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Classification of cylindrical shell using acoustic shock wave in water

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1. Introduction

It is possible that detection of submerged target using their surface reflected wave. But in actual sea, there are many objects geometrically similar to submarine or sea mine which we want to find. And it is hard to decide it is real target or just unnecessary floating matter using target surface reflected acoustic wave only. To work out this problem, we use not only reflected wave of target surface also elastic echo wave of target which decided by boundary conditions between shell of cylindrical target and its inside materia[1]. The elastic echo has information of cylindrical target like radius, thickness of cylindrical shell and its inside material. Therefore it can be used classification of target process.

2. Numerical Simulation

The general expression of scattering pressure fielded by cylindrical target is as follow[2]

$$P_{scat} = P_0[(1-i)/\sqrt{\pi k_1 r}]\exp(2ik_1 a)$$
$$\times \exp i(2k_1 u - \omega t')\sum_{n=0}^{\infty}\varepsilon_n[D_n^{[1]}/D_n]\cos n\theta$$

Where P_0 is amplitude of incident plane acoustic wave, k_1 is wave number in water obtained by sound speed of water c_w and angular frequency ω ($k_1 = c_w$ /ω). r is distance between sound source cylindrical target, u is distance between sound source and surface of cylindrical target. ε_n is Neumann coefficient which has value of 1 if n=0 and has value of 2 if n ≠ 0. $D_n^{[1]}$ and D_n are determination which obtained from boundary conditions of three mediums. We obtained time signal from frequency domain pressure field using inverse Fast Fourier transform (iFFT) process. We postulated broadband shockwave (1-60kHz) insonified hollow cylindrical shell(filled with air). Distance between source and target is 100 m free-field condition in water. Density, longitudinal wave velocity and transverse wave velocity are 7900 kg/m3, 5790 m/s and 3100m/s, respectively. Fig. x. shows backscattering. Radiu is 3, 6 m and thickness is 10, 20 cm. Fig. x. shows time signal and frequency spectrum of backscattering wave.

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The thickness of cylindrical shell can be estimated from frequnecy spectum of backscattering pressure filed. We can estimate thickness of cylindrical shell (=d) by following foulation with resonance frequency ($\hat{f}$) .

$$\hat{d} = C_L \,/\, (2 \times \hat{f})$$

The radius of the cylindricalshell ($\hat{R}$) can be calculated following fomulalation.

$$\hat{R} = \widehat{\tau C_m}/2\pi$$

Where $\hat{\tau}$ is time delay between surface reflected wave and elastic echo from time signal which obtind from iFFT of backscatteing frequency spectum. And C_m is group velocity in the material[3]. Calculation results are showed table 1.

3. Experimental measurement

To verify numerical simulation, we performed experimental measurement in laboratory tank. Fig. x. shows experimental setup. The experiment is downscale of numerical simulation with 1:100 ratio. Stainless steel air filled hollow cylindrical shell was used as target (Radius: 30 mm, thickness: 1 mm, 2 mm). We used center frequency 2.25MHz (Olympus V304) acoustic transducer as sound source. To generate broadband signal, the transducer was generated by pulser/receiver (Olympus 5072PR). Acoustic wave is perpendicularly incident to cylindrical shell and backscattering wave was received by transmitting transducer (mono-static method). Fig. x. shows time signal and frequency spectrum of backscattering aoustic wave. Received acoustic signal was analyzed in time and frequency domain. As numerical simulation expected, surface reflected

TABLE Ⅰ. Thickness and radius estimation

True Thickness (d)	Maximum Frequency ($\hat{f}_r$)	Estimated Thickness ($\hat{d}$)
10 cm	27.1 kHz	10.7 cm
20 cm	13.3 kHz	21.8 cm
True Radius (R)	**Time Delay ($\hat{\tau}_R$)**	**Estimated Radius ($\hat{R}$)**
3 m	4.1 ms	2.9 m
6 m	8.2 ms	5.8 m

echo and elastic echo were observed in time domain. And resonance peak was observed in frequency domain. We can estimate radius and thickness of cylindrical shell.

