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PHYSICAL MODELLING OF THE ACOUSTIC EFFECTS ON EXPOSURE OF BIOLOGICAL SYSTEMS TO U.H.F. FIELDS*

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A physical model of radiosound is proposed based on the phenomenon of excitation of mechanical vibrations in liquid medis on absorption of the energy of u.h.f. pulses. It is shown that a restricted volume of liquid may be regarded as an acoustic resonator with a natural frequency of vibrations. Interference occurs for certain ratios between the period of succession and the duration of the pulses. Oscillograms of the mechanical vibrations recorded are presented. An explanation of the low frequency type of radiosound is offered. It is concluded that the proposed method of investigating the phenomenon of radiosound is correct.

WORK on the effect of radiosound [1–5] has reliably confirmed the appearance of subjective sound sensations on irradiation of the human head with a pulse-modulated u.h.f. field. Nevertheless, there is still no conclusively formed idea of the mechanisms of origin of such sensations. The socalled thermo-elastic hypothesis of the mechanism of radiosound proposed by Lin [6] is the best researched and most consistent. Its essence is to assume that absorption of the energy of the u.h.f. field occurs not uniformly over the whole volume of the brain but is concentrated in its very narrow regions ("hot spots") with their subsequent rapid thermal expansion and detection on the skull bones. Thanks to the presence of bone conductivity the mechanical vibrations reach the organs of hearing where the sound image also forms. But since the author of this hypothesis regards the head as an acoustic resonator he derives a number of consequences consistent with some experiments on radiosound. However, this theory cannot explain a large body of experimental evidence and is in conflict with some of it. Therefore, it may be desirable in order to define certain aspects of this phenomenon to stage experiments on models which would exclude a subjective evaluation by the subject of a particular characteristic of the effect. Foster and Finch observed excitation in a cubic vessel with a side of 300 mm filled with 0·15 M KCl solution of mechanical vibrations on exposure to a pulsed u.h.f. field [7]. This phenomenon was taken as the basis of our experiments.

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In choosing the conditions of the experiments the authors sought to follow the parameters and characteristics of the objects known from the literature on the phenomenon of radiosound and also the conditions of earlier experiments.

As objects we used 1 M NaCl solution and ethyl alcohol poured into tubes with an internal diameter 7 mm and height 100 mm. The height of the column of liquid changed within the limits 30–50 mm. The choice of 1 M NaCl solution is explained by the fact that the electrical and acoustic parameters of a given liquid, according to [6], correspond to the parameters of brain tissue. The choice of ethyl alcohol was largely arbitrary though dictated by the wish to show that the advent of mechanical vibrations on irradiation with e.m.f. pulses is not exclusively the property of electrolytes but occurs to an equal degree for non-conducting pure liquids. Irradiation was carried out in a rectangular waveguide with section 31×240 mm^2. To raise the concentration of the field in the zone of the tube on the wide wall of the waveguide was sealed a brass tube of height

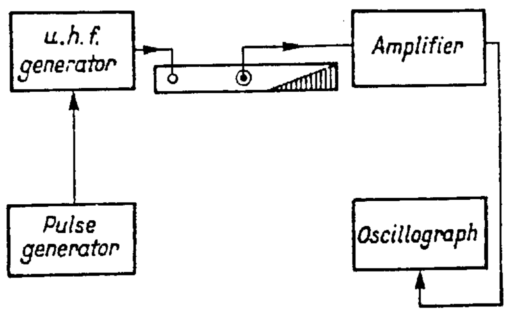

FIG. 1. Circuit diagram of experimental apparatus.

50 mm with an internal diameter 14 mm. The power of the generator in the pulse was 72 W, the repetition frequency of the pulses changed within the limits 10–3000 Hz and the duration of the pulses was 10 μsec–1 msec. The mechanical vibrations excited in the liquid were recorded by a bimorphous crystal. The variable electrical signal recorded from the detector was amplified with a UBP1-02 bipotential amplifier and recorded on the screen of a S1-19B oscillograph. As source of u.h.f. e.m.f. we used a modified GS-6 generator, carrier frequency 0·8 GHz. In [6, 7] this phenomenon is considered on exposure to e.m.f. pulses with a carrier frequency of 918–2400 MHz from which it may be concluded that the character of the effect over a wide frequency range is quite general. The apparatus at the disposal of the authors operates at the frequency of 800 MHz which is quite close to the values presented in the literature. Modulation of the u.h.f. vibrations with pulses of square form was carried out with a G5-54 generator. The circuit diagram of the apparatus is indicated in Fig. 1. Figure 2 shows arrangement of the tube with liquid in the waveguide and bimorphous crystal used as detector of the mechanical vibrations. Preliminary investigation established that the amplitude of the vibrations in the tube filled with ethyl alcohol is considerably higher than in the case of NaCl solution. Qualitatively the character of the vibrations for these and other liquids used in the experiments completely matches. Therefore,

for convenience of description below we give the results obtained for ethyl alcohol if no special qualifications are made.

