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RADIOPHYSICS, ELECTRONICS, ACOUSTICS

The Peculiarities of the Effects of Underwater Currents on Low-Frequency Hydroacoustic Stationary Vertically Distributed Receiving Systems

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Abstract—Features of the behavior of long vertically distributed receiving systems (VDRSs) for use in the low-frequency tomography of the ocean are considered. In the most common design variant, VDRSs are structures that consist of a cable rope of up to several hundreds of meters in length with receiving modules placed coaxially (hydrophones) or axis-perpendicularly (accelerometers) on it, a buoy, and an anchor, which support the predetermined spatial position of the system. The results of the experiments carried out using VDRSs of 32 and 128 m in the White Sea are discussed. Underwater-current forces on a VDRS result in vibrations on system elements, especially on the cable–rope, which are transmitted to hydrophones and are responsible for the formation of a pseudo sound signal at frequencies below 10–12 Hz that, under certain conditions, can considerably exceed the background noise level of the water area. These facts may considerably reduce the efficiency of a VDRS and limit the frequency range of measurements from the bottom. The similarity of the results obtained by different experiments suggests that there is a general mechanism for the occurrence of vibrations and pseudo sound. The definition of such a mechanism can point the way to eliminating these undesirable effects and extending the frequency range of a VDRS into the infrasonic range.

Keywords: ocean tomography, acoustic arrays, vertically distributed receiving systems, extended hydroacoustic receiving systems, hydroacoustics, vector-phase methods, combo receiver, vector receiver, vibration noise, hydrodynamic noise, flow pseudo sound, sound power flow, Umov's vector, localization of sound sources, noise immunity, sonographic analysis of high-resolution metrology, high-frequency geoacoustic emission.

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1. INTRODUCTION

Vertically distributed hydroacoustic stationary receiving systems (VDRSs) are being widely used in the acoustic tomography of the ocean [1]. However, acoustic tomography itself is being modernized. First and foremost, this involves the use of the modern computer base, which allows one to enhance the obtaining of information on the characteristics of a water area under study. Moreover, the acoustic tomography of the ocean is being regarded as one of the main methods for obtaining information on the structure, as well as the time and spatial variability of large (hundreds and thousands of kilometers) water areas of the world ocean; the problem of monitoring the large regions of the world ocean is still extremely topical. This has required the reduction of working frequencies and a new area has been established: low-frequency ocean tomography. As is well known, only low-frequency signals can propagate to great distances in water without considerable attenuation. In this case, rather lengthy antenna arrays are to be used, resulting in problems due to water currents and other natural phenomena in the ocean depth including their spatial instability in time. Altogether, this has resulted in using different engineering solutions to protect VDRSs against various vibrations, changes in the configuration of antennas, their spatial orientation, etc. [2].

In the literature (on descriptions of the designs of long antennas), the engineering solutions that are based on analyzing experimental data are generally mentioned. However, the reference data are lightly cited in the literature.

Reasoning from this fact, we present the experimental results from studying low-frequency vibrations of VDRSs that were obtained in the Kandalaksha Gulf of the White Sea, which is distinguished by rather variable water currents. According to long-term observation data [3], the velocity of constant currents in the Kandalaksha Gulf is relatively small and averages from 0.2 to 0.6 knot. Tidal currents are also weak and are

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† Deceased.

about 0.3 knot on average. The Kandalaksha Gulf is the deepest water area of the White Sea. The antennas described in this paper are sited at a depth of 260 m in the vicinity of a trench up to 330 m in depth. Two vertically distributed antennas 32 and 128 m in length were used for the experiment.

The duration of the recording of the acoustic signals received by sound detectors of the antennas is generally determined by the time interval within which tidal and other currents are changed from their maximum to minimum velocity values.

2. THE EXPERIMENTAL PROCEDURE AND MAIN SOURCE DATA

During the experimental studies on VDRSs of the most suitable design we used a cable–rope 17 mm in diameter, on which slots for primary transducers were positioned with a certain fixed pitch. Hydrophones (or accelerometers) were placed into the slots that were arranged perpendicular to the axis of the cable-rope. The top end of the antenna was fixed to the buoy and the autonomous breaker, to which a load was fastened using a steel wire 80 m in length, was fixed on the bottom end. Hydrophones and single-component accelerometers were installed into the nonuniformly spaced antenna array 32 m in length, so that the distance between an accelerometer and a closest hydrophone was 2 m (see Fig. 1a). The vertical position of the system was provided by a spherical buoy with a positive buoyancy of about 60 kg. An additional hydrophone–accelerometer pair was mounted on the lid of the sphere to compare the recorded signals with the signals recoded by sound detectors within the antenna.

In terms of design, the antenna that was 128 m in length was similar to the antenna that was 32 m in length except for the number of receiving elements, length, and pitch between the elements (Fig. 1b). Hydrophone *1* in this antenna was placed at a depth of about 84 m; next, hydrophones *2*–*8* with a pitch of 16 m were placed so that the last hydrophone was found at a depth of about 196 m.

The receiving system recorded signals within the frequency domain of 1–2500 Hz with a wide dynamic range. Enhanced signals were recorded using a digital multichannel data-gathering system and a magnetic recorder. For further analysis, the data were digitally filtered and were thinned up to the frequency of 25 Hz using the algorithms that were previously described in [4, 5].

Simultaneously with measurements of the noise levels, the vector of current velocity and environment temperature was recorded using Potok-2M vector-integrating current meters that were developed in the Experimental Design Bureau of Oceanological Engineering of the Russian Academy of Sciences.

During the experiments, there was a calm sea.

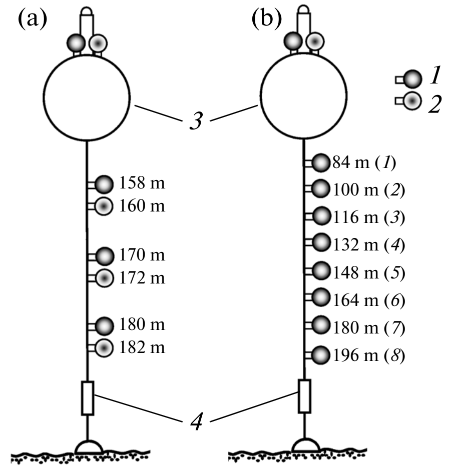

Fig. 1. Geometric arrangement of hydrophones for VDRSs (a) 32 and (b) 128 m in length: *1*, hydrophone; *2*, accelerometer; *3*, the framework of the buoy with signal-recording equipment; and *4*, an autonomous acoustic breaker with the load on the bottom (the approximate distance from the surface to the corresponding hydrophone is indicated).

