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Development Of Principles Of Computer Appliance Functioning, Determination Of Characteristics Of The Biological Object

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Abstract

The objective of the study is to develop a method for determining the capacity-voltage characteristics of the biological object implemented in the computer appliance of characteristics of the biological object. The method is that the biological object is energized via the electrodes with predetermined amplitude and frequency, and then the amplitudes of the harmonic voltage of the other electrodes are measured. Based on these data, the inverse problem of harmonic balance is solved and the approximation coefficients of the expression describing the desired capacity-voltage characteristics of the biological object, i.e., dependence of its non-linear capacity from the current flowing through a biological object, are determined. The effect of the degree of approximation expression on the error of the measurement result has been studied. The developed method has shown in the model its applicability for determining the capacity-voltage characteristics of biological objects while maintaining acceptable accuracy.

Keywords: computer appliance, capacity-voltage characteristics, biological object, methods of measurement, harmonic balance, Fourier series, inverse solution.

1. Introduction

The capacity-voltage characteristics (CVC) of the biological object (BO) includes an important diagnostic information. The developed method allows determining CVC, which may further infer either presence or absence of abnormalities in the studied BO.

Tissues of the body [1] consist of structural elements - the cells that are washed with well-conductive tissue fluid. Cytoplasm inside the cell is also a good conductor. A poorly conductive layer of the cell membrane separates them. This system has a capacitance which is caused by the presence of structural features of its membrane. Lipids are arranged in the membrane in the form of a bimolecular layer and cause high electrical resistivity of biological membranes, which is about 10^7 ohm · m, and a large specific capacitance (5 10^3 F/м^2). Thus, the biological membrane may be considered as an electrical capacitor, which conducting plates form electrolytes of external and internal solutions (cytoplasm and extracellular solution). The conductors are separated by the lipid bilayer, which plays the role of a dielectric with a dielectric permittivity equal to 2. Features of such structure of biological tissues also provide the body with capacitive properties. Living tissue, in the modern view, have no inductance.

The impedance of biological tissues can be modeled using the equivalent electrical circuits [1]. They represent different combinations of the capacitor *C* and the resistors *R*. The Figure 1a shows the simplest equivalent circuit consisting of series-connected resistive and capacitive reactance. This circuit describes the electrical properties of superficial tissues.

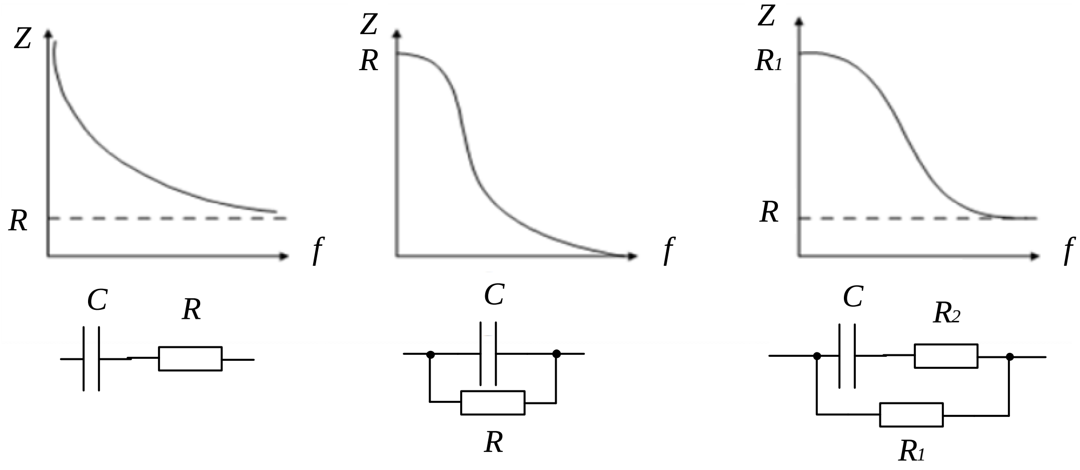


Figure 1. Equivalent circuits of BO

Parallel connection of the ohmic *R* and capacitance *C* resistance is typical for deep-lying tissues (Fig. 1b).

The skin and subcutaneous tissue layers may be represented by the circuit with significant capacity C, connected in series with a small resistance R_2 of about 100 ohms [2, 3], and in parallel with high resistance R_1 of about 5000 ohms (Figure 1c).

