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Experimental Identification of Input Power to the Plate Using the Transient Structural Intensity Map

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Key Words : Nearfield acoustical holography, transient wave field, structural intensity.

ABSTRACT

Transient acoustic pressure in the near field of an impacted plate carries information that can be utilized for recovering the impact force history. The inverse calculation approach using BEM-based NAH, which is conventionally used for time harmonic excitation, can be applied for reconstructing the transient waves using the principle of Fourier transform and spectral analysis. Then, using the recovered velocity in normal direction of the plate surface, the corresponding structural intensity can be obtained and the identification of input power can be performed. However, several manipulations should be given to overcome numerical artifacts, such as aliasing and erratic oscillation at discontinuity, and to suppress the effect of noise. Experiment using a simply supported plate is presented for demonstration purpose.

1. INTRODUCTION

The measurement of structural intensity offers an insight to understand the vibrational behavior from the exchange of power, flowing through the structure. By knowing the harmonic displacement of the structure, the transmission of structure-borne power flow can be traced [1]. In fact, the method is applicable for the problems involving transient excitation [2]; the reason that makes it an attractive approach because a lot of structures are subject to transient excitations.

By means of inverse calculation scheme known as the nearfield acoustical holography (NAH), the structural intensity can be measured indirectly from the measurement of sound pressure at a very close distance to the surface of the structure [3, 4]. In particular, there are a few methods that can be adopted for transient problems [5-7]. The calculation strategy proposed in this paper is, first, to reconstruct the transient source velocity using NAH based on the inverse boundary element method (BEM) and Fourier analysis; a method that is capable for dealing with complex shaped sound generating structures, as demonstrated in [8]. And, second, to calculate the transient structural intensity using the finite difference scheme. An experiment to identify input power given to a simply supported thin flat plate by impact hammer is presented as a demonstration example.

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2. FORMULATION

Let consider the bending wave is propagating in thin plate. The structural intensity, $\vec{I} = I_x + I_y$, representing the vectorial quantity of the power flux, or the power, Π, per unit cross-sectional area, dA, is defined as,

$$\Pi = \oint_s \vec{I} \cdot \hat{n}\, dA \tag{1}$$

where

$$I_x = \left\langle D\left[\frac{\partial}{\partial x}\left(\nabla^2 w\right)\frac{\partial w}{\partial t} - \left(\frac{\partial^2 w}{\partial x^2} + \upsilon\frac{\partial^2 w}{\partial y^2}\right)\frac{\partial^2 w}{\partial x \partial y} - (1-\upsilon)\frac{\partial^2 w}{\partial x \partial y}\frac{\partial^2 w}{\partial y \partial t}\right]\right\rangle_T \tag{2}$$

Here, w, D, and υ represent the normal surface displacement, bending stiffness, and Poisson ratio, respectively. The formula of I_y can be derived by interchanging the subscripts x and y.

The relation between the spectrums of surface displacement, $W(\omega)$, and sound pressure, $P(\omega)$, can be expressed as,

$$P(\omega) = G_v V(\omega), \quad V(\omega) = j\omega W(\omega) \tag{3}$$

where G_v is the vibro-acoustic transfer matrix given by BEM [9]. Accordingly, the expression,

$$W(\omega) = G_v^{+}\, P(\omega) / j\omega \tag{4}$$

is the inverse formulation for the reconstruction of surface displacement. Here, $[\,]^+$ denotes the pseudo inverse operator. Regularization should be employed to suppress the effect of measurement noise [10]. There are also some problems to be overcome in using the Fourier analysis, i.e., Gibbs phenomenon, spectral leakage, aliasing in time, and aliasing in frequency. Windowing and filtering techniques can be used to cure the problems.

3. MEASUREMENT SETUP

A sheet of flat steel plate of 1 mm thickness was attached to a rigid box using steel frame and bolts, as shown in Fig. 1(a). The size of the plate was 500 mm (w) by 600 mm (l). To condition a simply supported boundary condition, denoted as SSSS, narrow trench of 0.5 mm in depth was grazed around the plate edges. The boundary element (BE) model of the plate was made of 710 linear triangular elements and 357 nodes having the maximum characteristic length of 40 mm. The high frequency limit was about 1.43 kHz, based on the $\lambda/6$-criterion.

