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Study of the effect of sugar concentration on the characteristic impedance of a magnetic coil

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Abstract. The work is devoted to the development of technology for non-invasive measurement of glucose in human blood. Modern blood glucose meters are discrete devices that do not fully provide a picture of the level of glucose in the blood. Some cases of hyperglycemia or hypoglycemia may not be recorded between measurements. In addition, finger piercing causes pain and subsequently leads to tissue damage. In this paper, the effect of glucose concentration in the human body on the complex resistance of an inductance coil, with the finger of a test person placed in it, is investigated.

1. Introduction

The incidence of diabetes is increasing every year. The number of people with diabetes over the past 35 years has increased 4 times. Now, more than 400 million people in the world have diabetes, and the prevalence of the disease continues to grow [1]. The World Health Organization estimates that by 2030, diabetes will be the seventh leading cause of death. Possible treatments include monitoring blood glucose through dietary regulation, oral medication or insulin administration, all of the methods presented have an adverse effect on daily life [2]. At present, patients with diabetes are advised to regularly check their blood glucose levels with a glucometer. This practice can help closely monitor blood glucose levels. Thus, diabetics and their doctors can get a clear picture of blood glucose levels to optimize therapy. This is an indicator for adjusting insulin dosage among diabetics who need daily insulin injections.

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However, it is difficult to puncture the blood glucose level for diabetics who check their blood sugar levels several times a day [3]. Finger piercing causes pain and subsequently leads to tissue damage. A patient who has been suffering from diabetes for 20 years and who checks blood glucose three times a day will have his finger pricked more than 21,900 [4]. It also increases the risk of infection.

It is worth noting the minimally invasive methods for measuring glucose levels - spectroscopic. They are based on the integration of subcutaneous sensors that determine the concentration of glucose in the tissue fluid. However, the disadvantage of this technology is the need for frequent calibration and high susceptibility to biological fouling [2]. Among the technologies of non-invasive glucometer, one can also note: infrared and near-infrared; Raman spectroscopy; optical coherence tomography; fluorescence spectroscopy; bio-impedance spectroscopy and others [2].

The most advantageous is the bio-impedance spectroscopy method, which is based on measuring the impedance of a biological object in the frequency range [3]. One of the existing instruments for measuring sugar using this method is PENDRA (Pendragon medical). It is a bracelet, like a watch. With the help of an open oscillating LC circuit embedded in the bracelet, the measurement of the complex resistance is performed. Using the values of the complex resistance, the change in the concentration of glucose in the blood is calculated [3-4]. Given its design, it can be said that the device is not completely non-invasive. The contacts of the LC circuit, touching the skin surface, are exposed to external influences of temperature changes and contact with sweat, which adversely affect the operation of the device. To date, a sufficiently large number of other works promoting the theory and technique of non-invasive glucometer are already known [5–16].

Summing up a brief overview of existing non-invasive methods of glucometers, we can say that the simplest approach is based on measuring the impedance characteristics of a part of the human body with a developed blood system. Such a body could be, for example, a hand - body, almost always naked for inspection. In this paper, we propose to consider the possibility of non-contact spectral analysis of the impedance of a person's hand, more precisely of one finger, depending on the level of sugar in his blood.

2. The method of measuring the total complex resistance

Since all measurements of the impedance of any part of the human hand are significantly dependent on the contact of the measuring system with the skin and this gives large errors. Human skin is a complex protective shell, which even in one person is in constant change. Hair and fat cover do not give full contact. The slightest bias in the contact clamp significantly changes the measurement. In addition, it should be added that the blood does not flow across the surface of the arm and the electric current will have to make its way through the layers of muscles, ligaments, fat and other formations. Non-invasive method should penetrate to the carrier blood - vein, contactless. There are two options - electromagnetic wave or magnetic field. Leaving aside the possibility of using an electromagnetic wave, let us focus on the use of a variable magnetic field.

We will use the simplest measuring sensor - a coil, which is both a source and a receiver of a magnetic field (Figure 1). The measured variable impedance is the impedance that should respond to the appearance of a finger inside the coil.