Figure 2 shows the impedance-frequency relationship for living (a) and dead (b) biological tissue.

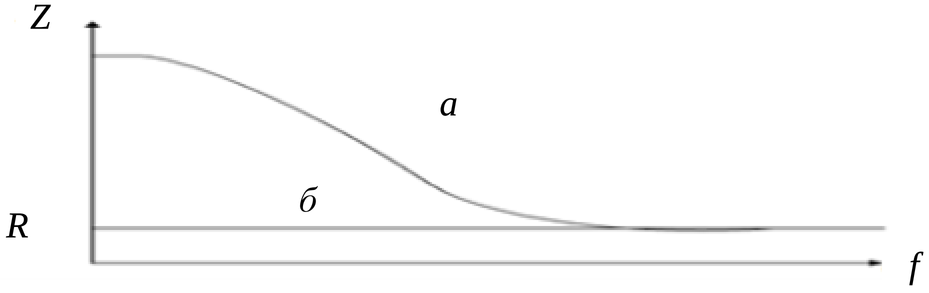


Figure 2. Impedance relationships of living and dead biological tissue

Frequency dependence of the impedance allows estimating the viability of tissue that is used to define the boundaries of necrosis and the transplantability of bio-substances.

Since the parameters characterizing the electrical properties (conductivity, capacitance, dielectric permittivity, impedance, etc.) of organs and tissues, depend on their physiological state, the may serve as its indicators, that may be used in the various studies. For example, the resistance of the object at low frequencies can serve as a measure of membrane permeability to different ions, which electrical properties change due to pathological processes in the tissues.

Thus, the initial stage of an inflammatory process is characterized by cell swelling, decreasing in the volume of intercellular space, which results in increased ohmic resistance. More advanced stages of inflammation are characterized by deep structural changes, increase in cell permeability, which is accompanied by a decrease in capacitance and resistance. Therefore, changes in the electrical parameters of the BO may serve as an indicator for diagnosing the inflammatory processes.

Known methods of impedance measuring [4] help to determine its active and reactive (capacitive) components, and not designed to define with CVC the internal regions of BO, information on which could serve for diagnostic purposes [5, 6], according to the authors.

2. Methods of harmonic balance

Method of harmonic balance (MHB) is used to investigate nonlinear circuits [7, 8]. The direct problem of HB is to determine voltage form in the non-linear element (NLE) [9] with its known current-voltage characteristic, amplitude and shape of the current flow. The idea of the method is based on the decomposition of periodic dependence functions of the current applied to the NLE and the voltage across it in a Fourier series. The unknown variables in a nonlinear electrical circuit are non-sinusoidal in general and contain an infinite spectrum of harmonics. An expected solution can be represented as the sum of the primary and high-order harmonics. By substituting this sum into a non-linear differential equation written for the unknown quantity, and setting the coefficients in the resulted expression equal to the harmonics (sine and cosine functions) of the same frequency in its left and right sides, we obtain a system of n algebraic equations, where n - number of harmonics recorded. Solving the system of equations, we obtain the required unknowns. The basis of this method is the inverse problem of the MHB, which is to determine the unknown current-voltage characteristics in the NLE with a known form of the current flowing through it, the shape and amplitude of the voltage in the NLE.

Solving the direct problem of HB allows determining the form of the voltage loss $u(t)$, in the BO, with nonlinear capacitance (NLC), presented in the form of a chain model (fig. 1c), by means of Fourier series expansion:

$$u(t)=\sum_{m=1}^{n} U_{(2m-1)} \sin((2m-1)\omega t), \qquad (1)$$

where $U_{(2m\text{-}1)}$ - an amplitude of (2m-1) voltage harmonic. At the same time, the form and amplitude of current I_a flowing through the NLC are known:

$$i(t) = I_{\text{a}}\sin(\omega t), \tag{2}$$

as well as NLC CVC, defined by the approximated expression:

$$C(u) = \sum_{m=0}^{n} k_m u^m , \tag{3}$$

where k_m – coefficients of CVC approximating expression, $m = \overline{(1,n)}$, u- voltage in the NLC.

The inverse problem of HB for determining NLC CVC is formed as follows. There is a NLC with unknown CVC, the laws of variation of the current flow (2) and the voltage loss in the NLC (1) are known. It is required to determine the coefficients k_m of the CVC approximating expression (3).

