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PRINCIPLES OF BUILD-UP THE MODEL OF A SHALLOW SEA REVERBERATION
AND RESULTS OF ITS REALIZATION

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The acoustic reverberation in the shallow sea, being by a major factor restricting the possibilities of hydroacoustic systems of ocean testing, represents by self the composite poorly known process requiring careful examination in the theoretical and experimental aspect. In present paper the results of build-up of numerical model of a bottom reverberation in the shallow sea are given. The phenomenological model is achieved as related plurality of simple (or enough investigated) processes. Such approach allows empirically and analytically to estimate the contribution of each element of the model and by comparison the results of model operation with experimental data to estimate spatial properties of a water and bottom layers of a waveguide. The model allows doing the modal estimation of the bottom reverberation that dilates diagnostic properties of model. This work is carried out at the support of RFBR (grant 04-02-17193) and grant of the president of Russian Federation «Leading scientific schools» № HIII-10261.2006.2.

The study of physical and acoustic properties of a reverberation in shallow sea is considerable important in acoustics of ocean always. However, the qualitative understanding of forming reverberation mechanisms already exist, it does not exist of its adequate analytical or numerical model up to now. The designed model of a direct acoustic propagation allow concordantly with medium to calculate practically any parameters of a field, including its level, while to forecast the performances of a reverberation practically not possible, except separate qualitative properties can be estimated.

At the same time, recent publications about attempts of development of numerical models of a reverberation have appeared [1].

As the reverberation represents a composite signal, which is shaped by many physical mechanisms and phenomenon, the major interest is building the numerical model as bound plurality of simple appearances and mechanisms supposing the analysis and quantitative model operation. In the present paper the results of investigation and numerical modeling of a bottom reverberation (MBR) of shallow sea and its comparison with experimental data are given. Undoubtedly, such model will allow not only to estimate the energy performances of a reverberation and to predict the possibilities of hydroacoustic systems, but also will enable to estimate the properties of medium by the analysis of the performances of a reverberation.

According to [3] the reverberation is « acoustic scattering on inhomogeneities breaking a continuity of physical properties of medium». The shallow sea, which with respect to sound propagation represents by self a waveguide, has boundaries that break a continuity of medium. However, reflection and some part of a scattering of signal on boundaries forms the modal field structure. Therefore, a reverberation is only the part of an acoustic field, which cannot be taken into account within the framework of the determined models of an acoustic propagation. It is not the signal from the localized object of sondage but it is multiplicative noise to the solution of a problem of underwater sound system.

Let us try to present the structure of MBR based on a bound chain of simple physical processes.

- The reverberation can (and must) depend on a type of a source and a character of interaction of its field with medium (in other words, in the shallow sea from modal structure of the excited field).
- The model of a reverberation consists of an acoustic propagation both from a source up to inhomogeneities and up to the receiver after scattering.
- In each moment of the time the reverberation signals formed by inhomogeneities from a certain surface of a bottom, captured by pulse volume come to the receiver. Depending on impulse delay, this area varies also and it is necessary to take into account. Generally, we can

suggest the uniform distribution of elements of a scattering in a bottom, thus the level of a scattered signal can be proportional to the captured area. Depending on concrete conditions (bathymetry), there can be deviations from it, which can take into account.

- At the interaction of a direct field with bottom inhomogeneities, there is its scattering that forms a reverberation. Thus, obviously, it is necessary to take into account the energy parameters of a scattering and spatially - angular excitation of a secondary field leading to transformation of modes.
- All components of MBR have frequency dependences, which the model should take into consideration. The features of dispersion propagation of signals in a shallow sea can require the separate examinations of pulses and composite signals.

The submitted below numerical model is build according to all abovementioned features.

In underwater acoustics at a frequency band from unities up to thousands Hz only the sources consisting of the separate monopole sources are used now. Therefore, the sources coordinates in a waveguide fully define structure of a field by using modal coefficients of excitation. These coefficients are defined by amplitudes of modes on depth of a source.

