METHODS OF MEASUREMENTS OF PARAMETERS OF THE ACOUSTIC FIELD CREATED BY IONIZING RADIATION

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Abstract: in the report, having a survey character, methods and measuring apparatuses of the parameters of acoustic field created by ionizing radiation are presented. The basic attention is given to works of the Russian scientists from VNIIFTRI (ВНИИФТРИ) and the Institute of Theoretical and Experimental Physics – ITEP (ИТЭФ) and to the experimental results obtained by proton beams. A method of a scanning hydrophone is developed, realized as a device, and approved for the investigation of the space-time structure of the hydro acoustic field created by the beam of high energy particles. The space - time structure of the acoustic field, excited by the beam, has been obtained, for the first time, with good resolution, in experiments on ITEP proton synchrotron. Parameters of the angular distribution of the hydro acoustic radiation created by proton beam have been measured. The results of experiments, performed in collaboration with the scientists of the Scientific Research Institute of Nuclear Physics (SINP) at the Moscow State University in a water target on the electron accelerator are reported. The offered methods and means and the formulated metrological concept allow, at the modelling of the cascade shower in water medium by a beam of protons or electrons, to obtain values of the acoustic radiation parameters, having high extent of metrological reliability. The developed method gives the possibility of both revealing of general laws of acoustic field generation by different nature particles and the differences in radiation effects, created by them.

Keywords: sound generation, ionizing radiation, beams of protons and electrons, hydro acoustical measurements, a method of scanning hydrophone, the thermo radiation theory, acoustic detection of high-energy particles, space – time structure of the acoustic field, Bragg's peak, metrological concept

1. Theoretical part.

A new asymptotic solution for the problem of thermoradiative sound excitation by a beam of high energy particles - an original quadrature formula, is presented, allowing to determine the pressure distribution in space and time from a thermoradiative sound source. The system of eigenfunctions of acoustic radiation is type N-waves. The application of the models and the results obtained at the use of the proposed original approach is checked in the extreme case of semi-infinite field of deceleration with a homogeneous longitudinal intensity of excitation pressure.

That has allowed to determine an adequate variant of the physical model of the process which provided exact coincidence to known effects in the given extreme case. The obtained theoretical results [1] are new and, in comparison with known analytical descriptions [2, 3], provide a more convenient mathematical apparatus for the quantitative analysis of the ultrasonic field of ionizing radiations, and also provide better coincidence with experiments results.

As a basic approach at the solution of the problem of thermoradiative sound excitation, which in its nature concerns the type of incorrect tasks in mathematical physics, a construction of a pseudo- Green function of the system of thermomagnetohydrodynamic equations in approach of Bussinesk for the first time has been applied. Noise immune methods of acoustic signals processing have been developed and metrologically studied. In particular, a new, nonparametric algorithm for separation of the useful nonsteady signal from stationary noises allows to determine parameters of the useful signal at relations signals/noises up to a minus 15 dB [4].

2. Experimental part

A method of a scanning hydrophone for examination of space-time structure of the hydroacoustic field created by a beam of high-energy particles [5, 6] has been realised and constructed. The receiving and analyzing equipment consists of two measuring hydrophones – a subject (scanning) one and a reference one (fixed, intended to account the radiation instability factor). Original high-sensitivity hydrophones have been specially constructed by experts at VNIIFTRI and calibrated on the State Standard of the unit of sound pressure. Hydrophone movement was provided by a specially constructed precision electromechanical scanner, allowing to move the hydrophone discretely with a step of 4,5/9 mm within the linear aperture in length of 0,4 m. Remote electrical control of the scanner was provided from an apparatus hall. That allows, unlike the procedures applied earlier by scientists in the USA [7, 8] and in the USSR [9, 10], to avoid frequent entrances of radiative action zone and the necessity of multiple adjustments of the parameters of the beam. These methods and equipment have allowed modelling of a cascade shower in water medium by a beam of protons to obtain the parameters of the acoustic radiation for the dependences having a high degree of metrological reliability. At the experiments on the ITEP proton synchrotron accelerator the space time structure of the acoustic field excited by the beam has been obtained for the first time with good resolution. The shape of the registered acoustic impulses [5, 6] substantially coincides with theoretical one [9].

