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Short Note

A New Method of Calculating Radiation Impedance for Vibrating Surface with Finite Baffle

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In this paper, by defining a vibrating surface to be a set of small point sources, a new calculation method for the rectangular vibrating surface with a finite baffle is suggested by considering the effect of the finite baffle on the source strength of each point source. As an example, the variation in self-radiation impedance for a rectangular vibrating surface is calculated based on the size of the baffle.

KEYWORDS: radiation impedance, finite baffle, transducer, rectangular vibrating surface, calculation method, point source

Because the research on radiation impedance, in general, has been performed for a vibrating surface with an infinite baffle, we have difficulties in applying the results obtained to the design of real transducers with finite baffles. Nimura *et al.*[1)] calculated radiation impedance for the circular vibrating surface with a finite baffle as an extreme case of an oblate spheroid. However, their calculation method cannot be applied except in the case where the shape of the vibrating surface is circular. Furthermore, the method uses very complicated polynomials even for a circular vibrating surface.

Previously, we proposed an algorithm for the calculation of the acoustic radiation impedance of a rectangular vibrating surface with an infinite baffle by considering this as a set of point sources. The algorithm significantly reduced computation time and improved the precision of results by presenting duplicated calculations as a general form in a series in consideration of the mutual effects among point sources.[2)] In addition, the acoustic radiation characteristics of a point source in a rigid baffle can be analyzed by introducing an imaginary point source.[3)]

In this paper, the outside of a finite baffle is considered as an imaginary negative acoustic source. The source strength of a point source is represented as a function of the baffle size. We derived equations for the radiation impedance with the finite baffle using this function. Using the derived equations, the radiation impedance of a regular square vibrating surface with a finite baffle is calculated.

The effect of a finite baffle on an acoustic point source is considered as shown in Fig. 1. Figure 1(a) shows that the source strength Q_0 of an acoustic point source with an infinite baffle is equivalent to $2Q_0$ in free space without a baffle.[4)] However, as shown in Fig. 1(b), the source strength of a point source with a finite baffle is not equivalent to $2Q_0$ in space because the diffracted pressure wave from the point source cannot be reflected from the no-baffle area. By introducing a negative source strength $-q$, which is a function of average baffle radius d, for the effect, the source strength of a point source with a finite baffle is equal to $Q' = 2Q_0 - q$ in free space. For the calculation of radiation impedance of a regular square vibrating surface with a finite baffle, we divide the surface into $n \times n$ acoustic point sources with a source strength Q' as shown in Fig. 2. The distance from the center of the vibrating surface to the side of the baffle is regarded to be the average radius d of the baffle. Considering a surface to be an aggregation of infinitesimal vibrating elements and computing the mutual radiation effects among these elements, a new calculation method of radiation impedance for rectangular vibrating surface with an infinite baffle had been propose.[2)] Using this method, the radiation impedance of the regular square vibrating surface with the finite baffle, shown in Fig. 2, can be obtained as follows:

$$\frac{Z_\mathrm{b}}{\rho c S} = \frac{jk}{2\pi}\left(\frac{1}{n}\right)^4 \times \left[\sum_{x=1}^{n-1} s_1(n)\, f_1 + \sum_{x=1}^{n=1} s_2(n)\, f_2 + \sum_{y=2}^{n=1}\sum_{x=1}^{y=1} s_3(n)\, f_3\right], \tag{1}$$

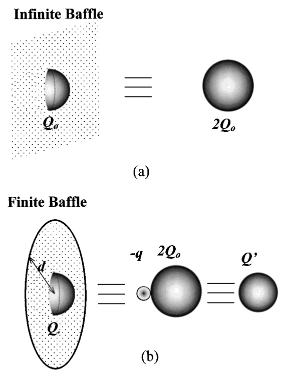

Fig. 1. Equivalent source strength of a point source with finite baffle.

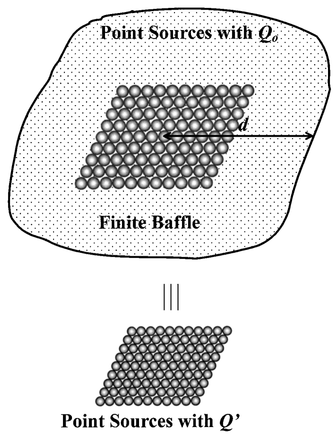

Fig. 2. Equivalent source strength of rectangular piston source with finite baffle.