The plate was impacted at a point in the middle, 300 mm from the bottom edge, using a hammer (PCB086c03). Then the generated sound pressure was scanned in the nearfield, at 15 mm away from the plate, using a line array of 15 microphones (B&K 4935), to result an equally spaced grid of 195 points. The microphones spacing was 40 mm. A second measurement was conducted using a different boundary condition, named SSSX. The upper side of the frame, portrayed in Fig. 1(b), was removed to introduce friction.

4. EXPERIMENT RESULTS

The sound pressured data collected from the measurement was calibrated and synchronized. Based on this data, the source normal velocity on the plate surface was reconstructed and the transient structural intensity was subsequently computed. Figure 2 shows the map of structural intensity, averaged over a period of 61 ms. For the SSSS plate, a portion of power flows moved from the impact point to the upper side of the plate and the other went to the lower one. Both of the paths were returning back after meeting the boundary and creating four circles at the plate corners. This means that the energy is circulated in the plate and dissipated slowly by internal damping.

For the SSSX plate, the majority of the power flow headed to the upper side of the plate where all the bolts were removed. The plate upper side, which is not actually a free end, provides the friction and air squeezing as sources of structural damping for the energy absorption. In fact, the sound decay rate for SSSX plate is higher than SSSS plate.

The input power, which represents the power accumulated in the control area, was calculated according to Eq. (1) and presented in Fig. 3. As time goes by, the power flows outward and inward the control area, creating the peaks and notches. One can clearly confirm the effect of boundary condition, SSSS and SSSX, in terms of reflection and decay rate. It was found that in the early stage, the energy exchange between the plate and the boundary are nearly the same. But later, with the friction and air squeezing mechanisms, the energy was greatly absorbed in the SSSX case.

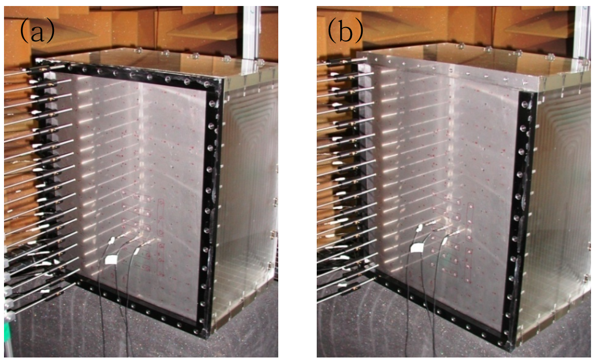

Fig. 1. The arrangement of the plate system and the microphones: (a) SSSS; (b) SSSX.

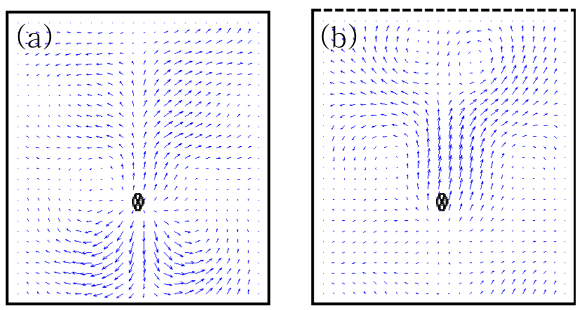

Fig. 2. Structural intensity: (a) SSSS; (b) SSSX.

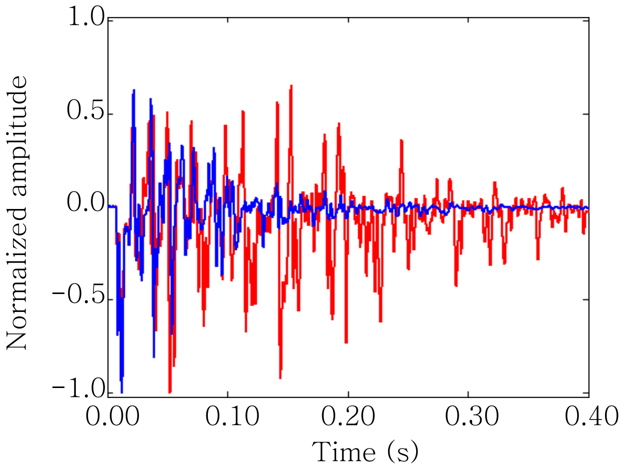

Fig. 3. Input power: (········) SSSS; (———) SSSX.

5. CONCLUSION

The identification of input power to the plate using the transient structural intensity map has been presented. The experiment demonstrated the ability of the method to measure structural intensity and the power flow, which is also able to shows the contribution of boundary condition.

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