Characterization of a dipole radiation by Laser Doppler Velocimetry

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Introduction

Characterization of near field radiation of complex structures needs to measure acoustic pressure and acoustic velocity in the vicinity of the structure. Usually, techniques such as acoustic intensimetry or holography are used. These methods are well known and used for industrial applications. However, in case of near field measurements, the probe (microphones) modifies the radiated field especially in the vicinity of the structure.
Laser Doppler Velocimetry (LDV) is an optical technique which enables to measure fluid velocities using tracers suspended in the fluid. This technique is currently used for fluid mechanics [1] and has been developed for measuring acoustic velocities ([3], [4]). Results presented in literature show that it is possible to estimate acoustic velocity amplitude greater than $1mm/s$ up to $2kHz$.

The aim of this work is to study the feasibility of the acoustic particle velocity measurement in the near field of a simple structure. The structure is a dipole of which the acoustic near field shows acoustic short circuit. The principle of the study consists by comparing the acoustic velocity calculated with a radiation model to the velocity measured by means of LDV.

First part of this work recalls briefly the LDV principle. Second part presents the radiation model used for estimating the reference velocity. Third and fourth parts present respectively the experimental set-up and the results.

Principles of LDV

Laser Doppler Velocimetry is a technique for punctual measurement of the velocity of microparticles travelling within a fluid at the local velocity of that fluid. Its principle is based on the determination of the Doppler shift of light scattered from these seeding particles. Two laser beam of equal intensity are focussed and crossed at the point under investigation, forming an ellipsoïdal volume consisting of equidistant dark and brigth fringes called probe volume [1].

The scattered light by the particle is making up an optical signal whose intensity is modulated at the Doppler frequency f_D related to the velocity of the particle v_p. The scattered light is collected on a photomultiplier (PM) whose output signal is sampled and processed in order to estimate the velocity particle parameters.

Acoustic radiation model

Pressure

The aim of this part is to calculate the acoustic velocity in the vicinity of the dipole using an analytical model. The acoustic field is produced in a half space by two pistons moving in opposite phase and with the same amplitude. This system is mounted in an infinite baffle. In this configuration, for a harmonic excitation, the pressure radiated by the dipole at the position $\vec{r}$ can be calculated with the Rayleigh integral :

$$p_1(\vec{r}) = jk_0\rho_0 c_0 v_p \left[\int_{S_1} \frac{e^{-jk_0|\vec{r}-\vec{r_1}|}}{2\pi|\vec{r}-\vec{r_1}|} dS_1 - \int_{S_2} \frac{e^{-jk_0|\vec{r}-\vec{r_2}|}}{2\pi|\vec{r}-\vec{r_2}|} dS_2 \right] \quad (1)$$

where k_0 is the wavenumber, ρ_0 the air density, c_0 the sound speed, v_p the piston velocity. $\vec{r}_1$ and $\vec{r}_2$ are the elementary source position.

In the far field, this expression can be simplified

$$p_2(\vec{r}) = -k_0^2 \rho_0 c_0 (1 + \frac{1}{jk_0 r}) \frac{e^{-jkr}}{4\pi r} Q_0 \frac{\vec{r}}{r} \vec{r}_0 \quad (2)$$

where Q_0 is the volume velocity of each monopole and $|\vec{r_0}|$ the distance between the two monopoles [2].

Velocity

The acoustic velocity can be calculated in the far field using the Euler equation :

$$\begin{cases} v_R &= -k_0^2 M_0 (1 + \frac{2}{jk_0 r} - \frac{2}{k_0^2 r^2}) \frac{e^{jkr}}{4\pi r} \cos\theta, \\ v_\theta &= jk_0 M_0 (1 + \frac{1}{jk_0 r}) \frac{e^{jkr}}{4\pi r} \sin\theta, \end{cases} \quad (3)$$

where $\vec{M}_0 = Q_0 \vec{r}_0$ is the acoustic momentum and $\cos\theta = \frac{\vec{r}.\vec{r}_0}{r r_0}$.
The acoustic velocity is calculated in the near field by means of equation (1) and using a spatial finite difference technique. Figure (1) shows an example of the acoustic velocity field in the near field.

Experimental set-up

The LDV device used in this study is a dual beam system operating in the differential Doppler mode. The back scattering mode (optical set-up and PM are located on the same side) is chosen to permit the velocity measurement near walls. Only one velocity component is measured.

For the experiments presented in this paper, the acoustic dipole is formed by two loudspeakers enclosed in a cavity.

