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ON THE HORIZONTAL STRUCTURE OF THE SOUND FIELD IN THE OCEAN

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In the ocean that has the canonical distribution of the sound speed the horizontal structure of the sound field is calculated by the method of geometrical acoustics. The sound field is determined for purely water-path rays as a sum of individual rays arriving at a given point with it's own amplitudes and phases. It is shown that the distribution of the field on the fixed depth is a function that has a little information: on the length of one circle the distribution consists of 1-3 maximums that created by caustics which present on the fixed depth. Width of caustics is about 0.1~ 1 km. Among caustics and when they are absent the amplitude of the field much smaller than in the caustics and have quasi-random character. Hence compare the calculated and measured of horizontal structure of the fields is difficult.

Calculation of horizontal structure of the sound field in the ocean waveguides has a big meaning with the utilization of horizontal antennas in experiments of sound propagation. For calculation of sound field in ocean by ray method it is needed to determine ray's trajectory, propagation time along ray (phase incursion) and amplitude of sound field transferred each ray. Calculation trajectories and the travel times of the sound field along trajectories execute with big accuracy. That testifies in many experiments about tomography of ocean, for example [1,2]. In these papers are shown that calculated and measured the travel times of the sound field with ray theory for distances ~ 17000 km are equal with grate accuracy. Marked that a mistake in defining the travel time of the sound field depends in many cases from accuracy knowledge of ship's movement with the source (receiver) the sound but not with changes the ocean in time. Results in [1,2] of measure sound field with the horizontal antenna length ~ 1.5 km showed that it is impossible to define regions of constructive and destructive interference along antenna and to differ time and space changes along antenna in experiments.

In paper [3] is shown results of calculation and measure the intensity of horizontal sound field structure in ocean on distances where zones of convergence overlap. Received that there are exist regions where intensity sound field is great (maximums). Authors [3] in ray method showed that sound field maximums are created with rays that have a big factor of focusing and create caustics. But distances where big intensity of the sound field in experiment exists are later then calculated. In ray theory the coordinates of caustic may be determined with very much accuracy if to build the ray trajectories near of the region of proposed existence of caustic or if to build angle distribution ray's coordinates as a function of angle's departure from the source, [4,5]. It may be assumed that difference between calculated and experimental regions of caustics in [3] exists because of calculating with factor of focusing or not full knowledge of conditions of the sound field propagation.

The objective of this work is to show mechanism of forming the sound field horizontal structure, it's maximums and distinguish those elements in field structure that may be compare with measured ones. For this purpose there were calculate sound field with taking into a count amplitude and phase each ray using ray method when the depth of source and receiver varied.

It is shown that compare measured horizontal field structure and calculated may be done only in regions of good visible maximums, which in many cases are caustics and their number on the length of circle not bigger then 3. Between maximums calculated field has a quasi-random character without any exclusive features and can't compares with experimental horizontal field structure.

Calculation was done for wave-guide with canonical distribution sound speed along depth. Vertical coordinate z is calculated from a surface of wave-guide, where $z=0$ towards the bottom, horizontal coordinate r from $z=0$. The depth of wave-guide 4 km, sound speed minimum lies on the depth $z_0=1$ km. Introduce term "horizon". It is a line that parallel to the axis r and cross axis z in a given point $z = \text{const}$. Along this line sound horizontal structure is calculated. The length of piece of a horizon for which sound field is calculated is equal to $\Delta r=70$ km and bigger the maximum circle in

this waveguide at ~ 13 km. The angle of departure rays from the source $\pm\theta$ is calculated from axis z . The source of sound field is the omnidirectional monochromatic radiation with a frequency of 233.6Hz. In calculations the axis z is digitized with a sampling step of $\Delta z=0.25$ m. The interval between calculating points along the horizontal coordinate is equal to 1 m. The angle interval between nearest rays is so that depth's difference of their turning points is equal to the sampling step Δz . The ray's amplitudes are equal the angle width of rays (angle distance between nearest rays) which depends of the angle of departure. This easily show with the law of Snellius, [4].

