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ON MEASUREMENT OF THE RADIATION LEVEL OF AN ACOUSTIC SOURCE IN THE FAR FIELD UNDER SHALLOW-WATER CONDITIONS USING A VERTICAL ARRAY

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An algorithm for measuring the spectrum-angular distribution of the radiation power of acoustic sources in the far field under shallow-water conditions using a vertical receiving array is developed and results of model investigations of its characteristics are presented. The possibilities of traditional measurements in the near zone are compared to those of the examined algorithm. Stability of the measurement with respect to inter-modal interference and its stability with respect to the background noise of water area are demonstrated.

Measurements in the near zone are employed now to measure the radiation level of weak acoustic sources [1, 2]. The results of these measurements are extrapolated to the far zone, but this extrapolation may cause essential errors. The two main obstructions, which complicate direct measurements in the far zone in shallow sea, are:

- interference in the waveguide, related to multimode propagation of acoustic signals;
- a decrease of the signal/noise ratio (SNR) at the reception points compared to that in the near zone due to an increase of the measurement distance.

One more difficulty is motion of the acoustic radiation source (e.g., of the hydrodynamic origin) with respect to the receiving system.

The use of a vertical receiving array for measurements in the far zone enables one to perform focusing on the signal source and suppress the rays reflected from the waveguide boundaries, eliminating thereby the parasitic interference. The vertical array simultaneously increases the SNR in the output signal by means of spatial filtration of the background noise and compensates the decrease of the SNR at the receiving points in the far zone.

As is known, the optimal algorithm for measuring the radiation level of the local source carried out with an extended array in free space is reduced, under some additional conditions, to focusing of the array on the source and further spectral analysis of the output signal of the array with the level measurement [3, 4]. The optimal estimation of the level in the waveguide implies coherent weight accumulation of all signals, including those reflected from the bottom and surface [5]. Its practical realization requires exact knowledge of all propagation conditions at the measuring instant (including the sound velocity profile, the bottom profile, the complex coefficient of reflection from the bottom at all angles, etc.) and exact knowledge of the measurement geometry, which is often unreal. Besides, the selective properties of the array sufficient for separation of all propagating modes are also needed.

The method suggested for measuring the spectral-angular distribution of the radiation power of the acoustic source moving in the horizontal plane, based on focusing of the vertical array on the source in the waveguide, includes a simpler (compared to the optimal one in the waveguide) but robust spatial processing. Being at some disadvantage in relation to the strictly optimal processing in the theoretically achievable (if all the above-mentioned information is available) characteristics, this processing provides a reliable measurement in the considered problem.

The angular dependence of the far field $\hat{P}_q(\alpha)$ in the assigned third-octave frequency band can be found if the source moves along the horizontal line with respect to the vertical receiving array, which is focused on the current coordinates (the distance and depth) of the source. The appropriate radiation levels $\hat{P}_q(\alpha)$ are estimated by the formula:

$$\hat{P}_q(\alpha)[dB] = 10 \cdot \lg \left[\left(P_q(t(\alpha)) - \overline{P_{oq}(t(\alpha))}^{T_n} \right) \cdot \left(\frac{1}{N} \sum_{j=1}^N R_{sj}(t(\alpha)) / R_o \right)^2 / S_o^2 \right]^{-T(\alpha)} \quad (1)$$

where:

$$P_q(t) = \left| \sum_{j=1}^N \left[S_{qj}(t + R_{sj}(t)/C) \cdot R_{sj}(t)/K_j \right] / \sum_{j=1}^N R_{sj}(t) \right|^2 \quad (2)$$

is the squared amplitude of the output signal of the array focused on the source trajectory ($P_q(t)$ called power-versus-time dependence [2]); $S_{qj}(t)$ are acoustic signals received by the array hydrophones and subjected to third-octave filtration; j is the hydrophone number in the vertical receiving array; q is the third-octave frequency band number; t is the time; α is the current value of a bearing; $t(\alpha)$ is the function inverse to the dependence of the bearing on time for the moving source; N is the quantity of hydrophones in the array; $R_{sj}(t)$ is the distance between the source and the hydrophone of the number j of the array; C is the sound velocity in water; K_j are the transmission coefficients of the receiving units (including the hydrophones); $P_{0q}(t)$ is the power-versus-time dependence of the array focused on the imaginary path of the source in the absence of a real source (the background noise); R_0 is the standard distance, at which the source radiation level is determined; S_0 is the standard reference level, with respect to which the measured level is calculated in decibel; $T(\alpha)$ is the averaging time interval depending on the angle; T_n is the averaging time constant of the background noise. The length of the array section used in each frequency range is chosen so that the vertical size of the source does not exceed the size of the focal spot.

