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Reconstruction of instantaneous surface normal velocity of a vibrating structure using interpolated time-domain equivalent source method

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ABSTRACT

Interpolated time-domain equivalent source method is extended to reconstruct the instantaneous surface normal velocity of a vibrating structure by using the time-evolving particle velocity as the input, which provides a non-contact way to overall understand the instantaneous vibration behavior of the structure. In this method, the time-evolving particle velocity in the near field is first modeled by a set of equivalent sources positioned inside the vibrating structure, and then the integrals of equivalent source strengths are solved by an iterative solving process and are further used to calculate the instantaneous surface normal velocity. An experiment of a semi-cylindrical steel plate impacted by a steel ball is investigated to examine the ability of the extended method, where the time-evolving normal particle velocity and pressure on the hologram surface measured by a Microflown pressure-velocity probe are used as the inputs of the extended method and the method based on pressure measurements, respectively, and the instantaneous surface normal velocity of the plate measured by a laser Doppler vibrometry is used as the reference for comparison. The experimental results demonstrate that the extended method is a powerful tool to visualize the instantaneous surface normal velocity of a vibrating structure in both time and space domains and can obtain more accurate results than that of the method based on pressure measurements.

1. Introduction

Measurement of structural vibration is of importance to study the vibration characteristics of an excited structure, and it provides important data support for force source identification and fault diagnosis of industrial equipments. Nearfield acoustic holography (NAH) [1–5] is one of the popular methods to measure the vibration information of a structure due to its characteristic of non-contact measurement. By measuring the acoustic quantities radiated by the structure in the sound field, the vibration information on the structural surface can be reconstructed by NAH. Compared to the laser Doppler vibrometry (LDV), NAH can avoid the optical requirements in LDV by measuring the easily available acoustic quantities. However, the conventional NAH often focuses on the stationary vibration and only provides the reconstructed results in the frequency domain.

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In order to reconstruct the instantaneous sound fields whose statistical quantities change with time, several time-domain NAH techniques, such as time domain acoustical holography based on the Fourier transform [6] and Laplace transform [7,8], real-time nearfield acoustic holography (RT-NAH) [9–11], time-domain plane wave superposition method (TD-PWSM) [12,13], transient Helmholtz equation least squares method (THELSM) [14,15], time-domain near-field equivalence source imaging technique [16,17], time-domain boundary element method [18,19] and time-domain equivalent source method (TD-ESM) [20–24], have been developed. Among them, the time domain acoustical holography based on Laplace transform [8], RT-NAH [11] and TD-PWSM [13] have been used to reconstruct the surface normal velocity or acceleration on a planar structure, and the THELSM has been used to reconstruct the surface normal velocity of a vibrating sphere [14]. However, the reconstruction of the instantaneous vibration on an arbitrarily-shaped structure is still not involved.

TD-ESM [25,26] has the ability to deal with arbitrarily-shaped structures. In the method, the time-evolving acoustic quantities in the sound field are expressed as the superposition of time-domain convolutions between the equivalent source strengths and the corresponding Green's functions, and the equivalent source strengths are used as the intermediate quantity to relate these acoustic quantities. By making significant improvements on numerical algorithms of TD-ESM, Lee et al. [27,28] further developed the interpolated TD-ESM, and this interpolated TD-ESM has been employed to reconstruct the transient pressure field generated by a static source in free space [20,21] and half space [22,23] and to locate and quantify rotating sound sources [24].

However, the interpolated TD-ESM is only used to reconstruct the time-evolving pressure in the sound field, and the input quantity is also the pressure. In recent years, a pressure-velocity (p-u) probe produced by Microflown Technologies has been successfully used to measure the particle velocity in the sound field [29], and it has been found that the NAH based on particle velocity measurements is less sensitive to measurement errors than that based on pressure measurements. Especially, in the reconstruction of the surface normal velocity at one frequency, the NAH with the particle velocity as the input can provide higher reconstruction accuracy than that with the pressure as the input [4,5,30]. Inspired by that, in the present paper, the interpolated TD-ESM is further extended to reconstruct the instantaneous surface normal velocity of a vibrating structure by using the time-evolving normal particle velocity as the input, and its advantage is to be proven by comparing with the method using the time-evolving pressure as the input.

This paper is organized as follows. In Section 2, the theories for reconstructing the instantaneous surface normal velocity of a structure using the interpolated TD-ESM based on particle velocity measurements and pressure measurements are to be introduced. Section 3 presents an experiment of a semi-cylindrical impacted steel plate to evaluate the feasibility of the extended method and show its advantage in comparison to the method based pressure measurements. Finally, conclusions are drawn in Section 4.

2. Theoretical background

Fig. 1 shows the position relations of the structural surface *S*, the hologram surface *H* and the equivalent source surface *E*. According to the TD-ESM, the time-evolving acoustic quantities can be expressed as the superposition of time-domain convolutions between the equivalent source strengths and the corresponding Green's functions. Suppose that there are *L* points, *M* measurement points and *K* equivalent sources distributing on the surfaces *S*, *H* and *E*, respectively, the time-evolving pres-

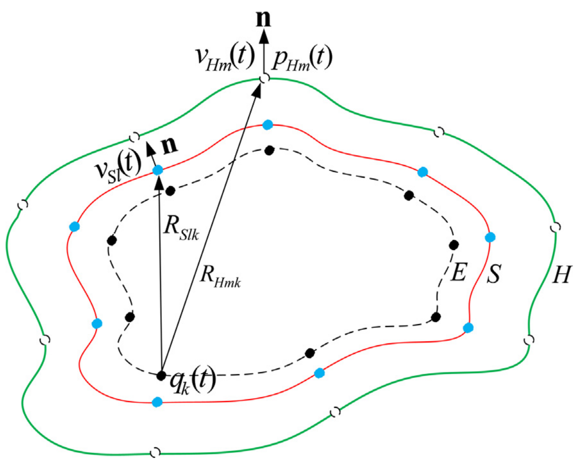

Fig. 1. Position relations of the structural surface *S*, the hologram surface *H* and the equivalent source surface *E*. $p_{Hm}(t)$ and $v_{Hm}(t)$ denote the time-evolving pressure and normal particle velocity at the *m*th measurement point on the hologram surface *H* at any time *t*, respectively, $v_{Sl}(t)$ is the time-evolving surface normal velocity at the *l*th point on the structural surface *S* at any time *t*, $q_k(t)$ denotes the *k*th equivalent source strength at time *t*, R_{Hmk} (or R_{Slk}) denotes the distance between the *k*th equivalent source and the *m*th measurement point on the surface *H* (or the *l*th point on the surface *S*).