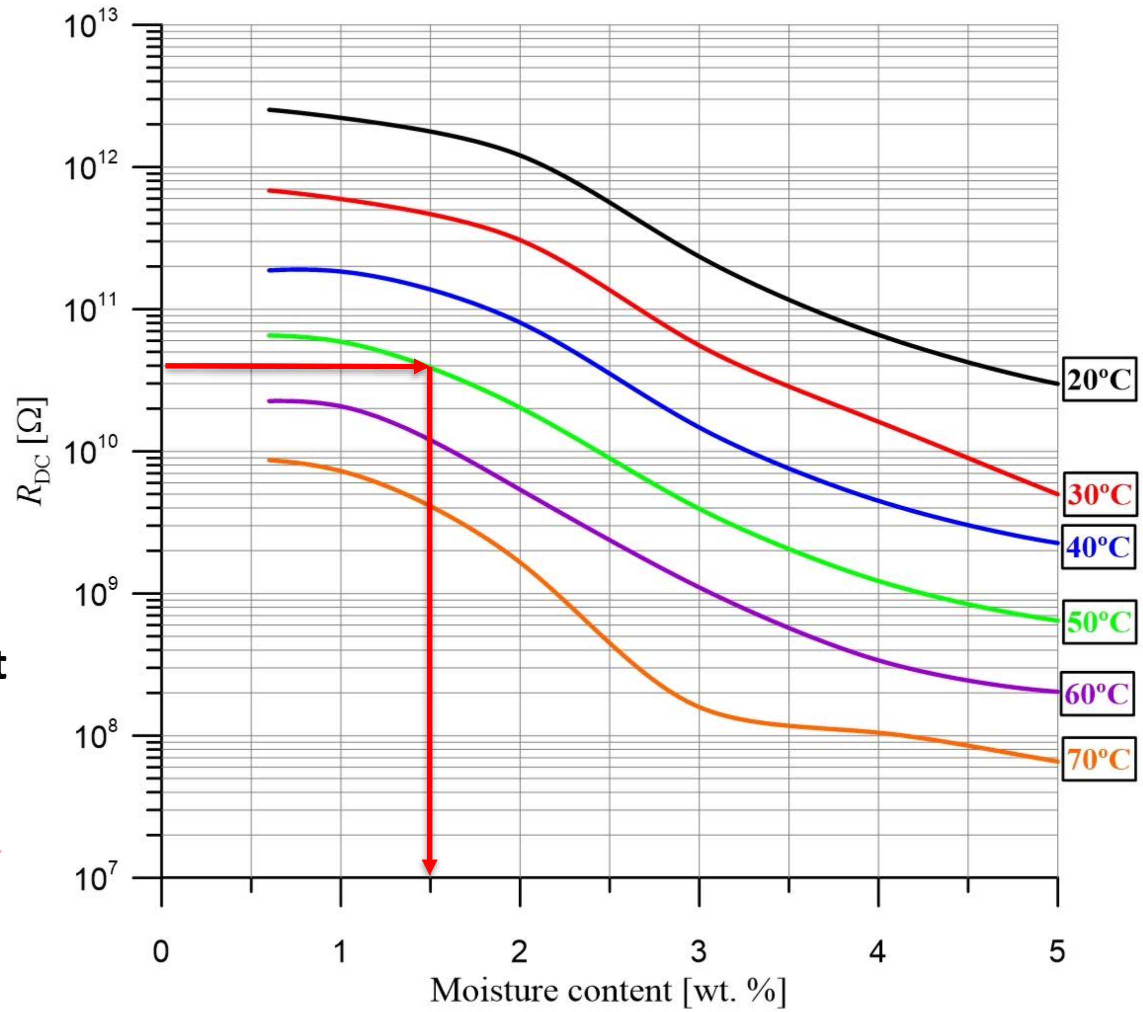


Fig. 6. Histogram of the dependence of the DC resistance of the sensor on the moisture content of the pressboard for temperatures from 20 °C to 70 °C.