4. Result and discussion

We try to classify cylindrical shells by numerical method and experimental method. We used broadband shockwave as incident wave to precisely decide time delay of backscattering signal and resonance frequency. Estimated values of radius and thickness are closely matched up to true input values. It shows we can estimate radius thickness at ideal condition. To apply actual condition, we compared with numerical value and experimental value. As a result, thickness values are similarly estimated. It shows broadband shockwave is effective to classify thickness of immersed cylindrical targets. But estimated radius shows relatively large difference between numerical value and experimental value. We need to consider more conditions to math both values.

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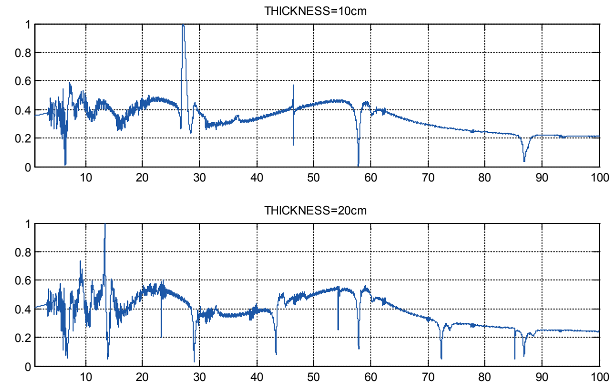

Fig. 1 Backscattering spectra for thickness 10, 20 cm.

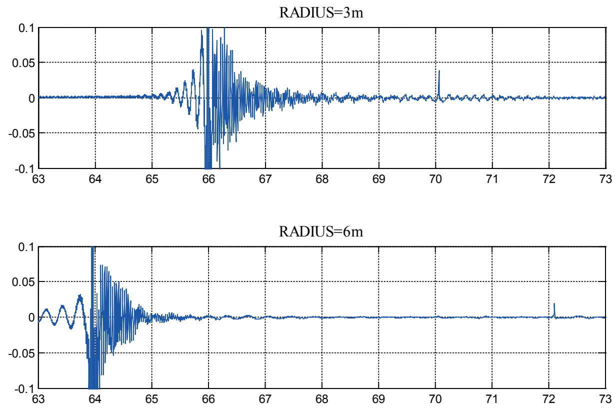

Fig. 2 . Backscattered signal in the time domain and time delay for radius of 3, 6 m.

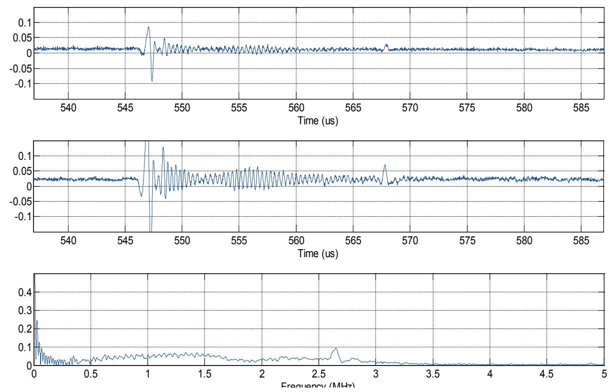

Fig. 3 Experimental time signal and frequency spectrum for radius 3cm, thickness 0.1 cm

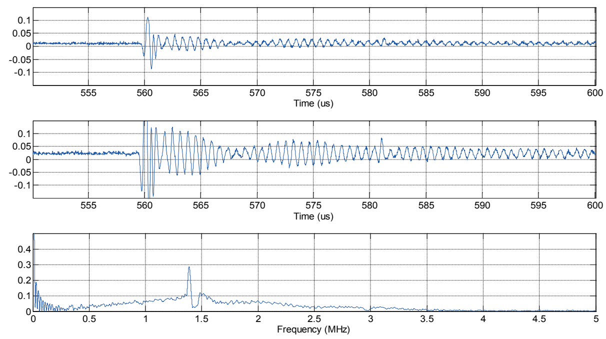

Fig. 4 Experimental time signal and frequency spectrum for radius 3cm, thickness 0.2 cm