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MEASUREMENT OF THE ACOUSTIC CHARACTERISTICS OF SEA BOTTOM FOR TASKS OF NAVIGATION OF UNDERWATER VEHICLES

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The way of measurement of coefficient of reflection of acoustic waves from a site of sea bottom is considered in work in view of the spherical principle of wave's propagation. Application of this way for creation of sea bottom maps is also considered. These maps can be used for tasks of navigation of underwater vehicles subsequently. The task of creation of a navigating map of sea bottom can be solved with the help of measurement of the sea bottom acoustic characteristics depending on geographical coordinates of a site of bottom.

At the using of the autonomous underwater vehicle it is important to determine of it location. For this purpose the maps of a relief and depths of the site of sea bottom are made. Lack of such maps is the inefficiency in areas with flat relief of sea bottom.

To create a map which is free from this lack it is possible with the help of measurement of dependence of the acoustic characteristics sea bottom on geographical coordinates of a site of sea bottom. In such cases other attributes are required to set up a correspondence the properties of the given area bottom site to its geographical coordinates. It is possible to create a pseudo-map which is a set of coefficients compared with sites of sea bottom [1]. As such information it is offered to use thickness of layers of a sea bottom and coefficients of reflection from a water-ground boundary.

After generating of square modulated acoustic pulse signal, the first reflected pulse will bring information on distance to bottom and the coefficient of reflection of water-bottom interface, the subsequent pulses carrying information on thickness of layers and the coefficients of layer-layer reflection. These values can characterize properties of the given site of sea bottom.

The main problem consists in dependence of these maps on the tool of measurement, conditions of measurements, in particular, of distance from the sonar antenna to the sea bottom. Thus, it is necessary to find such parameter of sea bottom which would characterize it in the certain point, in view of the spherical principle of wave's propagation. In this paper for the decision of this problem the theory is used, where consider a case of fall and reflections of a spherical wave on boundary of two mediums. The algorithm of measurement of coefficient of reflection for spherical waves reducing dependence of results of measurements the distance between the sonar antenna and sea bottom is developed.

The map of coefficients of reflection will have smaller dependence on a spherical divergence of waves if to calculate coefficients, using the following model [2].

Mathematical model of a task is the Helmholts equation (1) with boundary conditions (1a):

$$\Delta\varphi + k_m^2(\bar{\mathbf{r}})\varphi = q\left(\overline{\mathbf{r}_0}\right) \quad (1)$$

$$\rho_m \varphi_m \big|_{s_m} = \rho_{m+1} \cdot \varphi_{m+1} \big|_{s_{m+1}}, \qquad \frac{\partial \varphi_m}{\partial n}\bigg|_{s_m} = \frac{\partial \varphi_{m+1}}{\partial n}\bigg|_{s_{m+1}}, \quad (1a)$$

where φ - potential of oscillatory velocity,

m – number of layer,

ρ_m - density of m-layer,

c_m – phase velocity of m-layer,

$k_m = \frac{\omega}{c_m}$, ω=2πf,

$q(\overline{r_0})$ - density of distribution of the sources,

n - normal vector to boundary S,

$\bar{r}$ – coordinate of a point of observation,

$\bar{r}_0$ – coordinate of a point of a source location.

The solution of the equation (1) with boundary conditions (1a) in case of radiation of a set of point sources at the presence of boundary of two mediums is possible to write down [2] for top (first) medium as:

$$P_1(\bar{r}) = P_0 \cdot \sum_n \left[\frac{e^{ik_1 \cdot R_n}}{R_n} + K_{refl\,n} \cdot \frac{e^{-i \cdot k_1 \cdot R_{refl_n}}}{R_{refl_n}} \right], \qquad (2)$$

where P($\bar{r}$), P_0 – pressures of reflected and incident waves on transmitter and receiver correspondingly,

R_n - distance between points of source and receiver,

$R_{refl\,n}$ - distance between some imaginary source and point of receiver,

$K_{refl\,n}$ – function which dependent only on angular coordinates (is meaningful of coefficient of reflection of waves on boundary).

The theoretical expression for coefficient of reflection, proceeding from parameters of mediums, defines as [2]:

$$K_{refl} = \frac{\left(\begin{array}{l} \rho_1 c_1 \frac{\partial R_{rec}}{\partial n} h_0^{(1)}(k_1 R_0|_{S_b}) \cdot h_1^{(1)}(k_2 R_{rec}|_{S_b}) - \\ - \rho_2 c_2 \frac{\partial R}{\partial n} h_1^{(1)}(k_1 R_0|_{S_b}) \cdot h_0^{(1)}(k_2 R_{rec}|_{S_b}) \end{array} \right)}{\left(\begin{array}{l} \rho_1 c_1 \frac{\partial R_{rec}}{\partial n} h_0^{(2)}(k_1 R_0|_{S_b}) \cdot h_1^{(1)}(k_2 R_{rec}|_{S_b}) + \\ + \rho_2 c_2 \frac{\partial R}{\partial n} h_1^{(2)}(k_1 R_0|_{S_b}) \cdot h_0^{(1)}(k_2 R_{rec}|_{S_b}) \end{array} \right)}, \qquad (3)$$

where S_b, n – the boundary of two mediums and normal vector to boundary accordingly,

R_{rec} – distance between an imaginary source in second medium and point of receiver (is detailed account of coordinates of an imaginary source is stated in [2]).

