Free Field Measurements in a Reverberant Room Using the Microflown Sensors

W.F. Druyvesteyn, H.E. de Bree and R. Raangs

University of Twente, postbus 217, 7500 AE Enschede, The Netherlands; w.f.druyvesteyn@el.utwente.nl

Free field measurements in a reverberant room using the microflown sensors are described. The microflown is a sensor which does not measure the pressure, but the particle velocity in a sound field.

INTRODUCTION

The microflown is a sensor that measures the **particle velocity** in an acoustic disturbance [1]. It consists of two heated wires; the particle velocity is determined from the differential resistance changes [1]. When a microflown sensor is combined with a pressure microphone an intensity probe is obtained. Experimentally such a (simple) p-**u** intensity probe has been tested and found to be as good as the existing p-p intensity probes [2]. Main advantages of the p-**u** probe above the p-p probe as intensity probe are that errors (or uncertainties) in the phases do not lead to large errors in the estimated intensity, and that one probe configuration can be used for a broad frequency region (the p-p probe use different configurations for the low- and high frequency region). A disadvantage of the p-**u** probe can be that the calibration of the two sensors with respect to each other is more difficult.
An important property of the microflown is its directional characteristic. Denote the orientation of the microflown by a vector **n**[x,y,z], which is defined as follows. The vector **n** is in the plane through the two conducting wires of the microflown and perpendicular to the length of the wires (the maximum sensitivity of the microflown is when the particle velocity is parallel with **n**). When the direction of the particle velocity makes an angle θ with **n**, the measured output of the microflown is proportional to cos(θ), see [1] and [2]. This property makes it possible to obtain free field (no contribution of reflections) properties of a sound field in a reverberant environment.

One microflown

Consider the case that a sound source (a loudspeaker to which random noise is applied) is placed in a reverberant room. When the microflown is oriented such that **n** is in the direction of the free field particle velocity of the sound source the r.m.s. value follows from the square root of the squared free field- and reverberant particle velocity:
$u_{//}^2 = u_d^2 + 1/3 u_{rev.}^2$ The factor 1/3 comes from the integral over all angles in a sphere, representing all the image sources, contributing to the diffuse reverberant field: $(1/4\pi)\int_0^{\pi} 2\pi \sin(\theta).\cos(\theta).\cos(\theta)d\theta = 1/3$. When in a second experiment the microflown is oriented such that **n** is perpendicular to the free field velocity of the sound source, the r.m.s. value is given by: $u_{\perp}^2 = 1/3 u_{rev.}^2$. So by subtracting $u_{//}^2 - u_{\perp}^2$ the free field is obtained. Two recordings have been made of speech in a reverberant room, one corresponding to u// and the other corresponding to u⊥. When reproducing these recordings a clear difference is heard: the recording of u⊥ contains only the reverberant sound field. The recordings will be reproduced during the presentation at the conference.

Two microflowns perpendicular to each other

The contribution of a pure diffuse reverberant sound field to the cross-correlation of two microflowns perpendicular to each other, vanishes. To show this, consider the two dimensional case with two microflowns, having **n**-vectors $\mathbf{n_1} = [1,0]$ and $\mathbf{n_2} = [0,1]$. Suppose two uncorrelated sound sources with power strength s_1 and s_2 are oriented in perpendicular directions, e.g. one under an angle θ with the x-axis, and the second one having an angle θ + π/2 with the x-axis. When the output signals of the two microflowns are u1(t) and u2(t), the long term value of the cross-correlation $R_{u1.u2}(0)$ is written as:

$$\mathrm{Ru1.u2}(0) = (1/T)\int_0^{T} u1(t).u2^*(t).dt$$

; the symbol (0) in $R_{u1.u2}(0)$ refers to the fact that no time difference is taken between u1(t) and u2*(t). The contribution of source s_1 is proportional to –cos(θ)*(-sin(θ)) and of source s_2 to sin(θ)*(-cos(θ)); a positive signal is assumed when the components of the connection vector **r** from source to sensor are in the positive x- or positive y-direction. When the strength of the two uncorrelated sources are equal, $s_1 = s_2$, the contributions to $R_{u1.u2}(0)$ are equal but with different sign, thus $R_{u1.u2}(0)$ vanishes. To verify this experiments have been done with two sound sources (loudspeakers) perpendicular to each other and with $\theta = 45^0$. The loudspeakers were excited with two uncorrelated noise signals within a frequency band of 900 – 1100 Hz. The results of the experiments are shown in figure 1, where is plotted $R^*_{u1.u2}(0)$ as a function of the ratio's of the power strengths s_2/s_1; $R^*_{u1.u2}(0)$ being the normalized $R_{u1.u2}(0)$ value with respect to the $R_{u1.u2}(0)$ value at $s_2 = 0$. The crosses (+) are the experimental results. For $s_2/s_1 = 1$ the cross correlation is zero.