Figure 2 shows the examples of the modulus of the current-velocity vector, its direction, and temperature peculiar to the measurements carried out using antennas that were 32 and 128 m in length.

The fact that deep currents at the measurement points are not purely tidal is to be regarded as the main result of the measurements. In all the cases, constant (shearing) currents and variable currents of different nature are superimposed on tidal currents. In particular, additional measurements of vertical profiles of currents show that there was a strong underwater current on a horizon that approximates the half-depth of the spot (see Fig. 3).

The presence of the shearing currents proves the dissimilarity from zero of sample averages with respect to zonal and meridional components of vectors of average current velocity, which were recorded on all the horizons and in all the measurement points. The measurements were performed at different points in different times; however, for all the cases, the time can be regarded as approximately multiple of the tidal cycle. Therefore, the sample averages of zonal and meridional components U and V are assumed to be components of shearing currents. They are used to calculate the moduli and directions of the vectors of average current velocity.

3. PSEUDO-SOUND NOISES DUE TO VIBRATIONS OF STRUCTURAL ELEMENTS

The effect of underwater currents on a VDRS results in vibrations on system elements, especially on the cable–rope [6]. The vibrations are transmitted to

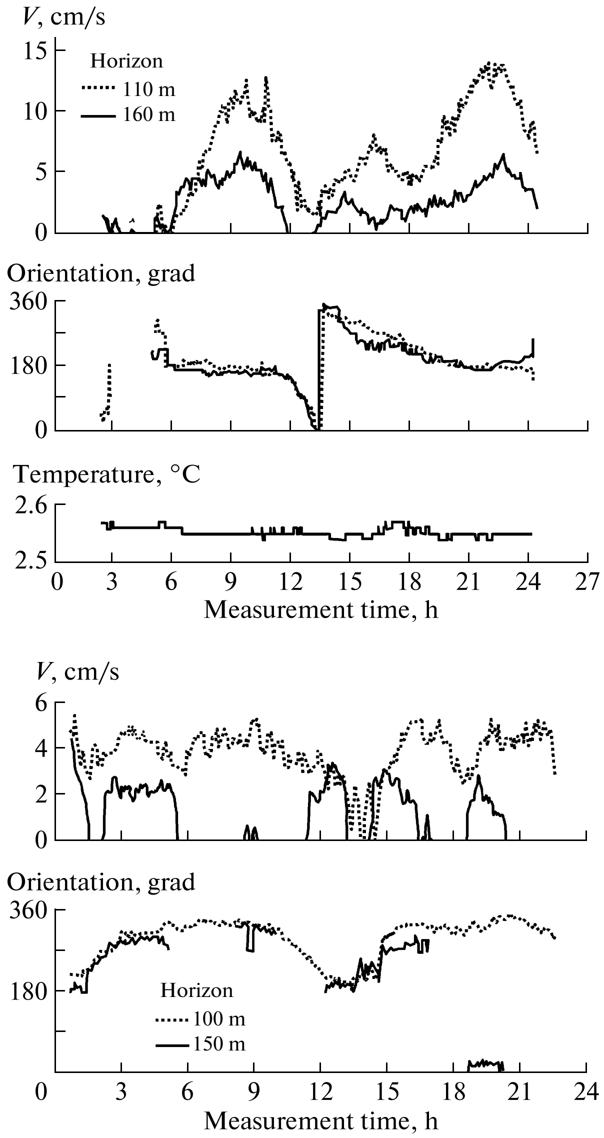

Fig. 2. Record examples of the modulus of the current-velocity vector, its direction, and temperature peculiar to the measurements carried out using antennas that were 32 and 128 m in length.

hydrophones and lead to the formation of a pseudo-sound signal that, under certain conditions, can considerably exceed the background noise of the water area [7].

The experiment with a VDRS that was 32 m in length revealed the sources of pseudo sound, their frequency content, and temporal variability.

For signals recorded by each hydrophone and accelerometer, the sonograms of narrowband spectrum with a frequency resolution of 0.037 Hz are constructed for the frequency range from 0 to 12.5 Hz with respect to all the records with allowance for the start time of each record and the current velocities measured for this time. The general level was almost the same in all the sonograms and is due to background noises of the water area. Figure 4 shows sonograms recorded by the middle hydrophone of the antenna (from the left) and a hydrophone located on the buoy's framework (from the right).

It can easily be seen that on the sonogram sections that correspond to relatively high velocities of recorded currents (see Fig. 4, the time is 1–3 and 5–8 h from the beginning of the record), there are tone components in the antenna that especially manifest themselves when the current velocity on the horizons of sound detectors is close to maximum.

One such spectrum is presented in Fig. 5. The frequencies of the components generally prove to be multiples and are changed slightly with changing current velocity. The change of the frequencies of tone components is accompanied by the change of their level; the maximum levels are observed approximately at the time instants that correspond to the maximum current velocities. Moreover, redistribution of energy between individual components occurs, which is expressed in gradual increase and attenuation as the current velocity changes.

In the sonograms of signals recorded by the accelerometers placed in the antenna, the same tone components occur as in the signals recorded by the antenna hydrophones, which indicates the origination of quite strong vibrations of the cable–rope in the transverse direction. The last statement is illustrated by Fig. 6 where a comparison of signal levels of the antenna hydrophone and the accelerometer closest to it is presented. Signal spectrums are expressed using the same units of measurement (Pa s^2/m) and are led to the input of corresponding sensors with allowance for their calibration. On the background of the acoustic signal of the hydrophone, the signal induced by vibration of the hydrophone itself is clearly distinguished. As is seen, the same discrete components dominate in both the spectrums. The difference in levels of the two signals in these components does not exceed 6 dB on average. This result must be taken as quite accurate; with the hydrophone and accelerometer being located at a distance of 2 m from each other, the vibration levels may differ slightly. For example, the difference in the levels of the signals that were recorded by the three closest hydrophones in the antenna reached 10 dB for the same components.

