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Reducing the error in measuring bioimpedance when studying body composition

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Abstract. Automated bioimpedance measurement systems are part of modern medicine because they provide the ability to determine body composition and provide performance parameters. Bioimpedance analysis has the advantage of being able to test non-invasively, and accuracy and availability continue to improve every year. Currently, when assessing bioimpedance parameters, special attention is paid to the methods and accuracy of measurements. This article discusses key aspects of bioimpedance determination related to measurement errors. Various approaches to reducing errors in bioimpedance measurements are also presented.

Keywords: impedance, measurement, Cole model, error, object

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Уменьшение погрешности измерения биоимпеданса при исследовании состава тела

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Аннотация. Биоимпедансные диагностические системы являются неотъемлемой частью современной медицины, поскольку они предоставляют уникальную возможность исследовать состав тела и ключевые физиологические параметры. Они являются золотым стандартом в области неинвазивного тестирования, и их точность и доступность продолжают улучшаться с каждым годом. В настоящее время при оценке параметров биоимпеданса особое внимание уделяется методам и точности измерений. В данной статье обсуждаются ключевые аспекты определения биоимпеданса, связанные с ошибками измерений. Также представлены различные подходы к снижению погрешностей при измерении биоимпеданса.

Ключевые слова: импеданс, измерение, модель Коула, погрешность, объект

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Introduction

Automated bioimpedance measurement systems being developed offer a simple and rapid method for assessing body composition by measuring physiological parameters that are important indicators of physical health [1]. These systems have advantages over analogues in terms of technical and economic indicators, they are portable and do not require specialized training for use. Many modern devices for measuring bioimpedance use an alternating current with a constant amplitude, applied to the sample through two electrodes. The resulting voltage between the other two electrodes serves to determine the characteristic. To obtain the most accurate results, the current excitation system must provide operation in a wide frequency range, determined by the excitation method and the external device. The impedance measurement is then performed and equivalent electrical parameters are derived from the model of the sample being compared [2].

For the research, we used a developed software and hardware complex for measuring bioimpedance with a modernized symmetrical current source capable of carrying out measurements in a wide frequency range from 300 Hz to 2000 kHz. This ensures high repeatability of measurement results and brings bioimpedance analysis closer to a reliable method for diagnosing human health [3, 4].

Bioimpedance measurement and results analysis

In order for the measurements to be reliable, it is important to calibrate the measuring unit using a calibration resistor. In this work, a 910 ohm calibration resistor is used. Calibration creates a table of complex coefficients to measure a known resistance at all frequencies in a given range. The dependence of the impedance modulus and phase angle tangent on frequency is shown in Figure 1.

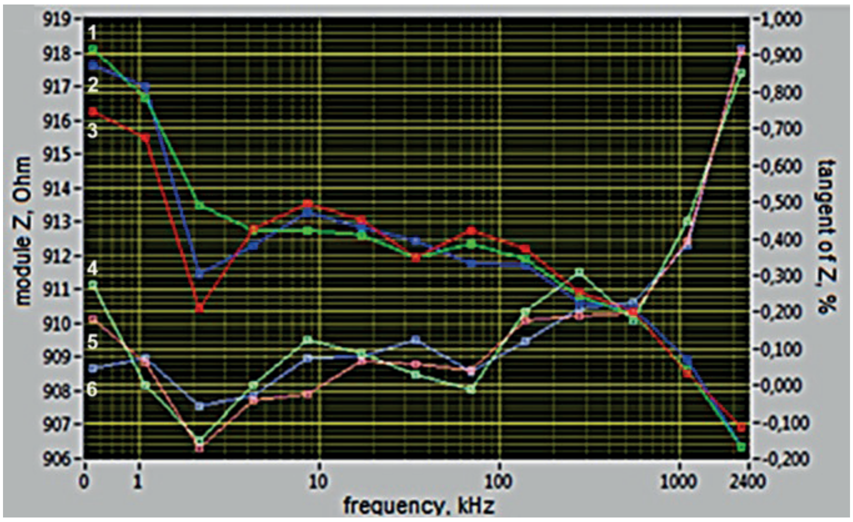

Fig. 1. Frequency response R = 910 Ohm, after calibration using a 910 Ohm resistor

Figure 1 shows the frequency response on the left along the ordinate on a logarithmic scale, the total impedance module is displayed, on the right – the phase shift angle in percentage. The X-axis displays frequency.

Notation: 1, 2, 3 – indicate the impedance modulus; 4, 5, 6 – indicate the phase shift angle

The graph clearly shows that the maximum absolute resistance deviation is 8 ohms. The maximum relative deviation is 0.87%, which indicates a slight change in this parameter. In turn, the maximum absolute deviation phase shift angle is –0.9%, which indicates the stability of this indicator.

