ЗАСОБИ ВИМІРЮВАНЬ ЕЛЕКТРИЧНИХ ТА МАГНІТНИХ ВЕЛИЧИН

MODELING OF HUMAN BODY TISSUES IMPEDANCE COMPONENTS IN FREQUENCY RANGE

МОДЕЛЮВАННЯ СКЛАДОВИХ ІМПЕДАНСУ ТКАНИН ОРГАНІЗМУ ЛЮДИНИ У ЧАСТОТНОМУ ДІАПАЗОНІ

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Анотація. Розглянуто результати математичного моделювання складових імпедансу багатоелементного двополюсника, яким подаються тканини організму людини. Результати аналізування відомих способів та їхньої реалізації за електричними моделями і досліджень різні. Зумовлено це тим, що для досліджень використовують різні електричні моделі, різні типи сенсорів, різні частотні діапазони, схеми під'єднання сенсора до вимірювального засобу тощо.

У роботі досліджено залежності активних та реактивних складових імпедансу триелементної електричної схеми заміщення біологічного об'єкта від зміни параметрів приелектродного імпедансу.

Встановлено, що значення активної та реактивної складових імпедансу майже не відрізняються за сталих значень опорів та різних значень ємності схеми об'єкта дослідження, а також параметрів приелектродного імпедансу. В разі зміни опорів значення активної та реактивної складових майже не залежать від частоти у частотному діапазоні від 10 кГц. Форми кривих при цьому також неістотно змінюються. Аналіз отриманих графічних залежностей реактивної складової від впливу параметрів приелектродного імпедансу показав, що криві набувають екстремальних значень. Реактивна складова набуває екстремального значення у діапазоні низьких частот (до 1 кГц), а частота, на якій складова набуває екстремального значення, залежить від параметрів приелектродного імпедансу. До частоти 1 кГц результат вимірювання безпосередньо залежить від вибраного типу електродів. Це можна використати для ідентифікації тканин біологічних об'єктів з урахуванням площі струмових електродів, їх форми та контактного опору, оскільки цим визначається приелектродний імпеданс.

Ключові слова: реактивна складова; імпеданс; адмітанс; еквівалентне електричне коло.

Abstract. The dependence of the active and reactive impedance components of a three-element electrical circuit of substitution of a biological object on the change of the parameters of the electrode impedance is investigated.

The results of mathematical modeling of the impedance components of a multielement two-pole representing the tissues of the human body are considered. Analyzing the known methods and their implementation by electrical models showed different research results. This is due to the fact that the research uses different electrical models, different types of sensors, different frequent ranges, circuits for connecting the sensor to the measuring instrument, etc. The measurement result can be used to identify the tissue of biological objects (taking into account the area of current electrodes, its shape and contact resistance, since these factors determine the electrode impedance).

Key words: Reactive constituent; Impedance; Admittance; Equivalent electrical circuit.

Introduction

One of the methods that provide promptness and objectivity of morphological and physiological parameters of the organism estimation in a wide range, rapid diagnostics of the functioning of the human body and detection pathologies is impedancemetry [1, 2]. A great deal of research is aimed at determining the biological viability of tissues by measuring the electrical parameters of their impedance at different frequencies [3, 4, 5].

According to the characteristics of the object under study, there are different ways to implement the impedance method. However, the level of informative nature of such measurements depends on the chosen parameters of the impedance of the biological object, on the accepted frequency range of studies [6], the sensors electrodes connection [7] and their constructive execution, on the level and shape of the test signal [8, 9]. Due to the use of different informative parameters in the frequency range, the measured results are different. It is also important to note that the heterogeneity of the research object places appropriate requirements for measuring instruments.

This applies to both the varieties of the primary transducers and the electrical equivalent substitution circuits of the human body tissues, as well as ensuring the invariance of the measurement results to various non-informative parameters, including non-informative electrode impedance. That's why the analysis of mathematical models of electrical equivalent circuits of the human body tissues is relevant.

Disadvantages

Analyzing the known methods and their implementation by electrical models showed different research results. This is due to the fact that the research uses different electrical models, different types of sensors, different frequency ranges, circuits for connecting the sensor to the measuring instrument, etc.

