THE MICROFLOWN: AN ACOUSTIC PARTICLE VELOCITY SENSOR

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ABSTRACT: The Microflown is an acoustic sensor directly measuring particle velocity instead of sound pressure, which is usually measured by conventional microphones. Since its invention in 1994 it is mostly used for measurement purposes (broadband 1D and 3D-sound intensity measurement and acoustic impedance). Possible applications are near and far field sound source localization, in-situ acoustic impedance determination and a non-contact method to measure structural vibrations (an alternative for a laser vibrometer). The Microflown, invented only a few years ago, is now commercially available.

1. INTRODUCTION

The search for a reliable particle velocity sensor started about a century ago. These sensors were based on the (single) hot wire anemometer concept. The single hot wire however is not linear, not very sensitive and not very directional [1].

A particle velocity sensor known as the Microflown was invented at the University of Twente in 1994 [2–4]. At first research efforts were aimed at finding construction and calibration methods. Later co-operation with several science groups and industry was established to find applications [5–7]. A few years after its invention, the Microflown became commercially available [11].

2. THE MICROFLOWN SENSOR

The Microflown sensor consists of two closely spaced heated wires. The length of the wires is 1mm, the width is 5mm and the thickness is 200nm platinum, see Fig. 1.

The temperature sensors of the Microflown are implemented as platinum resistors and are heated by an electrical power. An increase of the temperature of the sensors leads to an increase of the resistance as well because of the temperature dependence of their resistance [8,9]. The temperature difference of the two sensors quantifies the particle velocity in a linear manner.

Due to the construction method, micro-mechanics, the sensors are very robust. An assembled ½″ probe (see Fig. 3) for example is much more robust than a regular ½″ pressure microphone.

If no particle velocity is present the sensors have a typical operational temperature of about 300°C. When particle velocity is present, it alters asymmetrically the temperature distribution.

Due to the operation principle based on the asymmetry of the temperature profile the Microflown can distinguish between positive and negative velocity direction.

There are three types of Microflown sensor elements, the Atlas, the Io and the Titan. The Titan element is optimised for higher frequencies than the Io element, see Fig 5. The Atlas is an element designed for low frequency, infrasonic applications.

Frequency response

The sensitivity of the Microflown decreases at higher frequencies. The first high-frequency roll-off is caused by diffusion effects which can be estimated by a first order low pass frequency response that has a (diffusion or thermal lag) corner frequency (f_d). The second high frequency roll-off is related to the heat capacity (thermal mass or thermal inertia). It shows an exact first order low pass behaviour that has a heat capacity corner frequency ($f_{heat\,cap}$).

The frequency response of a Microflown can be approximated by:

$$output = \frac{LFS}{\sqrt{1+f^2/f_{heatcap}^2}\sqrt{1+f^2/f_d^2}} \qquad (1)$$

LFS being the low frequency sensitivity, the output signal at frequencies below the thermal diffusion corner frequency.

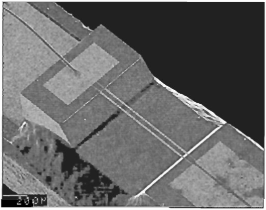

Fig. 1: SEM photo of a Microflown.

The phase response of a Microflown can be modelled by a similar double low pass system:

$$phase = K_1 \tan^{-1}\frac{f}{C_1} + K_2 \tan^{-1}\frac{f}{C_2} \qquad (2)$$

K and C being constants.

Amplitude and phase correction

There are three possibilities to correct for the amplitude and phase response. A dedicated preamplifier can correct both phase and amplitude response (A&P preamplifier). An analyser can be programmed in such way that the response is corrected [11]. It is also possible to store the uncorrected values and post-process the data afterwards.

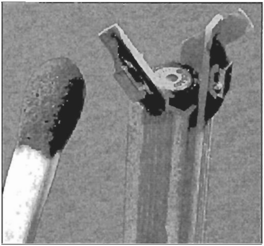

Fig. 2: The sensor part of the USP (it is slightly larger than a match) with the orthogonal orientations of the three Microflowns and the miniature pressure microphone in the middle.