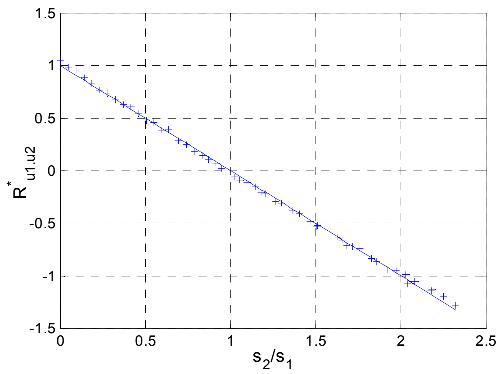

Figure 1. The value of the cross correlation $R_{u1.u2}(0)$ normalized to the value at $s_2 = 0$ as a function of the ratio of the power strengths s_2/s_1 of the two sound sources.

In a pure diffuse reverberant sound field the contribution of an image source to $R_{u1.u2}(0)$ is always compensated by the contribution of another image source in a perpendicular direction. Intensity measurements have also the property that the contribution of a diffuse sound field vanishes. So free field measurements in a reverberant environment can be done using an intensity p-**u** (or p-p) probe or using two microflowns oriented in perpendicular directions. An important difference is of course that with two microflowns perpendicular to each other one measures the product of two perpendicular components of the free field particle velocity vector, while with the intensity the free field product of p and **u**, being the energy flow.

Three microflowns combined with a pressure microphone

A more sophisticated device is to combine one pressure microphone with three microflowns oriented in perpendicular directions, e.g. $\mathbf{n_1} = [1,0,0]$, $\mathbf{n_2} = [0,1,0]$ and $\mathbf{n_3} = [0,01]$. The four sensors are quite small and are positioned close to each other, thus measuring the different sound quantities at almost the same point. A photograph of such a device is shown in figure 2.

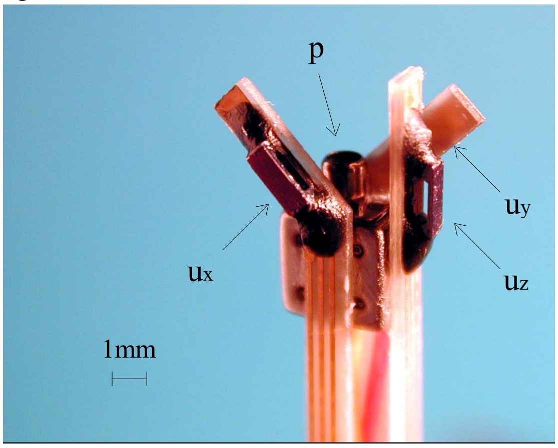

Figure 2. A photograph of the u_x-u_y-u_z-p sensor.

Information of the direction and the strength of a sound source in an arbitrary direction can be found from the determination of the six possible cross-correlations. As was explained above the diffuse reverberant sound field does not contribute to each of the possible six cross-correlations. On the other hand the reverberant field does contribute in the four auto-spectra's. Some experimental results are shown in table 1. The abbreviations I_x refers to the found intensity in the x-direction, $R_{ux.uy}$ to the cross-correlation between the signals from microflown with $\mathbf{n_x} = [1,0,0]$ and $\mathbf{n_y} = [0,1,0]$. The direction of the sound source was [0.43,0.41,0.50].

Table 1. Results using the u_x-u_y-u_z-p sensor.

	Experimental	**Calculated**
I_x/I_y	1.05	1.04
I_x/I_z	1.05	0.85
$R_{ux.uy}/R_{ux.uz}$	1.11	0.82
$R_{uy.uz}/R_{ux.uz}$	0.98	0.96

ACKNOWLEDGEMENTS

The authors whish to thank the Dutch Technology Foundation STW for the financial support.

REFERENCES

1.H.E. de Bree, The Microflown (book) ISBN 9036515793; www.Microflown.com (→R&D→Books).

2. W.F. Druyvesteyn, H.E. de Bree, Journal Audio Aud Eng. Soc. **48**, 49-56 (2000); R. Raangs, W.F. Druyvesteyn and H.E. de Bree 110th AES Convention Amsterdam 2001, preprint 5292.