It is significant that the signal from the hydrophone that was located on the buoy's framework contains almost none of the above tone components, except for several components that coincide in terms of frequency with components in the spectrum of the signal from the array hydrophone (Fig. 5). It is also significant that on two records that begin approximately at 4.5 and 9.5 h from the start of record (Fig. 4, from the left), there is no pseudo-sound signal on the three hydrophones in the antenna. In this case, the vibration levels recorded by the antenna accelerometers are also

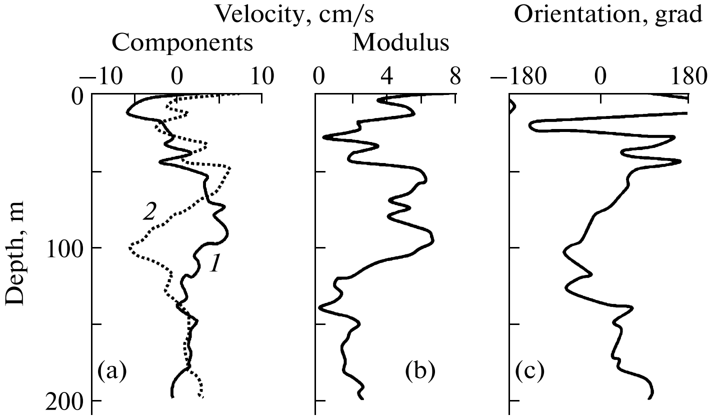

Fig. 3. An example of a vertical profile of the horizontal mutually-orthogonal zonal and meridional components *U* and *V* (*1*, *2*) of (a) the current-velocity vector, (b) the modulus of the velocity vector, and (c) its orientation with respect to north in the horizontal plane.

minimal and for most of the range are due to noises of the measuring system itself.

The observed regularities of the manifestation of pseudo-sound noises, as well as the coincidence of both the frequency of individual components and the character of their temporal variability for the hydrophones and accelerometers located in the antenna show that the source of the pseudo sound recorded by antenna hydrophones is transverse vibrations induced on the cable—rope.

Obviously, the mechanism of the origination of mechanical vibrations of VDRS elements under the action of underwater currents is closely related to the pseudo sound that arises when placing a body into a flow of liquid or gas: vortices are formed behind the body, whose periodic separation is accompanied by the sharp change of pressure that can induce the mechanical vibrations of the body placed into the flow [8, 9]. Manifestations of the process for VDRSs are rather diverse, but the common fact is that the vibrations generally take place at eigenfrequencies of the mechanical system perpendicular to the current direction.

It is reasonable to suppose that the mechanical system of a VDRS is self-vibrating and, therefore, nonlinear [8, 9]. Actually, the structure of the system corresponds to the general structure of self-vibrating systems: there is a constant energy source (the kinetic energy of a liquid flow) that is related to a regulator (vortex separation) that, in turn, has an effect on the vibrating system (the body in a flow). There is a feedback between the vibrating system and the regulator, which controls moments of energy transmission from the source. The energy is expended in the vibrating system to overcome resistance forces of the environment; therefore, the balance between the consumed and expended energy can be reached, and stable vibrations will arise in the system [10, 11].

A regulator is the most complex element of any self-vibrating system and generally determines its behavior. Unfortunately, there is no mathematical model that describes this phenomenon of the three-dimensional case. The two-dimensional problem has been solved by Carman, while the dependence of the frequency of vortex sound on the flow velocity, shape, and size of a body has experimentally been obtained by Strukhal': the frequency is directly proportional to the velocity and is inversely proportional to the characteristic size of a body (the diameter for a cylinder and the width for a plate). The proportionality coefficient depends on the shape of a body and is 0.2 and 0.14 for a cylinder and plate, respectively [7, 9]. There is much less known about the effect of the motion of a streamlined body on the processes of vortex formation.

Thus, a satisfactory mathematical model has not been constructed even for an idealized system. In an actual system, it is required to take into account the fact that, first, the current velocity considerably changes with respect to the depth, module, and direction as well as being variable in time; second, the cable—rope is not a homogeneous vibrating system (tension and density are not constant with respect to length) and its shape deviates from a rectilinear one under the action of a complex velocity field and is described by a three-dimensional curve; third, transverse vibrations of the cable—rope are not the only possible type of vibration. Moreover, longitudinal vibrations of the cable—rope, as well as torsional vibrations of hydrophones with respect to the pinning point in horizontal and vertical planes, can occur and the transfer of energy from one type of vibration to another is theoretically possible.

Nevertheless, it can be said that the number of factors and parameters of the system that affect the antenna is small. According to the general structure of self-vibrating systems, the parameters can be categorized as follows: (1) those related to the energy source

