SPECTRUM OF ECHO SCATTERED BY SIMPLE OBJECT PLACED AT FOCAL PLANE OF ULTRASONIC TRANSDUCER

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A better understanding of scattering process is essential to interpret images obtained by ultrasonic pulse echo system. Scattering process in plane or spherical waves sound field has been analyzed so far, but it has hardly known about the scattering in focused beam sound field. In this paper spectrum of echo scattered by a simple object in focused sound field is analyzed by using the mathematical expressions of echo presented at the previous symposium. It becomes clear that frequency dependence of spectrum changes due to the geometrical figures of scatterers as well as the degree of focusing of the sound beam and some of the respects are verified experimentally.

INTRODUCTION

Recently an ultrasonic pulse echo system has been widely used in medical diagnosis and nondestructive testing. Roughly speaking images of scattering strength are observed in the system. The scattering of waves in plane or spherical sound field has been analyzed so far [1-3] but it has hardly known about the scattering in focused sound field. Since almost all pulse echo systems use focused sound beam, the analysis of echo signal scattered by an object in focused sound field is essential if we want to get more information about acoustic characteristics of the scatterers other than the locations of their discontinuities from the echo signal.

New mathematical expressions of the echo signal have been reported at the previous symposium which work for arbitrary objects in arbitrary sound field [4]. By using these expressions the spectrum of echo scattered by a simple object, that is, a point, line, film, and plane object, is analyzed and the ratios of spectra of the
point and line objects with that of the plane object is calculated and compared with experimentally obtained spectrums. It becomes clear that the frequency dependence of spectrum changes by the geometrical figure of scatterers as well as the degree of focusing of the sound beam and some of these respects are verified experimentally.

PRINCIPLES

Expressions of echo signal

According to the previous report, the frequency component $E(\omega)$ of echo signal $e(t)$ can be expressed as follows

$$E(\omega) = j2\omega \rho_0 G(\omega) \int \frac{R(\mathbf{r}) (jk\Phi(\omega, \mathbf{r}))^2 dV}{V'}$$

where $\rho_0$ shows the mean density of the medium, $k$ shows the wave number of ultrasonic waves ($k = \omega/c_0$, $c_0$ shows the sound velocity of the medium.), $G(\omega)$ shows electrical characteristics of an ultrasonic transducer and it is assumed that the same transducer is used as a transmitter and a receiver. $R(\mathbf{r})$ shows the distribution of amplitude reflection coefficient of the scatterer and is given by

$$R(\mathbf{r}) = \frac{Z(\mathbf{r}) - Z_0}{Z(\mathbf{r}) + Z_0}$$

where $Z(\mathbf{r})$ shows the distribution of specific acoustic impedance of the scatterer, $Z_0$ shows the mean specific acoustic impedance of the medium, and $\mathbf{r}$ shows the position vector. In Eq. (1) $V'$ shows volume of the scatterer after the effect of sound velocity difference is compensated. If the inside of the scatter is uniform, Eq. (1) can be expressed by a surface integral on the scattering volume as follows

$$E(\omega) = j\omega \rho_0 G(\omega) R_0 \int \Phi(\omega, \mathbf{r}) N \cdot \nabla \Phi(\omega, \mathbf{r}) ds$$

where $R_0$ shows the amplitude reflection coefficient of the uniform scatterer, $N$ shows outer normal to $S'$, and $S'$ shows the surface of the scatterer which is modified in order to compensate the sound velocity difference. In Eqs. (1) and (3) $\Phi(\omega, \mathbf{r})$ shows a velocity potential and is given as follows at the focal plane of a concave circular transducer

$$\Phi(\omega, \mathbf{r}) = (a^2/2r_0)f(kasin\theta)e^{-jkr}$$

$$f(x) = \frac{2J_1(x)}{x}$$

where $(r, \theta)$ shows a spherical coordinates system whose origin is taken at the center of the transducer (Fig. 1), $r_0$ shows a focal length of the transducer, and $J_1$ shows a Bessel function of 1st order.