Figures 3 and 4 give the oscillograms of the mechanical vibrations for the different time parameters of the e.m.f. u.h.f. pulses. For long durations (Fig. 4) the vibrations excited by both fronts of the thermal pulse are clearly visible. The vibration in the duration of the e.m.f. u.h.f. pulse with interference between the mechanical vibrations excited by the leading and trailing edges is observed. The periodicity of the appearance of the maxima (minima) of the amplitude of the mechanical vibrations $\tau = 1/f$ where f is the frequency of the vibrations excited in the liquid, is inversely proportional to the height of the liquid column.

The graphs (Figs. 5 and 6) indicate the dependence of the amplitude of the excited mechanical vibrations on the duration of the acting pulse. The frequency of the mechanical vibrations was determined from the zero beats between these vibrations and the acoustic signal from an electrodynamic emitter. The emitter was 30 cm away from the tube with detector. At the moment of equality of the frequencies of the tonal acoustic signal and the mechanical vibrations excited in the liquid zero beats were observed on the oscillograph screen. In this case the detection itself served as a vibration mixer. Simultaneously on rearrangement of the frequency of the sound generator beats are

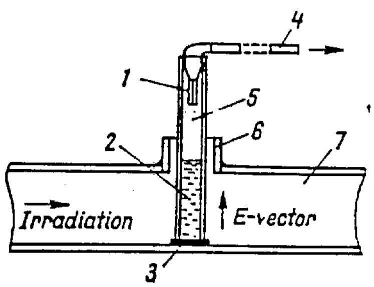

FIG. 2. Arrangement of tube with liquid in waveguide and bimorphous crystal in tube: *1* – detector of mechanical vibrations (bimorphous crystal); *2* – test liquid; *3* – packing (fluoroplast); *4* – coaxial cable; *5* – test tube; *6* – tube; *7* – waveguide.

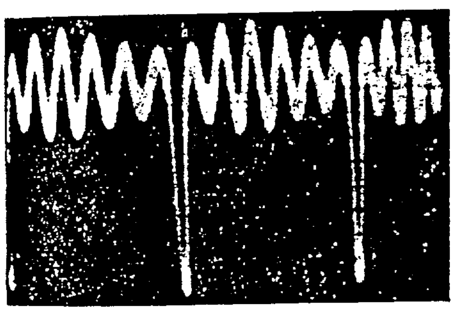

FIG. 3

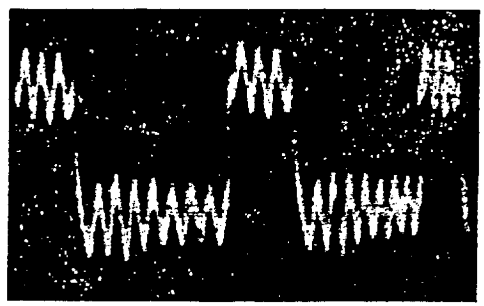

FIG. 4

FIG. 3. Mechanical vibrations excited in ethyl alcohol with a short u.h.f. pulse (duration of pulse less than the half period of mechanical vibrations).

FIG. 4. Mechanical vibrations exicited in ethyl alcohol with a wide u.h.f. pulse (duration of the pulse amounts to several periods of the mechanical vibrations).

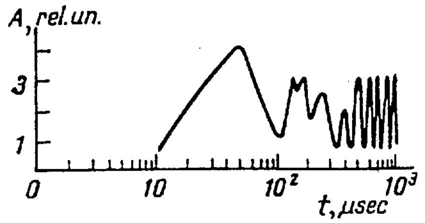

FIG. 5

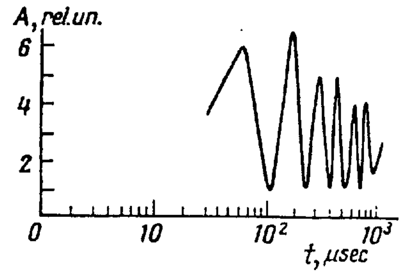

FIG. 6

FIG. 5. Amplitude of mechanical vibrations excited in 1 M NaCl solution as a function of the duration of the u.h.f. pulse.