<center>a</center>

<center>b</center>
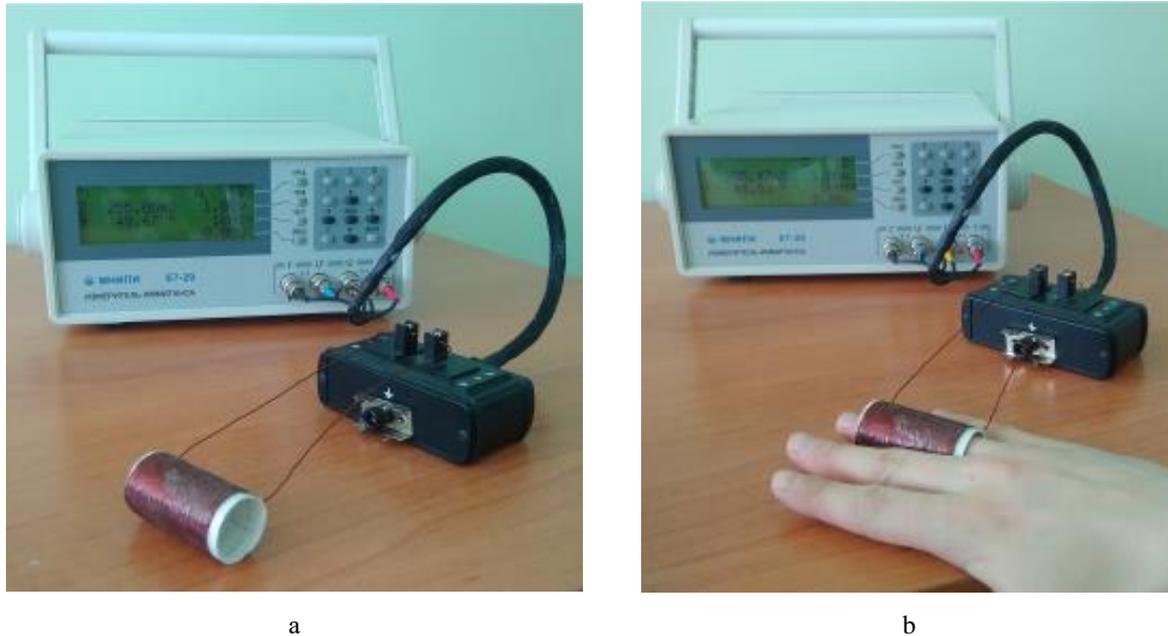
Figure 1. Measuring coil: in calibration mode (a) and in measurement mode (b).

Measurements are performed using the E7-20 instrument, which is a standard immittance meter in a wide band of tunable frequencies from 25 Hz up to 1 MHz. Immittance is a generalized concept for full (complex) resistance - impedance and full (complex) conductivity - admittance.

The principle of operation of this device is based on methods for measuring the parameters of electrical circuits, namely, bridge methods and the method associated with the use of Ohm's law relation to alternating current. The principle of operation of immittance bridge meters is based on the use of a measuring bridge, for balancing which the instrument contains sets of exemplary active and reactive (capacitive) resistances. Such devices can operate only at fixed frequencies. In the experiments, a device with a frequency range from 25 Hz up to 1 MHz was used (splitting the band into 17 frequencies: 25, 50, 60, 120, 200, 500, 1000, 2000, 5000, 10000, 50000, 100000, 20000, 500000, 1000000 Hz.)

An inductor with a winding diameter was designed and wound, so that any finger of the average person's hand can be placed into it. Subjects placed their fingers inside the coil and waited an average of 170 seconds while the instrument made measurements (10 seconds at each frequency). The principle of measurement of such immittance meters is based on the analysis of the passage of a test signal (usually sinusoidal) with a given frequency through the measured circuit, which has complex resistance. The voltage of the operating frequency from the internal generator is fed to the measured object. The voltage, current and phase shift between them is measured on a dedicated part of the circuit. The measured values are used to calculate the parameters of the circuits, in our case the complex resistance. Further, by analogy with the already well-established measurement methods in near-field diagnostics, we fix the offset of the measured parameters from the norm position (when there are no heterogeneities, the sugar level does not exceed the allowable values).