Calculation sound field horizontal structure is based on calculation following functions of angle of departure θ : angle distribution (AD) coordinates of rays $r(\theta)$; incursion phase along trajectory of each ray; ray's amplitude. Remark that angle of crossing the horizon by ray may be calculated according to Snellius's law when it is known depth of departure and receiver of ray and the angle θ .

Let us consider AD coordinate of rays when choused horizon is the axis of waveguide z_0 and on it the source and receiver of sound are placed. In that case all rays cross axis of waveguide and form horizontal structure of the field. On Fig 1 a, b functions $r(\theta)$ show at distances $r_1=490$ -560 km, (a), and $r_2=2000$ -2060 km, (b).

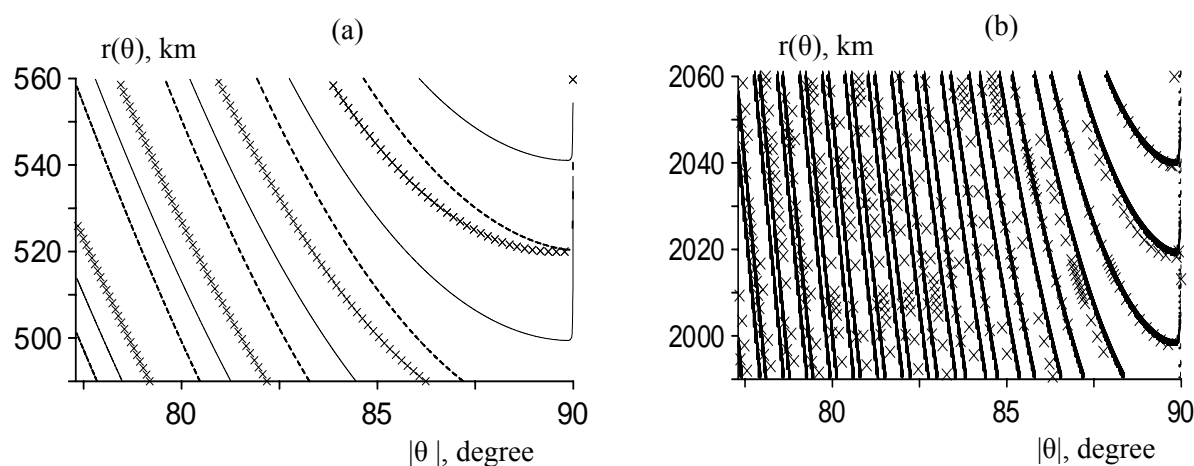


Fig. 1 Angle distributions of ray coordinates.

Horizontal axis is angle $|\theta|$, along vertical axis – distance from the source r . Function $r(\theta)$ is shown with an assemblage of curves. Each curve unites rays with equal number of turning points above and below the axis of waveguide. Curves $r(\theta)$ that unite rays with even sum of tuning points is shown with solid lines in Fig 1 a. They cross the axis of waveguide on the distance that equal to whole number of cycles and coincide for rays leaving the source above and below z_0 with symmetric angles. Curves with odd sum of turning points and leaving the source to bottom show with dashed lines, to surface with crosses. In Fig. 1 b solid lines with crosses unite rays with even number of turning points, solid curves and creating with crosses to odd number of turning points leaving the source above and below z_0 .

Similar in Fig 1 a, b are the character of functions $r(\theta)$. Difference concludes in number of curves that is grater in Fig.1 b then in Fig. 1 a by a factor of 4. This difference is explained with growing number of overlap cycles when the distance from the source grows [4,5].

Functions $r(\theta)$ have a minimum when θ is very near to 90° . It means that on the axis of waveguide there is a caustic. Caustics in distances $r_1=541$ km and $r_2=500$ km are similar and dispose on a distance between them equal to a length of one cycle when θ is very near to 90° . These two caustics create with rays that have even number of turning points when rays leave the source above and below z_0 . Caustics between them are practically coincide with each other. They create with rays when the number of turning points is odd.