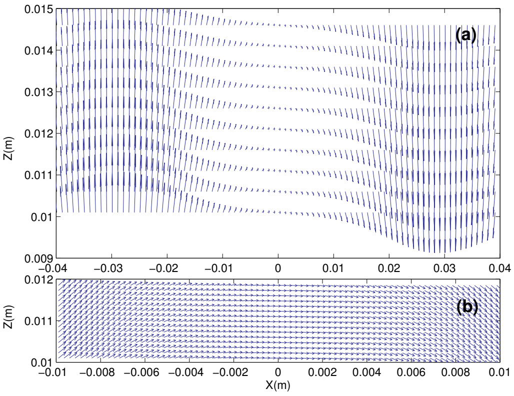

Figure 1: Calculated acoustic velocity field for a dipole centered on $(0, 0)$ ($r_0 = 6$ cm, piston diameter 2 cm). Figure (b) is a view between $x = [-1, 1]$ cm and $z = [1, 1.2]$ cm of the velocity field.

Both loudspeakers are excited by a sinusoïdal signal with a phase difference of π. The two monopole volume velocity amplitudes are adjust using a microphone mounted inside the cavity, the pressure in the cavity being minimum when the two monopole radiate in opposite phase. The dipole is embedded in a table to avoid any diffraction on the boundaries. The experiments are conducted in a semi-anechoïc room (see figure 2).

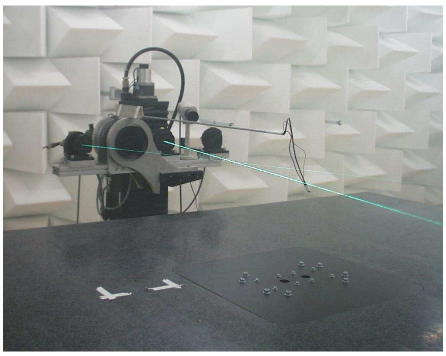

Figure 2: View of the experiment.

Results

The radiated pressure and velocity are measured along the dipole axis (x axis) in the near field ($z = 5$ mm). The excitation frequency is 500 Hz.

Acoustic pressure measurement

The aim of this part is to estimate the acoustic momentum $\vec{M}_0$ generated by the dipole. The experimental results and the calculated results are fitted in order to estimate the momentum using a least mean square method. The measured pressure radiated by the dipole is shown in figure (3).

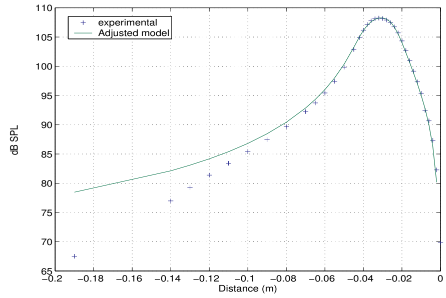

Figure 3: Acoustic pressure radiated by the dipole.

Figure (3) shows that the model is in good agreement with experiment results for near field (x included $[-8, 8]$ cm). For $|x|$ greated than 8 cm, the experimental conditions (finite dimension of the table) do not respect model hypothesis. Nevertheless, assuming that the dipole distance spacing $\vec{r}_0$ is known, the dipole momentum is calculated by extimating the volume velocity Q_0.

Acoustic velocity measurements

Figure (4) shows the projection of the measured and calculated acoustic velocities on the x axis. The analytical model uses the volume velocity estimated with the pressure measurement (previous section).

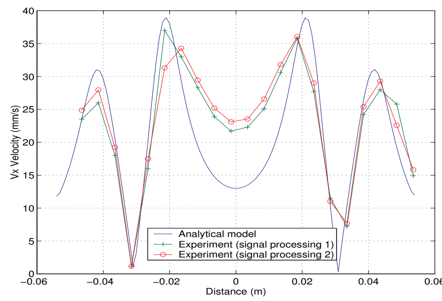

Figure 4: Projection on x-axis of the acoustic velocity along the dipole axis.

These results show a good agreement between experimental and calculated data except for $|x| < 1.5$ cm. For this region, the low values of acoustic pressure amplitude lead to a great uncertainty in the velocity calculation (estimation of the gradient in the Euler equation).

References

[1] H.-E. Albrecht, N. Damaschke, M. Borys, C. Tropea. Laser Doppler and Phase Doppler Measurement Techniques. Springer Verlag, 2003.

[2] M. Bruneau. Manuel d'Acoustique Fondamentale. Hermès, Paris, 1998.

[3] J. C. Valière, P. Herzog, V. Valeau, G. Tournois. Acoustic velocity measurements in the air by means of Laser Doppler Velocimetry : dynamic and frequency range limitations and signal processing improvements. Journal of Sound and Vibration, 229(3), 607-626, 2000.

[4] J. S. Cullen, C. A. Greated and D. M. Campbell. LDA measurement of sound: amplitude modulation of laser Doppler signals. Meas. Sci. Technol. 10, pp. 812-823 (1999).