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CLASSIFICATION OF UNDERWATER OBJECTS BY MEANS OF AN ACOUSTIC METHOD

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Abstract

The underwater object detection, identification and classification that are immersed or buried by means of an acoustic method have been of great interest for a few decades by acousticians' marines and archaeologist. There are used the objects e.g. mines, amphorae in a finite cylindrical shape or similar. The method of active location (echolocation) is very popular in detection of the immersed or buried objects. In the shape of reflected sounding pulse one can observe the ridged part of sounding pulse and also so-called tail. In this tail we can find a substantial feature of the object that scattered the sound pulse.

The paper deal with the basic problem connected with the free vibration of finite cylindrical steel shell immersed in water. There is described the simplified theoretical model of this problem and next the results of numerical investigations are presented. The final results are the acoustics characteristics obtained in the sea. These ones are compared to numerical results abstract.

INTRODUCTION

Underwater object detection identification and classification immersed or buried by means of acoustic method has been of great interest for a few decays by acousticians, marines and archaeologists. There are often used the objects in a finite cylindrical shape.

In this paper are presented some results connected with both theoretical and experimental investigation of sound backscattering on a finite cylindrical shell exctied to vibrations by a very short pulse. One of the methods that are used is pulse response function analysis [2, 3].

The theoretical description is rather complicated due to the boundary conditions mainly on a target surface. One can do some simplifications of real conditions to such one that allow solving this problem.

The main goal of this work is to find the analytical description of back scattering field of pressure pulse on a finite cylindrical shell that generated broadband response. There is also done a comparison between results obtain experimentally and carried out theoretically.

In the first part of this work there are presented theoretical solution of sound radiation by a finite circular cylinder. There are taken into account stationary vibrations connected with own functions of a shell. Knowing normal velocity on the radiating surface one can find pressure distributions in a far field.

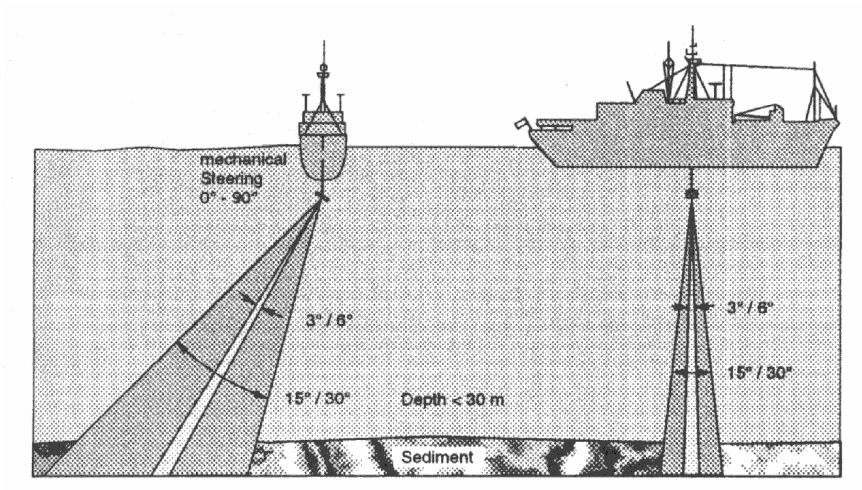

Figure 1 – An example of investigation of sea bottom by means of acoustic method

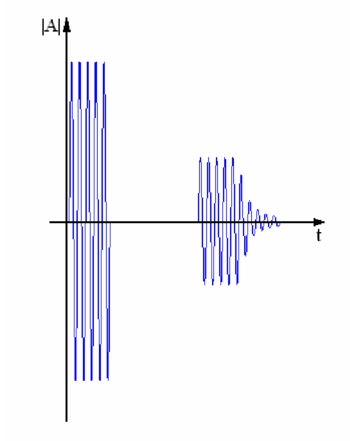

Figure 2 – Sounding and reflected signal

PROBLEM FORMULATION

For describing the pressure distribution in a far field we used the Helmholtz equation in the following form [1]:

$$\Delta\Phi(R)+k^2\Phi(R)=-f(\breve{r}_0) \tag{1}$$

where:

$$\Delta=\frac{1}{q}\frac{\partial}{\partial q}(q\frac{\partial}{\partial q})+\frac{1}{q^2}\frac{\partial^2}{\partial\varphi^2}+\frac{\partial}{\partial x^2},$$
$$q=\sqrt{z^2+y^2},\quad R=\sqrt{q^2+x^2} \tag{2}$$