3.2. Phase shift angle

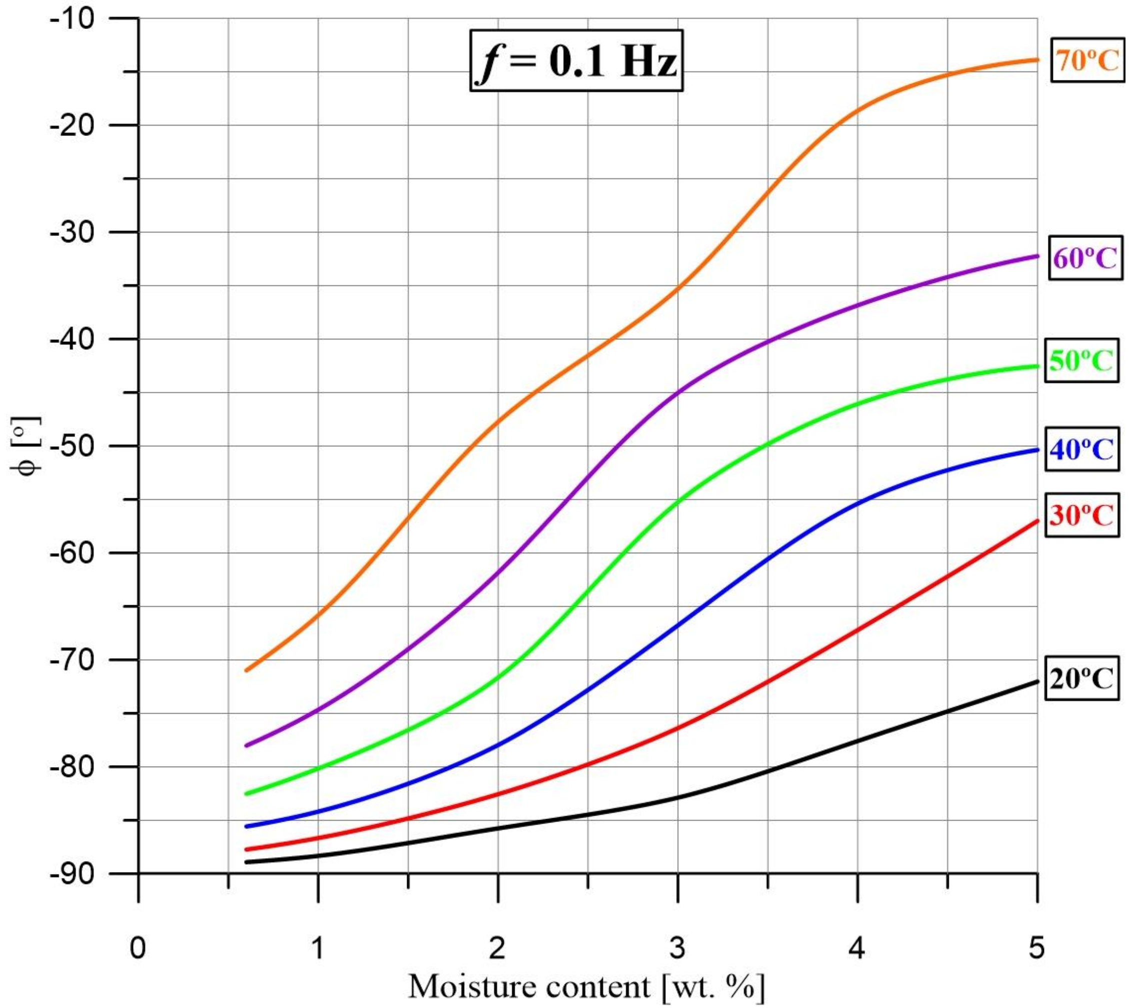


Fig. 7. Histogram of the dependence of the phase shift angle of the sensor on the moisture content of the pressboard for temperatures from 20 °C to 70 °C. Measurement frequency of 0.1 Hz.