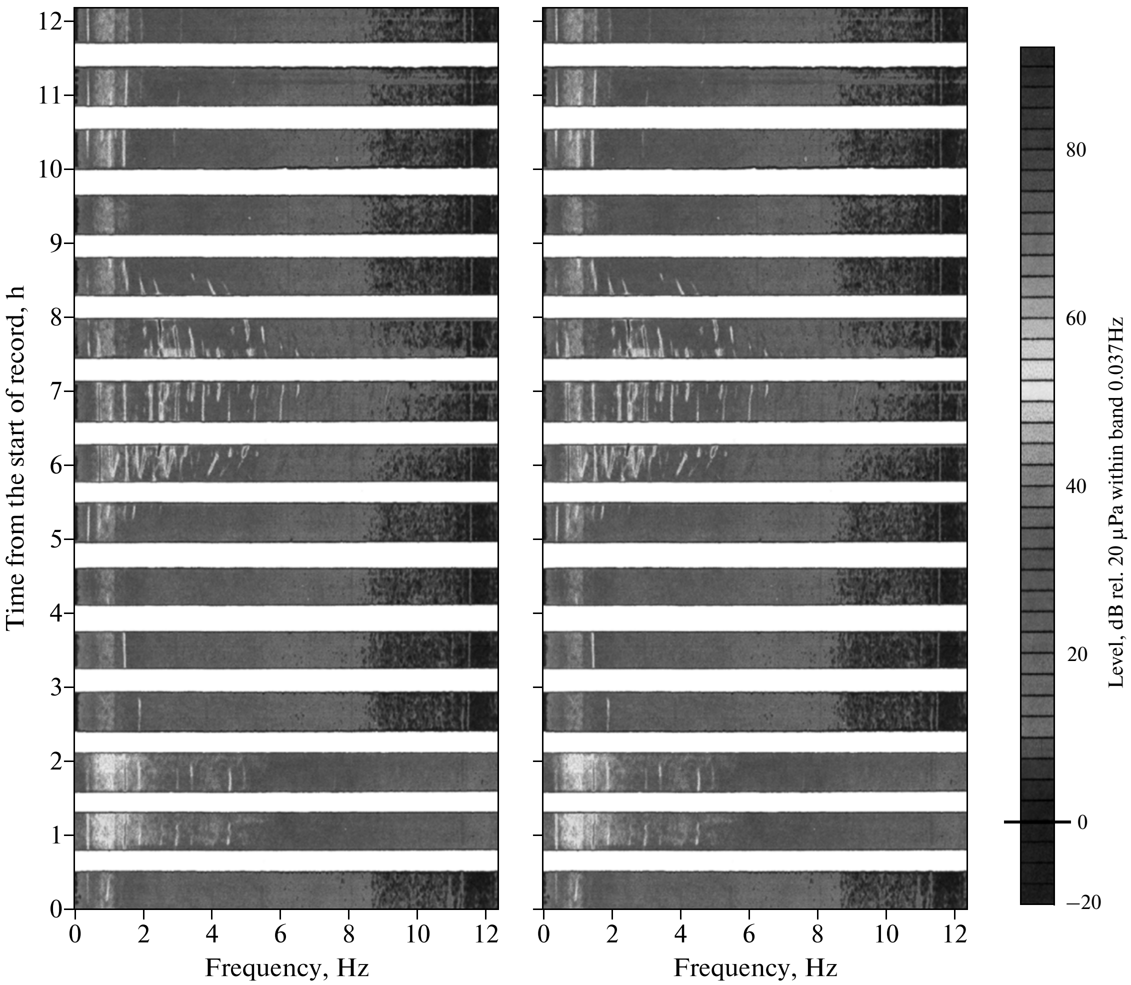

Fig. 4. An example of a sonogram of the narrowband spectrum (the frequency-analysis band is 0.037 Hz) within the frequency range from 0–12.5 Hz for the middle antenna hydrophone (from the left) and buoy hydrophone (from the right).

(the velocity field of the flow); (2) those related to the regulator (the diameter of the cable–rope that affects the frequency of vortex formation); and (3) parameters of the vibrating system (the tension, density, and length of the cable–rope that determine the eigenfrequencies of transverse vibrations, as well as the length and diameter that affect the resistance force of the environment).

In order to practically suppress the pseudo-sound signal that is due to the vibrations of the cable–rope that are transmitted to the hydrophone, the effect of the parameters can experimentally be studied to optimize the structure of a VDRS. The experiments discussed in this paper are dedicated to the solution of this important problem.

Note that the tone components in the signal spectrums of hydrophones and accelerometers possess a large Q factor (see Figs. 5 and 6). Most probably, this is due to the fact that the vibrations are induced on eigenfrequences of transverse vibrations of the caple–rope. This, in turn, is supported by the fact that for the duration of the experiment the signal spectrums of the hydrophones and accelerometers placed in the antenna possess amazing stability for most of the half-hour records. The complex temporal variability of the vibration spectrum, which manifests itself in the redistribution of energy with respect to eigenfrequencies, as well as the appearance and disappearance of multiple harmonics, must be due to the changes of the current that affect the system [11].

In order to determine the long-period variability of the infrasonic signal recorded by a VDRS, an experiment with a receiving system 128 m in length was carried out. A station with two Potok-2M current meters placed on two horizons was located at a distance of about 300 m from the VDRS station. The measurements of currents were carried out uninterruptedly for the duration of the experiment (almost 4 days). As a result, 86 records that were 10 min in length each and more than 98 h of measurements of currents on two horizons were obtained.

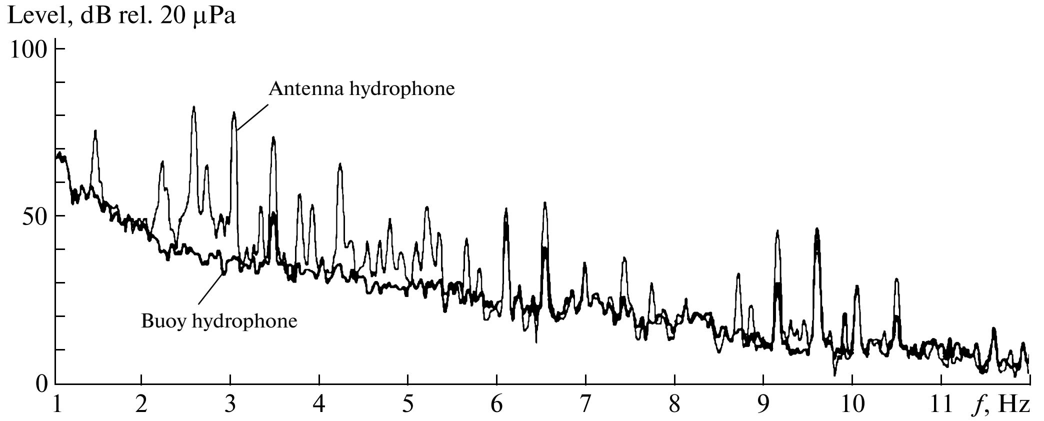

Fig. 5. A comparison of the levels of the signals recorded by different hydrophones: (a) antenna hydrophone *1* and buoy hydrophone for the narrow-band analysis of the signal (0.037 Hz) and (b) signals recorded within 1/3-octave bands by hydrophones placed on a VDRS.

