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Acoustic excitation of electric field in water solution NaCl

Abstract. The electric field value has been measured in an electroconducting water solution with NaCl, arising at simultaneously action on it of ultrasound and a direct magnetic field. Basic approaches and scheme of the laboratory device are proposed and designed. The basic characteristics of ultrasonic radiation in a place of measurement of electric field are defined, proceeding from its value and the experimental installation parameters. It is possible to assume, that at constant values of intensity of radiation and a magnetic field the value of measured voltage in the set areas of a body will give the new quantitative information on an organism state. Possibility of use of measurements of electric field for studying of properties of the biological tissue is discussed.

Keywords: ultrasonic radiation, magnetic field, biological tissue, magnetohydrodynamics.

Introduction

The physical phenomena, research methods and devices are widely used in modern biological technologies [1,2,3]. One of the physical phenomena poorly studied in these technologies is action of a direct magnetic field on movement of particles of the electroconducting medium.

Forward moving of the charged particles with some speed \( v \) in a direct magnetic field (DMF) with induction \( B \) causes occurrence of electric field \( E \) in space. Vector \( E \) is directed under some corner to directions of vectors of speed and a magnetic field [1]. This physical phenomenon has been opened in 19 century great English experimenter Michael Faraday, but has started to be applied only in the middle of 20 centuries. It has been used by Van-Allen for an explanation of electromagnetic properties of an ionosphere of the Earth [4], for creation powerful magnetohydrodynamic (MHD) generators of electric energy [1] and for creation of pumps for swapping of liquid metals [5]. In the given work we study possibility of application of it phenomenon for the decision of problems of biological technologies.

Magnetohydrodynamic (MHD) generators of ultrasonic energy are constructed, in particular, on the basis of this law. The value and direction of a vector of intensity of direct electric field in this case is defined by the formula of vector product:

\[
E = v \times B
\]  

The scalar product of the velocity and induction of the magnetic field determines the magnitude of the electric field strength if the velocity and induction vectors are mutually perpendicular:

\[
E = v \cdot B
\]  

Features of moving of the charged particles with a variable on a value and a direction of the speed are studied in the given work. In particular, such collective moving can make ions of electroconducting liquid under the influence of a wave of ultrasonic radiation (USR). Biological tissue (BT) is basically an electroconducting liquid. Periodic high-frequency compression and expansion of a liquid under the influence of USR can be considered as one of not trivial ways of contactless moving of the electroconducting tissue. Advantage USR in comparison with electromagnetic radiation is its weaker attenuation on the distances comparable to the sizes of a human body. Experimental researches are necessary for definition arising under the influence of USR electric field. It is necessary to notice, that to us works of similar type are not known. It, apparently, speaks in the small speed of moving of a liquid under the influence of ultrasonic and difficulty of measurement of small value of \( E \). The purposes of the present experimental researches are check of possibility of supervision and the value of MHD - effect under the influence of ultrasonic in water solution of NaCl, and also definition of USR characteristics by means of measurement of value of electric field arising in the solution [8-11].

Calculated ratios

As is known from physics [6], USR of small and average frequencies in the material environment (gas, a liquid, a firm body) extends in a radiation direction basically in the form of flat waves of expansion and compression.

The length of USR wave is defined by the formula:

\[
\lambda = \frac{c}{f}
\]  

where \( c \) is speed of a sound in the environment, \( f \) is a USR frequency. Density of BT is close to water density where speed of a sound makes about 1500 m/s. Each particle of environment moves on distance \( x \) along a radiation direction under the harmonious law [12,13]:

\[
x = A \cdot \sin(2\pi ft)
\]  

where \( A \) and \( t \) there are an amplitude of particles oscillation and time. Oscillatory speed \( v \) of particles is equal:

\[
v = \frac{dx}{dt} = 2A\pi ft \cos(\pi ft)
\]  

The amplitude of oscillatory speed is equal:

\[
v_m = 2\pi fA
\]  