The solution of this equation is as follow:

$$\Phi(\mathring{R})=\int_{S_0}\frac{\partial\Phi(r_0)}{\partial N_0}G(R,r_0)dS_0 \tag{3}$$

where S_0 is a radiated surface and $G(R,r_0)$ Green function.
On the source surface for r_0=a should be satisfied the boundary condition so-called Neumann condition in this form:

$$-\frac{\partial\Phi(\breve{r}_0)}{\partial N_0}\bigg|_{r_0=a}=w(\mathring{r}_0) \tag{4}$$

where $w(r_0)$ - normal velocity of the shell vibration.
The pressure distribution is described by the following formulae:

$$p_{mn}=\frac{ac\rho}{4R}W_{mn}e^{-i\pi/2(n+1)}e^{-i(\omega t-kR)}[J_n(ka\sin\Theta)+iE_N(ka\sin\Theta)]\psi \tag{5}$$

where:

$$\psi=\frac{\sin(kL/2\cos\Theta)}{\cos\Theta}[1+\frac{(kL\cos\Theta)^2}{(2m\pi)^2-(kL\cos\Theta)^2}] \tag{6}$$

c - speed of sound
ρ - medium density
Jn(.), En(.) - Bessel and Weber-Lommel functions order n respectively.

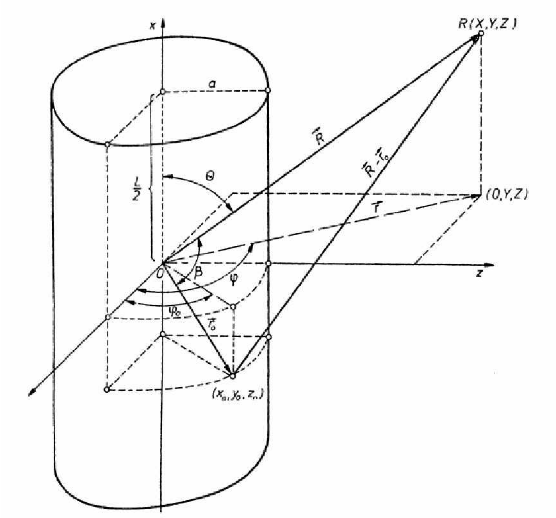

Figure 3 – Geometric configuration of radiating cylinder

We assume that cylindrical surface is covered by ccontinuous distribution of single sources given by:

$$\hat{W}_{mn}(\mathring{r}_0) = \frac{\hat{W}_{mn}}{2}[1-\cos\frac{m\pi}{L}(2x_0+L)]\cos N\varphi_0 \tag{7}$$

where m,n are modal and nodal number respectively, W_{mn} is amplitude of normal velocity.

Another relation is obtained when we take into account the pressure wave radiation by a part of an infinite cylinder. It is given by these formulae:

$$p_{mn} = \frac{i\rho\omega_{mn}}{\sqrt{2\pi}} e^{in\varphi} \int_{-\infty}^{\infty} \frac{A_n(\xi,\varphi_0) H_n(\tau R) e^{ix\xi}}{\tau H_n'(\tau a)} d\xi \tag{8}$$

where ξ is a wave number in x direction.

After simplification we obtain:

$$p_{mn} = \frac{c\rho\varepsilon(n)}{4\pi kR} \hat{W}_{mn} e^{-i\pi/2n} e^{-i(\omega_{mn}t-kR)} \frac{\psi}{(\sin\Theta) H_n'(ka\sin\Theta)} \tag{9}$$

where: $\varepsilon(n) = 1$ for $n=0$ and $\varepsilon(n)=2$ for $n\geq 1$.

Distribution of sound pressure can be find by mean of the relation:

$$p_{mn} = \frac{ac\rho}{4R} \hat{W}_{mn} e^{-i\pi/2(n+1)} e^{-i(\omega t-kR)} [J_n(ka\sin\Theta) + iE_N(ka\sin\Theta)]\psi \tag{10}$$

or

$$p_{mn} = \frac{c\rho\varepsilon(n)}{4\pi kR}\hat{W}_{mn} e^{-i\pi/2n} e^{-i(\omega_{mn}t-kR)} \frac{\psi}{(\sin\Theta)H_n'(ka\sin\Theta)} \tag{11}$$

for the cases when we know ω_{mn} and connected with them W_{mn}.

