control methods. Fuzzy logic extends the ways of implementation of automated control methods that are used in applications and adds the ability to use observations in system management. A simple example is a gantry and bridge cranes that use fuzzy inference system can provide a clear and simple solution to the problem that much more difficult to be solved using traditional management methods.

Fuzzy-based crane control system uses linguistic rules based on crane operator knowledge for managing cargo swings during crane installation work.

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UDC 621.317

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METHODICAL ERRORS OF MEASUREMENT OF THE HUMAN BODY TISSUES ELECTRICAL PARAMETERS

Sources of methodical measurement errors of immitance parameters of biological tissues are described. Modeling measurement errors of RC-parameters of biological tissues equivalent circuits into the frequency range is analyzed. Recommendations on the choice of test signal frequency for measurement of these elements is provided.

Key words: biological tissue, equivalent circuit, impedance, methodical error, frequency range.

Introduction

The method of bioimpedance is widely used in the diagnosis of human physiological state, monitoring of chronic diseases and the evaluation of body composition [1, 2]. This method is non-invasive, relatively inexpensive and simple of implementation.

There are different methods of bioimpedance analysis depending on the purpose of using, methods of implementation, the frequency range. The main methods are the method of using a single frequency of the test signal, multifrequency method, bioimpedance spectrometry, analysis of bioimpedance of the whole body and individual segments [3]. Condition of the human body as a whole or its individual tissues is evaluated by monitoring the temporal changes or comparison the parameters of impedance or admittance.

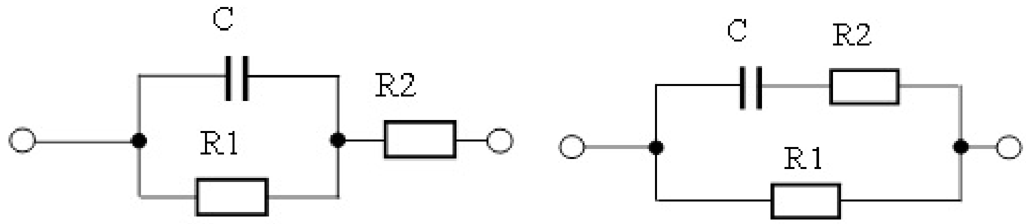
One of the promising methods of bioimpedance analysis is to determine the condition of human tissues by calculating the parameters of the biological tissues electrical equivalent circuit and comparison of these results with specific parameters [4, 5]. Since these measurements must be made with high accuracy, the analysis of measurement errors of impedance parameters (admittance) and elements of circuits of biological tissues in a frequency range is important.

The main errors of bioimpedance measurements are instrumental and methodical errors. The most studies are focused on analysis of instrumental errors. Researchers analyze error of impedance measurement and errors of its active and reactive components in the frequency range [6, 7, 8]. Researchers pay much attention to methodical errors that arise from the impact of near-electrode effects [9, 10]. It is therefore important to consider methodical error of measurement of individual elements parameters of biological tissues equivalent circuits.

Relative errors of measurement of admittance and capacitance C depending on the sampling frequency and time measurement are analyzed in the work [11]. The results of research showed that the measurement error of capacitance C can linearly increase or decrease on individual frequency of the test signal. Admittance measurement error decreases with increasing duration of measurements. However, studies of two-element equivalent circuit (parallel connection resistance and capacitance) were conducted on specific frequencies (100 kHz, 1 MHz, 10 MHz, 100 MHz) and not in the frequency range.

The results of elements measurement of biological tissues equivalent circuit in different environments of the experiment are discussed in the paper [12]. Measurement of RC-elements parameters of two-element biological tissues equivalent circuit was conducted in the frequency range of 100 Hz to 1 MHz. The results showed that measurement error in-vitro is higher than for measuring in-vivo. And its dependence on the frequency of the test signal is not linear throughout the frequency range. Calculation of methodical error was carried out by comparing the measured parameters of biological tissues models with the relevant parameters for living tissue.

The measurement of impedance (admittance) or parameters of individual elements of biological tissues equivalent circuit is carried out using the most widespread equivalent circuits: Cole model (Fig. 1, a) and Freke-Morse (Fig. 1, b) [13, 14]. That's why analysis of the relative measurement error of RC-elements in a wide frequency range is important.



a *б*

Fig. 1. Electrical equivalent circuit of biological tissues: a – Cole model; b – Freke-Morse model

Resistance R_1 and capacitance C characterize the upper layers of tissue and resistance R_2 characterizes the inner layers of tissue.

The object, purpose and objectives of the study

The object of investigation is mathematical model of biological tissues equivalent circuits.

