Nearfield Acoustical Holography

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Abstract Nearfield acoustical holography (NAH) is a method by which a set of acoustic pressure measurements at points located on a specific surface (called a hologram) can be used to image sources on vibrating surfaces on the acoustic field in three-dimensional space. NAH data are processed to take advantage of the evanescent wavefield to image sources that are separated less that one-eighth of a wavelength.

1 • Introduction

Acoustical holography is a process by which the measurement of the pressure at a set of points on a surface in the vicinity of an acoustically radiating object is analyzed to yield the velocity vector field, the acoustic pressure, and the acoustic intensity map in three-dimensional space. If the measurement points are recorded on a surface that is located at a distance of at least one acoustic wavelength from the actively vibrating surface, then processing these data results in an acoustic image that can only resolve sources that are separated by at least one acoustic wavelength. However, if the measurement points are taken in the nearfield of the source region, then the spatial resolution can be reduced to a fraction of a wavelength, resulting in what is known as nearfield acoustical holography (NAH). The measurement
surface is termed the hologram surface and the area subtending these points constitute the aperture. These measured pressures are then processed by using backward propagators to image the structure’s surface pressure as well as the vector velocity and intensity fields. In addition, using forward propagators can image the acoustical field in 3D in the region outside the hologram surface and the source area. The need for a nearfield measurement, well within an acoustical wavelength, ensures that sources which are separated less than one wavelength can be resolved [1–7]. If the measurement hologram plane is located outside one wavelength, the only sources that are separated by one or more wavelengths can be resolved [8].

The imaging of the vector velocity and pressure field starts with recording the acoustic pressure amplitude and phase over an enclosing surface. These are filtered, digitized, and processed to compute the pressure, the velocity vector, and the vector intensity fields on the surface of the vibrator or at any point in 3D space enclosing the vibrating structure.

2 • Planar Nearfield Acoustical Holography

Planar nearfield acoustical holography is a method of imaging the source field of a planar or near planar vibrating structure and the 3D half-space in front of the structure. The hologram is thus a plane of measurement points.

2.1 Imaging Analysis

The imaging analysis requires the use of Fast Fourier Transform (FFT) techniques on the measured acoustic pressure hologram. Defining the Fourier transform integrals as

\[
\tilde{u}(k_x, k_y) = \frac{1}{2\pi} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} u(x, y) e^{-i(k_x x + k_y y)} \, dx \, dy,
\]

\[
u(x, y) = \frac{1}{2\pi} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \tilde{u}(k_x, k_y) e^{i(k_x x + k_y y)} \, dk_x \, dk_y,
\]

then the transform of the wave equation on the acoustic pressure \(p(x, y, z)\) is

\[
\frac{d^2\tilde{p}}{dz^2} + k_z^2 \tilde{p} = 0, \text{ where } k_z^2 = k^2 - k_r^2, k_z = k_x + k_y,
\]

where the \(e^{-i\omega t}\) factor has been omitted. For outgoing waves in \(z\),

\[
\tilde{p} = Ae^{ik_z z},
\]

where

\[
k_z = \sqrt{k^2 - k_r^2} \text{ if } k^2 > k_r^2 \text{ and } k_z = i\sqrt{k_r^2 - k^2} \text{ if } k^2 < k_r^2
\]