Investigation of Fluctuations of Difference Frequency Wave Sound Field of Parametric Array in Non-Stationary Medium

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Fluctuations of sound pressure amplitude of acoustic signals practically always are observed in real environments. They are caused by the natural or artificial reasons. The reasons most obviously causing fluctuations of sound pressure have experimentally been simulated. Researches of influence of a non-uniform hydrodynamic flow on the process of nonlinear interaction of acoustic waves have shown, that, besides increasing of the level of sound pressure of difference frequency wave (DFW), there were periodic fluctuations of its level. During researches of DFW back scattering on the models of hydrophysical irregularities such as non-stationary structure of gas bubbles fluctuations of amplitude of scattered DFW also were observed. It is shown that one of the reasons of sound signal amplitude fluctuations is redistribution of the phase difference between secondary sources. The spatial correlation radius was calculated which has shown, that the additive to total DFW field due to heterogeneity of environment is coherent.

1 Introduction

In real ocean’s conditions fluctuations of sound pressure amplitude of acoustic signals are usually observed. By the physical nature they can be conditionally divided into the fluctuations caused by reflection and sound scattering by ocean bottom, by the movement of the carrier of acoustic system, by the application of frequency-modulated signals. As major factors resulting in occurrence of fluctuations at movement of the carrier, swing of beam pattern of acoustic system, caused by rolling and pitching of the vessel, instability of signal amplitude, transmitted in water medium, formation of acoustic system of air bubbles and hydrodynamic currents near water surface can be concerned [1].

Acoustic waves in the ocean scatter on discrete obstacles. These are various underwater heterogeneity, the volume of each is precisely outlined, and on borders of the obstacle acoustic properties of environment (elasticity, density, etc.) rapidly change. Alive organisms and air bubbles brought in water by surface choppiness and wind concern to the basic discrete heterogeneity of ocean waters.

As air bubbles as alive organisms are essentially non-uniform distributed by the depth of the ocean. Air bubbles are situated directly under the water surface and form the layer of thickness 20-30 m. The field, scattered by the layer of these bubbles is practically inseparable from the field, scattered by the roughnesses of the water surface.

Main effects of underwater scattering by alive organisms are connected with so-called sound-scattering layers – horizontally extended biological congestion lying, as a rule, within the limits of the upper thousand meters of water thickness of the ocean. Prominent feature of the basic sound-scattering layers is their daily vertical migrations. Sound-scattering layers are the principal cause of occurrence of volumetric reverberation of fluctuating air of water thickness in which the acoustic wave is distributed. The level of reverberation will be higher with increasing of sound waves scattering.

Experimental research of influence of non-uniform hydrodynamic flow on process of nonlinear interaction of acoustic waves have shown, that, besides increase of sound pressure level of difference frequency wave there are periodic fluctuations of its level.

2 Experimental Investigations

2.1 Block scheme, geometry and conditions of experiment

Experimental investigations of volume back scattering of wave on the models of irregularities of thin structure of water medium were carried out in anechoic hydroacoustical tank. During preparation for researches at measurements of amplitude characteristics of sound pressure field of wave and processing of results of experiments rules and the techniques used in linear acoustics, radio measurements and features of measurement of sound pressure of difference frequency wave were taken into account [2].
Measurements on physical models of volumes in location mode were carried out in the range of difference frequency wave from 5 kHz up to 30 kHz. Bubble’s layer was formed in hydroacoustical tank by means of the air compressor. Bubble’s layer formed the truncated cone which basis diameter on the surface of the tank was about 0.5 m. The physical model of the scattering volume represents the kapron grid with the cell size (2x2) cm. The structure of layer was formed with six layers of grid located from each other on distance about 10 cm. The horizontal size of a grid was 1.5 m, the vertical size – 2.5 m. The vertical sizes of both models of scattering volumes exceeded the size of acoustic beam cross-section at the level 0.7 more than in 6 times, and the horizontal sizes - in 1.5 and 4 times for bubble’s layer and scattering volume, accordingly. The wave sizes of used models in the range of frequencies from 5 kHz up to 30 kHz in longitudinal direction on the axis of transmitting array were $ka=10^{-60}$, and in vertical plane $ka=50-300$ ($k$ is wave number, $a$ – characteristic bubble’s size). Such values of the wave sizes allow to exclude resonant effects in researched models of volume diffusers.

The block scheme of experiment is shown on Fig. 1, here: 1 – control panel, 2 – receiving channel 1, 3 – receiving channel 2, 4 – oscilloscope, 5 – two-channel ADC, 6 – pump signal’s former, 7 – power amplifier, 8 – plotter, 9 – computer, 10 – rotary-telescopic device, 11 – primary transducer, 12 – receiver (channel 2), 13, 15 – crossbar device, 14 – receiver (channel 1), 16 – bubble’s veil (model 1), 17 – compressor, 18 – hydroacoustical tank, 19 – scattering layer (model 2).