Purpose

The purpose of this work is to study mathematical models of equivalent electrical circuits of the human body tissues.

1. Implementation of impedance spectro-scopy method

1.1. Mathematical model of equivalent electrical circuits for biological objects

Equivalent electrical circuits, which are described in the literature [10, 11], are mainly used for biological tissue modeling. In circuits, impedance R_1 and capacitance C characterize the upper tissue layers, resistance R_2 characterizes the inner layers of tissue (muscles, vessels, etc.), and in bioimpedance analysis, it characterizes the internal fluid of biological tissue [12].

The result of measuring impedance parameters depends on various factors, one of which is non-informative electrode impedance [7] when using a two-electrode electrical circuit. Biological objects equivalent electrical circuit is shown in Fig. 1. It taking into account the pre-electrode impedance given by the parallel connection of resistance R_p, capacitance C_p and parallel-impedance circuit with the elements R_1, R_2, C.

The impedance of such equivalent electrical circuit (Fig. 1) is described by the expression

$$Z_{1-2} = Z_{p1} + Z_{p2} + Z_x =$$

$$= \frac{2R_p}{1 + j\omega C_p R_p} + \frac{R_1}{1 + j\omega C R_1} + R_2 \quad , \qquad (1)$$

where Z_{p1} and Z_{p2} are the pre-electrode impedance formed by two electrodes, and Z_x is the biological object impedance.

According to expression (1), the value of the active component $\mathrm{Re}(Z_{1-2})$ of the impedance is calculated by the formula (2), and the value of the reactive component $\mathrm{Im}(Z'_{1-2})$ is calculated by the formula (3)

$$\mathrm{Re}(Z_{1-2}) = \frac{2R_p}{1+(\omega C_p R_p)^2} + \frac{R_1}{1+(\omega C R_1)^2} + R_2 \quad , \qquad (2)$$

$$\mathrm{Im}(Z_{1-2}) = -\frac{2\omega C_p R_p^2}{1+(\omega C_p R_p)^2} - \frac{\omega C R_1^2}{1+(\omega C R_1)^2} \quad . \qquad (3)$$

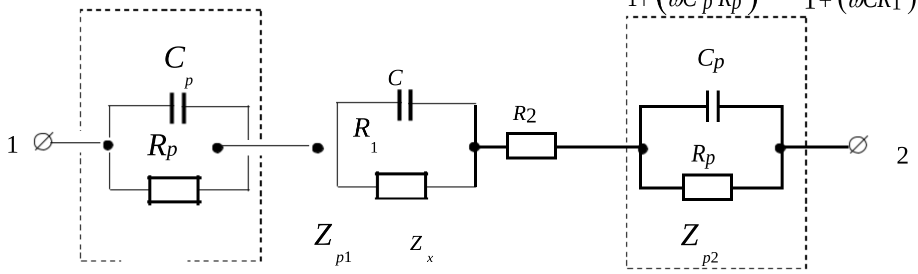


Figure 1. Examples of biological objects equivalent electrical circuit with an electrode impedance element

1.2. Biological object tissues impedance components of equivalent electrical circuits modeling by the method of Impedance Spectroscopy

The study was carried out on the example of the equivalent circuit of the human body tissues (1) in the frequency range. Previous studies of the human body tissue impedance components show that the shape of the dependence curve is the same for the same measured objects, however, the value of the impedance parameters changes according to the object of study [13]. It is advisable to study these components for different impedance parameter values C, R_1, R_2 of the object in the same frequency range. These parameter values are changed according to the applied electrodes place.

The results of modeling the impedance components in the frequency range for constant values of resistances are obtained $R_1 = 2{,}5$ kΩ, $R_2 = 56$ kΩ, $R_p =$ 50 kΩ, $C_p =$ 26 nF, and capacitance values: C = 33 nF, C = 100 nF, C = 1000 nF (Fig. 2).

