한국소음진동공학회 2013년 추계학술대회논문집, pp. 389~390

EVALUATION OF DIRECTIVITY PATTERNS IN FLOOR IMPACT SOUNDS BY USING NEARFIELD ACOUSTIC HOLOGRAPHY (NAH)

Muhammad Imran† · Jae Ho Kim * · Jin Yong Jeon**

1. Introduction

Prior to the selection and design of control measures, noise sources must be identified and must be carefully evaluated. To adequately define the noise problem, the following factors should be considered

o Type of noise
o Noise levels and temporal pattern
o Frequency distribution
o Noise sources (location, power, and directivity)
o Noise propagation pathways, through air or through structure

Noise levels should be evaluated at locations occupied by personnel's ears. Any noise problem may be described in terms of a source, a transmission path and a receiver. The noise source is where the vibratory mechanical energy originates, such as mechanical shock, impacts, friction or turbulent airflow. In fact, there may be a multiplicity of paths, both in air and in solid structures. The total path, which contains all possible avenues along which noise may reach the ear, has to be considered. The complete directivity pattern around the residential room was investigated by performing emission measurements inside the room. Furthermore, the dominant sound source is taken as impact source. From a field study it was found that there was a distinguishable directivity of the sound.

1.1 Directivity of sound

The directivity of sound means that the sound level emitted from a source varies in strength depending on the different directions from the sound source. Thus, the sound has a directional component and consequently a sound source can be considered as Omni-directional or directional. If the sound is directional, the strength of the noise level may vary in different directions from the sound source, this can be represented as a pattern of sound radiation, also called the directivity of the sound.

1.2 Nearfield acoustic holography (NAH)

The basis of NAH lies in the assumption that a two-dimensional surface of pressure measurements satisfies the homogeneous acoustic wave equation in the region exterior to the sources, given by

$$\nabla^2 P(r) + k^2 P(r) = 0 \qquad (1)$$

where **k** is the wavenumber and **r** is the desired point (**x,y,z**) of projection. The solution to Eq.(1) can be expressed as the convolution integral

$$P(r) = \iint_S P(r') G_D(z - z')\, dxdy \qquad (2)$$

where G_D is a Green's Function specific to the geometry of the two-dimensional surface and r'=(x',y',z') at the measurement position. The Green's Function describes the manner in which acoustic waves propagate from the sound source(s). Since Eq.(2) is in the form of a convolution, a two-dimensional FFT can be utilized to evaluate it efficiently in the wavenumber domain.

With P(r), one can determine the acoustic particle velocity, U, by considering Newton's law for fluids in terms of the pressure gradient

$$U = \frac{-j}{\rho_0 \omega} \nabla P \qquad (3)$$

where ρ_o is the density of the acoustic medium and ω is the frequency of interest. This calculation is also performed in the wavenumber domain as a simple multiplication and inverse Fourier Transformed into the spatial domain. Once both the sound pressure and particle velocity have been determined on a desired surface, the second order acoustic quantities such as sound intensity and sound power may be calculated. Practically, to implement an NAH algorithm, a two-dimensional FFT is employed to transform each partial pressure field into the wavenumber domain, where the partial pressure fields can be calculated on the desired plane from

$$p(k_x, k_y, z) = \frac{p(k_x, k_y, z')}{e^{-jk_z(z-z')}} \qquad (4)$$

and the acoustic particle velocity from

$$u_\eta(k_x, k_y, z) = \frac{1}{\rho_o c} \frac{p(k_x, k_y, z')\left[\frac{k_\eta}{k}\right]}{e^{-jk_z(z-z')}} \qquad (5)$$

Applying a 2-D inverse FFT, the acoustic quantities are transformed back into the spatial domain at the desired plane exterior to the sources. Sound intensity can be computed from

$$I(x, y, z) = \frac{1}{2}[p(x, y, z)u^*(x, y, z)] \qquad (6)$$

where the real part of I, is the active intensity and the imaginary part is the reactive intensity.

2. Methods

The ultimate goal of any technique is to accurately project the sound origin on an image of the test object. The sound source is represented as a red spot as shown in Fig. 1.

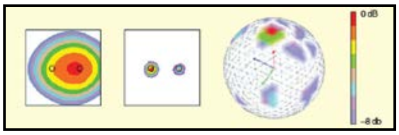

Figure 1 Spatial resolution and dynamic range

Spatial resolution is the ability to separate two sound sources. It is expressed in centimeters. It represents the closest distance between two sources, where they still appear separately and do not merge into a single source. Near-field acoustic holography (NAH) is a technique where the microphone array is placed relatively close to the sound source. It provides good results over the entire frequency range. The near field can be described as the area that is closer to the sound source than one or two wavelengths of the highest frequency. NAH measures sound pressure by arranging several microphones in a rectangular planar array. Microphones are regularly spaced both horizontally and vertically. The sound pressure in the plane is then back-propagated to the actual surface of the object. The spacing between the microphones determines the half-wavelength of the maximum frequency, and the size of the array determines the half wavelength of the minimum frequency. The spacing also determines the spatial resolution.

In the near field, NAH helps analyze impulsive impact on floor. An impact source is used to generate vibration. An array is then placed in the near field on the floor. In this case, the array has a microphone spacing of 8 cm, resulting in a 216 by 48 cm hologram. This limits the maximum frequency to 2140 Hz. NAH is best suited for this analysis. It offers the required spatial resolution at the low frequency of 512 Hz.

3. Discussion and Conclusions

NAH requires a rectangular array with evenly spaced microphones, both horizontally and vertically. However, NAH cannot be performed with a beamforming array, because it is not rectangular and it has a pseudo-random microphone distribution. This paper covers the sound source localization techniques commonly available today. Selecting the proper sound source localization technique is a task that needs to take into account the frequency range of interest, distance measured to the source, physical properties of the sound source, and its operational conditions. NAH shows a clear advantage, since it measures in the near field giving the best spatial resolution and dynamic range over a wide frequency range.