Automation of measurements permeability of materials

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Abstract. The results of creating a hardware-software complex based on a precision LCR Agilent E4980A meter and a measuring cell 16454A using the LabVIEW programming environment for automated measurements of the frequency dependences of materials permeability are presented. Spectra of the real and imaginary parts of the magnetic permeability of ferrimagnets were obtained in the frequency range from 2 kHz to 2 MHz. A comparison of the measurement results with known data is performed.

1. Introduction

The measurement of the permeability of substances is an important scientific and technical task. Creating accurate and reliable measuring equipment allows measuring the electrophysical and magnetic parameters of materials in large frequency and temperature ranges. Permittivity and permeability are fundamental parameters of substances.

Measurements of the permeability of steel can be used as a non-destructive method for determining its quality or wear [1, 2]. And in the field of geological exploration by the values of this parameter, one can judge the underlying rocks [3, 4]. A large number of studies are conducted on the measurement of permeability in different frequency and temperature ranges of both widely known and promising materials [5, 6].

At the moment, there is no equipment that can measure the permeability of a substance. This parameter can be obtained by measuring the primary values, depending on the chosen measurement method, and further conversion to the required value using analytical formulas.

High-precision measuring equipment, which allows such measurements, is in demand in various fields of industry and research. The growing interest in the frequency dependences of the permeability of materials and the limited budget are pushing modern research laboratories to carefully approach the issue of updating the measuring equipment fleet.

One of the ways out of this situation is the creation of automated and semi-automated measuring complexes based on existing equipment. The correct selection of measuring instruments, as well as software that allows to manage measuring instruments and to collect, process and transmit the data to external media, ultimately increases the productivity of the research process.

The flexibility of the measuring system and a high level of automation can be achieved through the use of universal measuring equipment and open-source software.

The LabVIEW programming system is precisely that software product that allows the development of virtual measuring systems with the ability to interact with the measuring complex and a computer for inputting, processing and transmitting measured parameters for further analysis of measurement results [7].

This article proposes the use of the LabVIEW platform as a software basis for automating the measurement of permeability of materials, together with the precision LCR Agilent E4980A meter located in the measuring equipment park of the Tomsk Regional Common Use Center: Center of radio-physics measurements, diagnostic and researching of parameters of natural and artificial materials [8]

The Agilent E4980A LCR meter's standard configuration and software allows measurements of various electrical parameters in the operating frequency range from 20 Hz to 2 MHz, averaging of measured data, and recording of measurement results on an external medium using the built-in file naming system. The device is controlled by buttons located on its front panel.

The article describes the program implemented in the LabVIEW system, which allows automating the process of measuring the permeability of materials. The program consists of two parts. The first part measures and averages the primary parameters necessary for the further calculation of the permeability at the calibration frequencies of the Agilent E4980A instrument. The second part calculates the required values, builds the spectral dependence of the real and imaginary parts of the permeability, and also writes the received data to a text file.

2. Materials and methods

Five LiTiZn ferrites with different percentages of ZrO_2, which composition and manufacturing method were described in detail in [9], were chosen as objects of the study. The mass percentage of ZrO_2 content in sample No 1 was 0%, for sample No 2 this indicator was 0.5%, sample No 3 was 1%, sample No 4 was 2%, and sample No 5 was 3%. All studied samples were made in the form of toroidal shapes with an external diameter of $D = 7.0$ mm, an internal diameter of $d = 3.05$ mm, and a thickness of $h \approx 1.5$ mm. The geometric dimensions of the objects under study were determined by the parameters of the Keysight 16454A Magnetic Material Test Fixture measuring cell.

The measurement procedure involved the measurement of the real and imaginary parts of the impedance of a cell without a sample and with an object placed inside. Before measurements, the measuring device was calibrated during a short circuit and at open circuit to compensate for the residual impedance of the transmission lines to which the measuring cell was connected.

Next, we measured the primary parameters necessary for further calculations. At the beginning of each measurement, for all samples, the impedance $Z_0 = R_0 + i \cdot X_0$ of an empty cell (without sample) was separately measured, where R_0 – resistance and X_0 – reactance, i – is the imaginary unit. Then a sample was placed in the measuring cell and the impedance of the cell with the sample $Z_S = R_S + i \cdot X_S$ was measured.
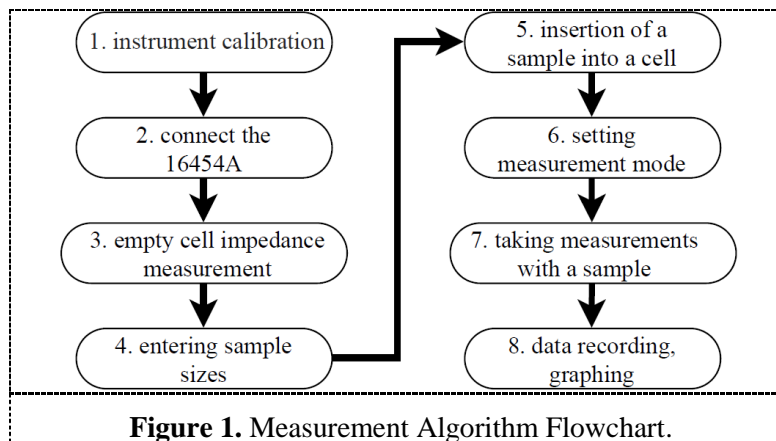
After measuring the primary parameters and their averaging at 16 measurements, the values of the real and imaginary parts of the permeability are calculated by the formulas:

$$\mu = \mu' - i\mu'' = 1 - i\frac{Z_S - Z_0}{f\mu_0 h \ln(D/d)}, \tag{1}$$

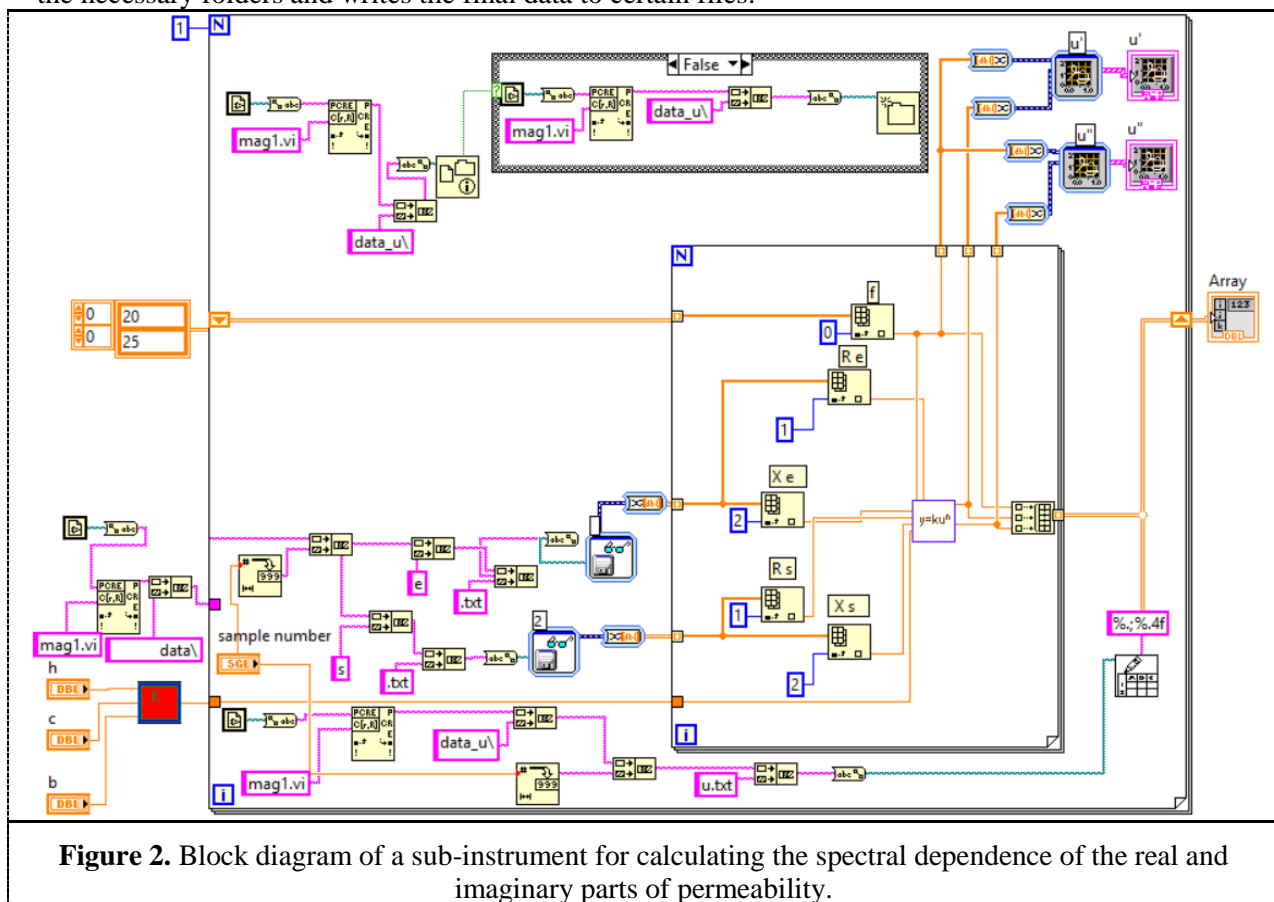$$\mu' = 1 + \frac{R_S - R_0}{f\mu_0 h \ln(D/d)}, \tag{2}$$

$$\mu'' = i\frac{X_0 - X_S}{f\mu_0 h \ln(D/d)}, \tag{3}$$

where μ' – is the real part, μ'' – is the imaginary part of the permeability, f – is the frequency of measurements, μ_0 – is the magnetic constant. h – is height, D – is external diameter, d – is internal diameters of the sample of a toroidal shape. An obvious block diagram of the measurement algorithm is shown in Figure 1.