3.3. Impedance

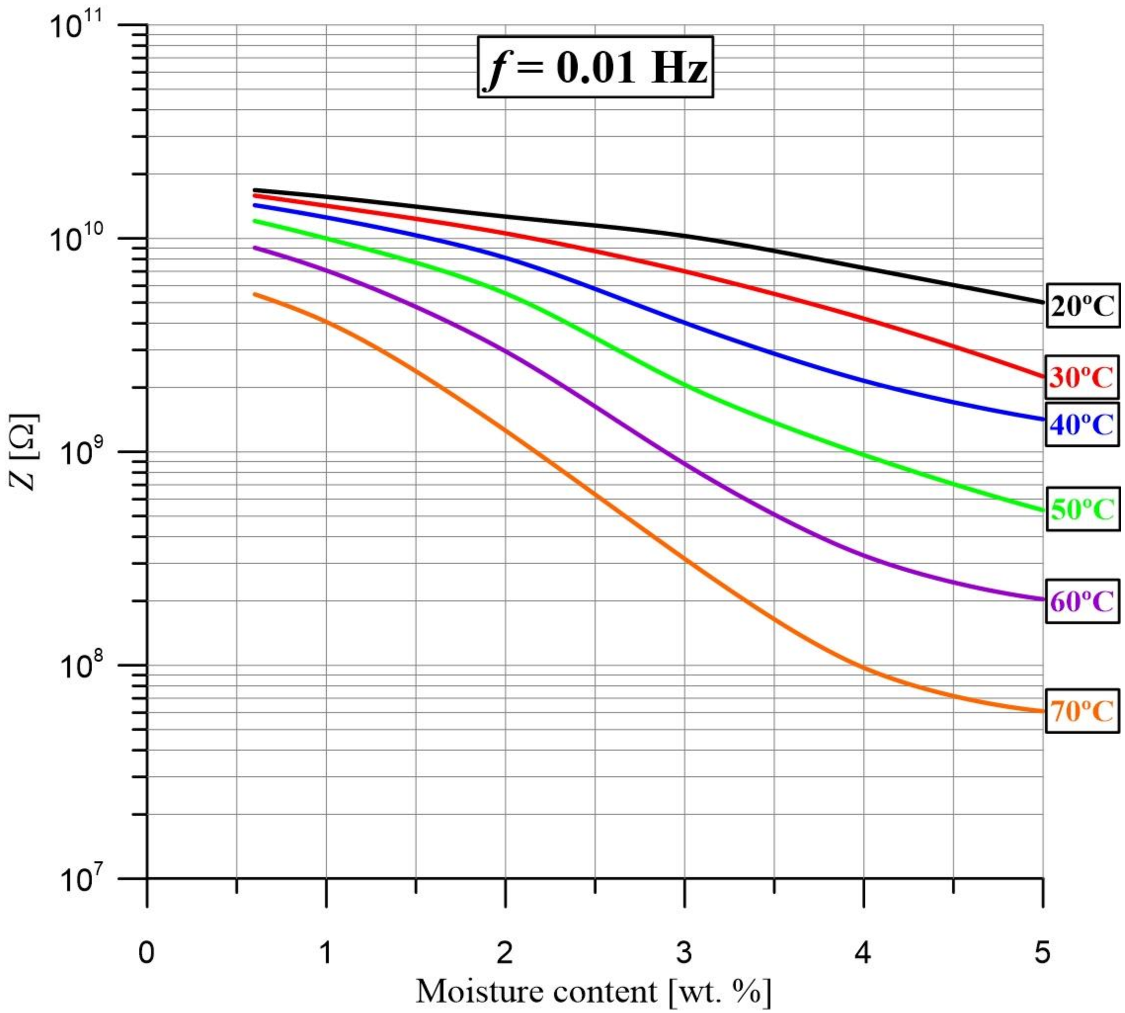


Fig. 8. Histogram of the dependence of impedance of the sensor on the moisture content of the pressboard for temperatures from 20 °C to 70 °C. Measurement frequency of 0.01 Hz.

