Vector-phase structure of ocean noise field

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The experimental and theoretical researches made for a long time at the acoustics department of Physics Faculty of Moscow Lomonosov State University have revealed presence of the fundamental laws connecting field of acoustic pressure and field of oscillatory velocities of signals and noise in real water areas of stratified ocean. Using of combined reception system consisting of sound pressure receiver and three-componential receiver of pressure gradient (the vector receiver) and recording three mutually orthogonal components of pressure gradient and amplitude of sound pressure simultaneously in hydroacoustic measurements allows receiving the additional information about signal and noise properties at real ocean.

Three acoustics models are usually employed to describe the noise field: surface noise model, bulk noise model and shore line model. If sound pressure P and three orthogonal components of oscillatory velocity V_i $(i=x,y,z)$ are measured simultaneously in the same point than by summing up the energy contributions of separate uncorrelated point sources and averaging over the time, which is much greater than the period of oscillations, for the surface noise and the homogeneous boundless medium, we have:

$$P^2/V_x^2 = P^2/V_y^2 = 2(n+1), \quad P^2/V_x^2 = (n=1)/n.$$

We shall assume the oscillatory velocity components to be expressed in the equivalent units of sound pressure by means of formally multiplying them by the wave impedance of the medium: $V_i \Rightarrow \rho c V_i$.

Similarly for the model of the isotropic noise we have $P^2/V^2{}_r=3$.

For the model of shore surf noise $P^2/V_x^2 \approx P/V_y^2 = 2 - O(h/r)$, where $O(h/r)$ is a small correction determined by the magnitude of the ration of the receiving system submersion depth h to the distance r from the noisy line.

For remote sources, whose energy primarily comes from horizontal directions (e.g. noises of distant navigation) the following relation are typical:

$$P^2/(V_x^2 + V_y^2) \approx 1, \quad P^2/V_z^2 = 15 - 30\ dB. \tag{1}$$

In the presence of remote locale sources in the direction r

$$P^2/V_r^2 = 1{,}0 - 1{,}05\ \ dB \quad or \quad 0 - 0{,}5\ \ dB,\ \Delta\varphi_{pr} \le 4 - 5^0,$$

where $\Delta\varphi_{pr}$ is the phase difference between field components P and V_r.

In all of the above mentioned cases the condition is fulfilled:

$$P^2/(V_x^2 + V_y^2 + V_z^2) = 1. \tag{2}$$

If condition (2) is not fulfilled, it demonstrates that either fields of the non wave origin are present (flow noises, turbulent pulsations, etc.) or the work is being done in the near fields of the sources.

Relation (1) were repeatedly verified in inland water areas and in the open ocean far from any shipping lines, and the observed values of the ratio $P^2/V^2{}_i$ corresponded to the values of $n \approx 0.9\ldots1.1$. Any value of the ratio P/V differing from those mentioned above, are the evidence of the presence of extraneous sources in the water area.

It is important that nearly 90% of the field energy generated by the disturbed surface is determined by a limited region of the nearby surface. The noise of distant navigation came primarily from horizontal direction. According to (2), the vertical channel of the vector receiver is screened from distant navigation noises, so that if there are no vessels or other sources in the immediate proximity of the receiving system, the channel V_Z provides information on the true level of surface noises. We denote by $P^2{}_S$ the levels of the noise pressure generated by the disturbed surface and by $P^2{}_g$ the analogous levels of noise coming from the distant zone; their relative contribution can then be estimated by the measured values of $P^2/V^2{}_Z$:

$$P_g^2/P_S^2 \approx (P^2/V_Z^2)n/(n+1) - 1. \tag{3}$$

Other basic results of our calculation of the noise field generated by the disturbed surface, conducted in terms of the above mentioned model concepts, include the finding that the ratios P^2/V_i^2 do not depend on frequency in the case of the presence of an impedance bottom at he depth H with the reflection coefficient (both varying in a broad range) provided that $kd_Z>3$ (k is the wave number and d_Z is the depth of submersion of the receiving system). The result also weakly depends on the focusing factor and on the reflection properties of the soil, and therefore it also retains its numerical values in the vertically stratified ocean.

Moreover, the average correlation coefficient ρ_{XY} of the mutually orthogonal channels V_x and V_y , as well as ρ_{PX} and ρ_{PY} is equal to zero for measurement made at the same point of the acoustic field with the time delay $\tau=0$.