The measuring coil in the proposed use case consists of three elements connected in series: - the resistance of the copper wire from which the coil is made, - the inductance formed by the wound coil, and - the additional impedance introduced by the finger into the electrical circuit. Thus, the total impedance - immittance, measured by the device can be described by the ratio:

$$Z_x(f) = R + i2\pi fL + Z(f).$$

In the general case, of course, one should add inter-turn capacitance, but as the analysis showed, in the selected frequency range it is insignificant. In Figure 2 shows the result of measuring the coil

resistance in a wide frequency range. Shown here is the impedance modulus. This relationship is very well described by the first two terms in the above formula. The resistance of the wire is $R = 0.16723$ Om, $L = 3.12*10^{-5}$ Henry. These are small values.
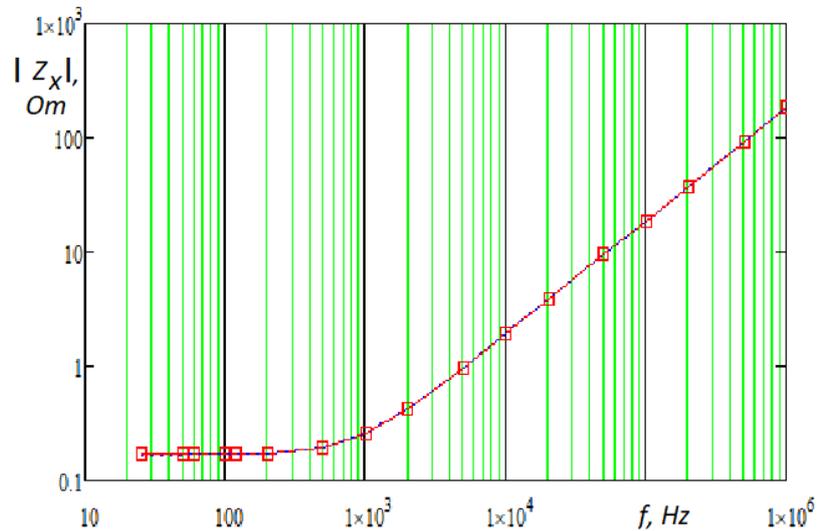

Figure 2. Modulus of impedance of the measuring coil in a wide frequency range.

3. The effect of sugar on the complex resistance

Immediately, we note that the effect of the finger is almost imperceptible on the background. To isolate this effect, it is necessary to perform a calibration for each measurement, which consisted in measuring the impedance in the absence of a finger $Z_0(f) = R + i2\pi fL$. This automatically takes into account the possibility, for example, of the thermal change in the ohmic resistance of the wire. In Figure 3 shows the dependence of

$$\delta = \left|\frac{Z_x(f)}{Z_0(f)}\right| - 1 = \left|\frac{Z(f)}{Z_0(f)}\right| - 1.$$

It can be seen, the influence of the finger as a whole is reduced to a few percent and falls on the frequency range up to 5 kHz.
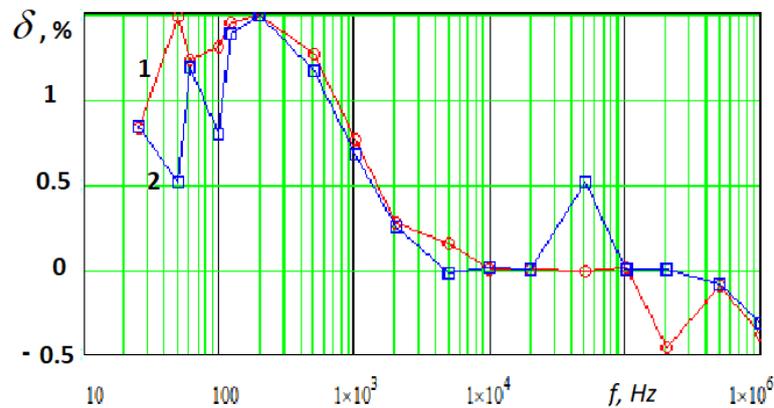

Figure 3. The influence of a finger on the measurement of complex resistance at different levels of sugar in the blood: 1 - sugar level 8.1 mmol / l and 2 - sugar level 5.7 mmol / l.