Let us write an equation of parallel-connected chain, NLC and active resistance R (according to the circuit in Figure 1) neglecting the voltage loss in R_2 and denoting $R=R_1$:

$$i(t) = \frac{u}{R} + \mathrm{C}\frac{du}{dt} \tag{4}$$

We rewrite it based on the known laws of change of current (2) and voltage (1):

$$I_{\text{a}}\sin(\omega t) = \frac{\sum_{m=1}^{n} U_{(2m-1)}\sin((2m-1)\omega t)}{R} + \\ + \sum_{m=0}^{n} k_m \Big(\sum_{m=1}^{n} U_{(2m-1)}\sin((2m-1)\omega t)\Big)^m \frac{d\big(\sum_{m=1}^{n} U_{(2m-1)}\sin((2m-1)\omega t)\big)}{dt} \tag{5}$$

Knowing the n degree of CVC approximating expression, we set n value of the argument of the sine function in equation (5). We obtain a system of n linear equations. The obtained system of equations has known current amplitude I_a,, the amplitude of the voltage harmonics $U_{(2m-1)}$, the value of active resistance R and the value of the angular frequency of current flow ω. These values can be measured during the BO test. Solving this system of equations, we obtain the coefficients k_m of the CVC approximating expression (3).

Let us consider examples of direct and inverse problems of HB:

1. We take an equation of circuit (4).
2. We set $i = 0.01\cdot\sin(\omega t)$, $\omega = 3.14\cdot 2\cdot 50000$ rad and $R = 5000$ Ohm, as well as the expression of an analytical approximation of the nonlinear dependence of the BO capacitance on voltage:

$$C = 10^{-10}u^2 . \tag{6}$$

3. We write down an expression of the unknown value in the form of a finite Fourier series with unknown amplitudes of U_m voltage harmonics (with two terms limited in this example):

$$u(t) = U_1\, sin(\omega t) + U_2\, sin(3\omega t), \tag{7}$$

where U_1, U_2– the unknown amplitudes of voltage harmonics.

4. We substitute the expressions (6) and (7) in the equation of circuit (4):

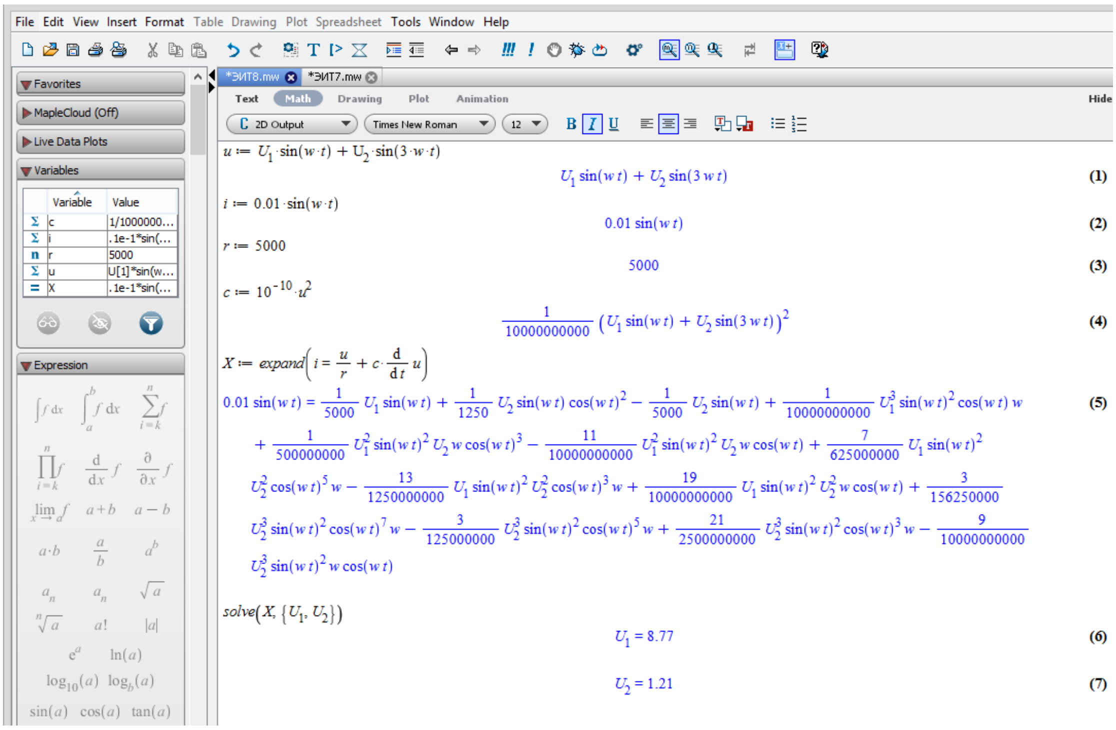
$$I_a \cdot \sin(\omega t) = \frac{U_1 \sin(\omega t) + U_2 \sin(3\omega t)}{R} + 10^{-10}(U_1 \sin(\omega t) + U_2 \sin(3\omega t))^2 \times$$

