

# Particle Velocity Sensor and Its Application in Near-Field Noise Scanning Measurement

Xuecong Zhang<sup>1</sup>, Di Liu<sup>1</sup>, Xiaoguang Li<sup>1</sup>, Yunfei Liu<sup>1</sup>, Qijie Tu<sup>1</sup>, Yu Zhou<sup>1,2\*</sup>

<sup>1</sup>Institute of Television and Electroacoustics, Beijing, China

<sup>2</sup>College of Underwater Acoustic Engineering, Harbin Engineering University, Harbin, China

Email: \*zycetc3@163.com

**How to cite this paper:** Zhang, X.C., Liu, D., Li, X.G., Liu, Y.F., Tu, Q.J. and Zhou, Y. (2019) Particle Velocity Sensor and Its Application in Near-Field Noise Scanning Measurement. *Journal of Applied Mathematics and Physics*, 7, 2902-2908. <https://doi.org/10.4236/jamp.2019.711199>

**Received:** November 10, 2019

**Accepted:** November 24, 2019

**Published:** November 27, 2019

---

## Abstract

The Particle Velocity Sensor (PVS) is a kind of acoustic transducer which measures the particle velocity directly with figure-of-eight directivity. This paper proposes a near-field noise scanning technology based on the research of PVS, pressure-particle velocity (P-U) probe, and its application in noise source identification. Firstly, the principle and characteristics of PVS are presented. Secondly, a P-U probe is designed on the basis of PVS development. Finally, the noise measurement experiment for a single source is arranged and conducted. The result shows that the proposed P-U probe performs well in near-field noise source identification and localization.

## Keywords

Particle Velocity, Pressure-Particle Velocity Probe, Near-Field Noise Scanning Measurement, Acoustic Imaging

---

## 1. Introduction

Sound intensity scanning is a near-field noise measurement method with high precision and efficiency, which can be used to measure sound power, identify and the position of noise source, etc. It is an effective means of monitoring and controlling of industrial vibration and noises [1].

Sound intensity measurement requires the use of sound pressure (scalar) and particle vibration velocity (vector) information, which are two important basic physical quantities of the sound field. These two characteristics propose rich sound field information and are indispensable to completely describe sound field [2]. At present, the measurement technology for sound pressure has been very mature. For example, Denmark's B&K and G.R.A.S have a series of commercial sound pressure microphones, which can be used to directly measure sound

pressure in air. The particle velocity provides more information than the sound pressure. T. J. Shults proposed a method for indirectly measuring particle velocity by measuring the sound pressure gradient, which is widely used in P-P sound intensity probes [3]. However, this method is limited by the phase consistency and physical distance between two microphones, and the operating frequency is difficult to cover the whole frequency range. In addition, in low-frequency measurement, the physical distance between microphones is required to be large, which makes it difficult to achieve miniaturization of P-P probe.

Dr. H.-E. de Bree *et al.* of Twente University firstly proposed a  $\mu$ -flown sensor, also known as particle velocity sensor (PVS), which realize direct measurement of acoustic particle velocity [4] [5]. Later, Dr. Bree and Microflown Technologies developed a series of products based on  $\mu$ -flown sensor [6] [7]. The PVS has a directional, figure of eight, response. This directivity effect is independent of frequency, which makes the PVS extremely suitable to measure in real operating situations with background noise and reflections. Moreover, its operating frequency covers the whole frequency band and has a wider frequency response range. The PVS is Micro Electronic-Mechanical System (MEMS) device and can be up to the size of mm. Therefore, PVS is well suited for near-field noise measurement, especially in reverberation environment.

Institute of television and electroacoustics has developed PVS suits for air acoustic measurement in 2015 [8]. And they have realized the batch production of multi-dimensional MEMS vector microphone, which are combined with sound pressure and particle velocity measurement.

In view of the superior performance of PVS, it has a very promising application prospect in the field of industrial noise measurement. Based on the principle of particle velocity measurement, a one-dimensional MEMS vector microphone is developed, also known as P-U probe, which combines the sound pressure sensor and PVS. This sensor realizes the synchronous and co-point measurement of sound pressure and particle velocity. Then, a near-field noise scanning measurement technology is provided on the basis of the P-U probe. High-precision scanning of sound intensity and accurate identification of noise source are achieved.

