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Optimization of acoustic profiler characteristics in the scope of underwater archeology and monitoring of underwater engineering objects

I A Kirichenko[1], I B Starchenko[2], V Y Vishnevezkiy[1], A I Markolia[3], I I Sizov[3] and T P Strochan[3]

[1] Southern Federal University, 2, Shevchenko St., Taganrog, 347922, Russia
[2] Parametika LCC, 19, Svoboda St., Taganrog, 347902, Russia
[3] Academy of Science of Abkhazia, Sukhum, Abkhazia

E-mail: ikirichenko@sfedu.ru

Abstract. In order to solve the problem of optimizing the characteristics of acoustic profiler with parametric transmitting array in the scope of underwater archeology and monitoring of underwater engineering objects, the results of theoretical studies of the influence of real conditions on the work of parametric hydro-acoustic systems and of the marine soils and bottom sediments features are presented. The necessary amplification range of the receiving path is estimated to compensate for losses during acoustic wave propagation in water and for the most common types of marine sediments: "coarse sand" and "sandy-silty clay". The necessary acoustic power is justified for the given values of the central pump frequency of the parametric profiler and the difference frequency. The most efficient penetration into the marine sediments which was commonly sand and silt occurred at 10-20 kHz of difference frequency. Penetration of frequencies higher than 20 kHz is not effective due to great power losses. The minimal gain of receiving unit must be at least 40 dB. Design and construction of parametric profiler was suggested. Main units were proposed according to the theoretical investigation. In the whole parametric arrays and hydro-acoustical devices with them occurred very effective in subbottom profiling. Small overall dimensions as was shown in construction allow achieving high resolution. So their application is perspective especially in local underwater archeology using small vessels.

1. Introduction

The shallow water environment is one of the most dynamic elements, including coastal zones that are subject to rapid sedimentary flows and are of significant interest to human activities. However, these environments often pose serious technological challenges due to shallow water, strong waves, strong currents, and a large tidal range. In addition, coastal and littoral zones are often marked by the presence of fine gas, which can severely restrict sound penetration [1-5]. As a result, these areas are rarely studied in a structured way, since it is known that such land-sea transition areas are rich in archaeological features [5, 6].

Acoustic profilographs are usually used as a mapping tool for the sea floor and the bottom structure in the upper layers of several meters. Increasing the efficiency and accuracy of profilographers can increase the productivity of research in terms of resolution and increases the potential of acoustic tools for classifying bottom layers and sediments [7].

2. Materials and methods

The most important parameter that characterizes a sonar detection or classification system is the range. This parameter, as it is known [8], significantly depends on the conditions of acoustic energy propagation and therefore the energy range in a homogeneous (boundless) medium and the range in real conditions are distinguished.

The efficiency of the radiating block of the Profiler largely depends on the properties of the medium in which the acoustic wave propagates. The attenuation value is characterized by an absorption coefficient, which shows the degree to which the amplitude of sound waves decreases with distance. To solve the problem of determining the energy loss of an acoustic wave caused by attenuation in water when profiling the upper edge of the bottom, we can use the expression [8], which takes into account these losses. The expression describing the dependence of attenuation K in the logarithmic range takes into account the possibility of using the obtained data for subsequent compensation of losses during propagation of an acoustic wave in the receiving unit of the profiler.

$$K(r) = 20\lg\left(r \cdot 10^{0.1 \cdot \beta_w \cdot r}\right), 0 \leq r \leq R_{max,}$$

where β_W – sound attenuation coefficient in the propagation medium, dB/m, r – distance, m, $R_{max,}$ - maximum distance to the object, m.

The technique that allows predicting the potential capabilities of the profiler, estimate the frequency range required for operation in specific situations, and select the energy potential depending on the parameters of the probing signal, interference conditions, and acoustic properties of the bottom soil is described in detail in the work [9].

To calculate the acoustic power for each of the pump frequencies required to detect a known target at a given distance in the presence of noise interference, you can use the formula [9]:

$$W_a\,(z) = \frac{z \cdot 10^{0.05\alpha z} \cdot \delta \cdot P_{n0} \cdot 10^3 \cdot 8 \cdot c^3}{e^{-(z/L_{att})} \cdot |I(z)| \cdot F^3 \cdot 3.5 \cdot \pi \cdot R_{eqv} \cdot \sqrt{\gamma_{tr} \cdot \tau}}.$$

where W_a – acoustic power, W, z –distance, m, δ - ambient noise level, Pa/Hz$^{1/2}$, P_{n0} - acoustic pressure at center pump frequency, Pa, c - sound speed, m/s, F - difference frequency, Hz, α - attenuation factor, dB/km, L_{att} - attenuation zone length, m, γ_{tr} – transmitting array axial concentration factor, R_{eqv} - equivalent target radius, m, τ - pulse duration, s, $I(z)$ - Bessel function.

To obtain information about the bottom structures in an acoustic parametric profiler, the most promising method is that associated with the movement of the receiving-emitting antenna system of the profiler due to the movement of the carrier [7]. Simultaneous scanning with the directional characteristic in the radiation mode in the traverse plane of the profiler carrier allows getting a strip on the bottom surface.