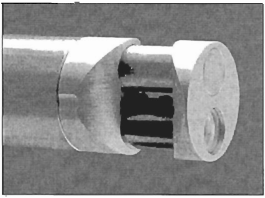

Fig. 3: The ½" PU probe.

3. REALISATIONS

Three realisations are manufactured standard by Microflown Technologies. Numerous variations on these standards are possible.

The USP, the ultimate sound probe is a ½" probe that contains three orthogonal Microflowns and a miniature pressure microphone, see Fig 2. It is the most advanced product that enables 3-dimensional broad-band sound (intensity) measurements.

The ½" PU probe, a half-inch PU probe that contains a Microflown and a miniature pressure microphone, see Fig 3. It is a robust probe that is used for one dimensional sound (intensity) measurements.

The scanning velocity probe is used for example for measuring structural modes being an effective alternative for a laser vibrometer or accelerometer, see Fig 4.

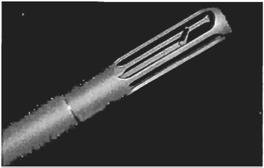

Fig. 4: The scanning velocity probe, the protective mounting can be removed.

4. ACOUSTIC PROPERTIES

With the standard Microflown realisations it is possible to measure broad band sound pressure (*p*) and the vector particle velocity (**u**) at one location and with an ultra miniature sound probe. Apart from the autospectra of sound pressure (S_{pp}) and the autospectra of particle velocity (S_{uu}) derivative acoustic properties are also directly available. *Sound intensity* is determined by the real part of the cross-spectrum: $I=Re(S_{pu})$, *sound energy* is given by: $E=[S^2_{pp}/(2\rho c^2)+\frac{1}{2}\rho S^2_{uu}]$ and the *acoustic impedance* by: $Z= S_{pu}/S_{uu}$

The *self-noise* of a half-inch Io and Titan Microflown is compared with a regular half inch pressure microphone and is shown in Fig 5. As can be seen at lower frequencies (f<1kHz) the Microflowns are better and at higher frequencies the Io Microflown becomes much worse and the Titan slightly worse. If the Microflowns are packaged with only a protective cap (such as the USP in Fig 2) the self-noise increases approximately 9dB.

The self-noise of the half inch Io PU intensity probe (the real part of the cross spectrum of p and u) is shown in Fig. 6. For comparison the threshold of hearing is put inside the figure as well: if one can hear the sound the Io PU intensity probe can detect it. The Titan probe performs better at higher frequencies than the shown Io probe.

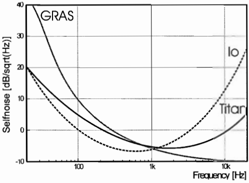

Fig. 5: Self-noise of a half inch packaged Io Microflown (dashed), a half inch packaged Titan Microflown (black line) and for comparison a regular half inch pressure microphone (GRAS 40AC, gray line).

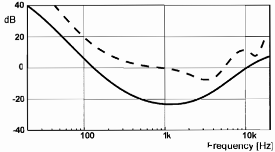

Fig. 6: Solid line: noise level of a half inch p-u Io sound intensity probe in dB SIL (re. 1pW)/√Hz.. Dashed line: threshold of hearing in dB SPL.

Polar pattern. Since the Microflown is sensitive to particle velocity, a vector value, the polar pattern (the directionality of sensitivity) has a full bandwidth cosϕ shape or a figure of eight response. Packages do not influence the polar pattern.

5. CALIBRATION

Several calibration methods to determine the frequency response of the Microflown have been tested over the years. Two methods came out best: an anechoic calibration and a standing wave tube (SWT) calibration [4,16,18] The SWT method is used for lower frequencies (10Hz–4kHz) and the anechoic calibration is used for higher frequencies (1kHz–20kHz). The anechoic calibration is well known and the SWT will be explained below.

The air in the tube is excited by a loudspeaker with amplitude U at the left-hand end and is terminated by a rigid boundary at the right hand end, see Fig 7.