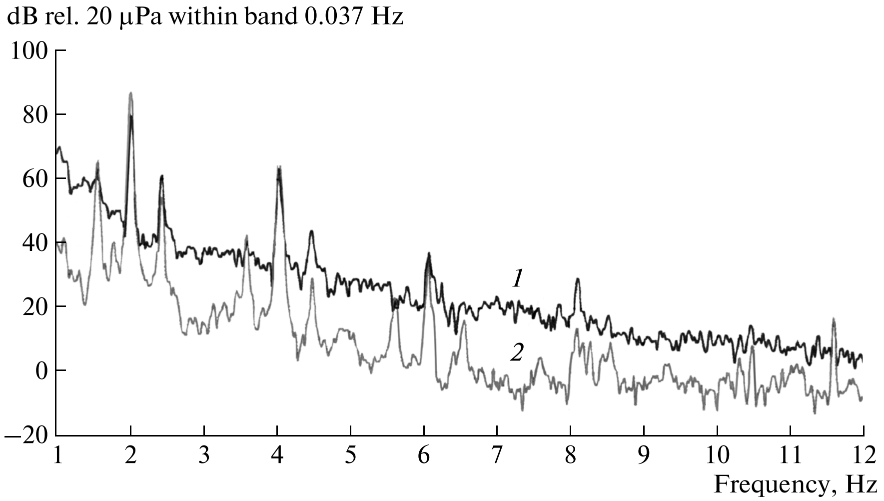

Fig. 6. Comparison of levels of the signal recorded by hydrophone *1* and accelerometer *2*.

The obtained sonograms for all the eight antenna hydrophones within the frequency range of 0–12.5 Hz were similar in terms of both the level and character of the temporal variability of signal spectrums. The characteristic form of one of the sonograms is shown in Fig. 7.

As in the experiment with the antenna that was 32 m in length, considerable variations of the spectral composition of signals are observed at frequencies below 8–10 Hz for all the sonograms. The pseudosound tone components that manifest themselves in the form of a series of discrete components with multiple frequencies are clearly defined. For the two experiments, the common result was records with no pseudo-sound noises (that generally correspond to time instants when the current meters recorded minimum velocities). The maximum difference in the levels of individual records was 60 dB. This somewhat exceeds the corresponding difference that was obtained in the first experiment (about 50 dB), which is probably due to the difference in environmental conditions of the experiments and the smaller overall time of the first experiment but not due to the design of the VDRS (particularly, its length).

We note the great variety of frequencies at which vibrations of the cable–rope are induced. Judging from the sonograms, the frequency content of vibrations is heavily affected by underwater currents. For an insignificant effect when the total vibration level is small, vibrations occur at lower frequencies and a great number of modes are induced. With an increasing effect, the number of the induced mode is increased and, besides this mode, several modes that are multiples of the former one occur. Taking into account the

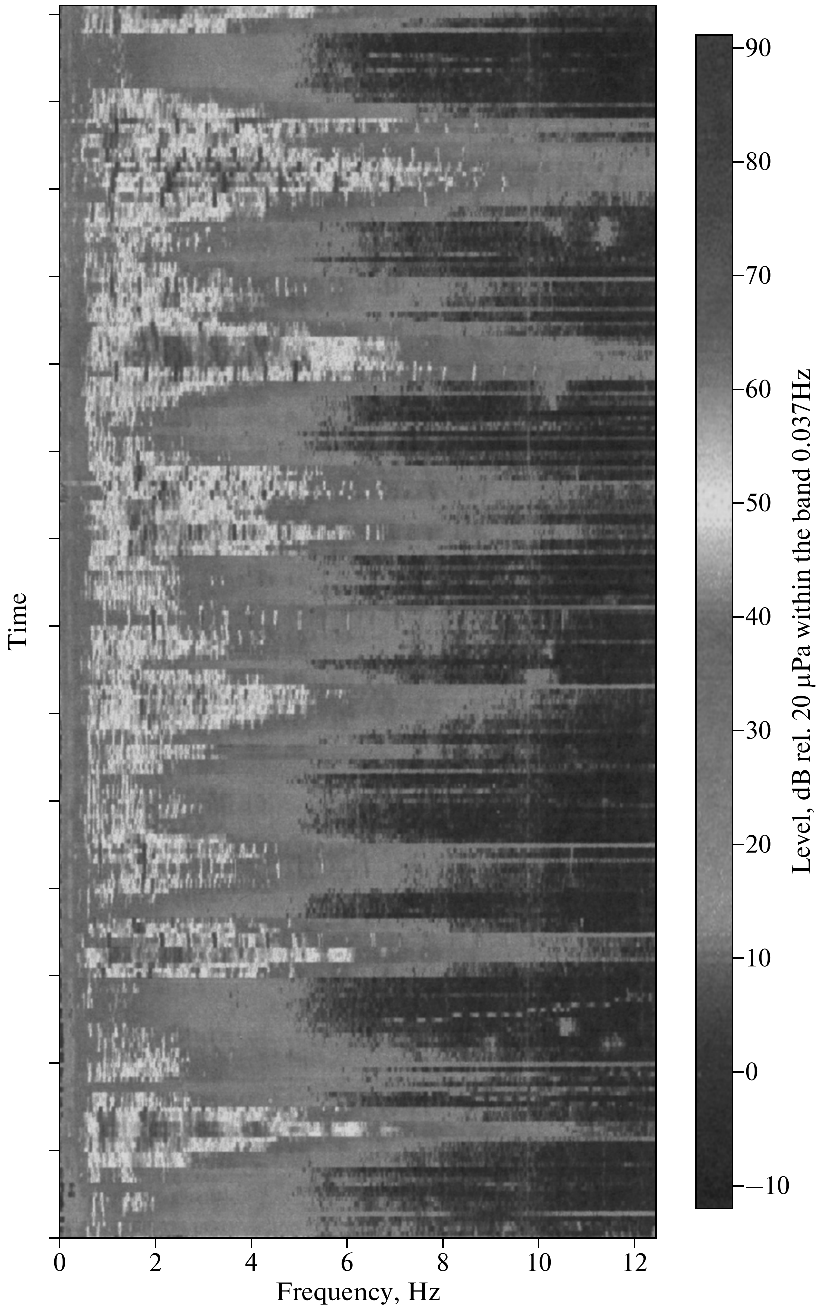

Fig. 7. The characteristic form of the sonogram from a hydrophone placed in a 128 m antenna.

fact that vibrations occur at the eigenfrequencies of the system, the dominant mode must have a frequency that is not above 0.1 Hz.