As it is shown in [9], the high efficiency of converting the energy of high-frequency pump waves into the energy of difference waves in the parametric radiating path is achieved only when a highly directed radiation with a width of the directivity characteristic of no more than 4-6°is formed.

The transmitting array of the profiler is an N-channel antenna array. Each of the N channels is a line of n piezoelectric elements, the distance between the acoustic axes of which is the same. Such antenna systems are called equidistant.

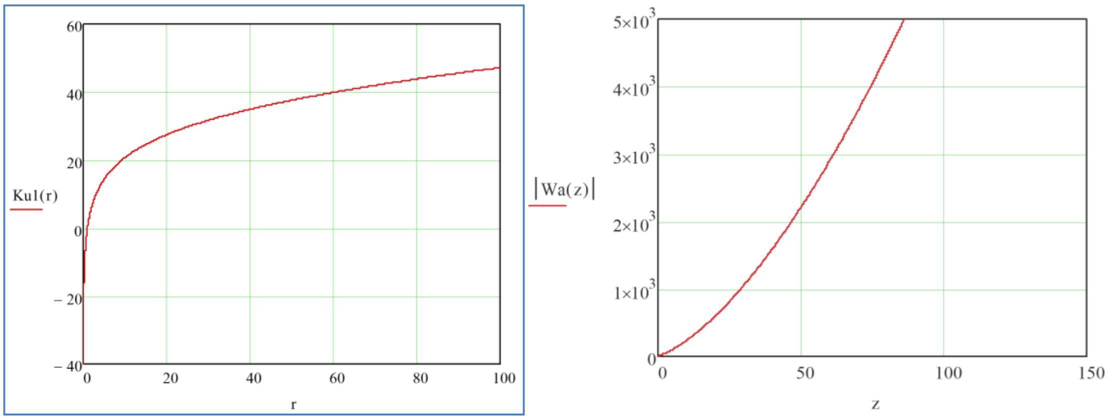
The need to use a separate receiving channel in the antenna of a parametric Profiler is associated with the irreversibility of nonlinear processes that underlie its principle of operation. The geometric dimensions and shape of the receiving antenna are determined based on the type of location scheme, the parameters of the Profiler in the radiation mode, and the manufacturability. The limitations of overall dimensions at difference frequencies, which in practice are 1-20 kHz, do not allow directional reception, which provides optimal spatial filtering when the solid angles of the antenna directivity characteristics are equal in the radiation mode and the reception mode. In this case, the receiving part of the profiler antenna may have a weak orientation and the main requirement for it is to ensure high sensitivity and the possibility of matching with the receiving and amplifying path.

When choosing the values of the width of the directional characteristic in the diametral plane, it is necessary to assume that the width of the main lobe of the transmitting array in the frequency band is 4°-6°, and the minimum distance of the Profiler from the bottom is h_{min}=1-5 m. The area of the bottom voiced by the transmitting array must fall into the solution of the main lobe of the receiving antenna's directional characteristic.

3. Results

Losses during propagation of an acoustic wave in water for a distance corresponding to the maximum range of the acoustic profiler R_{max}=100 m, determine the necessary gain range of the receiving path to compensate for propagation losses, shown in figure 1 (a).

For the maximum distance to the object R_{max}=100 m, the equivalent radius of small objects R_{eqv}=0.2 m, the reduced ambient noise level – 0.05 Pa/Hz 1/2, as well as the values of the central pump frequency of 250 kHz and the difference frequency of 10 kHz, the acoustic power was calculated for the central pump frequency, the results of which are shown in figure 1 (b).

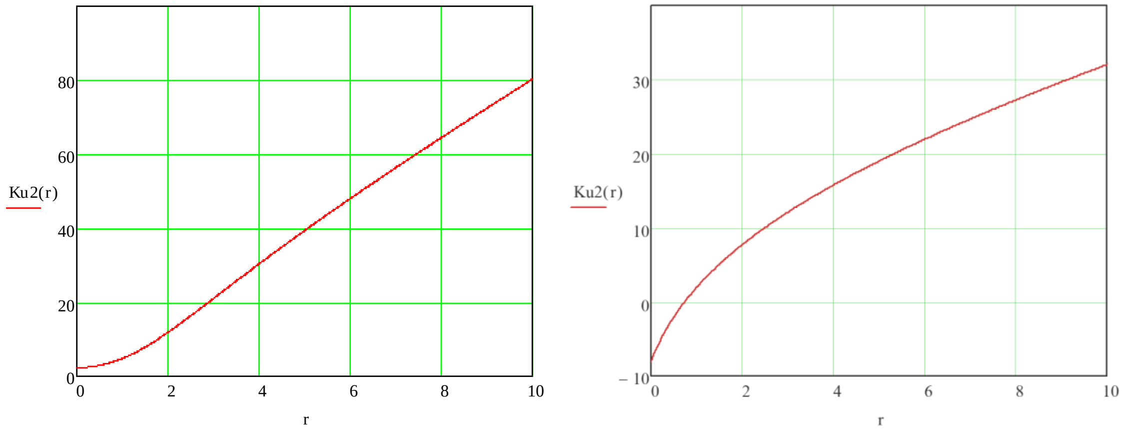


a b

Figure 1. Loss of acoustic wave propagation in water (a) and acoustic power of the profiler (b).

