

## 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.

**Streszczenie.** Wartość pola elektrycznego została zmierzona w elektroprzewodzącym roztworze wodnym z NaCl, powstającym przy równoczesnym oddziaływaniu na nie ultradźwiękami i bezpośrednim polem magnetycznym. Zaproponowano i zaprojektowano podstawowe podejścia i schemat urządzenia laboratoryjnego. Określono podstawowe właściwości promieniowania ultradźwiękowego w miejscu pomiaru pola elektrycznego, wychodząc z jego wartości i eksperymentalnych parametrów instalacji. Można założyć, że przy stałych wartościach natężenia promieniowania i pola magnetycznego wartość mierzonego napięcia w zadanych obszarach ciała da nową informację ilościową o stanie organizmu. Omówiono możliwości wykorzystania pomiarów pola elektrycznego do badania właściwości tkanki biologicznej. (Akustyczne wzbudzenie pola elektrycznego w roztworze wodnym NaCl).

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

**Słowa kluczowe:** promieniowanie ultradźwiękowe, pole magnetyczne, tkanka biologiczna, magnetohydrodynamika.

### 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-Alfen 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 the phenomenon for the decision of problems of biological technologies.

Magnetohydrodynamic (MHD) generators of electric 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:

$$(1) \quad E = v \times B$$

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:

$$(2) \quad E = v \cdot B$$

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:

$$(3) \quad \lambda = \frac{c}{f}$$

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]:

$$(4) \quad x = A \cdot \sin(2\pi ft)$$

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

$$(5) \quad v = \frac{dx}{dt} = 2A\pi ft \cos(\pi ft)$$

The amplitude of oscillatory speed is equal:

$$(6) \quad v_m = 2\pi f A$$

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

$$(7) \quad I_s = \frac{P v_m}{2} = \frac{P^2}{2c\rho}$$

where  $I_s$  there is USR intensity,  $P$  there is a sound pressure upon particles of environment,  $\rho$  there is a 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 parities (7) and (8) follows:

$$(9) \quad v_m = \left[ \frac{2I_s}{c\rho} \right]^{0,5}$$

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

$$(10) \quad A = \frac{[2I_s/(c\rho)]^{0,5}}{2\pi f}$$

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:

$$(11) \quad E_m = \left[ \frac{2I_s}{c\rho} \right]^{0,5} \cdot B$$

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.

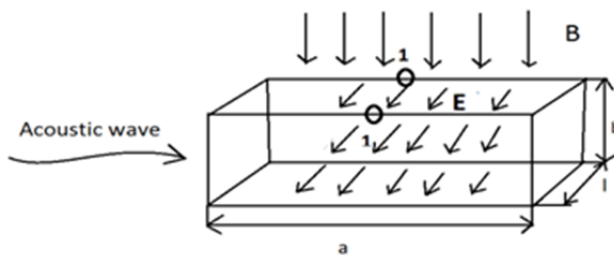


Fig. 1 Basic scheme of MHD - effect supervision on BT section with the sizes  $a \times l \times b$ ;

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]:

$$(12) \quad U_m = E_m l = \left[ \frac{2I_s}{c\rho} \right]^{0,5} B \cdot l$$

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

### Experimental

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

Weak (1 %) the water solution (3) of table salt with electroconductivity, close to conductivity of BT, was used as the modeling sample. The solution was in a copper glass (1) with internal diameter about 20 mm and with height

nearby 70 mm. Two auxiliary plates (2) of organic glass with a backlash between them in 2mm settled down along a glass axis [18,19,20].

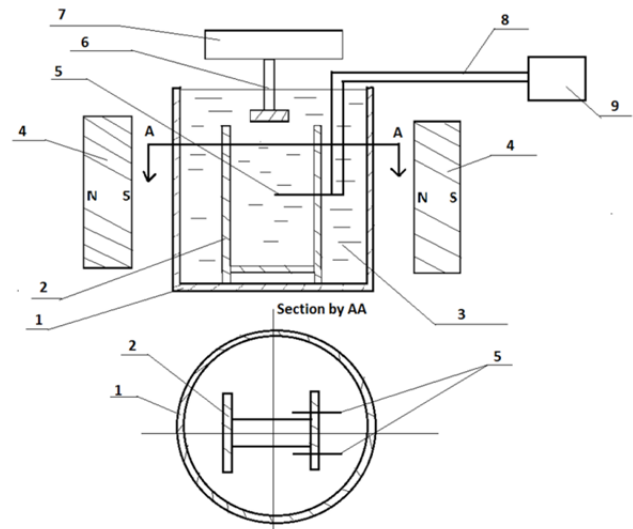


Fig. 2 Scheme of the measuring device: 1- copper glass, 2- plates for fastening of electric probes ,3- solution of NaCl, 4- direct magnets, 5- electric probes, 6- sound conductor of the USR generator, 7- USR generator, 8- electrical conductors from probes to voltmeter, 9- selective microvoltmeter.