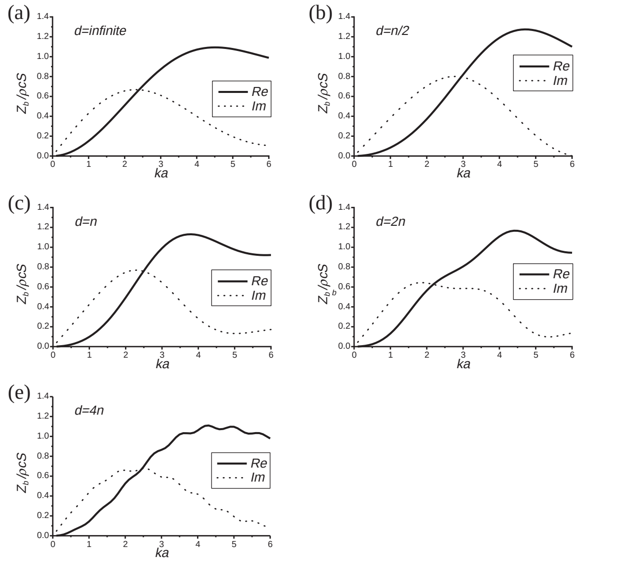

Fig. 3. Effect of baffle size on radiation impedance of rectangular vibrating surface.

where,

$$f_1 = \frac{\exp\left(\dfrac{-jkx\sqrt{2}}{n}\right)}{\dfrac{x\sqrt{2}}{n}} - \frac{\exp\left(\dfrac{-jk(x+d)\sqrt{2}}{n}\right)}{\dfrac{(x+d)\sqrt{2}}{n}},$$

$$f_2 = \frac{\exp\left(\dfrac{-jkx}{n}\right)}{\dfrac{x}{n}} - \frac{\exp\left(\dfrac{-jk(x+d)}{n}\right)}{\dfrac{(x+d)}{n}},$$

$$f_3 = \frac{\exp\left(\dfrac{-jk\sqrt{x^2+y^2}}{n}\right)}{\dfrac{x\sqrt{x^2+y^2}}{n}} - \frac{\exp\left(\dfrac{-jk(\sqrt{x^2+y^2}+d)}{n}\right)}{\dfrac{x\sqrt{x^2+y^2}+d}{n}},$$

$$s_1(n) = \begin{cases} 4(n-2)^2 & 1 \le x \le n-1, \\ 0 & \text{otherwise} \end{cases},$$

$$s_2(n) = \begin{cases} 4(n-2)n & 1 \le x \le n-1, \\ 0 & \text{otherwise} \end{cases},$$

$$s_3(n) = \begin{cases} 8(n-x)(n-y) & 1 \le x \le n-1, \\ & 2 \le y \le n-1, \\ 0 & \text{otherwise} \end{cases} \qquad (2)$$

Here, the average radius d of the baffle is defined as the average distance from each point source to each side of the baffle, and the length a of the side of vibrating surface is 1 for normalization.

To analyze the effect of baffle size on radiation impedance of a rectangular vibrating surface, Fig. 3 shows the calculating results of radiation impedance for various average radii d's. These results were calculated for $n = 200$. The results of radiation impedance for the infinite baffle are shown in Fig. 3(a). In the case where the baffle size is equal to that of the vibrating surface, that is, in the case of no baffle, the radiation impedance is calculated as shown in Fig. 3(b). From this result, in the range of ka less than approximately 3, where the acoustic wavelength radiated from the vibrating surface is longer than twice of the side length a of the surface, the radiation resistance is less than that in the case of an infinite baffle. This means that the acoustic pressure change in front of the vibrating surface is easily cancelled out by the acoustic medium in the lateral side of the surface. However, if ka is more than approximately 3, Fig. 3(b) shows a higher peak value than that shown in Fig. 3(a) because acoustic pressure change according to the vibrating frequency and canceling effect by the acoustic medium have a complicated relationship. If the radiated acoustic wavelength is much shorter than the side length of the vibrating surface, i.e., ka is very large, radiation resistance without a baffle converges into the value for an infinite baffle. Although radiation reactance shows a similar trend, the peak value in Fig. 3(a) lags behind that in Fig. 3(b). Current results show a trend identical to the calculation results of Nimura *et al.*[1] for a circular vibrating surface. The changes in radiation impedance are calculated for various baffle sizes as shown in Figs. 3(c)–3(e). From the results, it is evident that the radiation impedance changes irregularly depending on baffle size and wavelength. Therefore, radiation impedance for a vibrating surface with a finite baffle when d is less than $4a$ cannot approximate that for one with an infinite baffle when ka is less than 6.

In this paper, a regular square vibrating surface with a finite baffle is considered as a set of point sources. The source strengths of the point sources are represented as functions of baffle size. Using the function, the change in the radiation impedance of the vibrating surface can be calculated for various baffle sizes. From the results, it is evident that radiation impedance for a vibrating surface without a baffle is less than that for one with an infinite baffle where the acoustic wavelength is longer than twice that of the side length a of the vibrating surface. However, the radiation impedance for the surface without the baffle has a higher peak value than those in other cases in the given range of ka. When the baffle size is less than 64 times as large as the vibrating surface area, radiation impedance depending on baffle sizes changes markedly for $ka < 6$. Accordingly, if a transducer is designed or analyzed in this case, the radiation impedance should be considered and accurately calculated.

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