$$\times \frac{d(U_1 \sin(\omega t) + U_2 \sin(3\omega t))}{dt} \qquad (8)$$

5. We substitute the known values of the amplitude of the current I_a,, frequency ω and resistance R in the resulting expression (8).

6. We give two values of the argument (π/4 and 3π/4) and draw up a system of equations with the expressions (8).

7. We solve a system of equations with respect to U_1, U_2, using the Maple program [10] (Figure 3).



	Variable	Value
Σ	c	1/1000000...
Σ	i	.1e-1*sin(...
n	r	5000
Σ	u	U[1]*sin(w...
=	X	.1e-1*sin(...

$u := U_1 \cdot \sin(w \cdot t) + U_2 \cdot \sin(3 \cdot w \cdot t)$

$$U_1 \sin(w\,t) + U_2 \sin(3\,w\,t) \qquad (1)$$

$i := 0.01 \cdot \sin(w \cdot t)$

$$0.01 \sin(w\,t) \qquad (2)$$

$r := 5000$

$$5000 \qquad (3)$$

$c := 10^{-10} \cdot u^2$

$$\frac{1}{10000000000}\left(U_1 \sin(w\,t) + U_2 \sin(3\,w\,t)\right)^2 \qquad (4)$$

$X := expand\left(i = \frac{u}{r} + c \cdot \frac{d}{dt}u\right)$

$$0.01 \sin(w\,t) = \frac{1}{5000} U_1 \sin(w\,t) + \frac{1}{1250} U_2 \sin(w\,t) \cos(w\,t)^2 - \frac{1}{5000} U_2 \sin(w\,t) + \frac{1}{10000000000} U_1^3 \sin(w\,t)^2 \cos(w\,t)\,w + \frac{1}{500000000} U_1^2 \sin(w\,t)^2 U_2\,w \cos(w\,t)^3 - \frac{11}{10000000000} U_1^2 \sin(w\,t)^2 U_2\,w \cos(w\,t) + \frac{7}{625000000} U_1 \sin(w\,t)^2 U_2^2 \cos(w\,t)^5 w - \frac{13}{1250000000} U_1 \sin(w\,t)^2 U_2^2 \cos(w\,t)^3 w + \frac{19}{10000000000} U_1 \sin(w\,t)^2 U_2^2 w \cos(w\,t) + \frac{3}{156250000} U_2^3 \sin(w\,t)^2 \cos(w\,t)^7 w - \frac{3}{125000000} U_2^3 \sin(w\,t)^2 \cos(w\,t)^5 w + \frac{21}{2500000000} U_2^3 \sin(w\,t)^2 \cos(w\,t)^3 w - \frac{9}{10000000000} U_2^3 \sin(w\,t)^2 w \cos(w\,t) \qquad (5)$$