Dependence of signal amplitude in a short-range zone along the beam axis has been measured in [6] with significantly better resolution (43 points on the aperture of 0,4), than in previous publications of the American [7] and Russian [10] researchers (6 and 8 points accordingly). As a result it contains, unlike the curves given in mentioned publications, a strongly expressed maximum corresponding to Bragg's peak

At examination of angular distribution of the hydroacoustic radiation created by the thermoacoustic antenna (TA) [11], an enveloping curve is observed around the peak amplitudes in the form of a parabola which time co-ordinates correspond to the arrival moments to the hydrophone of the signal from Bragg's peak of the TA. In the region $t \cong 70$ mcs and $X \cong 0$ duration of impulses of the N-wave are minimal and are increasing in the process of moving away of the receiver from the source.

As to signal amplitude it is in the long-range point minimal and it is increased at reduction of $|X|$. Duration of the first half-period of the response of a hydrophone – the N-waves - makes ~35 mcs and ~7 mcs for the long-range and the short-range points, correspondingly. Such frequency change of a signal depending on the direction (angle) of recording reflects the geometrical sizes of cross section of the antenna in the given direction - greater frequencies correspond to the smaller sizes of radiating area.

The temperature dependence of amplitude of the hydroacoustic signal [12] generated by the proton beam, obtained in a wide (more than 100 kHz) frequency band and passing, unlike experiments [7, 8, 13], through the zero value of the amplitude, is measured as well at temperature 4˚C.

Researchers from Erlangen (Germany), working on AMADEUS project [14], later published a report [15] in which dependences of acoustic signal amplitude of a proton beam on the temperature, (also passing through zero) are presented at value 4˚C; the results, however, are presented as preliminary. The hydrophones used are characterized very shortly (a resonance on 50 kHz), the shape of impulses is not given, therefore to judge about the frequency range, also as about the relation signals/noises it is not obviously possible.

Authors [15] agree with the opinion that publications of 70-80th years do not confirm unequivocally the correctness of the thermoacoustic model. The researchers from Erlangen have developed also a noise resistant method of reception of signals in sea conditions [16]. It is necessary to note that in articles [14, 15, 16] as well in the review [3[], VNIIFTRI-ITEP publications are cited.

Experiments with a water target on the electron accelerator of SINP at the Moscow State University have been performed in 2006.

It has been established that acoustic signals form three trajectories in the plane, two of which have as a source the beam of electrons distribution area, and the third is a reflection of signals of the explored source from the bottom. The first trajectory in the form of ridges of variable amplitude corresponds the first half-wave of an acoustic signal (a compressing half-wave) from the nearest point of the radiating cylindrical antenna. The trajectory is almost parallel the axis of distances, since propagation time of the signal from the source to the receiver is equal to within change of the traversal sizes of the electron-photon shower. The signals, forming the second trajectory, begin with the decompression half-wave. Judging by time of occurrence of signals, by the shape (straight line) and to a trajectory direction, their source is in the neighborhood of the plug fitting, separating the water medium from air. Earlier similar signals from a pool plug have been registered in experiments with electron [9] and proton [6] beams. As a result of the featured experiment for the first time a detailed space – time description of the hydroultrasonic field created by a beam of electrons [17] is presented.

As a whole, the theoretical and experimental investigations, published in [1, 4 -6, 11, 12, 17] surpass the earlier results in practice and give qualitatively new level of the description of radiation acoustic effects in water medium.

The proposed methods and tools and the formulated in [18, 19] metrological conception give the possibility to obtain acoustic radiation values with high degree of metrological certainty at modelling of cascade shower in water media by a proton beam.

Scientists of three institutes have participated in the investigations.

VNIIFTRI for more than half a century specializes in constructing standards and precision measuring tools for hydro acoustic measurements, methods of measuring of parameters of acoustic signals in intensive noises from sea, and also in the field of measurements of ionizing radiation and their metrological maintenance. ITEP is known as the world center of investigations in the field of particles physics of high energies, participating in a series of the international projects on deep-water detection of neutrino. SINP at the Moscow State University possesses the necessary unique equipment for the investigations of physics of electronic beams and high qualification collective of scientists.

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