The manual correlation coefficient ρ_{PZ} is nonzero in the general case, and its magnitude depends on the submersion depth of the receiving system and on the acoustic properties of the bottom, varying from about 0.96 for deep water without marked vertical stratification to 0.1 … 0.3.

The experimentally determined ratios P^2/V^2 for three Pacific Ocean deep - water regions with various hydrological conditions at a distance from shipping lines are shown in fig.1. The first region (a) is characterized by hydrological conditions with a marked sound channel at a depth of 100-300 m (d). In the second region (b) the sound channel is situated no higher than 1100-1200 m (e). The third region (c) in the vicinity of the frontal zone is a two-dimensionally stratified ocean with a channel stable in space and time, whose vertical cross-section fragment is depicted in (g).

For the first two regions in the frequency range higher than 200-300 Hz, the values of the ratios observed at a depth of about 100 m show that the main part of the energy of the sound field is formed by the nearby section of the surface:

$$P^2/V_x^2 \approx P^2/V_y^2 = 5-7\,dB, \quad P^2/V_z^2 = 2-4\,dB.$$

The most significant distinctions were observed for the third region. Up to frequencies of the order of 1 kHz, the main part of the energy comes from horizontal directions. According to relation (3), the ratio of this energy to the level of sound pressure generated by the disturbed surface proper is P_g/P_s=3…5. A similar picture is also observed near shipping lines.

REFERENCES

[1] V. A. Gordienko, V.I. Il'ichev, and L. N. Zakharov, "Vector Phase Methods in Acoustics" (in Russian), Moscow, 1989.

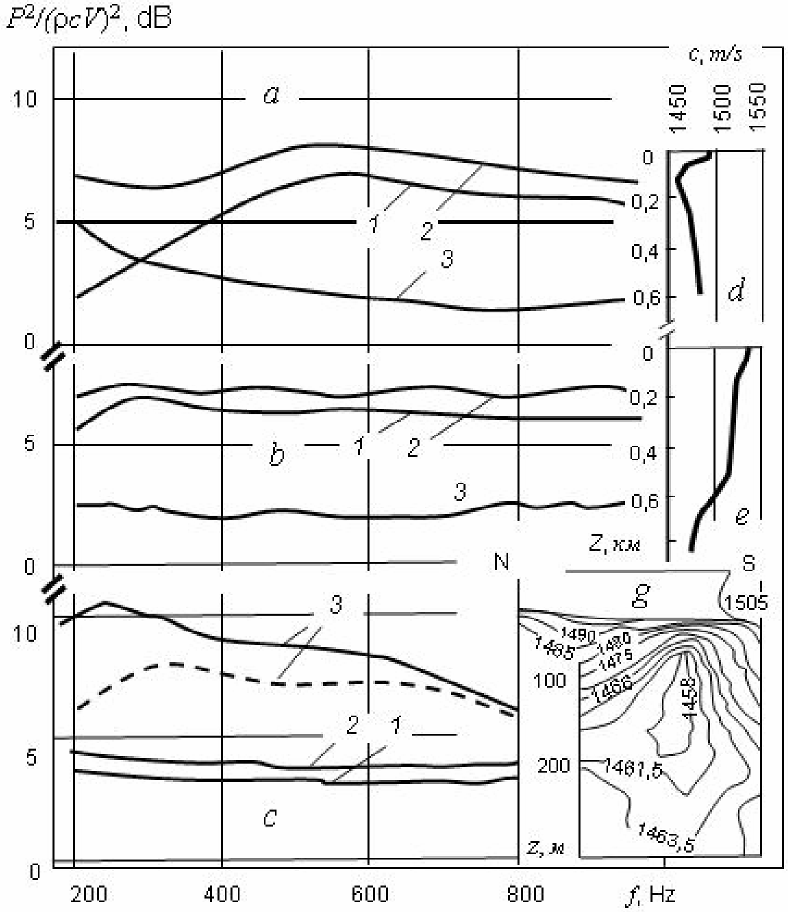

Fig. 1. Typical rations P^2/V_i^2 for three Pacific Ocean regions (a,b,c) with various hydrological conditions (d,e,g) where i: 1-x, 2-y, 3-z.