Two electric wire probes (5) with distance (base)  $l = 10$  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  $f = 22$  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  $V 6 -9$  (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)  $I_s$  of acoustic radiation of the generator varied from zero to the maximum value at level  $3 \times 10^{-2}$  W/cm<sup>2</sup> and measurements of voltage  $U$  by means of the microvoltmeter were made. Intensity (power)  $I_R$  of acoustic radiation varied from zero to the maximum value at level  $3 \times 10^{-2}$  W/cm<sup>2</sup> 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- effect is well observed in modelling BT sample. The amplitude of an alternating voltage on probes on frequency of ultrasonic has made  $U_{max} \approx 50$  microvolt at target intensity of ultrasonic

generator  $I_R \approx 3 \times 10^{-2} \text{ W/cm}^2$ . Corresponding value of alternating electric field has made  $E_{max} = 5 \times 10^{-3} \text{ V/m}$ . The voltage value depends on angular orientation of base of probes in relation to DMF direction. Voltage has the maximum value at mutually perpendicular position of base and a direction of DMF vector, and at parallel it addresses in zero. It in accuracy corresponds to vector product (1). 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:

$$(13) \quad I_z \approx U_{max}^2 \cdot \rho \cdot c / (2B^2 \cdot l^2)$$

where as the approached values  $\rho$   $u$   $c$  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:  $I_Z \approx 10^{-2} \text{ W/cm}^2$ . Values of the maximum speed ( $v_{max}$ ) 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  $U_m$ .



Fig. 3a. Appearance of measuring installation.



Fig 3b. General view of equipment with a selective microvoltmeter.



Fig. 3c. Appearance of a copper glass with established in it probes and connecting cable.



Fig. 3d. A photo of two constant magnets Nd-Fe-B with elements of their fastening.

The photo of two direct magnets fixed from each other by brass hairpins, providing a demanded backlash between magnets, in a Fig. 3d is shown.

The backlash size corresponds to diameter of a copper glass.

The backlash between them (nearly 20 mm) serves for installation in it of a copper glass with a solution. These values are presented in Table 1.

Table 1. Measurements.

f (kHz)	B (T)	l (m)	$U_{max}$ (V)	$E_{max}$ (V/m)	$V_{max}$ (m/s)	A (m)	$I_z$ ( $\text{W/m}^2$ )	$P_{max}$ (Pa)	( $\rho c$ ) ( $\text{kg/m}^2\text{s}$ )
22	0,4	$10^{-2}$	$5 \times 10^{-5}$	$5 \times 10^{-3}$	$10^{-2}$	$10^{-7}$	180	$2 \times 10^4$	$1,5 \times 10^6$

USR intensity in the field of an arrangement of probes ( $I_R \approx 10^{-2} \text{ W/cm}^2$ ) has less, than USR intensity of the generator ( $I_R \approx 3 \times 10^{-2} \text{ W/cm}^2$ ). 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 a 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  $\mu\text{V}$ ) on probes with small base (10 mm) at small speed (1 sm/c) 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. This possibility can be realized at ultrasonic focusing in demanded area of a body of the person. The parity (3) connects the value of voltage with local properties ( $\rho$ ,  $c$ ) fabrics of the person. 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.