3.4. Real capacitance

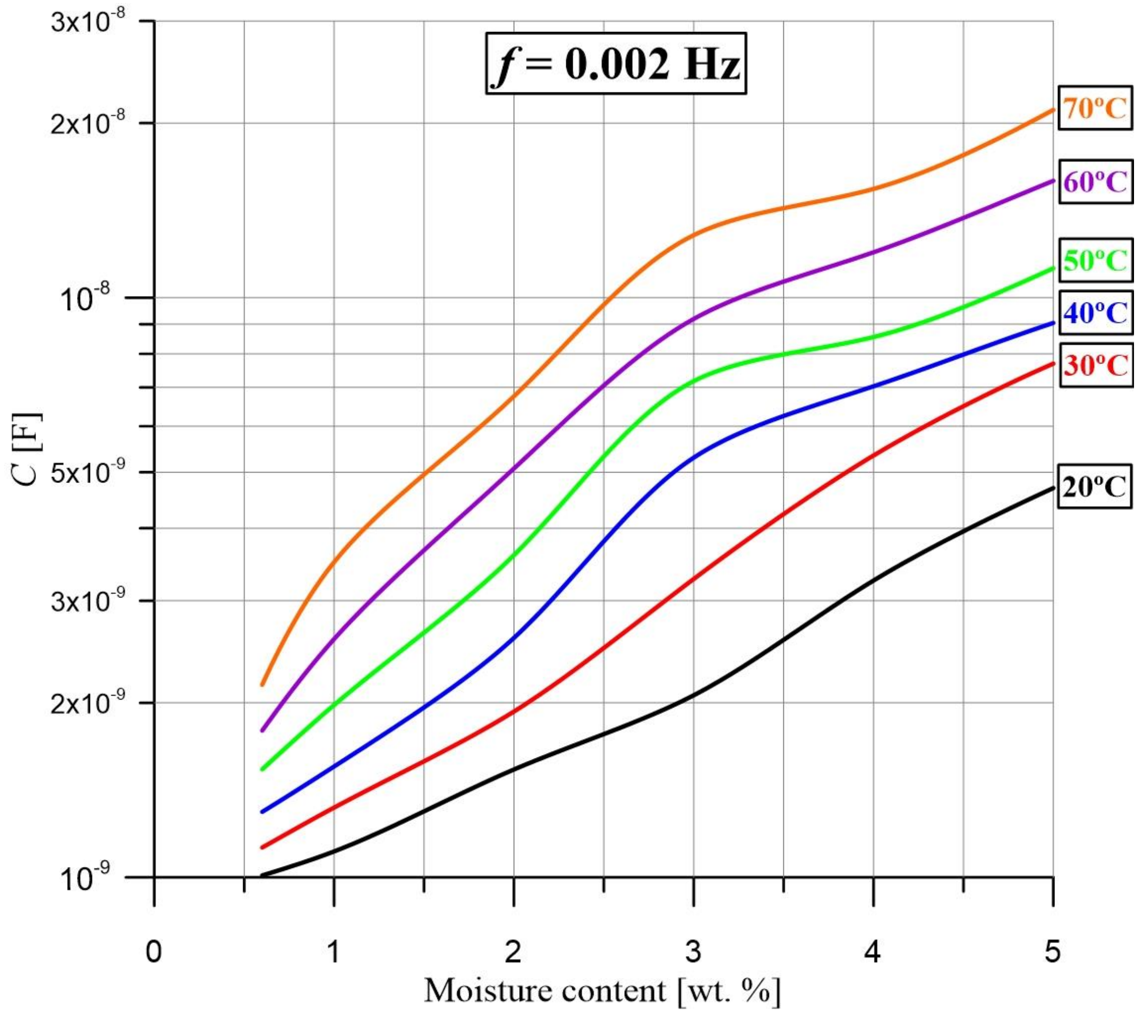


Fig. 9. Histogram of the dependence of real capacitance of the sensor on the moisture content of the pressboard for temperatures from 20 °C to 70 °C. Measurement frequency of 0.002 Hz.