To estimate of propagation the modal approach is used. For the calculation of modal, dispersion and dissipative properties of propagation in featured model the algorithm KRAKEN is used.

The propagation of impulse signals can be taken into account by precise calculation of modal performances of the dispersion, however significant effect of the performances of such signals begins at big distances that depend on a dispersion and frequency band of a signal. The estimates show that for signals with a centre frequency 250 Hz and frequency band 20 Hz this distances are more than 500 km that allows in the most practically of significant situations not take into account the broadband signal.

The dominant representations of acoustic bottom scattering are suggested on basic of two models of a scattering - isotropic and Lambert. The Raleigh model in generally used in a surface scattering, for which the spectrum of inhomogeneities is usual narrowband and the resonant part of the scattering can be considerable.

To estimate the modes transformation in isotropic model is possible by definition of coefficients of modes excitation in a bottom, and for Lambert model - by amplitude of the diagram of scattering in the directions of modal rays.

Let us give the forces of a backscattering for these two cases [4]:

$$\sigma_s = 10 \log\left(\frac{1}{\pi}\right) + 10 \log(\sin^2 \varphi) \quad \text{Lambert law} \quad (1)$$

$$\sigma_s = 10 \log\left(\frac{1}{\pi}\right) + 10 \log(\sin \varphi) \quad \text{isotropic scattering,} \quad (2)$$

where φ - angle of a modal ray.

Real laws of scattering can differ from above mentioned, because of in forming of reverberation participate not only surface of a bottom, but also sediment and rock inhomogeneities. The resonant properties of the sediment channels and other various stratum of a waveguide can give an unusually large scattering for some slip angles, and, hence, for the big modal numbers [5]. However, this effect is inappreciable for the lowest modes and hardly can have significant effect on an integrated level of a reverberation. Moreover, the scattering on local inhomogeneities of a bottom can give in magnification (increase) of a level of a reverberation from the some directions but integrated level of a reverberation thus can practically not increase.

The change of depth of a waveguide, even if thus there is no redistribution of energy of a direct signal on modes at scattering, can give the dependence of a level of signals on bottom angles. The estimation of a level of a reverberation in this case depends on a bathymetry of a sounded water area. However, accessible bathymetric database of Smith and Sandwell has the actual resolution not better than 4 km [6]. In this case, the information about a sea depth can be the first approach for an estimation of a level of a reverberation. The propagation of signals in the nonuniform by sea depth,

undoubtedly, should differ from distribution in a homogeneous waveguide. In numerical model of a reverberation these effects can be taken into account precisely and in an adiabatic approach. In our model the change of depth does not give a redistribution of a modal composition of a direct signal, however the depth variance changes the modal ray angles and, accordingly, modifies the performances of redistribution of a reverberation signal at anisotropic scattering.

The level of a reverberation for different delays, obviously, depends on the bottom area covered by impulse volume of sondage signal. Sum of signals scattering in each impulse volume on a receiving device must be calculated with incoherent average. The account of change of a scattering area in model depends on the performances of scattering. The level of a reverberation for certain delays, obviously, depends on the bottom area covered by impulse volume of a signal of sondage.

The reverberation and scattering of acoustic field on local inhomogeneities obviously should differ from a reverberation on a rough bottom surface. In the submitted model the spatial inhomogeneities of a bottom are taken into account as parameters of spatial devices (elements) of a bottom. The dissection of spatial properties of a bottom can be carried out on arbitrary meshes having homogeneous characteristics of scattering. The most convenient grid for dissection is Delonau triangulation [7], permitting to estimate gravity centers of each mesh and their squares easily (Fig. 1).

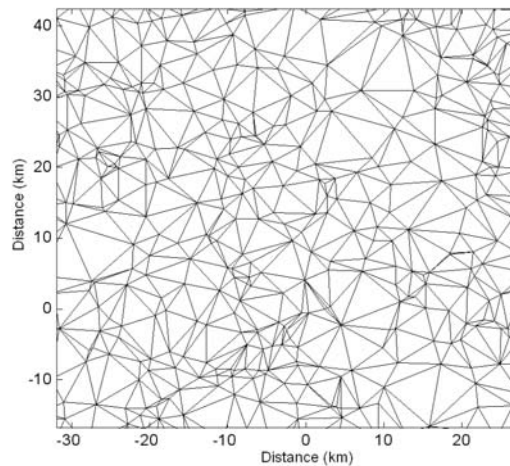


Fig. 1. An example of Delonau triangulation on a casual grid.

