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Laser Doppler vibrometry and near-field acoustic holography: Different approaches for surface velocity distribution measurements

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Abstract

Nowadays there are several direct or indirect measurement methods for the determination of the surface velocity in vibrating structures, but two of them seem to be the most promising and interesting, in particular for vibro-acoustic problems: laser Doppler vibrometry (LDV) and near-field acoustic holography (NAH). While LDV is a direct laser-based vibration measurement technique, NAH allows the determination of the particle surface velocity starting from simultaneous microphone measurements performed on a plane array positioned near the vibrating object, although with some limitations. In this work the two structural and acoustic techniques are compared on a simple laboratory case, specifically a plate, in order to carefully and quantitatively assess the measurement uncertainty in the indirect NAH method used to estimate the vibration velocity. Advantages and disadvantages of the two methods are discussed briefly. This study was conducted within the European Growth Project "ACES" (Optimal Acoustic Equivalent Source Descriptors for Automotive Noise Problems) GRD1-1999-11202.

Keywords: Vibration; Laser doppler vibrometry; Near-field acoustic holography

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1. Introduction

In many industrial and mechanical acoustic applications the determination and localisation of noise sources is of fundamental importance, for both noise reduction and diagnostic purposes [1–3]. However, noise source location performed with traditional acoustic methods (like intensity measurement) can often be an intricate task, for example in the low-frequency range, where the sources may show a reduced directivity. In these cases it can be very useful the direct measurement of the vibration velocity of the structure surface.

Near-field acoustic holography (NAH, [4–6]) allows the determination of the acoustic field in the 3-D space surrounding a vibrating object, starting from simultaneous microphone measurements performed on a plane array. Among the different acoustic quantities, also the particle velocity in correspondence of the structure surface can be computed, which can be of great help in the localisation of the areas subjected to higher

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vibration amplitudes, i.e. hot spots. Nevertheless, the accuracy in the determination of this velocity component may decrease in particular cases, e.g. when dealing with objects of complicated shape or with several non-correlated sources. Because of that, the possibility of measuring the vibration velocity with high accuracy using an independent mean can be of great interest for the validation of the NAH technique.

The measurement of the superficial vibration for such a validation should satisfy the following metrological requirements:

- capability of determining the velocity of vibration quantitatively (and not the displacement or the acceleration);
- measurement uncertainty below 2–3%;
- frequency range up to 5000 Hz;
- capability of measuring vibration mode shapes with sufficient sampling speed, in order to have the possibility of performing validation in several case studies for industrial applications;
- capability of measuring on objects with complex shapes;
- capability of determining the velocity component.

In [7] it was shown that scanning laser Doppler vibrometry (SLDV) can be suitably used for this task, as it satisfies the required metrological properties. A SLDV is an instrument consisting of two main parts: a single-point laser vibrometer (which measures the point velocity by exploiting the Doppler effect) and a scanning system that allows the laser beam to move over different points on the measurement grid defined over the object surface. With this arrangement the scans over even large vibrating surfaces become fast and easy to control. In addition to its fastness for the determination of the whole velocity field, the scanning vibrometry configuration is the most suited one, as it provides an accurate knowledge of the measured velocity component. In [7] a complex demonstration case study (a muffler) was approached, but only from a qualitative point of view: the vibration velocity maps were extracted from LDV measurements, while particle velocity maps were computed by NAH on a plane tangential to the muffler surface. Then a visual comparison was performed for each vibration mode. In theory, the two extracted quantities should be proportional and thus also their spatial distribution should be very similar, even if some differences can be expected, in particular for complex vibrations.

In the present work the same approach was used, but the comparison has been performed on a simpler object (a plate). In this case, the correspondence between air particle velocity, calculated by NAH, and surface vibration velocity, measured by SLDV, will be relevant. Therefore, a numerical correlation procedure has been applied in order to provide a more precise evaluation of uncertainty in NAH results.

It should be pointed out that, by considering the structural vibration measurements as reference, the comparison is done between the actual surface vibration velocity and the estimation of the air particle velocity over the object surface, calculated from the acoustic pressure measured in the near field. Only when a large amount of acoustic energy is radiated in the medium around the object, the exact surface vibration can be reconstructed from the acoustic signals measured at the receiver microphones. This situation is realized only if the spatial wavelength of the vibration is larger than the acoustic wavelength in the medium (i.e. slow spatial variation of the surface vibration).

In this paper the STSF (Spatial Transformation of Sound Fields [8,9]) technique from Brüel & Kjær is employed which applies NAH to determine the acoustic field from measurements performed simultaneously over a plane array of microphones.

2. Experimental set-up

The object under test, chosen for the comparison between NAH and LDV results is a simple rectangular steel plate with the dimension $0.6 \times 0.4 \times 0.003$ m. The measurement set-up is shown in Fig. 1. The plate was mounted on a supporting frame by means of elastic bands to realise a free–free constraint condition. The plate was excited with white noise in the frequency range between 20 Hz and 20 kHz by an electro-dynamic shaker which was connected through a screw to the rear right part of the plate.