The results of the active and reactive components study with changing resistances R_1, R_2 values are presented in Fig. 3 with the following designations: $\mathrm{Re}(Z)_1$, $\mathrm{Im}(Z)_1$ – results for resistances found by experimental studies; $\mathrm{Re}(Z)_2$, $\mathrm{Im}(Z)_2$ – changes of resistance R_1 of 10 kOhm; $\mathrm{Re}(Z)_3$, $\mathrm{Im}(Z)_3$ to change the resistance R_2 of 800 Ohms; $\mathrm{Re}(Z)_4$, $\mathrm{Im}(Z)_4$ to simultaneously change the resistance R_1 of 10 Ohms and the resistance R_2 of 800 Ohms.

Since the measurement result is influenced by the pre-electrode impedance, it is advisable to analyze the mathematical models (2), (3) over a wide frequency range for variables and for values that depend mainly on the parameters of the sensor.

To simulate the effect of the electrode impedance on the measurement result, the following parameter values were selected, which can vary from the selected electrode type (electrode material, area):

– $R_p = 50$ kOhm, $C_p = 25$ nF; $R_p = 60$ kOhm, $C_p = 55$ nF; $R_p = 70$ kOhm, $C_p = 75$ nF (fig. 4, a);

– $R_p = 48$ kOhm – const, $C_p = 10$ nF, $C_p = 25$ nF, $C_p = 50$ nF, $C_p = 75$ nF, $C_p = 100$nF (fig. 4, b);

– $C_p =$ 26 nF – const, $R_p =$ 20 kOhm, $R_p =$ 40 kOhm, $R_p =$ 60 kOhm, $R_p = 80$ kOhm, $R_p = 100$ kOhm (fig. 4, c).

The results of the electrode impedance influence modeling with the given set of values are shown in Fig. 4.

1.3. Analysis of experimental results

From Fig. 2, we see that the values of the active and reactive impedance components are almost indistinguishable from each other at constant resistance values R_1, R_2 and different capacitance values C of the study object, as well as the parameters of the electrode impedance R_p, C_p.

From the graph presented in Fig. 3, it can be concluded that the value of the measurement result also varies slightly. The shapes of the curves also do not change significantly.