FIG. 6. Amplitude of mechanical vibrations excited in ethyl alcohol as a function of the duration of the u.h.f. pulse.

observed between the repetition frequency of the e.m.f. u.h.f. pulses and the frequency of the acoustic vibrations from the electrodynamic emitter. The beats are recorded whenever the frequency of the acoustic vibrations is a multiple of the pulsed repetition frequency. As an example, Fig. 6 gives the oscillogram of such beats. The frequency of the acoustic signal is 6×10^3 Hz and the pulse repetition frequency of the e.m.f. u.h.f. is $1{\cdot}5 \times 10^3$ Hz. Zero beats may be observed when these frequencies are equal.

An interesting feature of the experiments is that the vibrations excited in the liquid have an intensity sufficient for their auditory perception from a distance of up to 1 m. The beats of the acoustic signal and vibrations excited in the liquid may also be perceived by hearing. In this case the mixer of mechanical vibrations emitted by the tube with liquid and electrodynamic emitter is the auditory apparatus of the observer. The zero beats on hearing may be recorded in parallel with their visual observation on the oscillograph screen. The values of the frequency of the natural vibrations of the liquid obtained by the method of zero beats recorded by the detector concur with those determined on hearing.

Similarly, parallel recording on the oscillograph screen and on hearing of the maxima and minima of the amplitude of the free vibrations the appearance of which is due to the presence of interference in the vibratory system is possible. Interference appears not only through change in the duration of the pulses (Figs. 5 and 6) at a low frequency of their succession. With increase in the repetition frequency of the pulses and for a short duration of them the excited mechanical vibrations do not have time to wane in the pauses between pulses and starting from a certain value of the repetition frequency interference of the mechanical vibrations is also observed: with agreement of the signs of the initial phases of the vibrations their amplitude grows, in counter-phase the vibrations die away (Fig. 7). At these moments a lower tone corresponding to the pulse repetition frequency is clearly perceived. In the experiment increase in the intensity of the low frequency vibrations perceived on hearing is noted with fall in the repetition frequency of the pulses down to 10 Hz. This is explained by the fact that in the energy spectrum with fall in the pulse repetition frequency the amplitude of the low frequency spectral component increases [8]. The tone corresponding to the free vibrations of the system is perceived on hearing starting from a pulse repetition frequency of the order 250 Hz.

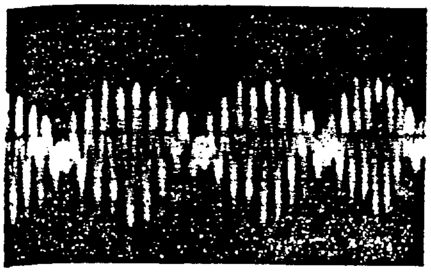

FIG. 7

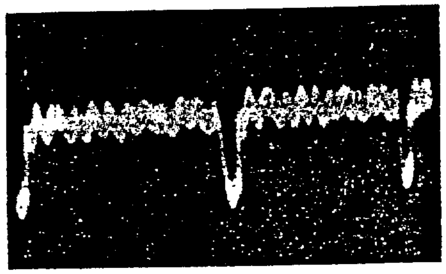

FIG. 8

FIG. 7. Beats between pulse repetition frequency and frequency of acoustic signal, a multiple of the pulse repetition frequency.

FIG. 8. Quenching of excited mechanical vibrations as a result of interference.

We also ran experiments on the character of the mechanical vibrations in liquid-filled beads on their irradiation with pulsed e.m.f. u.h.f. All the other conditions corresponded to those described earlier. A bead of diameter 20 mm with a tube 9 cm long filled with ethyl alcohol has a resonance frequency of about 9 kHz and filled with 1 M NaCl solution of the order 11 kHz. For a bead of diameter 30 mm with a tube 8 cm long the corresponding values are 6·4 and 8 kHz. A sealed 30 mm bead containing alcohol has a resonance frequency of 7·8 kHz.