3.5. AC resistance

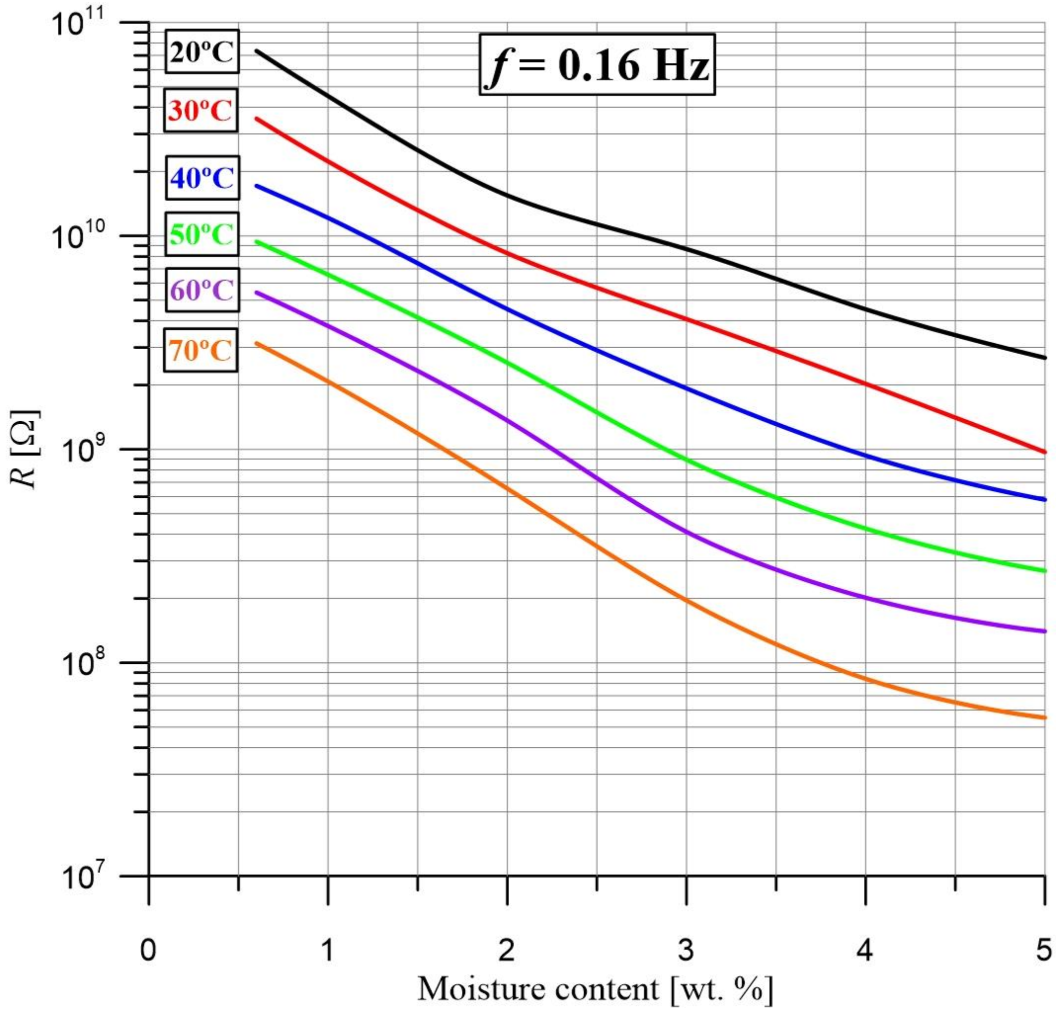


Fig. 10. Histogram of the dependence of AC resistance of the sensor on the moisture content of the pressboard for temperatures from 20 °C to 70 °C. Measurement frequency of 0.16 Hz.