If one takes a resistor of a different value, for example 300 Ohms, and take measurements using the previously obtained calibration table of coefficients, the dependence graph will turn into a curve. The resistor imitates the parasitic parameters of the human electrode-cell transition, and subsequently, during measurements, these parameters no longer affect the measurements. A prerequisite is to connect the cabling resistor and electrodes to the connector using the same (or identical) connecting cables. Calibration coefficients are recorded in the device's memory and saved. It is known that the active component of the impedance does not depend on frequency (Fig. 2).

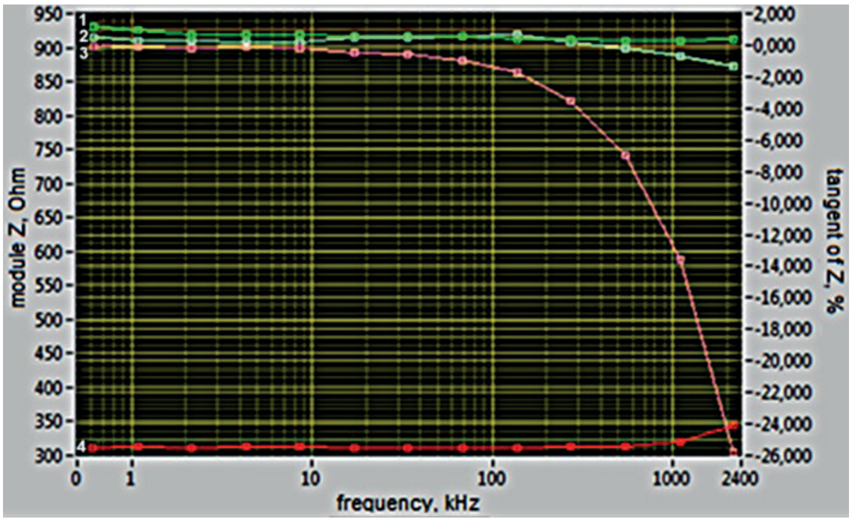

Fig. 2. Frequency response R = 300 Ohm and R = 910 Ohm, after calibration with a 910 Ohm resistor.

Notation: 1, 4 – indicate the impedance modulus; 2, 3 – indicate the phase shift angle

Next, we calculate the maximum absolute and relative error of resistance from the dependence graph (Fig. 1), it is respectively equal to $\Delta R = 45$ Ohm and $\delta = 13.1\%$. The absolute error of the tangent of the phase angle was $\Delta \mathrm{tg}\varphi = 26\%$.

Continuing the study of impedance measurements, significant discrepancies were revealed on a resistor with a resistance of 300 ohms from the calibration one. At high frequencies, the complex impedance changes sharply, which is caused by a discrepancy between the measured impedance and that taken into account during calibration.

Next, measurements are carried out, and the resulting spectral characteristic is visualized using a Bode diagram, reflecting the dependence of the module of the complex impedance and the tangent of the phase angle on frequency, after which it must be converted to the Nyquist format. Based on this information, it is necessary to establish the characteristics of the equivalent and mathematical models [5–7].

The measurement procedure produces a graph showing the frequency response of the impedance (Fig. 3).

To obtain active and reactive components of resistance, it is necessary to use formula (1) and (2):

$$R = |Z| \cdot \cos(\mathrm{arctg}\varphi), \tag{1}$$

$$X_c = |Z| \cdot \sin(\mathrm{arctg}\varphi). \tag{2}$$

Next, it is necessary to approximate the experimental data by a circle using the least squares method (Fig. 4). As a result, a circle with a radius of 140 Ohms is formed, the center of which lies at the point (570; –65).