The level of sugar was controlled using an AccuCheck Performa type household glucose meter. All measurements were carried out in 2 stages. The first stage of measurement - connecting the coil, measuring the complex resistance of the circuit. This is a calibration. The next stage was carried out invasive measurement of glucose in human blood and record testimony. Blood was taken from the ring finger of the right hand. Next, the subject placed the ring finger of his right hand inside an inductor coil (Figure 1). Then, the measurement of the complex resistance of the system is made; at the end of the first two measurements, the participant in the experiment was offered food with a high sugar content. After the meal, the person was in a calm, unsettling, and inactive physical state for 30 minutes. Then the measurement procedure was repeated starting from the first stage.

The measurements performed showed that the influence of a finger makes a small contribution (less than 1-2%) to the total complex resistance. Sugar level gives an even smaller footprint. However, this trace can be enhanced by highlighting the parameter that most clearly reflects the physics of the processes. Let us explain the essence of these considerations.

An alternating magnetic field creates in the body of the finger a varying magnetic flux that permeates the blood vessels of the body of the finger. As a result, eddy currents are induced in the largest vessels, which develop in the cross section of the blood vessels. The blood containing a certain amount of free charge carriers begins to react, taking away energy from the "bulging" of its external magnetic field. Mobility of charges depends on the content of sugar dissolved in the blood. As a result, this interaction is reflected in the complex resistance of the blood. Here it is especially important that this interaction is of a reactive nature, since reactive eddy currents. As a result, the reactive component of the coil impedance will increase. For us, this means that the phase of the measured coil impedance will be the most informative.

In confirmation of the above reasoning in Figure 4 shows the detected relative changes in the phase of the coil's impedance, which are allocated to a relatively empty coil at each of the frequencies used. Here is the argument (phase) of the resistance of the empty coil and is the observed change.
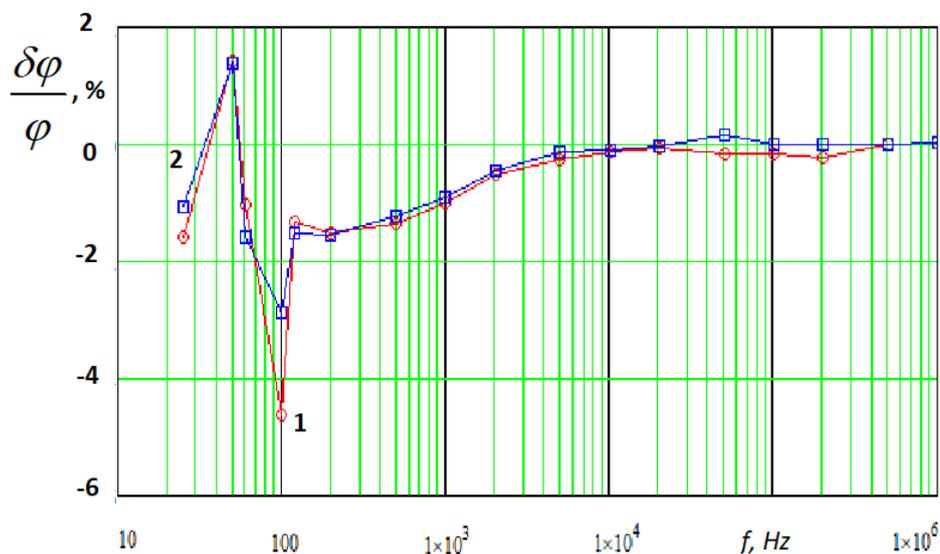

Figure 4. The change in the phase resistance of the measuring coil when inserting a finger at different levels of blood sugar: 1 - sugar level 8.1 mmol / l and 2 - sugar level 5.7 mmol / l.

It can be seen that the phase resistance of the measuring coil is the most sensitive value to the appearance of a finger in it and to the change in the sugar content in the blood. In the frequency range

of 25 Hz –5 kHz, even a small increase in the level of sugar from 5.7 to 8.1 mmol / l mmol / l causes a relative change of phase in units of%.

4. Summary

A study on the change in the complex resistance of the coil in the low-frequency region with a finger placed into it allowed, in a non-invasive way, to evaluate the increase in blood sugar levels. The most informative parameter is the phase resistance of the coil. The studies begun deserve wider continuation in world laboratories.

Acknowledgments

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