Figure 8 shows 1/3-octave signal spectrums for a hydrophone placed on the framework of the buoy of the 128 m VDRS and top hydrophone (hydrophone *1*) in the antenna for the frequency range from 1 to 2500 Hz, which were constructed using 11 records that were obtained successively during about 21 h. The wide scatter of the recorded signal levels within the infrasonic frequency range for the different records shown in the bottom chart is due to the pseudo-sound signal induced by vibrations. The maximum excess is observed within the frequency range of 2.5–4 Hz and is 40 dB, while the difference in levels for the infrasonic range, which is shown in the top chart, does not exceed 10 dB. We also note that, for the records where there is no pseudo-sound in the signal from the antenna hydrophone, the hydrophone placed on the station's framework records slightly excessive (by 6–8 dB) levels within the frequency range of 2–6 Hz, which, in our opinion, is related to the noise of the flow of the buoy framework due to the fact that the hydrophone is placed in the immediate vicinity of it. In the most part of the range, the 1/3-octave spectrums of both the signals are in good agreement, except for several bands where there are parasitic noises and electromagnetic interferences in the signal of the station hydrophone, which are due to the work of certain devices placed in the framework of the station. In the case of antenna hydrophones, the parasitic noises are not as strong owing to the remoteness from the noise source.

Figure 9 shows the signal spectrums of all the eight hydrophones in the frequency range of 1–12 Hz, which are constructed for the three most characteristic time instants. The charts illustrate the above regularities in the changes of the frequency content of vibrations. The spectrums with the minimum level with respect to all the records are shown in Fig. 9c. The coincidence of spectrums of all the channels takes place within the frequencies of 1–4.5 Hz, where the background noise of the water area is the signal source. Within the frequency interval of 4.5–7 Hz, the spectrums of individual channels are separated and the maximum difference between them reaches 20 dB. Judging from the spectrum profiles of channels *7* and *8* (see Fig. 9c) this exceedance can be assumed to be due to vibrations received mainly by the two bottom hydrophones of the VDRS. The spectrums shown in Fig. 9 are close to the maximum ones with respect to the level of tone components and correspond to the maximum velocities of currents.

Here, there are more than 20 harmonics of the frequency of 0.55 Hz; the levels of the even harmonics prove to be greater. The frequency of the first discrete component in the signal spectrums in Fig. 9b was approximately three times lower than the frequency of the first discrete component in Fig. 9a, but these frequencies are not multiples. The decrease in the level of harmonics and the increase of their number take place simultaneously. A decrease of the average spectrum level on the frequencies above 2 Hz as compared to the spectrums in Fig. 9b is also noticeable.

For the comparison of the results of the two experiments to be complete, 1/3-octave spectrums are shown in Fig. 9d that are constructed for the same time instants as the spectrums in Figs. 9a–9c. The pseudo-sound signal induced by hydrophone vibrations manifests itself within the infrasonic frequency range and changes can be made using this VDRS beginning with the frequencies of 10–12 Hz.

As in the previous experiment, a high Q factor of vibrations of the cable–rope and their temporal stability are observed. A stable correlation is found between the signals of all the VDRS hydrophones within the frequency range of 1–12 Hz for the records with the minimum signal level and records with strong manifestations of pseudo sound. In the first case, the form of the correlation function unambiguously points to the acoustic nature of the received signal (Fig. 10a), as well as to the presence of pseudo sound in the second one (Fig. 10b). It is seen from Fig. 10b that there is a stable phase difference between the vibrations that affect different hydrophones; stability of vibrations with respect to their level and frequency is also observed.

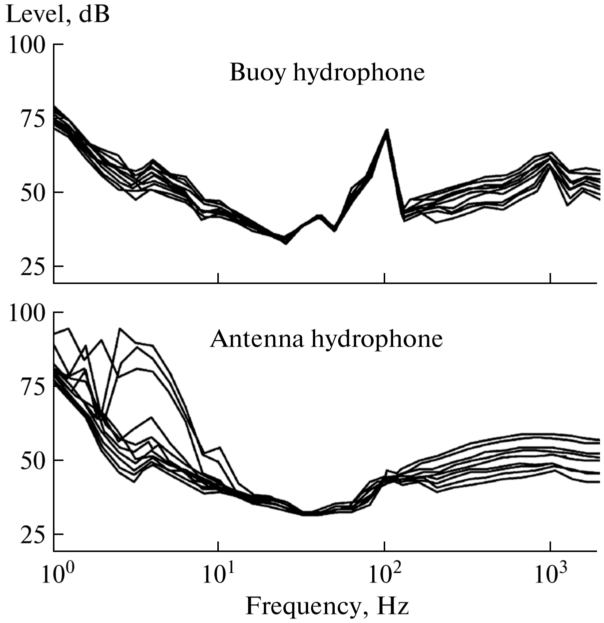

Fig. 8. The 1/3-octave signal spectrums for a buoy hydrophone and top antenna hydrophone, which were constructed using 11 records.

The comparison of the temporal variability of the signal of VDRS hydrophones in the infrasonic range and the current velocity on two horizons was further performed. For this purpose, the envelopes of the mean square value of hydrophone signals in the frequency range from 1 to 12.5 Hz, which are averaged within each record, were constructed. As noted, the signal levels recorded by eight hydrophones differ slightly; therefore, the averaged signal envelopes for all the channels within the above band coincide with an accuracy up to several decibels. For this reason, further comparison is performed with the envelope of hydrophone *4*. From the continuous record of current velocities on two horizons, 10-minute intervals are selected that correspond to the times of recording the signal by hydrophones. The velocity of the current is also averaged with respect to a record.