The results permit some assumptions on the possible mechanism of radiosound. The clarity of the effect investigated in the experiments, the possibility of direct auditory perception and visual observation on the oscillograph screen of the vibrations excited in the liquid on irradiation of the tube with pulsed e.m.f. u.h.f. support the assumption that the effect of radiosound is due to the same processes as generation of sound vibrations in a test tube containing liquid; namely: transformation of the diminishing e.m.f. energy into the mechanical energy of the absorbing substance. From this point of view the object on which the investigations were carried out may be regarded as a physical model of radiosound and the results of the model experiments be interpreted in relation to this phenomenon. However, it should be noted that within the model described it is not possible to explain the effect of high frequency radiosound [9, 10] of a non-resonance character. But, if one starts from the fact that the measured rate of rise in temperature in the tube was $0{\cdot}1°C\ sec^{-1}$ for $1{\cdot}5\ cm^3$ 1 M NaCl solution for a pulse porosity 20 then the UPM for this object has a value of the order 8·4 kW/kg in the pulse. The calculations show that for such a UPM the power absorbed by the tube must be about 8 W in the pulse. Accordingly, to excite the mechanical vibrations of the same amplitude in a volume of $2{\cdot}5 \times 10^3\ cm^3$ (the volume of the head of the human adult) a pulse power of the generator of not less than 13 kW is necessary. Naturally, in our experimental conditions such vibrations could not be recorded owing to the considerably lower power of the generator. Nevertheless, it is obvious that if resonance were detected in this system the quantitative results of the experiments would entitle us to give a reliable interpretation of them in relation to the effect of radiosound.

It is also interesting to compare the experimental results obtained with those presented in Lin's work [6]. The author considering the characteristics of the effect of radiosound proposed for its explanation a mathematical model of the action of a single e.m.f. pulse on a liquid-filled sphere. Lin moved away from the real situation automatically replacing the linear spectrum occurring on exposure to a sequence of pulses of a definite repetition frequency by a continuous one. The dependences obtained by Lin of the sound pressure on the duration of the pulse are not commented on. If one starts from the fact that the sound pressure must change in tandem with the frequency of the elastic mechanical vibrations then from the calculated graphs presented in Lin's work, it follows that a sphere of radius 3 cm must vibrate with a frequency of about 150 kHz and one with a radius of 7 cm with a frequency of about 66 kHz. However, here the dependence of the resonance frequency on the radius of the sphere is presented and the commentary gives the resonance frequencies for radii of 3 and 7–10 cm and 25 of 7·3–10·4 kHz. This contradiction is not explained and it remains only to postulate the causes of its appearance.

On the other hand, our experimental findings show that as a result of interference the maxima (minima) following each other allow one to determine the resonance frequencies for a liquid column as a four-wave resonator.

Thus, the following conclusions may be drawn from the work undertaken.

1) A tube filled with liquid may be regarded as a physical model for investigating the phenomenon of radiosound. This follows from the obvious assumption that radiosound and excitation of sound vibrations in a liquid are based on the same mechanism – transformation of the diminishing e.m.f. energy into mechanical vibrations of the absorbing substance.

2) The socalled second type of radiosound [9, 10], namely perception of a low frequency tone in the absence of resonance vibrations is explained by the presence of mechanical vibrations corresponding to the pulse repetition frequency at the moments when the high frequency components corresponding to the natural frequency are suppressed as a result of the run-on of the phase.

3) On detection of the resonance properties of the head which can be done only on a model since the calculated powers necessary for the advent of vibrations in such a system well exceed the safely norms, the quantitative results of the model experiments may be applied quite correctly to the description of the effect of radiosound.

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ASPECTS OF THE REGULATION OF HUMAN LOCOMOTOR MOVEMENTS*

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Transforming the experimental kinematic data to normal coordinates and calculating the moments of the muscular forces during walking the author found that the locomotor movements for each degree of freedom of the leg are regulated almost discretely so that the two bit constant control parameters are switched a small number of times in the cycle of the step. Therefore, the musculature acts like switchable elastic links and the energy expenditure depends significantly less on the trajectories of movement than on the kinematic conditions at fixed moments of switching.

Posing of problem. Earlier, it was shown [1] that muscular actions are theoretically possible for which the energy expenditure depends on the goal of the movement but not on the trajectories along which the goal is reached. The control of such muscular actions is characterized by parameters instantly changed when the next goal of movement arises and constant until the goal is reached. This priniple of control was called iso-energetic and the changes in the parameters termed switching. It was found [2] that iso-energetic control is used in rhythmic movements of the arm in the elbow joint.

Similarly during locomotions of man and animals the goal of movement consisting in the displacement of the body to the necessary point in space appears more important than the trajectories of movement. Statistical analysis of the published data showed that during walking by man the muscular actions in the joints resemble the actions of switched elastic links [3]. Let us see whether the intermediate goals of movement

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