Optical Techniques for Sound Generation and Detection in Acoustic Resonators

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Abstract. The most reliable method for sound speed measurement in gases is based on the use of acoustical resonators. The measurement consists in the determination of the resonance frequencies of the cavity, in the presence of a stationary acoustic field. Usually, the source and the receiver are condenser microphones. In this paper it is proved that it is possible to generate the acoustical field through a photoacoustic effect on the interior surface of the resonator. Moreover, it is also shown that sound can be generated by a silicon micromembrane facing the cavity, optically excited at the rear side. An effort is being made to investigate the possibility to substitute also the receiving transducer with an optical detection scheme, based on laser beam deflection.

INTRODUCTION

Speed of sound in pure fluids and mixtures is a characteristic and important physical property which depends on several intensive thermodynamic properties. This fact indicates that experimental evaluation of speed of sound can be used to determine several fundamental thermophysical properties and is the basic reason of the increasing interest in these acoustic measurements. Different experimental techniques have been developed in order to achieve determinations of increasing precision. The most accurate method has been proved to be based on the use of resonant cavities of constant volume. Even if the spherical enclosure allows to get the highest precision (1), cylindrical resonators are also largely used, especially for routine gas characterisation in consideration of less critical constructive problems.

The basic principle of the measurement is the determination of a number of resonance frequencies in the cavity, in presence of a stationary acoustic field. In general, the sound is generated and detected by means of electroacoustic transducers, typically condenser microphones. The main limit of these transducers is their incapability to be used in hostile environment, like when the gas filling the resonator is corrosive or the temperature reaches extreme values. So there is an increasing interest to overcome these limits in the use of resonators, and an attractive approach seems to be the development of remote optical techniques for sound generation and detection. In this paper it is shown that it is possible to generate the acoustical field through the photoacoustic effect, directly on the interior surface of the resonator, or on a silicon micromembrane facing the cavity, optically excited at the rear side. The sound detection looks much more critical, owing to the high sensitivity and low signal-to-noise ratio required. A candidate technique could be the “optical beam deflection”, which has proved as a simple and reliable method for the detection of small surface displacements, in the fields of photothermal spectroscopy and atomic force microscopy. This could be applied to a membrane facing the sound field inside the resonator.

EXPERIMENT AND RESULTS

Measurements have been performed in a gastight, stainless steel, cylindrical resonator, ~ 90 mm in diameter and length. A schematic representation of the optical path is shown in Fig. 1. An amplitude modulated laser beam (Ar+, 514 nm) enters into the cavity through an optical glass window and impinges over a black-painted point on the interior resonator surface. Conventional lock-in detection of the receiving microphone signal and measurement procedures are adopted (2).

The sound production mechanism is that typical of photoacoustic effect in solids. The illuminated spot on the resonator surface is heated and there is a periodic heat transfer to the gas filling the resonator. Only a thin layer of gas adjacent to the solid surface responds thermally to the periodic heat flow and can be regarded as a vibrating piston creating the acoustic signal detected in the cavity.

Fig. 2 shows the experimentally determined dependence on incident power of the amplitude of the first pure radial mode (001), when the resonator is filled with argon at 100 kPa near ambient temperature; the photoacoustic source efficiency shows its linearity over nearly one order of magnitude.
Resonances were recorded sweeping the modulation frequency through the resonance frequency $f_N$ at 11 discrete points in steps of $g_N/5$, where $g_N$ is the resonance half-width. At each frequency, the in-phase and quadrature voltages produced by the detector were measured. The 11 frequencies and 22 voltages were fit with a complex function with 8 parameters (3). As an example, Fig. 3a reports the resonance curves of a cavity normal mode generated by a 3mm photoacoustical source. Fig. 3b shows the corresponding normalised amplitude deviations for the same mode; the achieved precision is good enough to meet high accuracy applications. Qualitatively similar results have been obtained by illuminating at the rear side a micromachined silicon membrane, 20 μm thick, 1x1 mm$^2$ wide, facing the cavity.

The advantage of this type of source is not to have any spurious light inside the resonator, so diminishing the effect of coherent photoacoustic noise and increasing the signal stability.

An effort is being made to investigate the possibility to substitute also the receiving transducer with an optical detection scheme. In principle, it is possible to measure the dynamic deformation of a membrane facing the resonator cavity by means of an optical beam deflection method (4). A weak probe He-Ne laser is incident on the membrane, normal to its plane and forming a given angle with the perpendicular to the membrane; the beam is reflected on a position-sensitive detector. The position of beam on the detector being determined by the membrane movement gives a signal proportional to the amplitude of its displacement, i.e. to the acoustic pressure inside the cavity.

The results show that photoacoustic effect in solids is a valid method for the generation of the sound field in a resonator. Further work will be done to substitute also the receiving microphone.

REFERENCES