$solve(X, \{U_1, U_2\})$

$$U_1 = 8.77 \qquad (6)$$

$$U_2 = 1.21 \qquad (7)$$

Figure 3. Maple program listing in determining U_1, U_2

8. We obtain an expression of voltage in the form of a Fourier series:

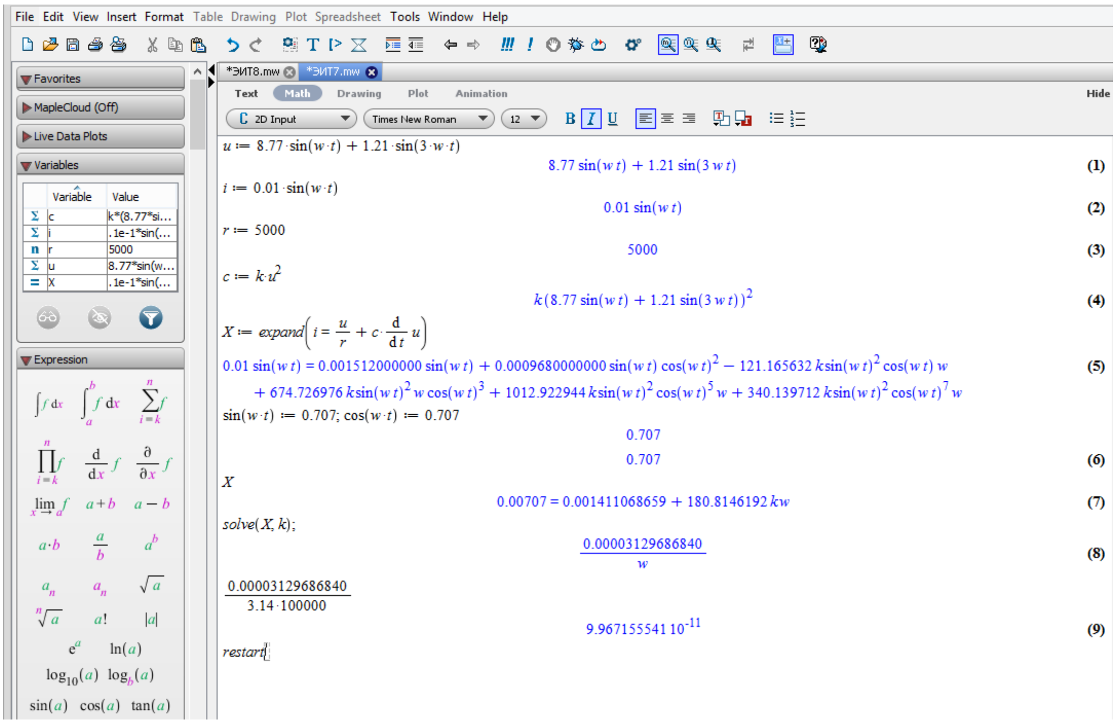
$$u(t) = 8.77 \cdot \sin(\omega t) + 1.21 \cdot \sin(3\omega t). \qquad (9)$$

We solve the inverse problem using the results the HB direct problem:

1. Let us substitute the laws of current $i = 0.01 \cdot \sin(\omega t)$ and voltage change (9) into the equation of the chain (4), carry out the differentiation and obtain as follows:

$$0.01\cdot\sin(\omega t)=\frac{8.77\cdot\sin(\omega t)+1.21\cdot\sin(3\omega t)}{5000}+k(8.77\cdot\sin(\omega t)+1.21\cdot\sin(3\omega t))^2\times$$
$$\times\,\omega\cdot 8.77\cdot\cos(\omega t)+3{,}63\cdot\omega\cdot\cos(3\omega t)$$

2. We solve this equation with respect to *k* (Maple program listing in Figure 4)



$u := 8.77\cdot\sin(w\cdot t)+1.21\cdot\sin(3\cdot w\cdot t)$

$$8.77\sin(w\,t)+1.21\sin(3\,w\,t)\tag{1}$$

$i := 0.01\cdot\sin(w\cdot t)$

$$0.01\sin(w\,t)\tag{2}$$

$r := 5000$

$$5000\tag{3}$$

$c := k\cdot u^2$

$$k\,(8.77\sin(w\,t)+1.21\sin(3\,w\,t))^2\tag{4}$$

$X := expand\left(i=\frac{u}{r}+c\cdot\frac{d}{dt}u\right)$

$$0.01\sin(w\,t)=0.001512000000\sin(w\,t)+0.0009680000000\sin(w\,t)\cos(w\,t)^2-121.165632\,k\sin(w\,t)^2\cos(w\,t)\,w + 674.726976\,k\sin(w\,t)^2\,w\cos(w\,t)^3+1012.922944\,k\sin(w\,t)^2\cos(w\,t)^5\,w+340.139712\,k\sin(w\,t)^2\cos(w\,t)^7\,w\tag{5}$$

$\sin(w\cdot t) := 0.707;\ \cos(w\cdot t) := 0.707$

$$0.707$$
$$0.707\tag{6}$$

X

$$0.00707=0.001411068659+180.8146192\,kw\tag{7}$$

$solve(X, k);$

$$\frac{0.00003129686840}{w}\tag{8}$$

$\frac{0.00003129686840}{3.14\cdot 100000}$

$$9.967155541\;10^{-11}\tag{9}$$

$restart$

Figure 4. Maple program listing in determining *k*

3. We obtain an expression of the dependence of BO capacity on the voltage:

$$C=9.967\cdot 10^{-11}u^2.$$

The above examples have shown the applicability of the HB inverse problem in determining the BO CVC. At the same time, the error in determining the coefficient of approximating CVC was less than 2%.