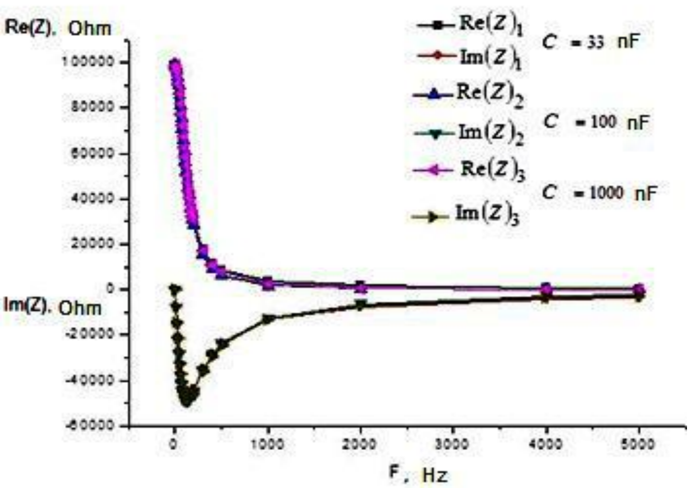


Figure 2. Modeling of impedance components at different capacitance values

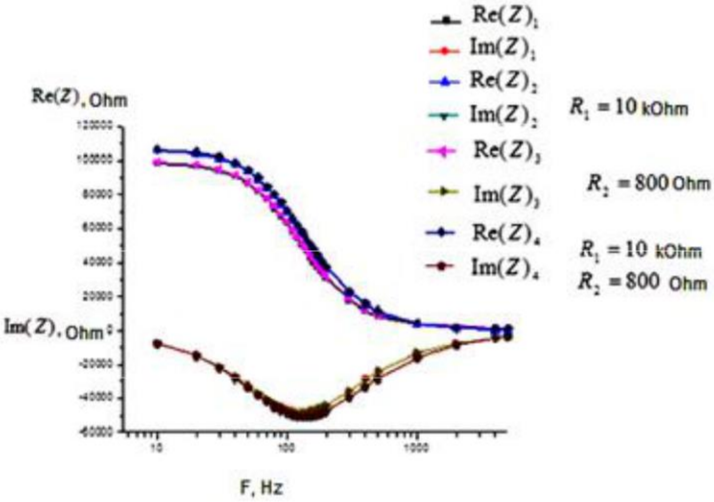
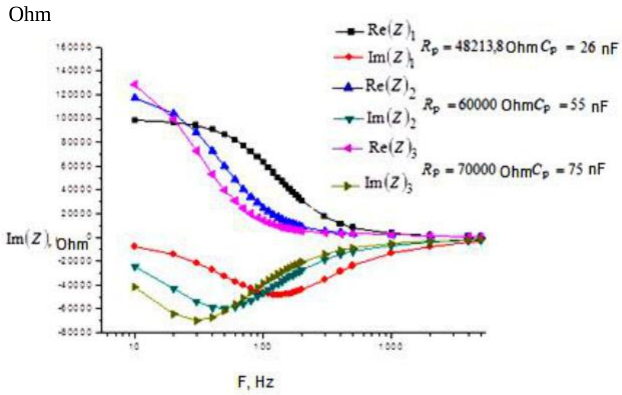
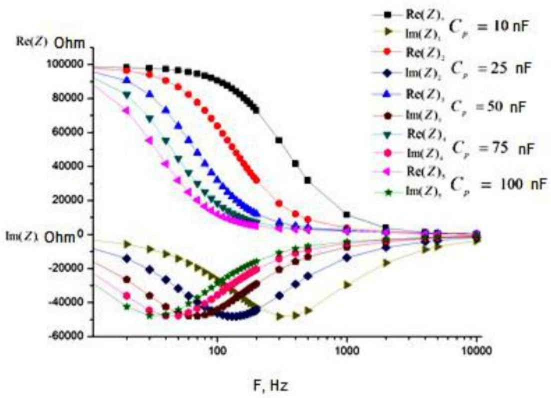


Figure 3. Modeling of impedance components for different values of resistances



a



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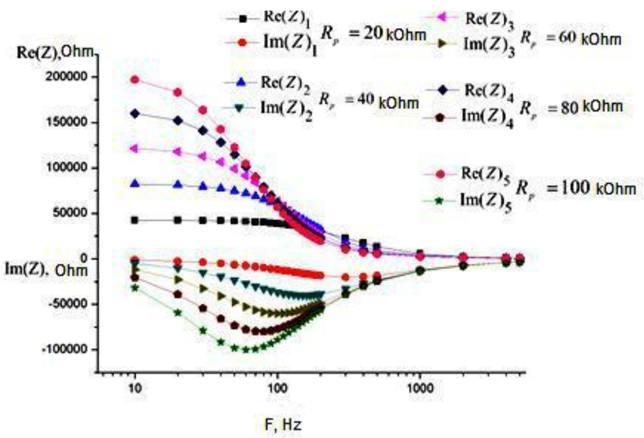

c

Figure 4. Modeling of impedance components for different values of pre-electrode impedance parameters

Analysis of the obtained graphical dependences in Fig. 4 showed that the extremum of the curve describing the dependence of the impedance reactive component in the frequency range shifts significantly to the low-frequency range with the increasing influence of the electrode effects. Similarly, with increasing electrode resistance, the extremum of the curve for the reactive impedance component shifts to the low-frequency range (Fig. 4, c). This dependence is observed in the frequency range of up to 1 kHz.

Conclusions

1. Analysis of graphical dependencies of mathematical models modeling for active and reactive impedance components showed that the reactive component takes an extreme value in the low-frequency range (up to 1 kHz), with the frequency-dependent on the parameters of the electrode impedance.

2. Up to a frequency of 1 kHz, the measurement result depends directly on the type of electrode. This can be used to the biological objects tissue identification, taking into account the area of the current electrodes, its shape, and contact resistance, since this determines the electrode impedance.

3. When changing resistances, the values of the active and reactive components are almost independent of frequency in the frequency range from 10 kHz.

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Conflict of interests

The authors declare that there is no financial or other possible conflicts regarding the work.

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