The aim of the research is measurement errors assessment of parameters of biological tissues equivalent circuits in the frequency range.

In accordance with this goal the following objectives are highlighted:

1. Definition of mathematical expressions for measurement errors assessment of RC-element of known biological tissues equivalent circuits.

2. Assessment and analysis of errors in the frequency range.

Mathematical modeling

Analysis of mathematical models describing the impedance and admittance of biological tissues equivalent circuits (Figur 1) showed that for the circuit on Fig. 1, a) it is expedient to measure impedance parameters, and it is expedient to measure parameters of admittance for the circuit shown on Fig. 1, b) [15].

Scheme of measurements with four electrodes is using in order to eliminate the influence on the measurement result of uninformative impedance at the border "electrode-object" [10].

The value of impedance for the equivalent circuit on Fig. 1, a) is found from the formula:

$$Z = R_2 + \frac{R_1}{1 + j\omega CR_1} = \frac{(R_2 + j\omega CR_1R_2 + R_1)(1 - j\omega CR_1)}{1 + \omega^2C^2R_1^2}, \quad (1)$$

The measurement results of impedance components at a frequency ω will be described by the formulas:

$$\mathrm{Re}(Z) = \frac{R_1 + R_2 + \omega^2C^2R_1^2R_2}{1 + \omega^2C^2R_1^2}, \quad (2)$$

$$\mathrm{Im}(Z) = -\frac{j\omega CR_1^2}{1 + \omega^2C^2R_1^2}. \quad (3)$$

We need to take boundary conditions, such as $\omega \to 0$ та $\omega \to \infty$ to determine the value of the equivalent circuit elements. Due to the condition $\omega \to \infty$ we will obtain the following formulas: $\omega^2C^2R_1^2 >> 1$ and $\omega^2C^2R_1^2R_2 >> R_1 + R_2$. The value of the components of impedance will be described by the following formulas:

$$\mathrm{Re}'(Z)_{\omega\to 0} = R_1 + R_2, \quad (4)$$

$$\mathrm{Re}''(Z)_{\omega\to\infty} = R_2, \quad (5)$$

$$\mathrm{Im}'(Z)_{\omega\to 0} = 0, \quad (6)$$

$$\mathrm{Im}''(Z)_{\omega\to\infty} = -1/\omega C. \quad (7)$$

However, it is expedient to determine the relative methodical error of measurement by the formulas (8-10), because measuring of RC-elements parameters is implemented in the frequency range or on the values of individual frequencies:

$$\delta_{R_1+R_2} = \frac{\mathrm{Re}(Z) - \mathrm{Re}'(Z)}{\mathrm{Re}'(Z)} \cdot 100\%, \quad (8)$$

$$\delta_{R_2} = \frac{\mathrm{Re}(Z) - \mathrm{Re}''(Z)}{\mathrm{Re}''(Z)} \cdot 100\%, \quad (9)$$

$$\delta_C = \frac{\mathrm{Im}(Z) - \mathrm{Im}''(Z)}{\mathrm{Im}''(Z)} \cdot 100\%. \quad (10)$$

We substitute formulas for the impedance components in boundary conditions (2-5, 7) in the formulas (8-10):

$$\delta_{R_1+R_2} = -\frac{\omega^2C^2R_1^2}{(1 + R_2/R_1)(1 + \omega^2C^2R_1^2)} \cdot 100\%, \quad (11)$$

$$\delta_{R_2} = \frac{R_1}{R_2} \cdot \frac{1}{1 + \omega^2C^2R_1^2} \cdot 100\%, \quad (12)$$

$$d_C = -\frac{1}{1 + w^2C^2R_1^2} \cdot 100\%. \quad (13)$$

It is expedient to measure admittance parameters for the electrical circuit shown in Fig. 1, b):

$$Y = \frac{1}{R_1} + \frac{1}{\frac{1}{jwC} + R_2} = \frac{1 + jwCR_1 + 1 + jwCR_2}{R_1(1 + jwCR_2)}, \tag{14}$$

$$\mathrm{Re}(Y) = \frac{1 + w^2C^2R_1R_2 + w^2C^2R_2^2}{R_1\left(1 + w^2C^2R_2^2\right)}, \tag{15}$$

$$\mathrm{Im}(Y) = wC\frac{1}{1 + w^2C^2R_2^2}. \tag{16}$$

If $w \to 0$, we will obtain the following formulas:

$$\mathrm{Re}'(Y)_{w\to 0} = \frac{1}{R_1} = G_1, \tag{17}$$

$$\mathrm{Im}'(Y)_{w\to 0} = 0. \tag{18}$$

If $w \to \infty$, we will obtain the following formulas:

$$\mathrm{Re}''(Y)_{w\to\infty} = \frac{R_1 + R_2}{R_1 \cdot R_2} = G_1 + G_2, \tag{19}$$

$$\mathrm{Im}''(Y)_{w\to\infty} = \frac{1}{wCR_2^2}. \tag{20}$$

We obtain the following formulas for errors:

$$d_{G_1} = \frac{\mathrm{Re}(Y) - \mathrm{Re}'(Y)}{\mathrm{Re}'(Y)} \cdot 100\% = \frac{w^2C^2R_1R_2}{1 + w^2C^2R_2^2} \cdot 100\%, \tag{21}$$

$$d_{G_{12}} = \frac{\mathrm{Re}(Y) - \mathrm{Re}''(Y)}{\mathrm{Re}''(Y)} \cdot 100\% = -\frac{R_1}{R_1 + R_2} \cdot \frac{1}{1 + w^2C^2R_2^2} \cdot 100\%, \tag{22}$$

$$d_C = \frac{\mathrm{Im}(Y) - \mathrm{Im}''(Y)}{\mathrm{Im}''(Y)} \cdot 100\% = -\frac{1}{1 + w^2C^2R_2^2} \cdot 100\%. \tag{23}$$

Graphical modeling of relative errors values into the frequency range

The following values of RC-elements were chosen for modeling of relative errors: C_1=0,02 uF, C_2=0,1 uF, C_3=0,5 uF, R_1=100 Ohm, R_2=1000 Ohm [16].

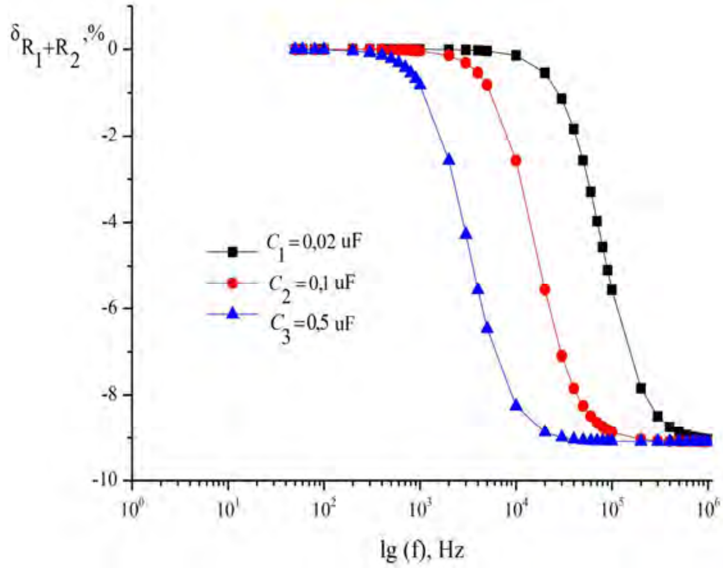
Results of research

Errors are different for each equivalent circuit, and also depend on the values of the equivalent circuit elements. Measurement errors of equivalent circuit parameters (Fig. 1, a) are represented on Fig. 2.

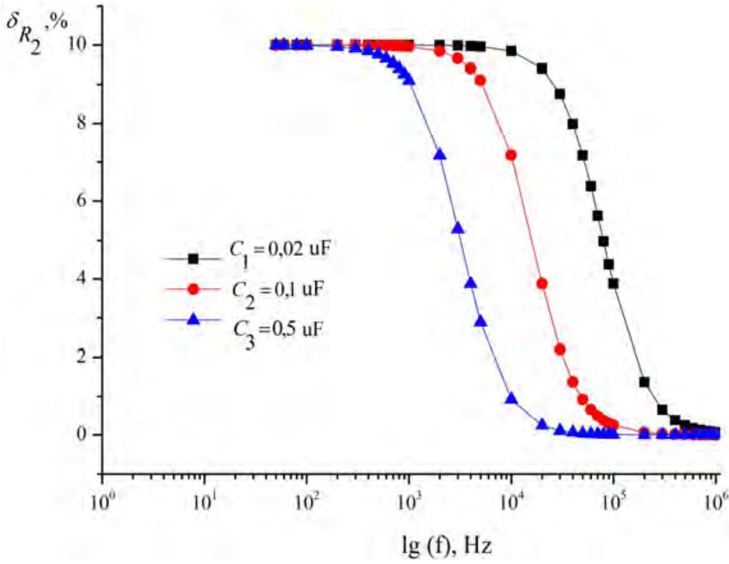
Measurement error of sum elements R_1 and R_2 increases with increasing frequency, and measurement error R_2 and C is decreases in the same frequency range.