The \( v_m \) value can be found from known parities of the theory [6, 7] of acoustics:

\[
I_s = \frac{Pv_m}{2} = \frac{P^2}{2\rho c}
\]
where \( I \), there is USR intensity, \( P \) there is a sound pressure upon particles of environment, \( \rho \) there is an environment density. From (7) follows, that

\[
(8) \quad v_m = \frac{P}{c \rho}
\]

The value \((c\rho)\) has the name of specific acoustic resistance of the environment. From parties (7) and (8) follows:

\[
(9) \quad v_m = \left[ \frac{2I}{c(\rho)} \right]^{0.5}
\]

From (6) and (9) for \( A \) it is received:

\[
(10) \quad A = \left[ \frac{2I}{l(c\rho)} \right]^{0.5}
\]

From the formula (2) for \( E \) and formulas (9) for \( v_m \) we receive the formula for the maximum amplitude \((E_m)\) of intensity of electric field in the environment:

\[
(11) \quad E_m = \left[ \frac{2I}{c \rho} \right]^{0.5} \cdot B
\]

Measurement of a value of electric field intensity is usually carried out by means of electrical potential difference measurement on two electric probes. These probes are located in the investigated environment in the field of distribution of an acoustic wave. The basic scheme of an arrangement of probes [7] is shown in a Fig. 1.

![Fig. 1 Basic scheme of MHD - effect supervision on BT section with the sizes a x l x b.](Image)

1-1 are points of installation of two electric probes for potential difference measurement on distance \( l \) from each other. \( E \) are lines of electric field, \( B \) are lines of an induction of an external magnetic field. The size of BT section along a direction of an acoustic wave should be less half of length of a wave to provide moving of all BT section with frequency USR. It is provided with a choice of USR frequency. For example, for a section with a size in 1 cm it is possible to choose length of a wave equal 6 cm. Thus USR frequency is equal to 25 kHz. The value of amplitude \((U_m)\) of an alternating voltage on probes is defined under the formula [7, 13):

\[
(12) \quad U_m = E_m l = \left[ \frac{2I}{c \rho} \right]^{0.5} \cdot B \cdot l
\]

The formula (12) allows to calculate \( E_m \) value on measured value of \( v_m \) and known value \((l)\) of distances (base) between probes.

**Experimental**

The device for carrying out experiments is shown in a Fig. 2.

![Fig. 2 Scheme of the measuring device: 1- copper glass, 2- plates for fastening of electric probes, 3- solution of NaCl, 4- direct magnets, 5- electric probes, 6- sound conductor of the USR generator, 7- USR generator, 8- electrical conductors from probes to voltmeter, 9- selective microvoltmeter.](Image)

Two electric wire probes (5) with distance (base) \( l = 10 \text{ mm} \) between them (position of probes is well visible on a projection of cut A-A of a glass and plates) have been fixed in one of plates. Probes serve for measurement of a difference of the variable potential arising in a solution under the influence of variable electric field with intensity \( E \). Metal sound conductor with diameter 15 mm (6) of ultrasonic generators (7) it was entered into the top part of a glass. Domestic ultrasonic dispergator USDN-2T with ultrasonic frequency \( f = 22 \text{ kHz} \) it was used as the generator. Measurement of potential difference \( U_m \) it was made by means of the selective microvoltmeter of an alternating voltage \( \sqrt{6} \cdot 9 \) (9). The direct magnetic field with an induction 0.4 T was created in the central area of a glass by means of two direct magnets (4). The field has been directed perpendicularly to an direction of USR, i.e. across a vertical axis of a glass with a solution. Thus, the direction of vector \( E \) coincided with a base direction \( l \) of the probes that is required according to (2) for reception of maximum of \( E \) value. Intensity (power) \( I_x \) of acoustic radiation of the generator varied from zero to the maximum value at level \( 3 \times 10^{-2} \text{ W/cm}^2 \) and measurements of voltage \( U \) by means of the microvoltmeter were made. Intensity (power) \( I_x \) of acoustic radiation varied from zero to the maximum value at level \( 3 \times 10^{-2} \text{ W/cm}^2 \) and measurements of voltage \( U \) by means of the microvoltmeter were made [14,15].