Proceeding from (2) and known measured values of received pressure (reflected from a ground) the waves, are possible to define value of coefficient of reflection:

$$K_{refl.meas.} = \frac{P_{rec}}{i \cdot 2 \cdot \pi \cdot f \cdot \rho_1 \cdot \left(h_0^{(1)}(k_1 \cdot 2 \cdot H) + 2 \cdot \sum_{n=1}^{\frac{N-1}{2}} h_0^{(1)}\left(k_1 \cdot \sqrt{4 \cdot H^2 + (n \cdot d)^2}\right) \right)}, \qquad (4)$$

where P_{rec} – received pressure,

f - frequency,

H – distance between the antenna and ground,

N – number of elements in array,

n - number of an element in array,

d – distance between elements of array.

Using the offered algorithm becomes possible having measured amplitude of the reflected signal and depth to calculate the coefficient of reflection $K_{refl.\,meas.}$ for spherical waves in the certain point of sea bottom, which will characterize parameters of medium of the certain site of a ground and at the same time will not depend on distance between sea bottom and sonar antenna. Advantage of a used method is the account of spherical divergence of wave, and also it is possible to find coefficients which not dependent on a sonar position, but only from acoustic parameters of mediums.

In a fig. 1 the diagram of size of coefficient of reflection for spherical waves $K_{refl.calc.}$ is given, calculated on the formula (3) and $K_{refl.\,meas.}$, calculated on the formula (4), depending on height of an arrangement of the sonar antenna above a ground (density of a ground - 1580 kg/м^3, phase sound velocity in a ground - 1578 m/sec, frequency 200 kHz).

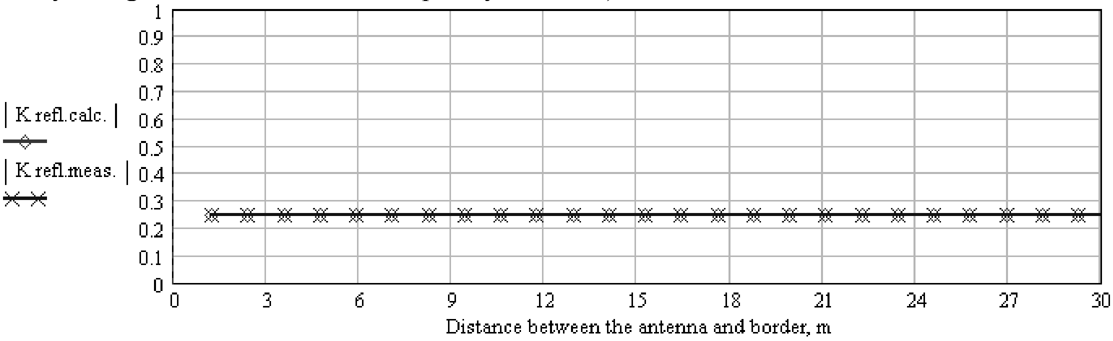

Fig. 1. The diagrams of coefficients of reflection

On the basis of calculations it is possible to make a conclusion that a coefficient of reflection for the spherical waves calculated on the formula (4) proceeding from measured values of acoustic pressure of a wave reflected from sea bottom does not depend on height above sea bottom and characterizes only acoustic properties of that site of sea bottom, where it was measured. Thus, given coefficient can be used for making up of a navigating map of coefficients of reflection for spherical waves from sea bottom.

Also it is possible to notice that registering reflections from M layers of some area of sea bottom the coordinates of this area can compare with value of coefficient of reflection and (M-1) of temporary intervals t_m, inherent only to it. Measuring these parameters for each area of sea bottom, it is possible to make a navigating pseudo-map. At initial map-making it is necessary to bypass area measuring these values and to set up a correspondence them to geographical coordinates of sites of sea bottom.

Accordingly offered scheme of structure the experimental system was made and the software for it was developed. The system consisted of: 1. Hydrolocator «Humminbird» with operating frequency, beamwidth, duration of pulse and frequency of pulse reiteration corresponding by: 200 kHz, 24°, 0.1 ms и 4 times in second; 2. Amplifier, to magnify signal from receiving unit exit till the level that is necessary for right operation of analog-to-digital converter; 3. 8-bit analog-to-digital converter; 4. Computer of "Pentium" type. Exit of receiving unit in hydrolocator through amplifier is connected to analog-to-digital converter.