Primary transducer has circular aperture with diameter 30 cm. It radiates primary frequencies with central frequency 150 kHz. Pressure amplitude of primary waves was about 250,000 Pa. The range of difference frequencies was 5-50 kHz that corresponds to the operating band of measuring hydrophone. Two receivers were used during investigations: one situated close to the pump transducer and second – on 1 m from pump transducer.

Figures 2, 3 illustrate the geometry of experiments.

Figure 2: The geometry of experiments on investigation of DFW scattering on the layer of air bubbles.

Figure 3: The geometry of experiments on investigation of DFW scattering on the model of scattering layer.

On fig. 2, 3 block 1 is pump transducer, 2 – receiver (channel 2), 3 – receiver (channel 1), 5 – hydroacoustical tank. Block 4 on fig. 3 is bubble’s layer, on fig. 3 – model of scattering volume.

For providing measurements of signals scattered on the flat border situated in the area of existence of bubble’s veil the device of formation of air bubbles has been applied. The end sizes of hydroacoustical measuring tank limited the area of nonlinear interaction. Therefore measurements were carried out in the near field on distances smaller than the length of diffraction zone.

The constant control of voltage supplied to the primary transducer was carried out in all experiments. For measurement of parameters of transversal distribution of amplitude of difference frequency wave (DFW) sound pressure both the standard measuring equipment (4, 8) and the measuring devices designed specially for given researches (2, 3, 5, 6, etc) were used. Duration of pulses was 0.5 ms that has allowed to model conditions of shallow sea. In this case spatial extent of the pulse was less sizes of area of bubble’s existence.

The layer of gas bubbles 16 was settled down on 2 m from the primary transducer 11. The measuring receivers 12, 14 were settled down in measuring hydroacoustical tank 18 before the layer of air bubbles on 1 m from transducer aperture and beyond the...
bubbles on 3 m from transducer. It is necessary to mention that the bubble’s veil plane was perpendicular to the axis of parametric array (sound beam).

Signal was accepted from all sounded volume in experiments. Validity of such statement is based on that the beam pattern of parametric array is constant in all range of frequencies, and its value is much less than width of beam pattern of receivers.

As bubble’s layer represents the system of scatters continuously changing in time amount of elementary scatters, their sizes, density of its distribution, spatial coordinates of elementary scatters, spatial characteristics of the scattering volume, etc., amplitude of scattered signal is continuously fluctuating.

During the measurements the constant level of sound pressure amplitude of initial pump waves which was monitoring by the measuring high-frequency hydrophone which was situated on distance 1 m from the surface of the pump transducer on its acoustic axis was kept.

Experimental measurements of scattering of difference frequency wave signals on bubble’s scattering volume were anticipated by the estimation of contribution to the scattered field by the tube, submerged in hydroacoustical tank. Tube was filled first with air and then with water. Results of measurements shown, that levels of signals, scattered by air-filled tube were not less than on 18–20 dB lower than level of signals, scattered by bubble’s layer, and for water-filled tube, the level of scattered signal was less on 24 dB. Thus we could neglect in experiments by the contribution of signals, scattered by tube. On fig. 4 the oscillograms, reconstructed from digitized signal are shown. Here 1 – signal scattered by bubble’s layer, 2 – by air-filled tube on difference frequency 21.5 kHz.

2.2 Results and discussion

During research of volume back-scattering of difference frequency wave in real conditions and on models of hydrophysical irregularities such as non-stationary structure of gas bubbles fluctuations of amplitude of difference frequency wave were observed.

The results of experimental investigations bubble’s layer normalized to the maximal level are shown on fig. 5, where 1 – signal scattered on bubble’s layer (channel 1), 2 – signal scattered on bubble’s layer (channel 2), 3 – signal scattered on air-filled tube (channel 1), 4 – signal scattered on air-filled tube (channel 2), 5 – signal scattered on water-filled tube (channel 1), 6 – signal scattered on water-filled tube (channel 2).

![Figure 5: Amplitude frequency dependence of sound pressure level of signal scattered on air bubble’s layer.](image)

Fig. 6 illustrates the results of frequency dependence of DFW amplitude scattered on physical model of scattering layer.

The investigated model of scattering volume in the contrast to before mentioned model of bubble’s layer has rather stable scattering characteristics in time. The estimation of fluctuations of sound pressure level of signals scattered on this model showed the fluctuations did not exceed 1 dB. Obviously they have different nature form the processes of acoustic waves scattering and these fluctuations can be neglected.
With the purpose of investigation of some mechanisms influencing on formation of DFW in the environment with non-stationary structure of gas bubbles transversal distributions of DFW and of initial pump waves scattered on the layer of air bubbles were measured and analyzed. On Fig. 7 transversal distributions of DFW 8, 16 and 32 kHz amplitude measured on 3 m from the transducer in homogeneous medium are shown. They have characteristic view for such distributions: DFW amplitude raises with increasing of frequency, the side lobes are practically absent.