3.6. Imaginary capacitance

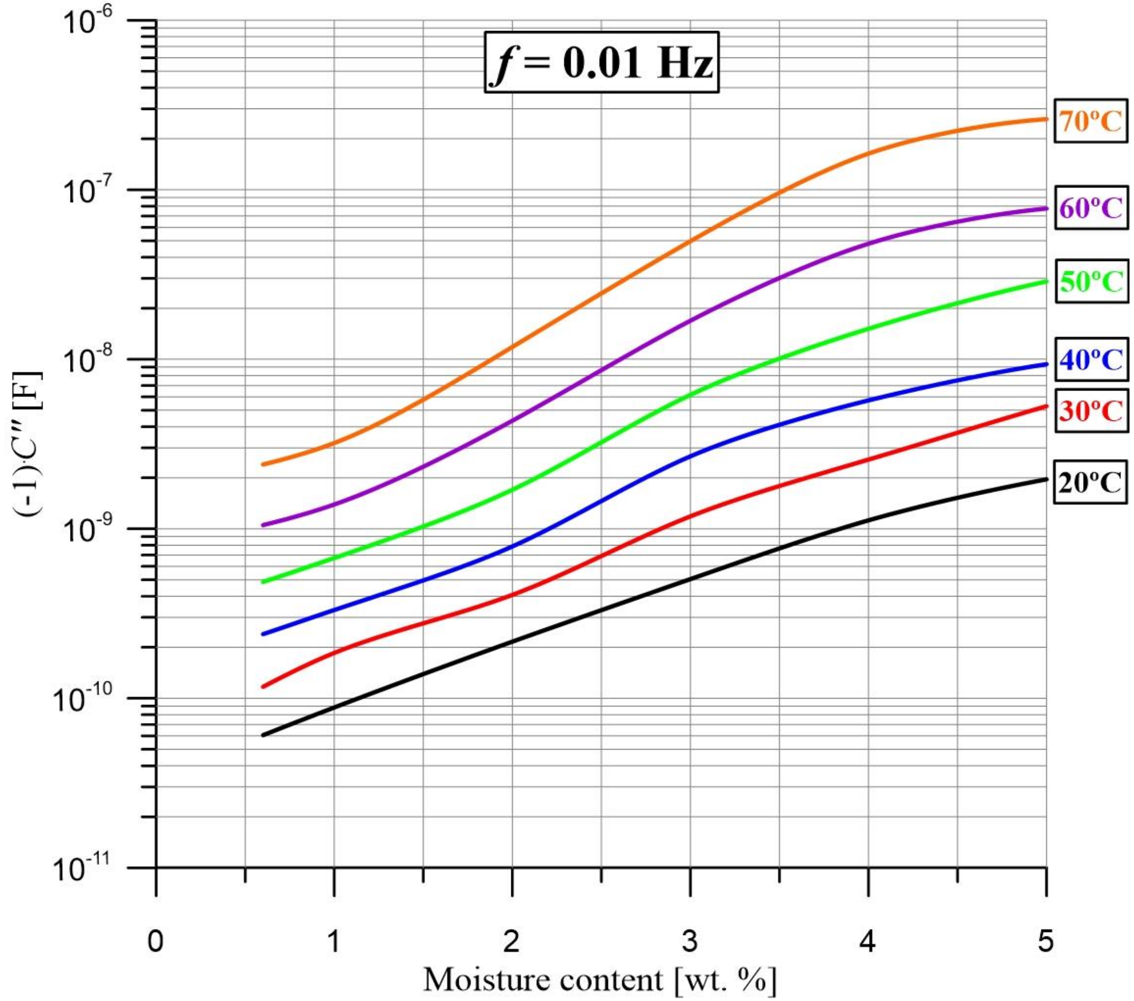


Fig. 11. Histogram of the dependence of the imaginary capacitance of the sensor on the moisture content of the pressboard for temperatures from 20 °C to 70 °C. Measurement frequency of 0.01 Hz.