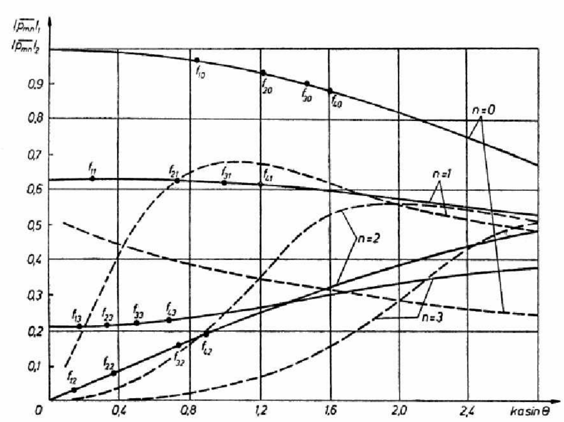

Figure 4 – Chart o $|p_{mn}|_1$ and $|p_{mn}|_2$ as function of casing Θ

Solid line:

$$\left|\bar{p}_{mn}\right|_1 = \frac{4R\left|p_{mn}\right|}{ac\rho W_{mn}\psi} = \left|J_n(ka\sin\Theta) + iE_n(ka\sin\Theta)\right| \tag{12}$$

Dashed line:

$$\left|\bar{p}_{mn}\right|_2 = \frac{4R\left|p_{mn}\right|}{ac\rho\hat{W}_{mn}\psi} = \frac{\varepsilon(n)}{\pi ka\sin\Theta}\frac{1}{\left|H_n'(ka\sin\Theta)\right|} \tag{13}$$

To normalize these function we divided it by factor:

$$\frac{ac\rho}{4R}\hat{W}_{mn}\varphi \tag{14}$$

EXPERIMENTAL INVESTIGATION

As a first step we are carried out examinations of the normal velocity distribution on the cylindrical steel shell. The cylindrical shell was immersed in water in an anechoic basin. On its surface was mounted velocity transducer as is shown in figure.

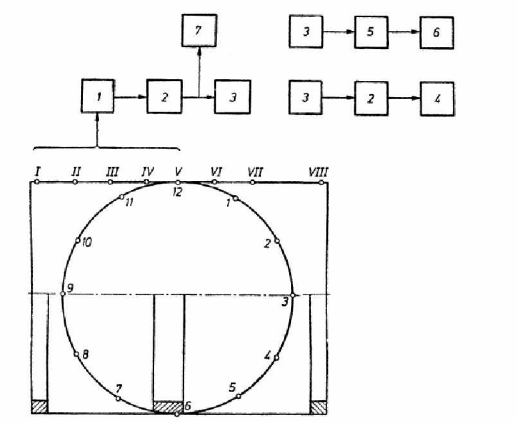

Figure 5 – Velocity transducer

These signals after a pulse excitation were recorded and analysed. On the base of this examination we can estimate fundamental frequencies connected with resonance frequencies. Figure below show an example of velocity signal observed at point VIII.

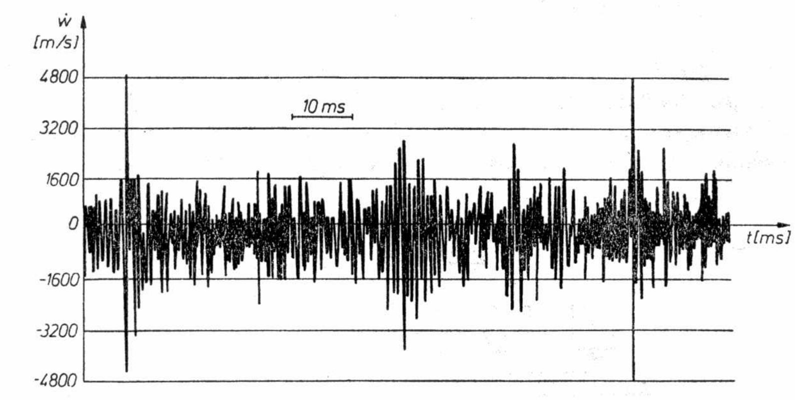

Figure 6 – Example of velocity signal observed at point VIII

In these figures are shown the form of function for different resonance frequencies.The velocity distribution along the x - axis and φ - angle.

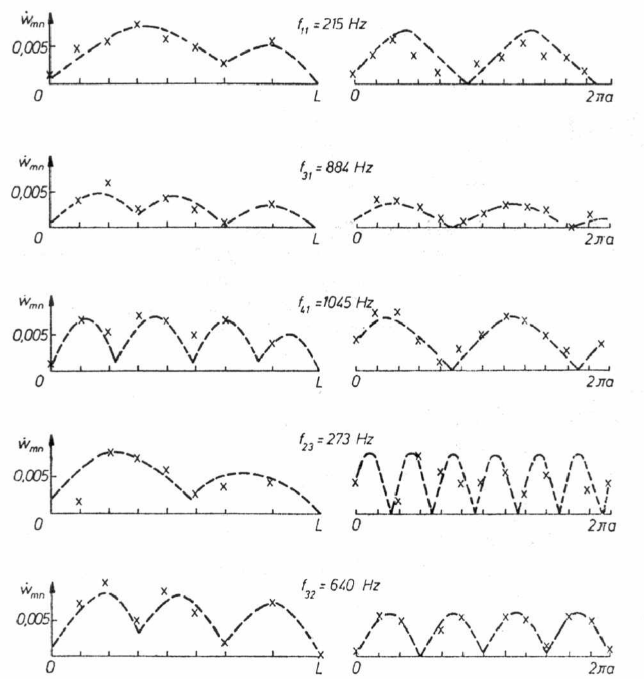

Figure 7 –The form of the function for different resonance frequencies

Amplitudes and their free oscillations frequency obtained from an experiment and spectral components of the sound pressure.