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#### REFERENCES

- [1] Sekhar P.C., Osman E.A., Avrunin E.G., Ali M.O., An Attempt of Determining the Force Characteristics of Fields in Magnetic Stereotactic System, *International Journal of Engineering Science and Innovative Technology (IJESIT)*, 1 (2012), nr. 2, 267-270
- [2] Avrunin O.G., Tymkovych M.Y., Pavlov S.V., Timchik S.V., Kisala P., Orakbaev Y., Classification of CT-brain slices based on local histograms, *Proc. SPIE 9816 Optical Fibers and Their Applications*, (2015), 161-168
- [3] Avrunin O.G., Alkhoraef M., Farouk H. I., Tymkovich M.Y., The Surgical Navigation System with Optical Position Determination Technology and Sources of Errors, *USA Journal of Medical Imaging and Health Informatic*, 5 (2015), 1–8
- [4] Rosa R., Magnetohydrodynamic energy transformation, (1979), 252
- [5] Frik P.G., Khripchenko S.Y., Magnetic hydrodynamics - from problems of metallurgy to galaxies, *Vestnik of the Perm Scientific Center*, (2009), 5–9
- [6] Elpiner I.Y., Ultrasound physicochemical and biological action, Moscow, (1963), 420
- [7] Avrunin O.G., Bondarenko I. S., Possibilities of joint application acoustic radiation and a direct magnetic field for biological researches, *ICBEM and RGC conference in Aachen*, (2018)
- [8] Vyatkin S.I., Romanyuk A.N., Gotra Z.Y., and etc., Offsetting relations and blending with perturbation functions, *Proc. SPIE 10445 Photonics Applications in Astronomy, Communications, Industry, and High Energy Physics Experiments*, (2017), 104452B
- [9] Tarczynska M., Gaweda K., Dajewski Z., et al., Comparison of treatment results of acute and late injuries of the lisfranc joint, *Acta Ortopedica Brasileira*, 21 (2013), no 6, 344-346
- [10] Pavlov S.V., Kozhemiako V.P., Kolesnik P.F., et al., Physical principles of biomedical optics: monograph Vinnytsya: VNTU, (2010)
- [11] Šliwa U., Skowron M., Analysis of the electric field distribution in the drum separator of different electrode configuration, *Informatyka, Automatyka, Pomiar w Gospodarce i Ochronie Środowiska*, 6 (2016), nr. 2, 79-82
- [12] Valtchev V.S., Teixeira J., Pavlov S., Energy harvesting: an interesting topic for education programs in engineering specialities, *Internet, Education, Science*, (2016), 149-156
- [13] Zabolotna N.I., Radchenko K. O., Tarnovsiky M. H., System of Mueller-Jones matrix polarizing mapping of blood plasma films in breast pathology, *Proceedings SPIE Volume 10407, Polarization Science and Remote Sensing VIII*, (2017), 1040714
- [14] Vyatkin S.I., Romanyuk A.N., Pavlov S.V. and etc., Fast ray casting of function-based surfaces, *Przegląd Elektrotechniczny*, 93 (2017), Nr. 5, 83-86
- [15] Serkova V.K., Pavlov S.V., and etc., Medical expert system for assessment of coronary heart disease destabilization based on the analysis of the level of soluble vascular adhesion molecules, *Proc. SPIE 10445, Photonics Applications in Astronomy, Communications, Industry, and High Energy Physics Experiments*, (2017), 1044530
- [16] Vyatkin S.I., Romanyuk S.A., Pavlov S.V. and etc., Using lights in a volume-oriented rendering, *Proc. SPIE 10445, Photonics Applications in Astronomy, Communications, Industry, and High Energy Physics Experiments* (2017), 104450U
- [17] Pavlov S.V., Kozhukhar A.T., et al., Electro-optical system for the automated selection of dental implants according to their colour matching, *Przegląd Elektrotechniczny*, 93 (2017) Nr. 3, 121-124
- [18] Rovira R.H., Pavlov S.V., Kaminski O.S., Bayas M.M., Methods of Processing Video Polarimetry Information Based on Least-Squares and Fourier Analysis, *Middle-East Journal of Scientific Research*, 16 (2013), 1201-1204
- [19] Zabolotna N.I., Pavlov S.V., Ushenko A.G., Karachevtsev A.O., Savich V.O., et al., System of the phase tomography of optically anisotropic polycrystalline films of biological fluids, *Proc. SPIE 9166, Biosensing and Nanomedicine VII*, (2014), 916616
- [20] Zabolotna N.I., Pavlov S.V., Ushenko A.G., Sobko O.V., Savich V. O., Multivariate system of polarization tomography of biological crystals birefringence networks, *Proc. SPIE 9166, Biosensing and Nanomedicine VII*, (2014), 916615
- [21] Nikolsky A.I., Krasilenko V.I., Bilynsky Y.Y., Starovier A., Using LabView for real-time monitoring and tracking of multiple biological objects, *Proc. SPIE 10170, Health Monitoring of Structural and Biological Systems*, (2017), 101703H