3. Experimental studies

The method for determining BO CVC was studied in the model of circuit simulation package MicroCap [11, 12]. The Figure 5 shows the experimental circuit.

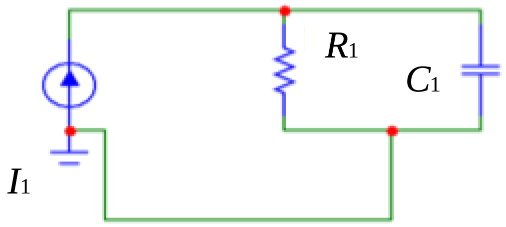


Figure 5. BO equivalent circuit model

A BO model contains series-connected NLC with the predetermined characteristic $C = 10^{-10}u^2$ and active resistance R_1 of 5000 ohms. BO is energized with frequency of 50 Hz and amplitude of 0.01 A.

The Figure 6 shows the forms of current applied to the BO and voltage in the BO. As can be seen from the figure, the current is sinusoidal, and the voltage has non-sinusoidal form.

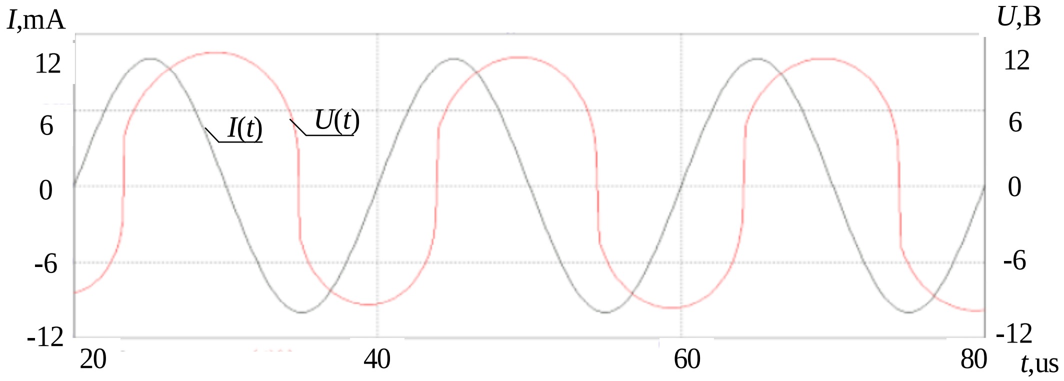


Figure 6. The forms of current applied to and voltage in the BO

The Figure 7 shows the spectrum of voltage in the BO. The figure shows that high-order harmonics can be determined from the first to seventh in addition to the first harmonic of voltage.

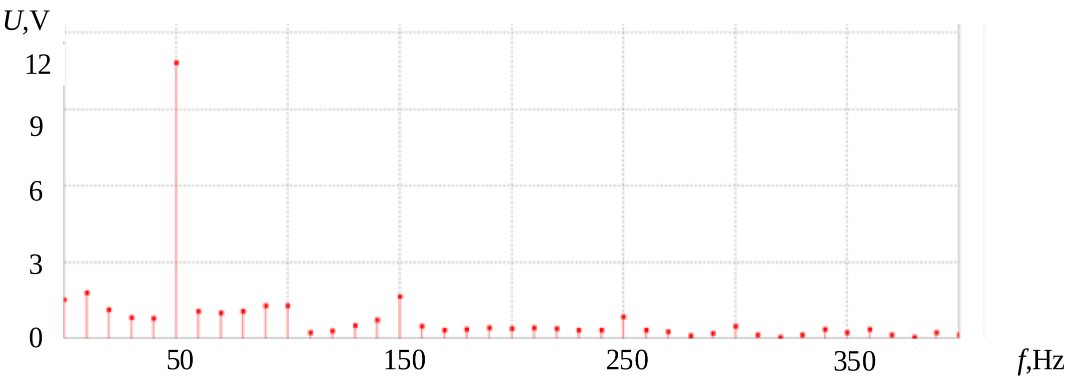


Figure 7. Spectrum of voltage in the BO

Determination of the estimated BO CVC is carried out using the proposed method based on the HB inverse solution. For this purpose, we define amplitudes of voltage harmonics from the spectrogram. The initial data for the HB inverse solution are shown in Table 1.

