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

ソーナードームからの反射波を考慮した放射インピーダンスの実験的考察

Jungsoon Kim[1‡], Moojoon Kim[2], Kanglyeol Ha[2], Heeseon Seo[3], and Cheeyoung Joh[3]
([1]Dept. Media Eng., Tongmyong Univ.; [2]Dept. Physics, Pukyong National Univ., [3]Agency for Defense Development)
金正順 [1‡], 金茂俊 [2], 河康烈 [2] ([1] 東明大 情通; [2] 釜慶大 自然科学)

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 above[1~3]. 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 caculate 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 Γ is placed in front of a transducer array with N 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[4]

$$Z_n = \sum_{m=1}^{N} \left(Z_{mn} + Z'_{mn} \right) \frac{u_m}{u_n}, \qquad (1)$$

$$Z'_n = \frac{1}{u_m} \int_{S_n} p'_{mn} dS_m \,, \; p'_{mn} = \frac{j\rho ck}{2\pi} u_m \Gamma \int_{S'_n} \frac{\exp(-jkl)}{l} dS'_m \,,$$

$$Z'_{mn} = \frac{j\rho ck}{2\pi} \Gamma \int_{S_n} \int_{S'_n} \frac{\exp(-jkl)}{l} dS'_m dS_n \,,$$

Z_{mn} is the mutual radiation impedance between the mth and nth vibrator, u_m and u_n are the vibration velocity of the mth and nth vibrator, respectively, p'_{mn} is the pressure from the reflector due to the vibration of the mth vibrator, and Z'_{mn} is the mutual radiation impedance between two vibrator due to the reflected pressure form the reflector.

Based on the equivalent circuit theory, input impedance can be modeled by an RLC resonance circuit as shown in **Fig. 2**, and the relation between the voltage and the current is expressed as follows:

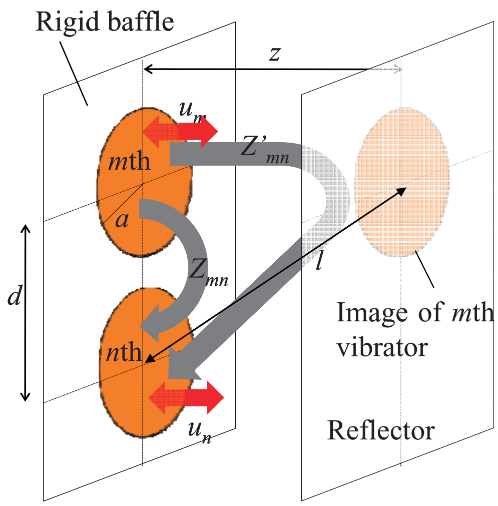

Fig. 1 Geometry of the simplified model.

$$\frac{1}{j\omega C_0}(i_0 - i_r) = V_s \,, \qquad (2)$$

$$-\frac{1}{j\omega C_0}(i_0 - i_r) + \left\{ R_1 + j\omega L + \frac{1}{j\omega C_1} + Z_r \right\} i_r = 0 \,. \quad (3)$$

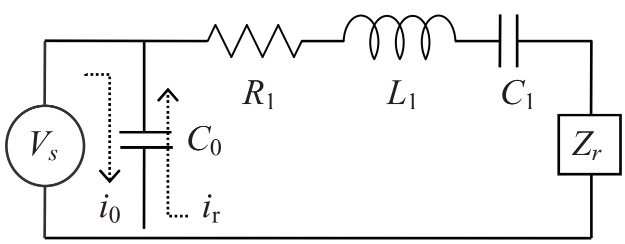

Fig. 2 Equivalent circuit with acoustic radiation impedance.

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

kimjs@tu.ac.kr; kimmj@pknu.ac.kr

$$\begin{bmatrix} z_{11} & z_{12} \\ z_{21} & z_{22} \end{bmatrix} \begin{bmatrix} i_0 \\ i_r \end{bmatrix} = \begin{bmatrix} V_s \\ 0 \end{bmatrix}, \quad (4)$$

Here, $z_{11} = \dfrac{1}{j\omega C_0}$, $z_{12} = z_{21} = -\dfrac{1}{j\omega C_0}$, $Z_r = \sum_{n=1}^{N} Z_n$,

$z_{22} = 1/j\omega C_0 + R_1 + j\omega L_1 + 1/j\omega C_1 + Z_r$, and Z_r is the acoustic radiation impedance of the array. Assuming an input voltage $1V$, input impedance, Z is given by

$$Z = z_{11} - \left(\frac{z_{12} z_{21}}{z_{22}} \right). \quad (5)$$

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 Ω, 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.

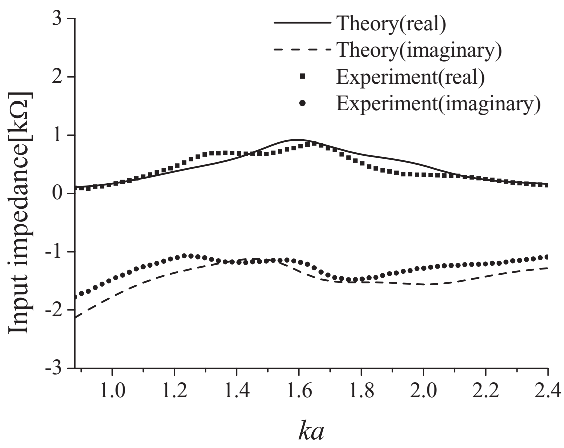

Fig. 3 Input impedance change with *ka* for the 13th vibrator in the 5×5 transducer array when one vibrator is driven.

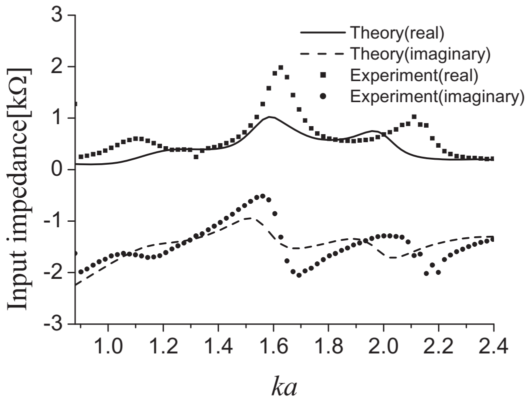

Fig. 4 Input impedance change with *ka* for the 13th vibrator in the 5×5 transducer array when 25 vibrators are driven.

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 tend.

4. Summary

To verify an effect of the reflected wave from sonar-dome on radiation impedance, the input impedance of the vibratos 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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