Appearance of of two parts of experimental installation is shown in a Fig. 3a, 3b. The photo of the copper cylinder which is carrying out a role of the electromagnetic screen protecting from external hindrances, in which electric probes settle down, is presented in a Fig. 3c. Leaving the screen radio-frequency the cable for connection of probes with measuring devices also is visible [16,17].

**Results and discussion**

Measurements have shown, that MHD-effects is well observed in modelling BT sample. The amplitude of an alternating voltage on probes on frequency of ultrasonic has made \( U_{\text{max}} \approx 50 \text{ microvolt} \) at target intensity of ultrasonic

The maximum intensity of ultrasonic \((I_Z)\) in the field of an arrangement of probes can be estimated on value of observable voltage on the basis of received by us before [2] formula:

\[
I_Z \approx U_{\text{max}}^2 \cdot \rho \cdot c \cdot (2B^2 \cdot f^2)
\]

where as the approached values \(\rho\) and \(c\) were the density of water and speed of a sound in water are taken. For parameters of our installation from the formula (3) it is received: \(I_Z \approx 10^{-2}\) W/cm². Values of the maximum speed \((v_{\text{max}})\) and amplitudes \((A)\) of ions moving of a solution, and also pressure \((P)\) of an acoustic wave can be received by means of the formula (2, 9, 10, 7, 13) on the basis of the measured value of electrical voltage \(U_{\text{max}}\).

USR intensity in the field of an arrangement of probes \((I_R \approx 3 \times 10^{-2}\) W/cm²) has less, than USR intensity of the generator \((I_R \approx 3 \times 10^{-2}\) W/cm²). It is possible to explain by not optimum arrangement of probes in relation to a maximum to the standing sound wave existing in the glass. Definition of an optimum arrangement of probes concerning the standing sound wave will be executed in following experiments [21].

**Conclusions**

It is experimentally proved, that in an electroconducting liquid in the form of water solution of NaCl there is an alternating electric field under the influence of ultrasonic radiation and a direct magnetic field. The direction and electric field value are defined by a base parity (1) between speed of moving of electric charges of a liquid and a magnetic field that corresponds to existence of magnetohydrodynamics effect in the liquid. Big enough value of registered voltage (50 μV) on probes with small base (10 mm) at small speed (1 cm/s) speaks movements of the spending environment about perspectivity of use MHD-effect, in particular, for definition of an increment of speed of movement of blood on vessels during heart reductions. Other possibility of application of MHD-effect in biological technologies is connected with use USR for generation and measurement of alternating electric voltage in advance set area of a body of the patient. These values are presented in Table 1.

<table>
<thead>
<tr>
<th>(f) (kHz)</th>
<th>(B) (T)</th>
<th>(l) (m)</th>
<th>(U_{\text{max}}) (V)</th>
<th>(E_{\text{max}}) (V/m)</th>
<th>(V_{\text{max}}) (m/s)</th>
<th>(A) (m)</th>
<th>(I_Z) (W/m²)</th>
<th>(P_{\text{max}}) (Pa)</th>
<th>(\rho) (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>22</td>
<td>0.4</td>
<td>10²</td>
<td>5×10⁻³</td>
<td>5×10⁻⁵</td>
<td>10⁻²</td>
<td>180</td>
<td>2×10⁴</td>
<td>1.5×10⁴</td>
<td>10⁻⁷</td>
</tr>
</tbody>
</table>

USR intensity in the field of an arrangement of probes \((I_R \approx 10^{-2}\) W/cm²) has less, than USR intensity of the generator \((I_R \approx 3\times10^{-2}\) W/cm²). It is possible to explain by not optimum arrangement of probes in relation to a maximum to the standing sound wave existing in the glass. Definition of an optimum arrangement of probes concerning the standing sound wave will be executed in following experiments [21].

The backlash between them (nearby 20 mm) serves for installation in it of a copper glass. The backlash size corresponds to diameter of a copper glass.

**Table 1. Measurements.**
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