3.7. Tangent of the loss angle

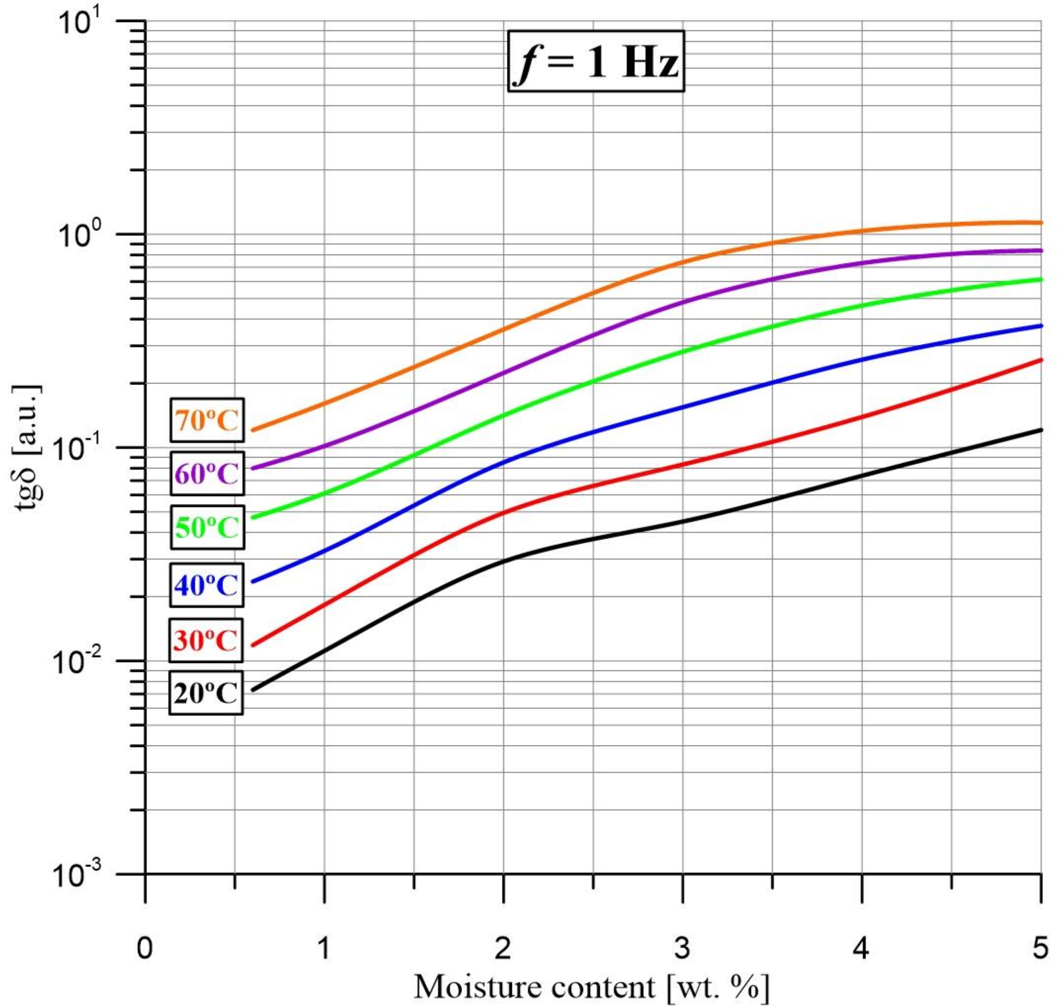


Fig. 12. Histogram of the dependence of tangent of the loss angle of the sensor on the moisture content of the pressboard for temperatures from 20 °C to 70 °C. Measurement frequency of 1 Hz.

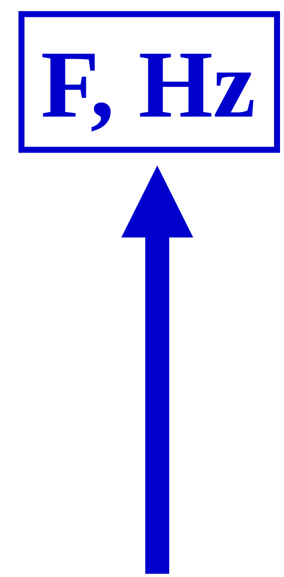
4. Conclusions

From the figures, it can be seen that in order to estimate the moisture content of the solid component of power transformer insulation using the developed sensor, it is enough to make measurements of the sensor temperature and:

1. **DC resistance** measurement

AC measurements at 5 frequencies:

2. **Tangent of loss angle** for a frequency of 1 Hz
3. **AC resistance** for a frequency of 0.16 Hz
4. **Phase shift angle** for a frequency of 0.1 Hz
5. **Imaginary capacitance** for a frequency of 0.01 Hz
6. **Impedance** for frequency of 0.01 Hz
7. **Real capacitance** for frequency of 0.002 Hz



4. Conclusions

When the results, obtained from all seven measured parameters are similar, the average value obtained from the seven measurements should be considered the actual moisture content.

The uncertainty of its determination should be calculated on the basis of the standard deviation of the results of determining the moisture content for the seven measured parameters.

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Thank you for your attention