After irradiation of acoustic pulse by hydrolocator the program takes sequence of 638 values of a signal reflected from seafloor structure on analog-to-digital converter with assigned temporal step (limited by 0.04 ms - 2.2 ms) recording it into file, then pictures it at the screen as horizontal line from left to right, and color of dot in line responds to value of a voltage at the exit of reception way of hydrolocator. This lines on the screen will be following downwards. Due to reflection of acoustic signal being occurred along the boundary of media with different acoustic parameters, the, change of color on the screen will respond to the boundary of layers separation. When the screen collect a lot of lines, it is possible to distinguish vertical lines with frontiers of water-ground separation and ground layer-layer boundary.

With the help of above-mentioned system there were conducted tests by onboard systems of ship traveling in the Golden Horn Bay and Patrokl Bay. The measured values are submitted as the diagrams. The part appropriate to a signal reflected from sea bottom is shown. Vertically the time of observation was depicted for given point and horizontally, the time after arrival of pulse reflected from the water-ground interface was marked, all these admitted to observe pulses reflected from boundaries of layers separation. Color of dots is commensurate with voltage at the exit of the hydrolocator receiving unit.

In a fig. 2 the results of measurements from a board of the motionless ship in the Golden Horn Bay are given.

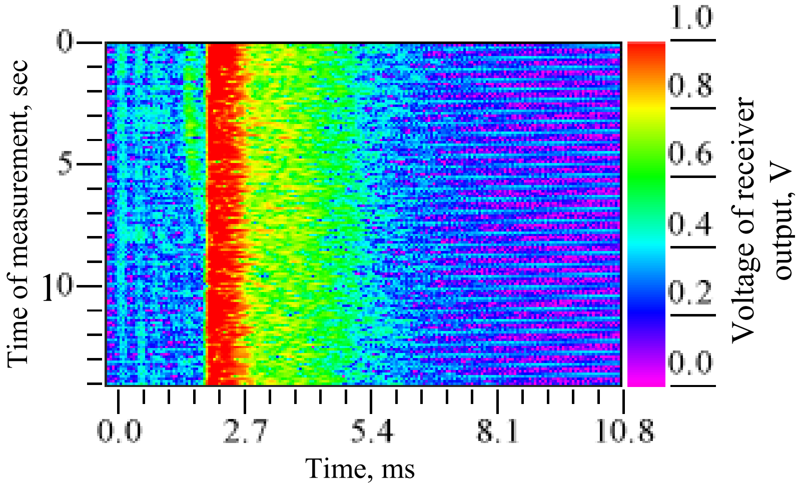

Fig. 2. Structure of layers of sea bottom

In a fig. 3 the diagram of magnitude of coefficient of reflection for spherical waves on a course of movement in the Patrokl bay is given. This coefficient was calculated with the help the formula (4) on the basis of measurements of depth and voltage on an output of the sonar receiver during movement.

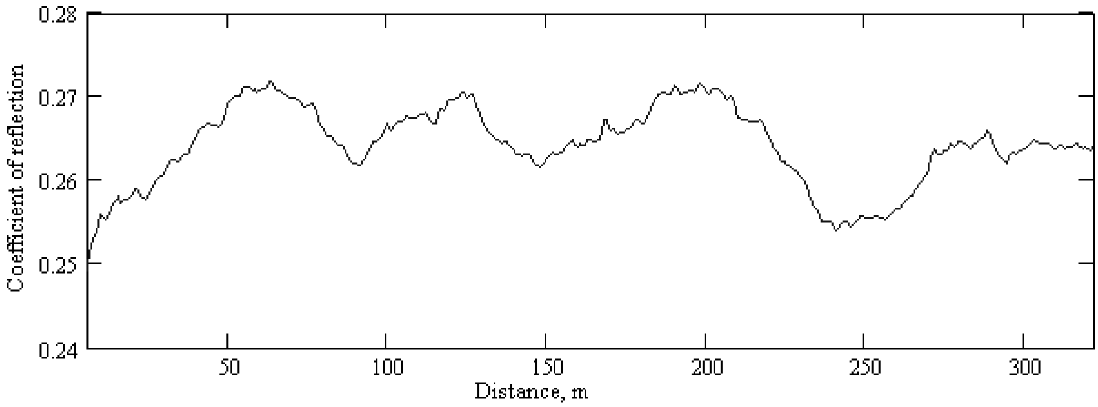

Fig. 3. The diagram of change of value of the coefficient of reflection from distance along tack

Based on results of measurements, it is possible to make a conclusion that to each point of sea bottom there corresponds the pattern of layers and coefficient of reflection on pressure for spherical waves. Comparing the pattern of layers, coefficient of reflection and coordinate of a location, where they were measured, it is possible to make a digital map of sea bottom, which is possible to use for navigation of underwater vehicles.

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