Table 1 - The initial data for the HB inverse solution

Parameter	I_a, A	R, Ohm	U_1, V	U_3, V	U_5, V	U_7, V
Value	0.01	5000	10.839	1.649	0.875	0,35

Let us solve the HB inverse problem using the proposed method:

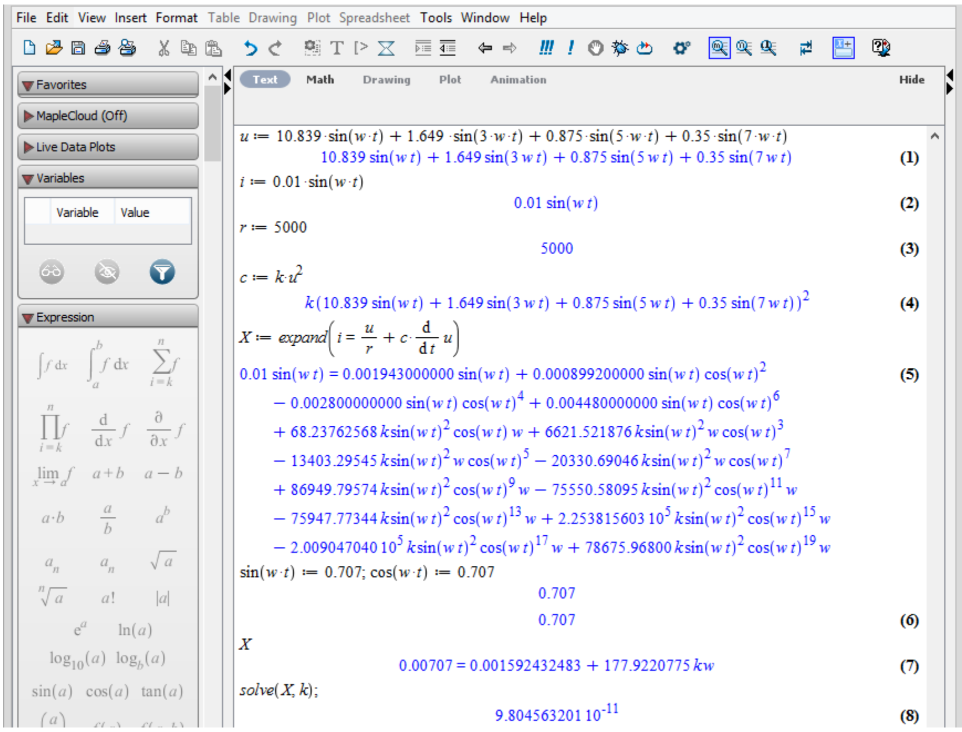
1. We write down an expression for the form of voltage in the BO as a Fourier series

$$u(t) = 10.839 sin(\omega t) + 1.649 sin(3\omega t) + 0.875 sin(5\omega t) + 0.35 sin(7\omega t) \quad (10)$$

2. We substitute the expressions (10), the value of active resistance *R*, ω frequency and amplitude of the current I_a. into the equation of the chain (5). Calculations are performed with the Maple software package. The Figure 8 shows the listing.
3. After solving the resulting expression with respect to *k*, we received:

$$C = 9.8 \cdot 10^{-11} u^2.$$

The computation error of the coefficient of approximating BO CVC does not exceed 2%.



$$u := 10.839\cdot\sin(w\cdot t) + 1.649\cdot\sin(3\cdot w\cdot t) + 0.875\cdot\sin(5\cdot w\cdot t) + 0.35\cdot\sin(7\cdot w\cdot t)$$

$$10.839\sin(w\,t) + 1.649\sin(3\,w\,t) + 0.875\sin(5\,w\,t) + 0.35\sin(7\,w\,t) \tag{1}$$

$$i := 0.01\cdot\sin(w\cdot t)$$

$$0.01\sin(w\,t) \tag{2}$$

$$r := 5000$$

$$5000 \tag{3}$$

$$c := k\cdot u^2$$

$$k\left(10.839\sin(w\,t) + 1.649\sin(3\,w\,t) + 0.875\sin(5\,w\,t) + 0.35\sin(7\,w\,t)\right)^2 \tag{4}$$