The initial data may practically prove to be insufficiently precise; therefore the processing algorithm involves estimation of three basic parameters: the depth of the source motion, the traverse distance from the source to the array center and the time instant of the source passage by traverse. The estimation is accomplished by seeking (in some range of additional search determined by the accuracy of the initial data) the global maximum by three parameters (depth, traverse distance and traverse instant) in the time function (2) as a result of array focusing. The estimates obtained after their specification are further employed for array focusing on the actual (specified) path of the source. This provides measurement of the power-versus-time dependences (2) in all considered third-octave frequency bands.

The third-octave levels of the background noise necessary for measuring are determined in the time intervals, where the signal source may be assumed to be absent (e.g., far from the traverse instant). These levels are averaged in the interval T_n (the averaging time constant of the background noise) which considerably exceeds $T(\alpha)$. The standard of residual fluctuations is also measured and the threshold measurement level is determined as a linear combination of the average and the standard of the noise.

The noise levels are subtracted from appropriate power-versus-time dependences and in the obtained difference the signal level received by the array hydrophones is compensated for the variation of the distance between the source and the receiving array. The obtained time function undergoes a sliding incoherent averaging with the variable averaging time $T(\alpha)$ proving equal intervals of averaging over a bearing in the range of angles of the source radiation diagram for all bearings. As a result, the angular dependence of the radiation level of the source in the third-octave band acquires the form (1). The measurement is considered to be performed in the bearing range, in which the power-versus-time dependence (2) exceeds the threshold level measured by means of the background (in the absence of the source).

Below are the results of computer simulation of the measurement, obtained for an isovelocity waveguide with the constant depth $H=275$ m and the reflection coefficient from the bottom 0.3. We employed a model of a non-directed source of tone radiation at the frequency 200 Hz, which moved with the constant velocity 3 m/s at the depth of 100 m along a straightforward path. The minimal horizontal distance between the source and the receiving array was 250 m. The calculations were carried out for the vertical receiving array comprising 13 hydrophones with the distance 3.75 m

between the neighboring hydrophones (the distance is equal to half the wavelength for the sound velocity 1500 m/s); the upper hydrophone of the array was placed at the depth of 105 m.

Figure 1 permits to compare the results of the radiation level measurement using the array focused on the source and the single central hydrophone of the array, depending on the distance

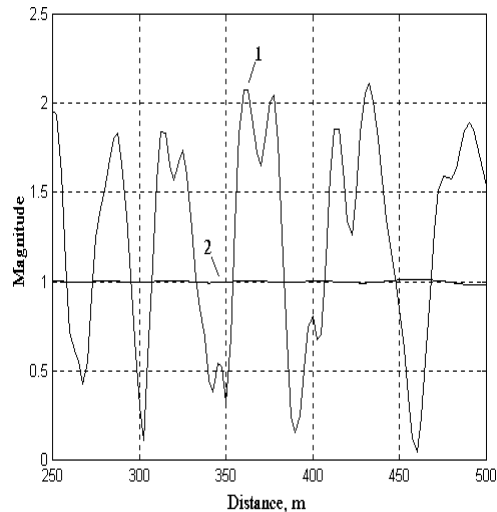


Fig.1. Results of measurement simulation of signal amplitude of tone source at frequency 200 Hz versus distance for array focused on source (1) and single central hydrophone of array (2).

between the array and the source. The plots are obtained without taking account of the background noise, because it can disguise the quality of interference suppression by the array, which is illustrated by the figure. The plots are constructed in the linear scale and if the measured value coincides with the real one, it is equal to unity (regardless of the distance). The plot for the single hydrophone shows that errors of the level measurement may achieve rather large values from -20 to $+6$ дБ. Under the same conditions the level measured with the help of the array focused on the source demonstrates minimal slight deviations from the real value for all distances.

Figure 2 illustrates the possibility of the vertical focused receiving array to separate the real and imaginary sources in the considered measurement scheme. The figure exhibits the dependence of the signal level from the focused array on the distance and depth of the focusing point for the same tone source. Negative values of depth in the plot correspond to focusing on the imaginary source located above the surface level. The bands with high resolution of the signal at the depth of the real source (100 m) and at the depth of “-100 m” corresponding to the first reflection from the surface, are well seen in the figure. The rest of the rays, including the first bottom reflection, are strongly disguised by interference. We should note the presence of a zone with a low signal level close to the depth of 250 m in the whole range of distance variation. Under real conditions this range of focusing depths free of the signal, enables one to measure the background noise level not only in the absence of the source, but also directly in measuring, which eliminates the requirement of stationary background interference, increases the measurement accuracy and decreases the minimal level of the measured signal.

