Experimental Study of Radiation Impedance with the Effect of Reflected Wave from Sonar-Dome

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1. Introduction

An underwater detecting system consist of many vibrator elements to control its radiating characteristics and the directivity of the ultrasound wave. The system is usually surrounded by a dome to protect from the underwater environment. Radiation impedance is one of the design factors of the array system described above¹⁰⁻³. In this study, the effect of reflected wave from sonar-dome on the radiation impedance is investigated experimentally. The equivalent circuit model for theoretical analysis is useful to calculate the radiation impedance change by the reflected wave.

2. Analysis of Equivalent Model

We assume that a plane reflector that has a complex reflection coefficient is placed in front of a transducer array with elements on a rigid baffle at arbitrary distance. To analyze the radiation impedance in this case, a simplified model with two vibrators is selected, as shown in Fig. 1. The total radiation impedance of the nth vibrator then can be written as

\[ Z_n = \sum_{m=1}^{N} (Z_{mn} + Z_{mm}) \frac{u_m}{u_n}, \]

\[ Z'_n = \frac{1}{u_m} \int_{z_m}^{z_n} \int_{z_n}^{z_m} \frac{p_m}{l} dS_m dS_n, \]

\[ Z_{nm} = \frac{1}{u_m} \int_{z_m}^{z_n} \frac{\exp(-jkl)}{l} dS_m, \]

\[ Z_{mn} = \frac{1}{u_n} \int_{z_m}^{z_n} \frac{\exp(-jkl)}{l} dS_n. \]

From Eq.(2) and Eq.(3), an impedance matrix then can be obtained as

![Fig. 1 Geometry of the simplified model.](image)

![Fig. 2 Equivalent circuit with acoustic radiation impedance.](image)
Here, $z_{11} = \frac{1}{j\omega C_0}$, $z_{12} = z_{21} = -\frac{1}{j\omega C_0}$, $Z_r = \sum_{n=1}^{N} Z_n$, $z_{22} = 1/j\omega C_0 + R_i + j\omega L_i + 1/j\omega C_i + Z_r$, and $Z_r$ is the acoustic radiation impedance of the array. Assuming an input voltage $V$, input impedance, $Z$ is given by

$$Z = z_{11}^{-1}\left(\frac{z_{12}z_{21}}{z_{22}}\right).$$

3. Experiment and Results

In order to verify the effect of the reflected wave from sonar-dome on the radiation impedance, 25 tonpilz transducers are mounted on the cylindrical baffle and a reflector is located in front of the array. Thickness of the reflector with the acoustic impedance of 9.72 Mrayl is 2 cm, and separation distance between transducer array and the reflector is 30 cm. In the equivalent circuit, mechanical characteristics of the tonpilz transducer($R_1, L_1, C_1$) and electric characteristic($C_0$) of the piezoelectric ceramic are measured as follows: $R_1 =$212.8 $\Omega$, $L_1 =$133.2 mH, $C_1 =$3.32 nF, $C_0 =$13.23 nF.

The input impedance of the array is measured according to the driving condition, and the results are shown in Fig. 3 and Fig. 4 together with the theoretically predicted curve from Eq.(5). In these figure, $k$ is wave number vector and $a$ is the radius of the vibrator. Figure 3 shows input impedance change with $ka$ when the 13th element is only driven. This result shows a trend identical to the calculation result. When 25 vibrators are all driven, the input impedance is measured as shown in Fig. 4. Although the peak values show lag behind that of theoretical results as well as a little difference, the real part and the imaginary part show a similar trend.

4. Summary

To verify an effect of the reflected wave from sonar-dome on radiation impedance, the input impedance of the vibrators is estimated from the experimentally measured data. Using simplified model for the array consists of 25 vibrators and a plane reflector the radiation impedance change is investigated theoretically. It is confirmed that the variation tendencies are in agreement with the theoretical predictions in the given range $ka$. These results would provide the useful information to design an underwater sonar system.

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References