Number of curves in each figure is equal to difference of the biggest and the smallest number of turning points on fixed distance. On the length of piece of a horizon Δr the number of whole cycles

that rays pass from the source, (Fig. 1 a) decrease from $N_1=13$ to $N_2=8$ when the angle θ decreases from 90° .

Mark that functions ray's coordinate $r(\theta)$ conclude a big information: with it can count the number of rays that come in each point, the length of cycles for each ray and it's angle of departure, number of caustics, their space on horizon and angles and the length of ray's cycle that create them.

Let us consider the mechanism of creating of caustics near $|\theta| \sim 90^\circ$, Fig 1 a. These caustics are very interesting for research sound propagation in the ocean because there are exist the grate density of rays near the axis of waveguide, [4] that make finding them easily. But in practice the use of this space for example in tomographic measures very difficult because sound pulses overlapped near the axis of waveguide and cannot be distinguish.

It is known that the length of ray's cycle depends from two factors - the angle's departure from the source and refraction of sound. They change the length of cycle in opposite sides. Near $\theta \sim 90^\circ$ in canonical waveguide the length of cycle changes bigger with changing the angle of departure but not with change of sound speed. Because this the length of cycle decreases when θ decreases. When the ray comes in depth where the influence of sound refraction on the length of cycle is the same as the influence of angle θ the length of cycle decreases not so quick and then begins to grow. In this canonical waveguide the minimum of the length of cycle creates when $\theta_{min}=89.858^\circ$ and equal $D(\theta_{min})=41.6172$ km. Just near θ_{min} are formed caustics that seen in Fig.1 a, b.

In papers [4,5] it is shown that on the depths $z_{1,2}=\pm 3.5$ km and distance $r=500$ km near axis are created two practically symmetric caustics which form with rays that leave the source to surface and to bottom when $\theta > 89.3^\circ$. There are no caustic centers on the axis of waveguide. The angle of departure of rays in centers of caustics is equal $\theta \sim 89.541^\circ$ and not the same as θ_{min} . On Fig. 2 a, b show trajectories of rays that form caustics near axis of waveguide in interval $\Delta\theta=89.94^\circ - 89.22^\circ$. Centers of caustics lye on the depths $z_{1,2}=\pm 3.5$ m.

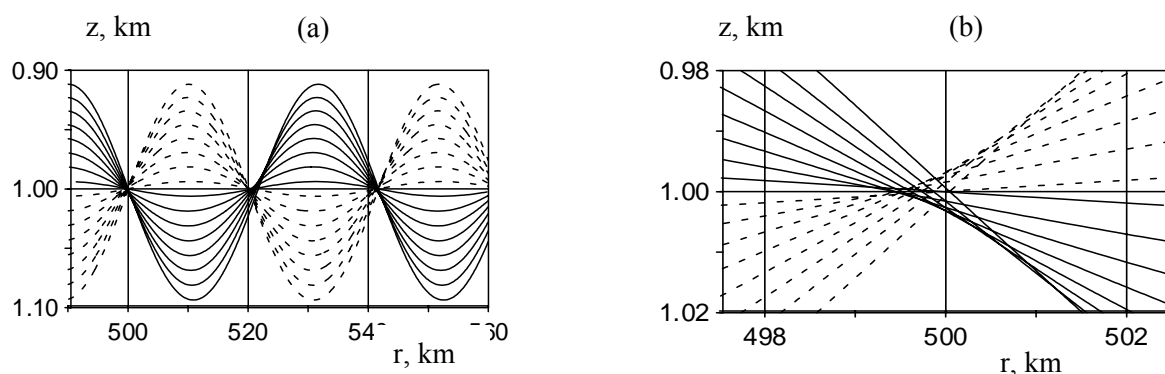


Fig. 2. Ray trajectories that form caustics near the axis of waveguide.

Solid and dashed curves correspond to the rays leaving the source towards the bottom and the surface respectively. In Fig. 2 a it is seen that near the axis of waveguide exist 6 caustics formed with rays that leave the source up and down. On Fig.2 b it is seen caustics on the distance $r \sim 500$ km on a large scale. Each caustic has its own turning round in plane (r, z) . From Fig. 2 b it is clear seen, that calculating caustics along horizon, Fig 1 a, b, not form a whole caustic. They is formed with rays that create two practically symmetric caustics near the axis of waveguide. As a functions of departure's angle "summed caustic" on Fig. 1 a has the center equal to angle of minimum length of cycle $D(\theta_{min})$.