On Fig. 8 transversal distributions of DFW amplitude for the same frequencies measured on 3 m in the medium with non-stationary structure of gas bubbles in the area of nonlinear interaction are shown. The measuring hydrophone in this case was settled down outside of non-uniform layer of gas bubbles that has allowed to exclude influence of processes of formation and collapse of bubbles. The obtained transversal distributions represent the result of influence of several mechanisms on the process of DWF formation: not resonant dispersion on the layer, absorption of acoustic energy of DFW and initial pump waves, attenuation, variations of sound speed and parameter of nonlinearity in the layer of air bubbles of the water. Actually DFW transmitted through the layer of gas bubbles was attenuated in comparison with result of interaction in homogeneous medium on 8-10 dB. It was caused obviously by the mechanisms described above that influence also on transversal distribution of initial pump waves shown on Fig. 9.

Transversal distribution of pump wave with 160 kHz frequency is shown on Fig. 9, a for homogeneous medium, and on Fig. 9, b for wave passed through the layer of gas bubbles. It can be seen that the initial pump wave is attenuated approximately on 5 dB.

Time dependence of DFW amplitude scattered on structure of gas bubbles, located in the field of the nonlinear interaction, is shown on Fig. 7, fluctuations of sound pressure level are ±3 dB. In the submitted dependence the periodic law of changes is visible that
is connected to the processes of formation of volumetric area of gas bubbles in the environment, to the change of its radiuses inside the area of their existence, to the life cycle of the bubble and non-stationarity of borders of its area.

One of the reasons of sound signal amplitude fluctuations is redistribution of phase difference between secondary sources. This factor is dominating for the case of scattering and reflection of sound waves from bottom and surface of the ocean [1]. Influence of gas bubble’s structure components does not result in destruction of structure of virtual sources in the field of nonlinear interaction of initial pump waves. Correct interpretation of experimental data allows to reveal features of nonlinear interaction of acoustic waves and to estimate adequacy of physical model of formation of characteristics of the field of parametric array in real conditions.

Such statement results in the problem of estimation of correlation of fluctuations of sound pressure level of DFW. By theoretical consideration of this problem the major task is definition of analytical expression for correlation time interval $\tau_0$, which is determined as time of recession of correlation function $b(t)$ by a factor of $e$. For the case when the point of observation is located in near field, the approached analytical expression for $\tau_0$ is [1]:

$$\tau_0 = \frac{1}{\sqrt{2\omega_0} (v/c) \tan \delta}$$  

(1)

where $\omega_0$ – circular frequency, $v$ – speed of movement of environment concerning the surface of acoustic system, $c$ – sound speed in the environment, $\tan \delta$ – tangent of aperture corner of beam pattern of acoustic system.

The spatial correlation radius $\rho$ in this case is defined as [1]

$$\rho = \tau_0 v = \frac{1}{\sqrt{2\omega_0} \tan \delta}$$  

(2)

As the result of processing experimental data values correlation time interval $\tau_0$ and spatial correlation radius $\rho$ have been determined. $\rho$ value was 5.1 m that allows to draw conclusion that the spatial correlation radius is much greater then wavelengths participating in the nonlinear interaction, and the additive to total field of DFW due to heterogeneity of environment is coherent.

Fig. 8 illustrates time dependence of sound pressure amplitude of DFW with frequency 32 kHz measured in the environment with non-stationary structure of gas bubbles in the field of nonlinear interaction.
tank, there are periodic effects as reduction of amplitude in comparison with homogeneous environment, and also increasing of DFW amplitude.

3 Conclusion

Experimental results showed that the presence in the area of nonlinear interaction of volumetric structure of gas bubbles which extent exceeds the spatial size of transmitted pulse and length of acoustic waves participating in nonlinear interaction, results in essential changes of transversal distributions of as initial pump waves as DFW. In DFW transversal distribution there appeared additional maximums which level on 6-12 dB exceeds the level of side lobes in homogeneous medium. The similar phenomenon was described in [3] where experimental investigations of influence of oceanic whirlwind on orientation of parametric array were carried out. Space-time fluctuations of DFW and initial pump waves sound pressure level as passed through the medium with non-stationary structure of gas bubbles and scattered on irregularities of the medium were observed. Transversal distribution of DFW with increasing of frequency has jagged character that can be caused by that the wave length in this case becomes commensurable with the resonant sizes of air bubbles.

References