The dependence of losses during propagation of acoustic wave in water is shown in figure 1 (a). It demonstrates that the distance with the maximum one to the object R_{max} does not significantly affect the propagation of acoustic wave. In this case, the dependence of the acoustic power of the pump waves, shown in figure 1 (b), allows determining the required level of acoustic power, which for a distance of 100 m is at least 5 kW.

For bottom rocks, the values of the acoustic wave attenuation coefficient significantly exceed the propagation losses in water [10]. Figure 2 shows the results of calculating losses in a uniform layer of bottom soil 10 m thick for the most common types of marine sediments: "coarse sand" (a) and "sandy-silty clay" (b).



a b

Figure 2. Losses during acoustic wave propagation in the medium: a - "coarse sand"; b - "sandy-silty clay".

The dependences of losses during acoustic wave propagation in the "coarse sand" and "sandy-silty clay", shown in figure 2, demonstrate that for bottom rocks, the values of the acoustic wave attenuation coefficient significantly exceed the losses during propagation in water. The obtained dependences of losses during propagation of an acoustic wave in various media can be used to establish the law of temporary automatic gain control of the receiving path of an acoustic profiler.

4. Construction

The main criteria for the design of the layout of the profiler compartment are: 1) minimal effect governing the input and output power signals to each other; 2) separation as far as possible control lines of transmitting array and the signal lines of the receiving array; 3) the minimum length of the connecting conductors and 4) optimal and uniform heat dissipation by the air convection inside the compartment on the outer wall of the housing.

Parametric profiler is structurally a hollow sealed cylindrical body made of aluminum alloy, inside which electronic equipment is located. The case is covered with protective powder enamel, the color of the coating is determined at the stage of working design documentation. The hydroacoustic receiving and transmitting array of the profiler with a fairing is fixed on the outside of the body. For protection during maintenance and transportation, the working surfaces of the antennas are protected by a removable cover. In the front and back of the profiler compartment, there are flanges for securing on the rod. Electrical connection is provided by connectors located on the side walls of the housing. A crate is located in the cylindrical case, which provides a rigid attachment of electronic units and modules and the ability to remove electronics. The appearance of the profiler is shown in figure 3.

The compartment and antenna housing are shown transparent, the fairing and protective cover are not shown. Figure numerals indicate: 1 – body; 2 – signal module; 3 – power supply module; 4 – receiving arrray; 5 – transmitting array; 6 – cable glands for antenna connection; 7 – electric connectors; 8 – housing o-ring; 9 – power amplifier (6 units); 10 – power cell crate. The antenna body must be protected from incoming water flow by a plastic or metal fairing with a window opposite the active surface of the antenna.

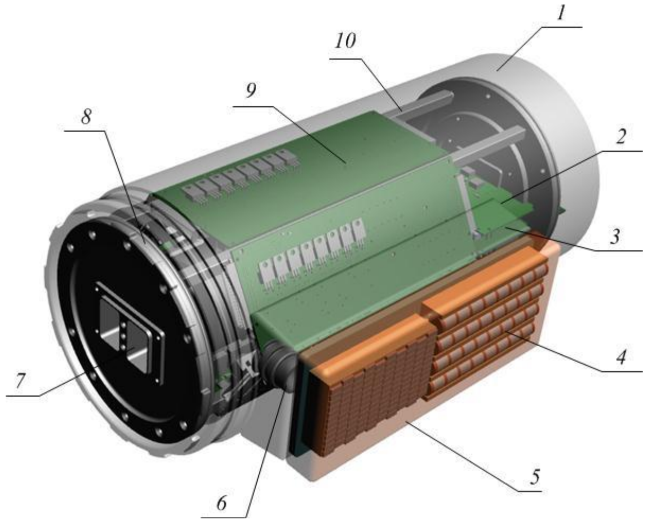


Figure 3. Appearance and layout of the profiler

5. Conclusion

After studying the main characteristics of the acoustic profiler, taking into account the nonlinear process of formation of waves of different frequency and parameters of marine precipitation, we can draw conclusions. The obtained dependence of losses during propagation of an acoustic wave shows that the distance determined by the depth of the place does not significantly affect the propagation of an acoustic wave in water due to the small value of the attenuation coefficient in water and the losses themselves can be easily compensated in the receiving unit with a gain of 40 dB.

The greatest efficiency of penetration into the bottom soil, which is sand and silt deposits, at optimal values of acoustic energy occurs in the frequency range of 10-20 kHz. At frequencies below 10 kHz, penetration is limited by the need to increase the acoustic power of the initial pump waves to a threshold close to cavitation. For frequencies above 20 kHz, penetration into a 10 m thick layer is limited by the attenuation of the acoustic wave in the ground itself.

Taking into account the obtained results make it possible to increase the efficiency of using acoustic devices with parametric antennas when conducting ocean research related to measurements in the interests of underwater archaeology and monitoring of underwater engineering structures.

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