Measurement errors of equivalent circuit parameters (Fig. 1, b) are represented on Fig. 3. Measurement error for admittance of elements R_1 and R_2, as well as the capacity C decreases with increasing frequency (Fig. 3, a, b). The value of measurement error for admittance of element R_2 increases with increasing frequency (Fig. 3, c).

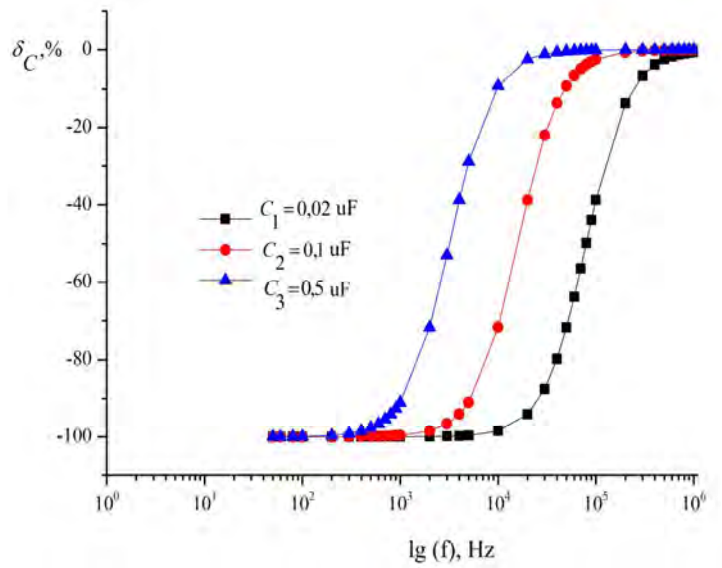
We selected three different capacitance values to measurement error modeling of RC-parameters. If the capacity is reduced, the error gets values at higher frequency values.