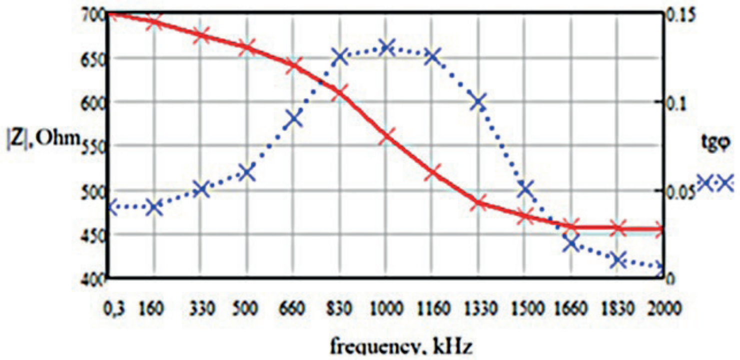

Fig. 3. Experimental frequency dependence of impedance

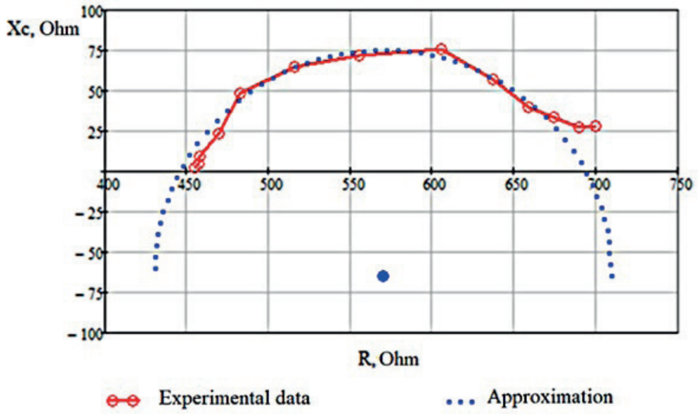

Fig. 4. Approximation of experimental data

Formula (3) opens up the possibility of determining the parameters of the Cole model, which describes the electrical properties of various materials.

$$\overline{Z} = R_\infty + \frac{R_0 - R_\infty}{1+\left(J\cdot\omega\cdot\tau_z\right)^\alpha}. \tag{3}$$

These parameters include resistance at infinite high frequency (R_∞), resistance at zero frequency (R_0), dimensionless parameter (α), time constant (τ_z) and circular frequency (ω). From the graph shown in Figure 4, we determine R_∞ = 445 Ohm, R_0 = 690 Ohm. We take $\alpha = 0.7$, ω = 40 Hz. The time constant is defined as:

$$\tau = \frac{1}{2\cdot\pi\cdot\omega} = 3.98[ms]. \tag{4}$$

Figure 5 shows a plot of the resulting Cole model.

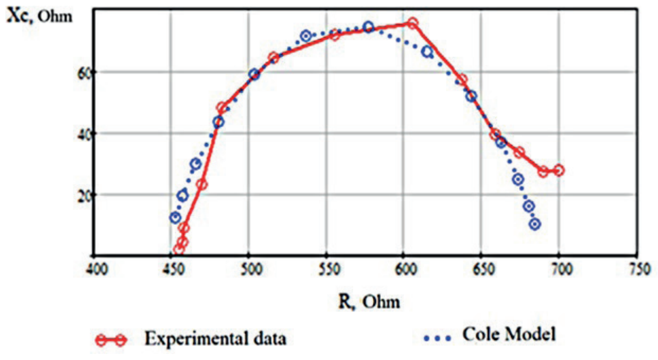

Fig. 5. Cole Model

Therefore, we can conclude that measuring different resistances of objects using the same calibration coefficients leads to measurement inaccuracy. The value of the resistance or measurement object must be selected close to the calibration value.

Conclusion

In this work, impedance measurements were carried out in the frequency range from 300 Hz to 2000 kHz. Thanks to repeated measurements and subsequent software and mathematical data processing and selection of the correct nominal value of the relative calibration resistance, the relative measurement error will be reduced to a minimum.

REFERENCES

1. **Dutra D., Bertemes-Filho P.,** Extracting parasite effects of electrical bioimpedance measurements, J. Electr. Bioimp. 9 (2018) 115–122.
2. **Qin E.S., Mindy M.J., Chen W.F.,** Diagnostic accuracy of bioimpedance spectroscopy in patients with lymphedema: A retrospective cohort analysis, Journal of Plastic, Reconstructive & Aesthetic Surgery. 71 (2018) 1041–1050.
3. **Antipenko V.V., Pecherskaya E.A., Tuzova D.E., Yakushov D.V., Artamonov D.V.,** Development of an automated system for measuring bioimpedance for the study of body composition, St. Petersburg State Polytechnical University Journal. Physics and Mathematics. 16 (3.2) (2023) 294–300.
4. **Antipenko V.V., Pecherskaya E.A., Zinchenko T.O., Artamonov D.V., Spitsina K.Yu., Pecherskiy A.V.,** Development of an automated bioimpendance analyzer for monitoring the clinical condition and diagnosis of human body diseases, J. Phys. Conf. Ser. 1515 (5) (2020) 052075.
5. **Sindeeva L.V., Kazakova G.N.,** Anthropometry and bioimpedansometry: parallels and divergences, Medical Sciences. 9 (2013) 476–480.
6. **Freeborn T.J., Crircher S.,** Threshold and Trend Artifacts in Localized Multi-Frequency Bioimpedance Measurements, IFAC PapersOnLine. 54–15 (2021) 55–60
7. **Anamika P., Mukesh R.,** Bioimpedance analysis of vascular tissue and fluid flow in human and plant body: A review, Biosystems engineering. 197 (2020) 170–178.

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