As noted above, the measurement of current velocities in this water area shows the presence of a significant component that is related to tidal phenomena. However, a simple and definite relationship between three processes (the level of the envelope of the mean square value of the hydrophone signal, the modulus of the current velocity, and the sea level) was not established. There is no correspondence even

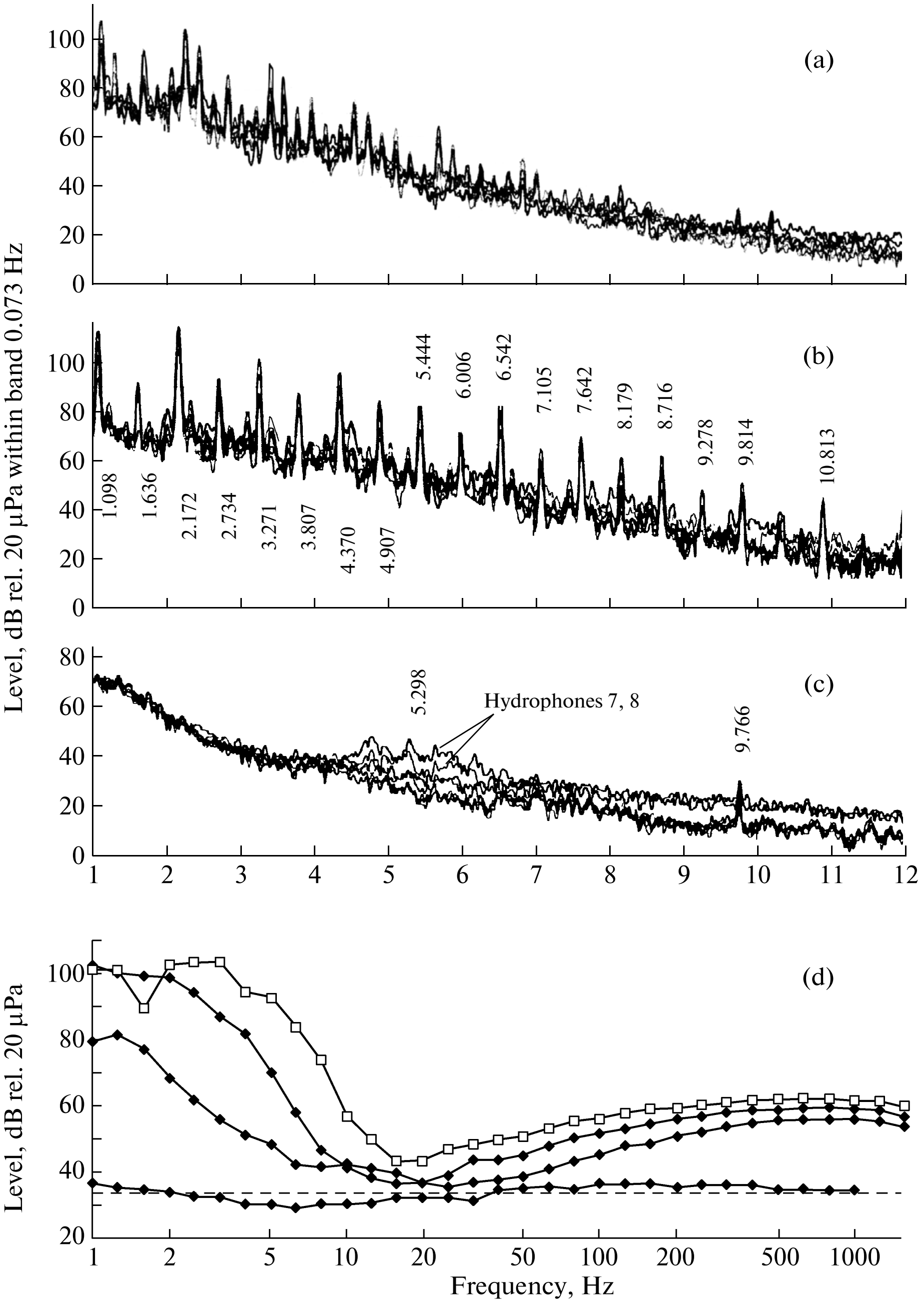

Fig. 9. The signal spectrums for eight hydrophones within the frequency range of 1–12 Hz, which are constructed for the three most characteristic time instants.

between the minimums of the envelope and current velocities, whose existence seemed obvious. In our opinion, this is due to the fact that underwater currents have a complex spatial and time structure so that measurements of current velocities only on two horizons do not provide a complete idea of the processes taking place along the entire length of the receiving system. This statement is in good agreement with the measured profiles of current velocities (see example in Fig. 3).

The form of the envelope of hydrophone signals and the temporal variability of current velocities indicate the presence of several periodic components in these processes; to determine them, the spectrums of three dependencies, as well as the cross spectrums of the envelope and variations of current velocities were constructed (Fig. 11). In the spectrum of the envelope, several periodic components that also exist on cross spectrums are clearly defined. The same periodicity substantiates the fact that there is a close relationship

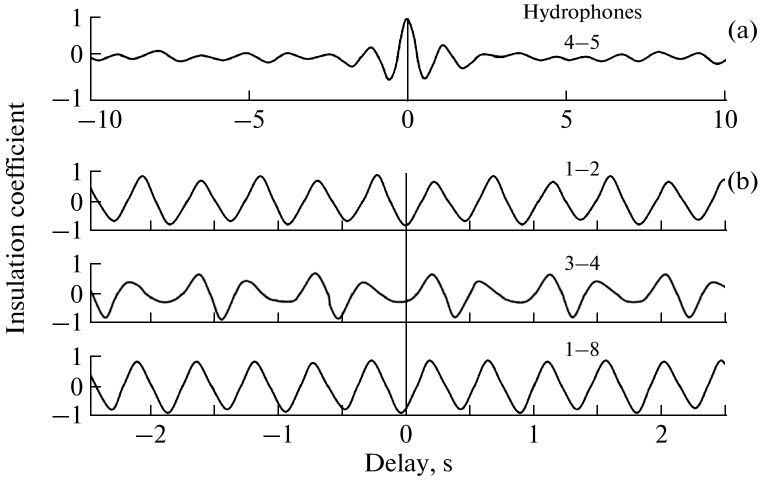

Fig. 10. Coefficient of cross correlation between pairs of hydrophones: (a) minimum current velocities and (b) significant levels of currents.