m	n				
	0	1	2	3	
1	708	215	116	158	$f_{mn}[Hz]$
	0.005	0.007	0.018	0.015	$\dot{W}_{mn}[m/s]$
	18.54	5.34	0.34	2.73	$p_{mn}[Pa]^*$
	7.62	1.84	0.03	0.001	$p_{mn}[Pa]^{**}$
2	1075	635	327	273	$f_{mn}[Hz]$
	0.0035	0.006	0.007	0.008	$\dot{W}_{mn}[m/s]$
	18.79	12.86	0.99	2.65	$p_{mn}[Pa]^*$
	6.69	12.97	0.28	0.014	$p_{mn}[Pa]^{**}$
3	1264	884	640	435	$f_{mn}[Hz]$
	0.0025	0.0045	0.007	0.01	$\dot{W}_{mn}[m/s]$
	15.17	13.32	4.11	5.17	$p_{mn}[Pa]^*$
	5.29	14.60	3.23	0.12	$p_{mn}[Pa]^{**}$
4	1392	1045	781	591	$f_{mn}[Hz]$
	0.002	0.003	0.0055	0.005	$\dot{W}_{mn}[m/s]$
	13.23	10.41	4.52	3.67	$p_{mn}[Pa]^*$
	4.47	11.36	4.75	0.38	$p_{mn}[Pa]^{**}$

$$^{*}\ p_{mn} = \frac{ac\rho}{4R}\dot{W}_{mn}e^{-i\pi/2(n+1)}e^{-i(\omega t-kR)}[J_n(ka\sin\Theta)+iE_N(ka\sin\Theta)]\psi$$

$$^{**}\ p_{mn} = \frac{c\rho\varepsilon(n)}{4\pi kR}\dot{W}_{mn}e^{-i\pi/2n}e^{-i(\omega_{mn}t-kR)}\frac{\psi}{(\sin\Theta)H_n'(ka\sin\Theta)}$$

Figure 8 –The table consists of values of frequencies connected with pressures for modal and nodal numbers

The next step of these investigations were measurements of scattered sound pressure by a finite cylindrical steel shell exciting by sound pulse generated by the impulsive source. This kind of source allows to excite low free oscillations of the cylindrical shell for e.g. less than f = 200 Hz.

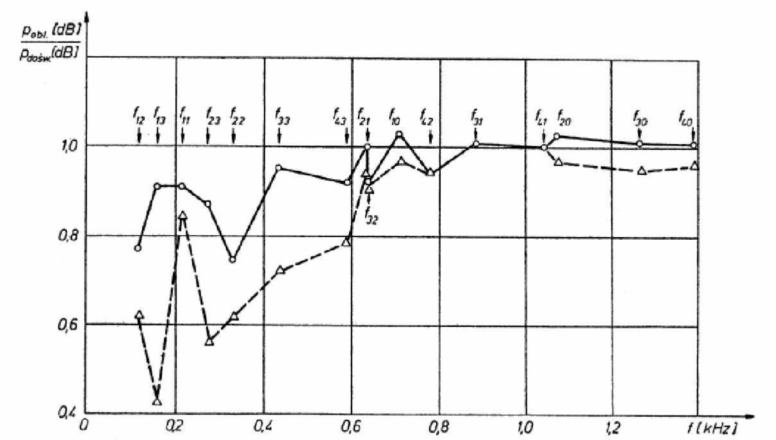

Figure 9 –Normalized values of pressure for determined frequencies

In this figure are shown two curves as results of comparison of two different relations between the values obtained by means of theoretical relation and measurement one. The better approximation gives the relation:

$$p_{mn} = \frac{ac\rho}{4R}\hat{W}_{mn} e^{-i\pi/2(n+1)} e^{-i(\omega t - kR)} [J_n(ka \sin\Theta) + iE_N(ka \sin\Theta)]\psi \quad (15)$$

CONCLUSIONS

Finding a free oscillation of a immersed finite cylindrical steel shell we can estimate its volume and shape and some times also inside content These investigations are a first step to find a method for interpretations some relation between geometrical relation of the target and scattered sound field.

The next step will be devoted to the proper signal processing allowing extracting the interesting information from scattered signal.

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