a

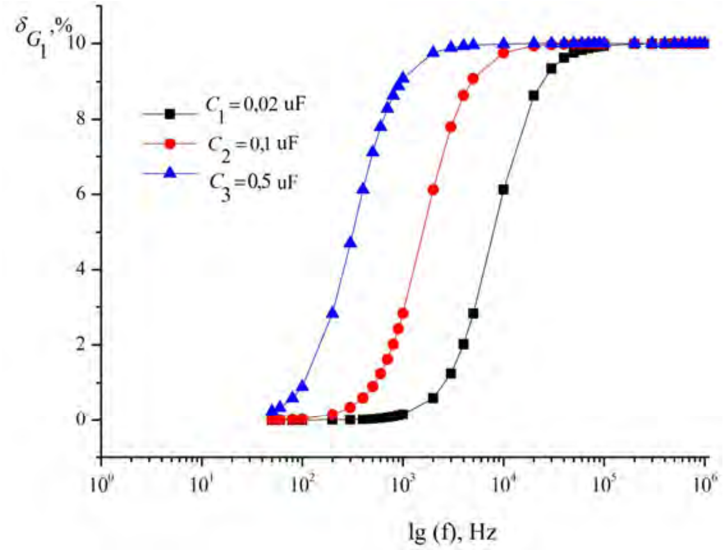


b

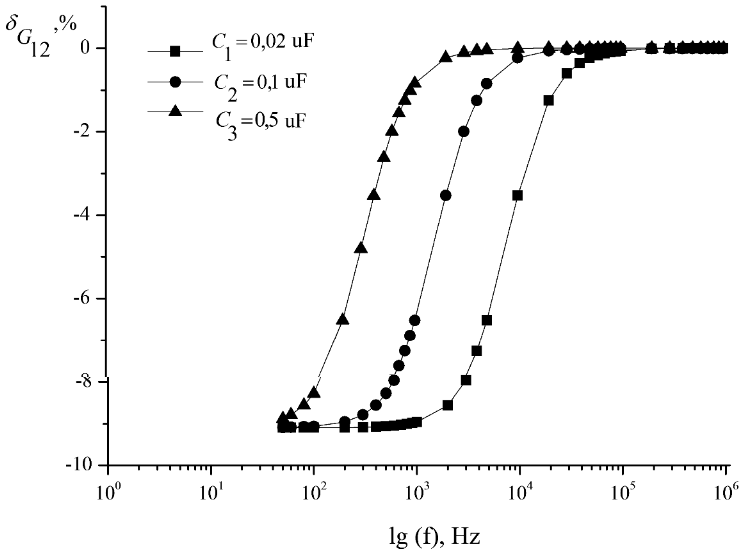


c

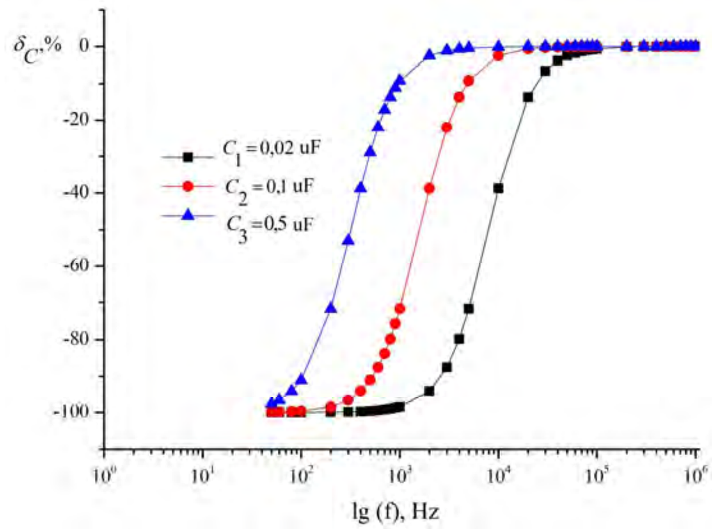
Fig. 2. Methodical error of measuring RC – parameters of equivalent circuit shown on Fig. 1, a



a



b



c

Fig. 3. Methodical error of measuring RC – parameters of equivalent circuit shown on Fig. 1, b

Formulas for the evaluation of RC-parameters measurement errors of biological tissues equivalent circuits and graphical modeling of relative errors values into the frequency range allow to choose the frequency of the test signal for a given measurement accuracy and to assess the accuracy of measurement at a given frequency.

Conclusions

So we got the following conclusions:

1. Formulas of RC – parameters measurement errors of the biological tissues equivalent circuit and its graphical modeling into the frequency range are analyzed.
2. Measurement error of RC -parameters of the biological tissues equivalent circuit depends on the chosen equivalent circuit and its parameters and changes in the frequency range.
3. We should measure the values of the elements R_2 and C at the high frequency range and we need to measure the sum of resistances R_1 and R_2 in the range of low frequencies for the electrical circuit on Fig. 1, a.
4. We should measure admittance of elements R_1 and R_2, C in the range of high frequencies and we should measure admittance of element R_2 in the range of low frequencies.
5. We can choose a frequency of the test signal for measuring each element of equivalent circuit according to the required accuracy of measurement.

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СИНТЕЗ КОМПОНЕНТІВ АПАРАТНИХ ПАРАЛЕЛЬНИХ НЕЙРОМЕРЕЖ ВЕРТИКАЛЬНО-ГРУПОВОГО ТИПУ

Розроблено паралельний метод вертикально-групового опрацювання даних у нейромережах, який порівняно з відомими підвищує швидкодію, збільшуючи розряди каналів надходження множників і кількості часткових добутків, які формуються у результаті їхнього аналізу. Вибрано принципи побудови, розроблено модель та структуру формального нейрона вертикально-групового типу з мультиплексуванням шин вагових коефіцієнтів і даних, яка забезпечує узгодження інтенсивності надходження даних із обчислювальною здатністю нейроелемента зміною розрядності каналів надходження і кількості розрядів множників у групі, які одночасно аналізуються для формування часткових добутків. Розглянуто основні етапи та методику синтезу паралельного нейроелемента вертикально-групового типу з високою ефективністю використання обладнання.

Ключові слова: нейроелемент, паралельний метод вертикально-групового опрацювання даних, модель формального нейрона, реальний час, ефективність використання обладнання.

An method of parallel vertical-group data processing in neural networks has been developed, which in comparison with known enhances performance by increasing the bit-width of input channels and the number of partial products, which are formed as a result of their analysis. Principles have been selected, the model and structure of formal neuron with vertical-group multiplexing of tire have been developed, which provides coordination of data flow intensity with computing ability of neuro element by changing bit-width of channel and number of digits in a group of factors that simultaneously analyzed for the formation of partial products. The main stages and methods of synthesis of parallel vertical neuro element of group type with high efficiency of equipment use have been reviewed.

Key words: neuro element, parallel method of vertically-group data processing, formal neuron model, real time, effectiveness of equipment use.

Постановка проблеми

Створення високоефективних нейромережевих засобів реального часу потребує широкого використання сучасної елементної бази, розроблення нових моделей нейрона, методів і алгоритмів, орієнтованих на реалізацію у вигляді надвеликих інтегральних схем (НВІС).