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# Reciprocity method in a small acoustic space to measure sound radiation from baffled perforated plates

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**ABSTRACT** – Reciprocity method has been used widely in vibro-acoustics especially to measure sound power from vibrating structures. One existing method is the measurement under a reverberant condition inside a reverberation chamber. This paper discusses the reciprocity method implemented in a small acoustic box rather than using a proper, large acoustic chamber. The result shows the radiation efficiency of perforated baffled plate with different number of holes and different perforation ratios to have good agreement between the measured data and the theory.

## 1. INTRODUCTION

The technique of vibro-acoustic reciprocity was based on the theory proposed by Lyamshev [1] where it is stated that the acoustic pressure at a point B due to a vibrating structure subjected to a harmonic mechanical force at a point A is 'equivalent' through a reciprocity relationship with the situation where the vibration velocity is produced at the point A on the structure due to acoustic excitation by a point source located in fluid at the point B. This is illustrated in Figure 1.

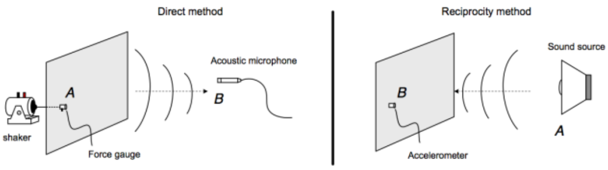



Figure 1 Illustrative diagram of reciprocity method.

From this fundamental theory, several techniques of reciprocity were expanded including to measure noise transmission in an aircraft fuselage [2], to measure sound pressure radiated by a combustion engine [3], to study the tyre induced vehicle interior noise [4] and is also used as noise source characterization [5].

Recently, Squicciarini et. al [6] used reciprocity method in reverberant condition to determine the radiation efficiency of vibrating structures including two components of a railway track test-rig and three different built-up structures. The results using the reciprocity method show good agreement between the direct measurement and those from the finite element model.

In this paper, the same technique in [6] is used, but using a small acoustic chamber and to measure the radiation from baffled plate condition.

## 2. FUNDAMENTAL EQUATION

The radiation efficiency of a vibrating structure can be determined by means of two measurements: an acoustic measurement (radiated sound power) and the spatially-averaged squared velocity representing by the mobility. This is represented by

$$\sigma = \frac{W / \overline{F^2}}{\rho c S \langle | Y_t |^2 \rangle} \tag{1}$$

where $\rho$ is the air density, $c$ is the speed of sound, $S$ is the surface area of the structure and $\langle | Y_t |^2 \rangle$ is the spatially-averaged transfer mobility.

The normalised sound power $W / \overline{F^2}$ can be conventionally measured using the sound intensity probe. However, using the reciprocity technique, this is defined as [6]

$$\frac{W}{\overline{F^2}} = \frac{\overline{a^2}}{< \overline{p^2} >}\left(\frac{\rho}{4\pi c}\right) \tag{2}$$

where $\overline{a^2}$ is the acceleration response of the structure due to acoustic excitation on the plate and $< \overline{p^2} >$ is the spatially-averaged mean-square acoustic pressure in the test room. Using the measured mobility, the radiation efficiency of the plate can then be obtained from Equation (1).

## 3. EXPERIMENTAL SETUP

The measurement for plate mobility was first determined by hanging the plate with soft rope to a rigid frame. A miniature accelerometer was attached to the plate to measure the plate vibration when the plate was excited by an impact hammer at ten locations across the plate surface. The acceleration (converted to velocity) from the accelerometer and the force recorded from the impact hammer were used to obtain the spatially averaged squared mobility as required in Equation (1).

In order to measure the radiated sound power using reciprocity method, the experiment was conducted in a small, fabricated acoustic chamber. The steel chamber is made with non-parallel walls to enhance the development of diffuse field in the chamber for reverberant condition and to fulfill the assumption used in Equation (2). Free-field microphone was used to measure the sound pressure radiated in the small chamber having volume of roughly 0.18 $m^3$ as seen in the Figure 2.

Perforated plates having dimension of 0.3 × 0.2 m and thickness of 1 mm with varying number of holes and diameters were placed in frame where all the edges are rested on soft foam to simulate free-free conditions. The frame was then laid on the top of the chamber, covering the square opening hole from where the sound from the loudspeaker inside the chamber excited the plate. The arrangement is considered baffled condition as the sound excited the plate from one surface only.

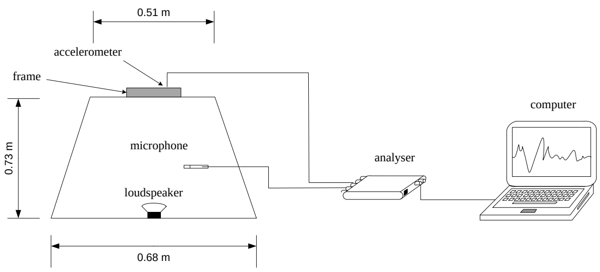



Figure 2. Measurement setup for reciprocity method in a small chamber.

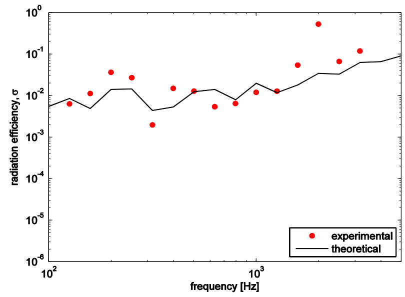
## 4. RESULTS AND DISCUSSION

Figure 3 shows the measured radiation efficiency for perforated plates with number of holes of $N$ = 20 and 34 and perforation ratios of $\tau$ = 20% and 30%. The measured results show the typical trend expected from radiation efficiency and follows that of the theory [7], starting with low value at low frequencies and increases towards the critical frequency.

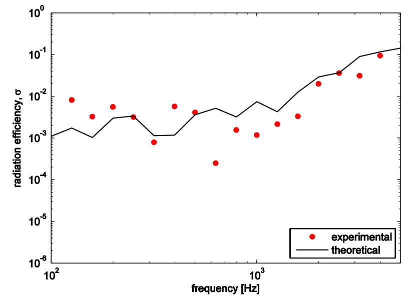
Good agreement with the theory can be seen across the frequency except at several frequency ranges for example around 2 kHz in Figure 3(a) and around 500-800 Hz in Figure 3(b). High possibility of error could come from the acoustic measurement where more sound source locations are required to obtain good 'average' of sound field in the chamber and directivity of excitation incidence on the plate.

## 5. CONCLUSIONS

The reciprocity method has been successfully conducted to measure radiated sound power from perforated baffled plates in a small acoustic chamber. The measured radiation efficiency shows good agreement with the theory. However care should be taken in the future measurement for example by considering several locations of sound source to obtain more representative averaged energy.




(a)




(b)

Figure 3. Radiation efficiency of perforated plate with (a). $N$ = 20, $\tau$ = 20% and (b). $N$ = 34, $\tau$ = 30%.

## 6. ACKNOWLEDGEMENT

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