The levels of reverberation signals for each mesh are calculated using the analytical or empirical laws of propagation of signals with losses on distances from a centre of gravity of a mesh up to a source and receiver of signals. The common level of a reverberation is defined as incoherent sum of energies come from meshes of a casual grid in certain pulsing volume. Unfortunately, the Boundary meshes of Delonau triangulation can be of incompact sizes, which lead to the large errors on the peak delay of a signal. Therefore, model calculation is made for a water area with more than interesting size and results of calculation for long distances are broken. In fig. 2a the result of calculation of a level of a reverberation for real water area, which is taking into account distribution of six modes is given. For calculation of the propagation the experimental sound speed profile and two-layer model of a bottom were used. The scattering happened on Lambert law.

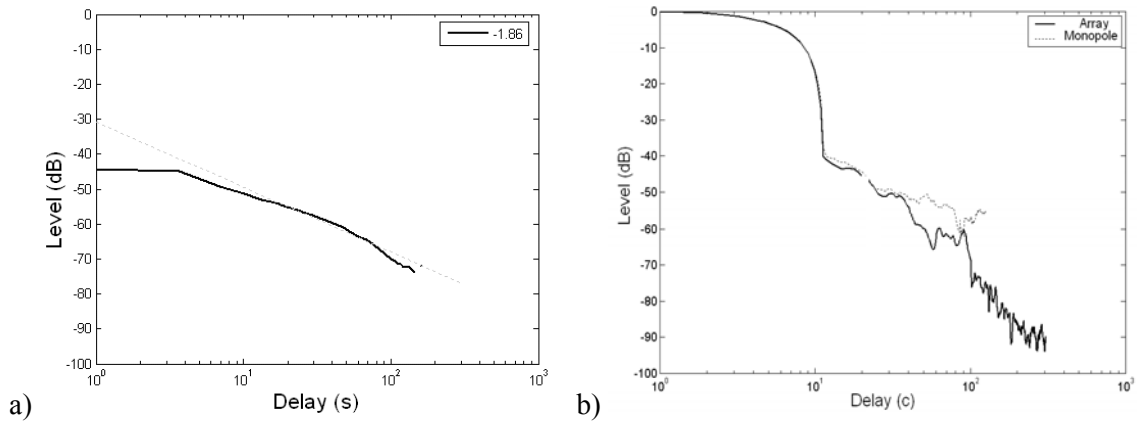


Fig. 2. A level of a bottom reverberation calculated by using the offered model (a) and experimentally measured (b).

In a fig. 2b the experimental dependence of a level of a reverberation on delay is given for comparison. The experimental dependence shows much more decrement of a degree reverberation level with a small exponential damping than is obtained in our model.

Still our model has given more exact result than in the case of simple but enough justified estimates. The submitted model allows estimate the modal structure of the reverberation (fig. 3) and its azimuth dependences of a level.

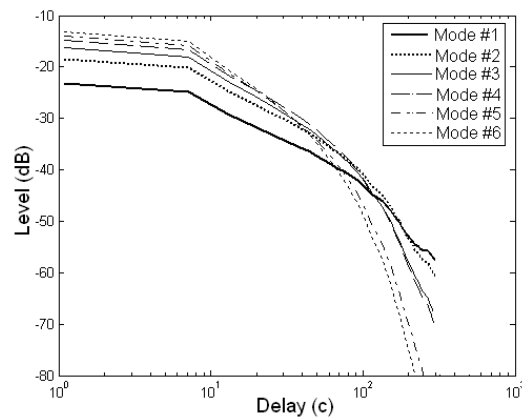


Fig. 3. Modal dependences of a bottom reverberation level.

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