On Fig. 3 a there are show sound field amplitudes on the axis of waveguide as a functions of distance along the whole horizontal segment. All three "summed caustics" are similar to each other. The extent of caustics along axis z is ~ 7 m but along axis r they are very greater their size along vertical and change in interval $\sim 0.5 - 1$ km. Ray's propagation times formed caustics differ on ~ 0.1

ms when $\theta = \theta_{\min}$ and to 70 – 3 ms on edges of caustics. Usually in tomography it is used the length of pulses ~ 10 ms. Thus separate pulses near the axis of waveguide can't be distinguished.

The field between caustics Fig. 3 b is formed by large number of rays coming in one point. Rays have near but different space frequencies along axis r . Thus sum of ray fields see as beats which change field amplitude so that summed field have a quasi-random character.

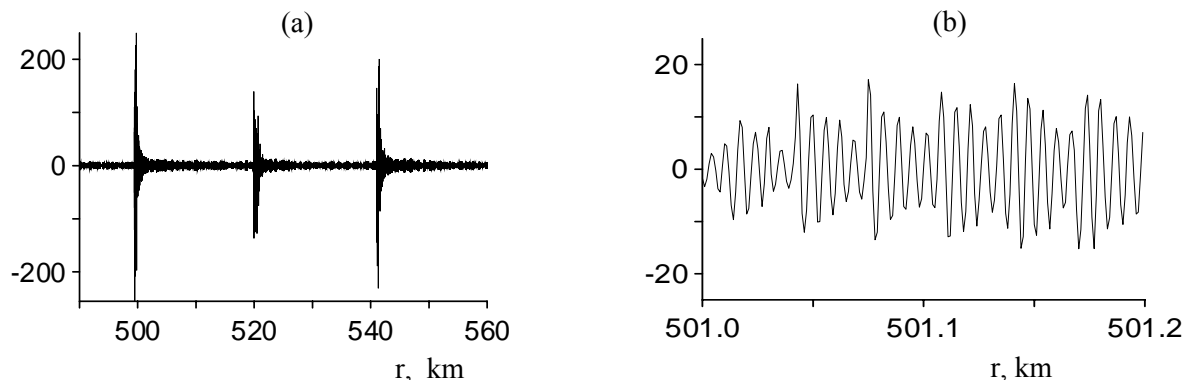


Fig. 3 Sound field structure on the waveguide axis.

On Fig. 4 it is shown sound field structure along horizon $z_1=2.6$ km. On this horizon there are the source and the receiver of sound. The big maximum forms with a part of rays that create the caustic near horizon z_1 . Second maximum which amplitude smaller forms with rays whose departure's angle near 90° and thus they have the large amplitude. Caustics near axis z_0 as on fig. 2 these rays not form because the maximum departure angle of these rays is greater very little θ_{\min} in which the length cycle is minimum. This case is interesting because it shows the possibility of creating sound field maximums not with caustics when θ is near 90° but because the depth of source and receiver coincide but it is not the axis of waveguide.

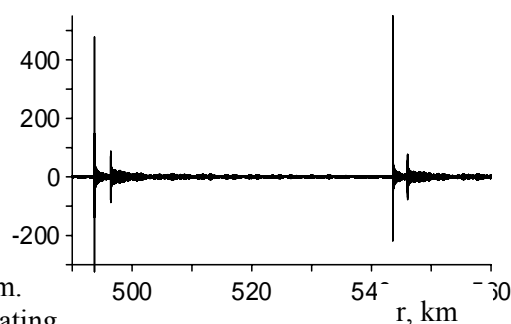


Fig. 4

Calculations of the sound field horizontal structures are shown that information about outstanding elements of the sound field - caustics – occupy a little part of horizontal structure. The last part of the quasi-random sound distribution can not be used in comparison calculating field with the experimental measurements.

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