Figure 1. Measurement Algorithm Flowchart.

The basis for the creation of a program for calculating the permeability of samples of a toroidal shape was taken from the official website of the manufacturer of measuring equipment, created in the LabVIEW environment. The standard program has been modified. A mode of changing the frequency dependence of permeability with the mandatory use of a Keysight 16454A measuring cell was added to it. A block diagram of a sub-instrument for calculating, recording, and plotting the spectra of the real and imaginary parts of permeability is shown in Figure 2. This part of the program is responsible for processing the obtained information during the measurement process. It calculates the required values, constructs the spectral dependences of the real and imaginary parts of the permeability, creates the necessary folders and writes the final data to certain files.

Figure 2. Block diagram of a sub-instrument for calculating the spectral dependence of the real and imaginary parts of permeability.

The result of the program is to create a folder with the measured parameters on the calibration frequencies of the precision meter on an external medium and build the spectra of measured values on the front panel.

3. Results

To verify the results, we chose a method of comparison with reference values. As mentioned earlier, to carry out work and debug the program, the objects of research were toroidal ferrites, which are on the balance of the collective use center at TSU. A study of the frequency dependence of their real and imaginary parts of permeability is presented in [9]. We took these results as reference values for analyzing the operation of the program and the measurement method as a whole. Table 1 presents the results of measurements of the real part of the permeability of the samples No 1, No 2, No 3, No 4 and No 5 obtained using the LabVIEW program, and the measurement results presented in [9]. The measurement method used and the equipment used allows us to obtain the values of the real part of the permeability with a measurement error of 5% only in a certain frequency range, for a certain size of the measurement object, namely from 300 kHz to 2 MHz for our samples of toroidal shape. At low frequencies (up to 10 kHz), the measurement error is about 20%. In the range from 10 kHz to 100 kHz, the measurement error is 10%.

Table 1. Frequency dependence of the real part of the permeability for the second, third and fourth samples.

Sample / Frequency		5 kHz	20 kHz	50 kHz	80 kHz	0.1 MHz	0.2 MHz	0.5 MHz	1 MHz	1.5 MHz	2 MHz
# 1	obtained value μ'	32.2	32.5	32.2	32.6	32.4	32.5	32.4	32.4	32.4	32.4
	μ' [9]	31.8	30.3	30.7	30.7	30.5	30.4	30.3	30.3	30.3	30.3
# 2	obtained value μ'	25.1	24.9	25.1	25.1	25.2	25.2	25	24.9	24.9	24.9
	μ' [9]	25.4	24.2	24.6	24.5	24.5	24.4	24.3	24.3	24.2	24.2
# 3	obtained value μ'	20.9	21.9	22.4	22.2	21.9	22.1	22.1	22.0	22.0	21.9
	μ' [9]	21.5	21.7	21.5	21.8	21.7	21.7	21.6	21.6	21.5	21.5
# 4	obtained value μ'	21	21.8	22.4	22.2	21.9	22.1	22.1	22	22	22
	μ' [9]	21.5	21.7	21.5	21.8	21.7	21.7	21.6	21.6	21.6	21.5
# 5	obtained value μ'	18.2	20.2	19.6	19.6	19.6	19.5	19.3	19.3	19.23	19.2
	μ' [9]	18.7	18.8	18.8	18.9	18.8	18.9	18.8	18.8	18.7	18.7

The relative measurement error relative to the reference values, both for high frequencies and for all five samples, is not more than 8%. This error may be related to the temperature flow where the measurements were made. All results can be associated with a high measurement error of the device itself in this frequency domain. The average relative error for these samples at frequencies above 10 kHz turned out to be 3%. The minimum values of the measurement error for all samples were observed at frequencies above 500 kHz.

4. Conclusions

The result of this work is the creation of the program for automating the process of measuring the spectral dependence of the complex permeability of toroidal materials using Agilent E4980A precision meter and Keysight 16454A measuring cell. This program allows to recalculate primary values to the required parameters, followed by writing data to a file and plotting spectra $\mu(f)$. The proposed method significantly reduces the measurement time. The analysis of test results showed the possibility of introducing the program into a real measuring process.

References

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