The ratio of the particle velocity (uprobe=u(x)) and the sound pressure at the end of the tube is given by:

$$\frac{u_{probe}}{p_{ref.}} = \frac{i}{\rho c}\sin(k(l-x)) \tag{3}$$

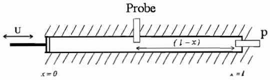

Fig. 7: A tube that is rigidly terminated at $x=l$ and in which the fluid is driven by a loudspeaker at $x=0$.

The relation of the particle velocity and the reference sound pressure at the end of the tube turns out to be a simple sine function, see Fig 8. The phase shift between them equals plus or minus 90 degrees.

The phase response of the Microflown can also be determined in a standing wave tube, see further [16].

PVL is the abbreviation of particle velocity level that has a reference of 50nm/s. In a plane wave a certain PVL in dB corresponds to the same amount number of SPL (re. 20μPa) in dB.

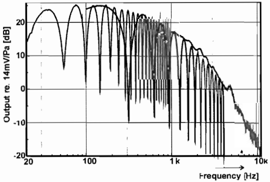

Fig. 8: Amplitude response of ½″ Io probe relative to a pressure microphone with a sensitivity of 14mV/Pa. In a large (8m/16cm) standing wave tube (grey line, 20Hz-1kHz), in a short (75cm/4,5cm) standing wave tube (black line, 100Hz-4kHz) and in a small (1m³) anechoic room (grey line, 1kHz-12kHz).

Because of the materials choice (platinum and silicon) and the measurement method (differential temperature detection), the sensitivity of the Microflown is quite stable. The sensitivity deviation of a random picked ½″ Microflown is in the order of 1dB.

The Microflown is sensitive to velocity (m/s) and not pressure (Pa). Therefore the sensitivity of a Microflown cannot be given in mV/Pa. To be compatible with pressure microphones we choose to express the sensitivity of a Microflown in mV/Pa*. The unit Pa* (velocity-Pascal) is the equivalent particle velocity for sound pressure in a plane wave: 1Pa*=1Pa/ρc=2.2mm/s particle velocity.

6. APPLICATIONS

Realisations of the Microflown are used in many applications. Apart from obvious applications like 1D and 3D broadband (20Hz-20kHz) sound intensity measurements [5,10,16] other will be presented here.

The first application, *a simple, fast and high resolution method for near-field sound source localisation* will be explained by an example [13,14], see Fig 9. A loudspeaker is put inside a 30cm by 20 cm rigid box with a small (20mm) hole in the front allowing sound to propagate.

Sound pressure is measured around the area of the hole (Fig 9A). The particle velocity measured in the direction of the box shows much more focussing (Fig 9B); a better source localisation is possible. The sound intensity perpendicular to a noise source is zero at the position of the source and the sign of the intensity alters when moving around the source (Fig 9C and D); this information locates the source very accurately. The USP is the most suitable probe for this method.

Far-field sound source localisation is possible by simply measuring the 3D sound intensity with an USP. However more advanced techniques are possible. From the cross spectrum of two orthogonal Microflowns more directional information can be derived, see further [12,13,15].

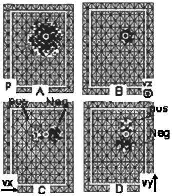

Fig. 9: Very near field sound source localisation.

In-situ impedance determination. The USP is able to measure both broadband the sound intensity vector (**I**) and sound energy (E) at the same time. When measured near to a surface and a sound source is aiming at this surface, the sound intensity is zero when the surface is fully reflecting. If the surface is absorbing, the intensity is dependent on the absorption and the level of the sound source. When the ratio **I**/cE is measured (with c the speed of sound) the value will be 1 if the surface is fully absorbing and 0 when it is fully reflecting [17].

Measurement of structural vibrations [11]. Very near (in the order of 5mm) to a vibrating surface the particle velocity of the surface equals the particle velocity of the sound field. The scanning velocity probe can be used to measure the particle velocity (contactless) and can therefore be used as an *alternative for a laser vibrometer*. Unlike a laser vibrometer, the Microflown is capable of: analyzing velocities in three dimensions around so-called non cooperative materials such as damping materials, foam, rubber, other black surfaces, scattering surfaces, airborne sound.

The three-dimensional impulse response can easily be measured with the USP but also other properties that relate to the time domain, like reverb time, speech transmission index, echo criteria and so on [11].

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