$$X := expand\left(i = \frac{u}{r} + c\cdot\frac{d}{dt}u\right)$$

$$\begin{aligned}0.01\sin(w\,t) = {}& 0.001943000000\sin(w\,t) + 0.000899200000\sin(w\,t)\cos(w\,t)^2\\ &- 0.002800000000\sin(w\,t)\cos(w\,t)^4 + 0.004480000000\sin(w\,t)\cos(w\,t)^6\\ &+ 68.23762568\,k\sin(w\,t)^2\cos(w\,t)\,w + 6621.521876\,k\sin(w\,t)^2\,w\cos(w\,t)^3\\ &- 13403.29545\,k\sin(w\,t)^2\,w\cos(w\,t)^5 - 20330.69046\,k\sin(w\,t)^2\,w\cos(w\,t)^7\\ &+ 86949.79574\,k\sin(w\,t)^2\cos(w\,t)^9\,w - 75550.58095\,k\sin(w\,t)^2\cos(w\,t)^{11}\,w\\ &- 75947.77344\,k\sin(w\,t)^2\cos(w\,t)^{13}\,w + 2.253815603\,10^5\,k\sin(w\,t)^2\cos(w\,t)^{15}\,w\\ &- 2.009047040\,10^5\,k\sin(w\,t)^2\cos(w\,t)^{17}\,w + 78675.96800\,k\sin(w\,t)^2\cos(w\,t)^{19}\,w\end{aligned} \tag{5}$$

$$\sin(w\cdot t) := 0.707;\ \cos(w\cdot t) := 0.707$$

$$0.707$$

$$0.707 \tag{6}$$

$$X$$

$$0.00707 = 0.001592432483 + 177.9220775\,kw \tag{7}$$

$$solve(X, k);$$

$$9.804563201\,10^{-11} \tag{8}$$

Figure 8. Maple program listing

3. Conclusion:

The paper shows the lack of methods for measuring active and reactive (capacitive) components of impedance of internal regions of the BO. It has been suggested to use the solution of the inverse problem of harmonic balance in order to achieve this goal. We carried out mathematical analysis of the inverse solution of harmonic balance and a simulation experiment using a model of circuit simulation package Micro-cap. The calculations were performed using the Maple package. The results obtained show that the proposed method of measuring the CVC based on the inverse solution of harmonic balance, allows obtaining the BO characteristic with an error of less than 2%.

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List of references:

1. Rubin A.B. Theoretical biophysics. - Novosibirsk: Publ. house “Universitet", 1999. - Vol 1 - p. 448
2. Impedance electrosurgery / D.V. Belik. - Novosibirsk: Nauka, 2000. – p. 237
3. Jan Bures, Mojmir Petran, Jozef Zachar Electrophysiological Methods in Biological Research – Academic Press, 2013. – p. 824
4. Remizov A.N. Medical and biological physics. - M.: GEOTAR Media 2013. - p. 648
5. Aleksanyan, G.K., N.I. Gorbatenko, D.A. Tarasov, 2014a. Modern Trends in Development of Electrical Impedance Tomography in Medicine. Bioscience Biotechnology Research Asia. V. 11, Spl. Edn. 1. pp. 85-91.
6. Aleksanyan, G.K., N.I. Gorbatenko, D.A. Tarasov, 2014b. Development of Hardware-Software Complex for Electrical Impedance Tomography of Biological Objects. Research Journal of Applied Science. V. 9, No. 12. pp. 1030-1033.
7. Bessonov L.A. Theoretical Foundations of Electrical: Electrical circuits. - M.: Higher school, 1978. - p. 528
8. Song Xing, Suting Chen, Zhanming Wei, Jingming Xia Unifying Electrical Engineering and Electronics Engineering. – Springer Science & Business Media, 2013. – p. 2310.
9. Richard H. Enns It's a Nonlinear World. – Springer Science & Business Media, 2010. – p. 396
10. Robert J. Lopez Maple via Calculus. – Springer Science & Business Media, 1994. – p. 166
11. Joachim Vester Simulation elektronischer Schaltungen mit MICRO-CAP. – Springer-Verlag, 2009. – p. 316
12. Amelina M.A., Amelin S.A. Schematic simulation program Micro-Cap 8. - M.: Hotline - Telecom, 2007. - p. 464