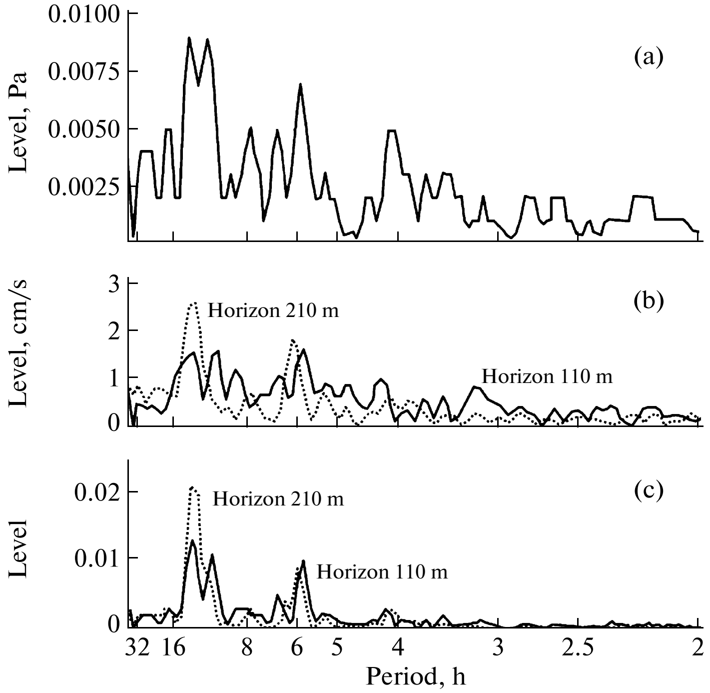

Fig. 11. The spectrums of (a) he envelope of the mean-square value of the signal from hydrophone *4* within the band of 0–12.5 Hz; (b) current velocities on two horizons; and (b) cross spectrum of the envelope of the mean square value of the signal from hydrophone *4* and the current velocity on two horizons.

between the vibrations of the receiving system and the current velocity. However, it is possible that the velocities that were measured during the experiment are not maximal and on a certain horizon a stronger current that has the greatest effect on the system occurred.

4. THE SPATIAL STABILITY OF A VDRS

In order to detect changes in the spatial position of elements, a combined receiving module (CRM) was included in the 32-m antenna at a certain working stage; the CRM recorded, along with the pressure, three mutually-orthogonal projections of the gradient vector of the sound pressure. The bearing is determined in the horizontal plane [4, 7] for selected narrow frequency bands in the range from 63 to 1000 Hz on a remote broad-band signal source that has fixed spatial coordinates. The spatial variability of the system's position is determined by long-term changes of

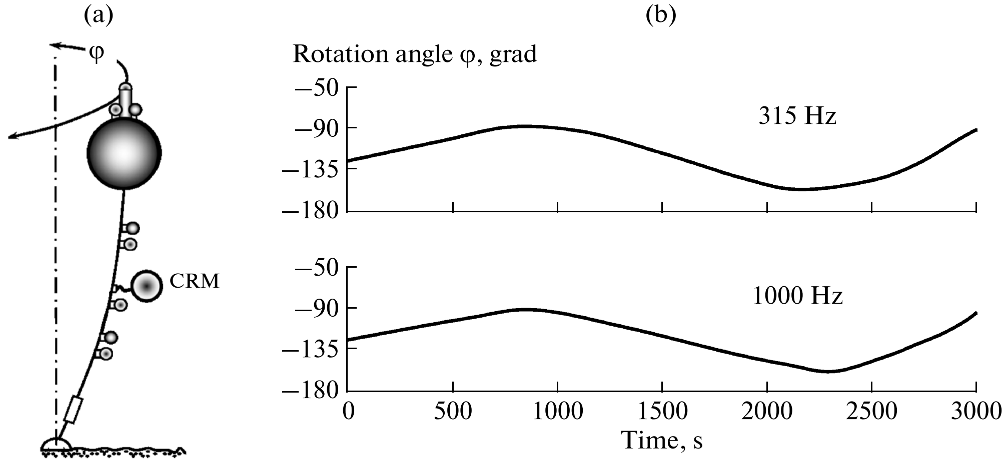

Fig. 12. (a) The configuration of a VDRS and (b) the experimental spatial variability of the system position, which is determined by changing the angle φ with respect to north.

the angle φ (Fig. 12à). The bearings that were determined for different frequencies coincided within the limits of the measurement error, which results in the conclusion that the change of the angle φ was recorded. Figure 12b shows the values of the bearings determined for two frequencies of 315 and 1000 Hz.

It is seen from Fig. 12 that the angular deflection of the VDRS around the vertical axis passing through the load on the bottom reaches a considerable magnitude of 60–70° with a period of about 50–60 min, which resulted in a rather great deflection of hydrophones in space during the operation of the VDRS, especially for upper hydrophones. The most complex character of vibrations was observed with the change of the current direction when an additional rotation of the VDRS through about 180° is superimposed on the long-period vibrations. It appears that it is almost impossible to eliminate the vibrations under conditions of actual water areas [12].

5. CONCLUSIONS

Under the actual conditions of a shallow water area, it was found that the efficiency of vertically distributed systems in the region of infrasonic frequencies is reduced because of pseudo sound, which manifests itself in the signal spectrum in the form of a series of tone components with multiple frequencies. The greatest excess of the pseudo-sound signal, which is due to vibrations transmitted to cable–rope hydrophones, over the background signal was observed within the range of 2–6 Hz and can reach a considerable magnitude of 40–60 dB.

The analysis of compatible data recorded by hydrophones and accelerometers allows one to make a conclusion that the main source of pseudo sound is transverse vibrations of the cable–rope that are induced by underwater currents. These vibrations have a complex spectral composition and time dependence, as well as a high Q factor and most likely occur at eigenfrequencies of the system. A great variability of the spectral composition of vibrations manifests itself in a several-fold change of frequencies of tone components depending on the velocity of the current. The character of the spectrum does not change considerably, i.e., there are a great number of multiple discrete components in it. At certain time instants (when current velocities are minimal), they almost disappear. The frequency content of vibrations is heavily affected by underwater currents. For an insignificant effect when the total vibration level is small, vibrations occur at lower frequencies and a great number of modes are induced. Vibration spectrums possess high stability, which can be explained by self-vibrations in the system.

The vibration spectrum is limited to the infrasonic frequency range (no more than 10–12 Hz on the average). There are no manifestations of the pseudo sound due to vibrations at higher frequencies.

Moreover, the effect of underwater currents on a VDRS results in the considerable temporal variability of its spatial position with respect to the vertical axis passing through the anchor system.

These facts may considerably reduce the efficiency of a VDRS and limit the frequency range of measurements from the bottom. For this reason, increased vibration-proofing requirements must be placed on VDRS hydrophones that operate in the infrasonic range. It is also obvious that the currently available hydrophones do not possess the required vibration resistance; therefore, the problem of optimizing the structure of a VDRS to reduce vibrations has become more important.

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