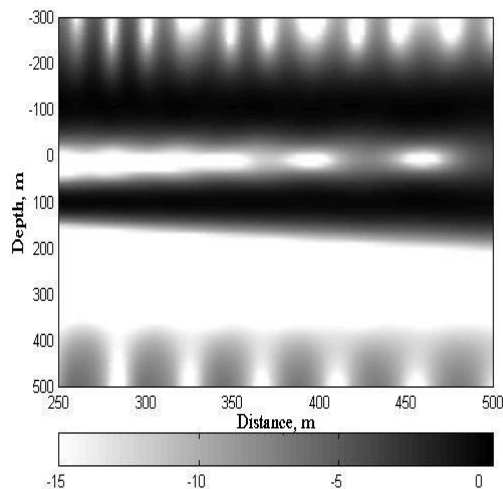


Fig.2. Result of array focusing on various points of waveguide depth for 200 Hz tone source located at depth 100 m versus distance.

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Figure 3 vividly demonstrates noise immunity of the focused array and its possibility to suppress interference in the waveguide in the presence of strong background noise (the model of the Gaussian noise occupying the third-octave frequency band is used; the average SNR at the reception point is 2 dB). The figure displays jointly for comparison the power-versus-time dependences – the time dependences of the signal level in the third-octave band with the central frequency 200 Hz obtained from one (central) hydrophone of the array by means of incoherent accumulation of signals from the array hydrophones and the focused array. Both for single hydrophone and for the incoherent array the

excess of maximum of the measured power-versus-time dependence over the background level

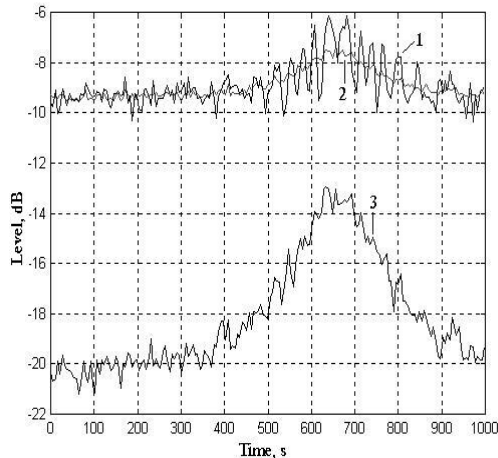


Fig. 3. Power-versus-time dependences for third-octave band of 200 Hz: 1 – single central hydrophone, 2 – incoherent array, 3 – focused array.

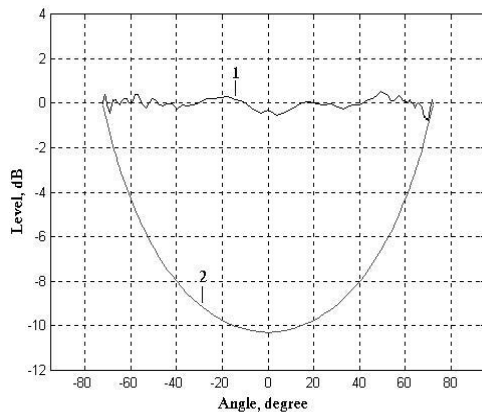


Fig. 4. Angular dependence of far field level in third-octave band of 200 Hz (1) measured using focused vertical array and minimal level of radiation source (2) measurable under these conditions.

amounts to 2 dB, which is insufficient for the level measurement (with allowance for the standard of residual fluctuations). At the same time the focused array provides the excess of 6 dB and a decrease of the background level by more than 10 dB, which allows obtaining a rather low measurement error and measuring weak signal levels.

The angular dependence of the radiation level in the far field, simulated and calculated according to (1) for the same SNR at the reception points (the real radiation level of the non-directed source 0 dB) is shown in Fig. 4. The initial transmission characteristics were averaged with a variable averaging time, so that the angular averaging interval remains constant and equal to 5° . The boundaries of the angular range of measurement were determined automatically according to the criterion of the background level excess by the value of more than four standards of residual fluctuations. As a result, at the frequency of 200 Hz the excess of the mentioned threshold was in the range of angles more than 60° .

Possibilities of measuring the radiation levels of weak sources (yielding low signal-to-noise ratios in the reception region) were also investigated by statistical computer simulation. The investigations have permitted to find out that the use of the suggested measurement method with a vertical focused array in the far zone provides measuring of the levels of both discrete and broad-band components of the radiation source under these conditions in a wide frequency range with the radiation level for the frequencies more than 25 Hz, which is even lower (by 3-4 dB) than usual measurements in the near zone.

The work is supported by RFFI (grant No. 05-02-17512) and the grant “Leading scientific schools” NSh 10261.2006.2.

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