## 2. Sensor Development

### 2.1. Particle Velocity Sensor

Thermal measurement mechanism of micro flow shows that the vibration of air particles will cause slight changes in the temperature field of sensitive elements. Then it can be converted into measurable electrical signals by using the principle of thermal resistance [9]. Institute of television and electroacoustics has developed the PVS based on above mechanisms, of which the sensitive structure is shown in **Figure 1**. It mainly includes two tiny, resistive wires of platinum (Pt) that are placed in parallel, and the distance between the Pt wires is up to micron level. The Pt wires will be kept constantly heated to 300°C at work. As shown in

**Figure 2**, the motion of the air surrounding the wires caused by acoustic waves will produce the forced convective heat transfer between them. Then, the first wire cools down a little and due to heat transfer the air picks up some heat. Hence, the second wire is cooled down with the heated air and cools down less than the first wire. A temperature difference occurs in the wires, which is proportional to the particle velocity. The temperature change of Pt wires alters their electrical resistance, which can be measured through double arm bridge. This effect is directional, which means that the temperature difference will reverse as the direction of the airflow reverses.

In the case of a single frequency sound wave, the air particle around the Pt wires will be vibrated according to the waveform and this results in a corresponding alternating voltage. The particle velocity can be written as:

$$u = u_0 \exp(i2\pi ft), \tag{1}$$

where,  $u_0$  is the amplitude of particle vibration;  $f$  is the frequency and  $t$  is the vibration time.

Based on the thermodynamic principle the temperature disturbance caused by air flow in the direction of platinum wire is:

$$\delta T(x, 0) = eu_0 \exp(i2\pi f) Px(1 - \sqrt{i\bar{f}} K_1(\sqrt{i\bar{f}})) / (i2\pi k l D \bar{f}), \tag{2a}$$

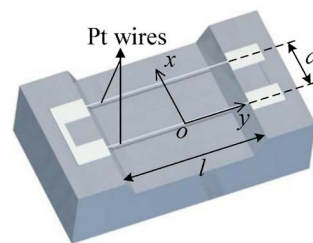
$$\bar{f} = f / (D/2\pi x^2). \tag{2b}$$

where,  $l$  is the length of Pt wire;  $d$  is distance between wires;  $P$  is the power dissipation of Pt wire;  $k$  and  $D$  is the thermal conductivity and thermal diffusivity coefficient of air, respectively;  $K_1$  is the first order modified Bessel function of the second kind.

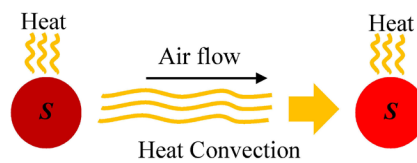
Then, the temperature difference between Pt wires is:

$$\begin{aligned} \Delta T &= 2\delta T(d, 0) \\ &= u_0 \exp(i2\pi f) P(1 - \sqrt{i2\pi d^2 f / DK_1(\sqrt{i2\pi d^2 f / D})}) / (i2\pi^2 k l d f). \end{aligned} \tag{3}$$

The voltage output is expressed by:



**Figure 1.** Structure schematic diagram of PVS.



**Figure 2.** Working principle of PVS.

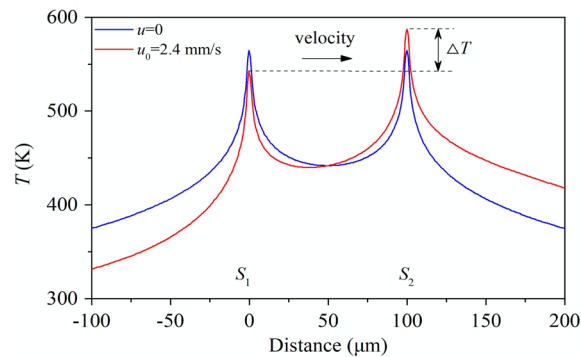
$$U_{out} = U_0 \theta \Delta T / 2. \quad (4)$$

where,  $U_0$  is working voltage and  $\theta$  is the thermal resistance of Pt wires.

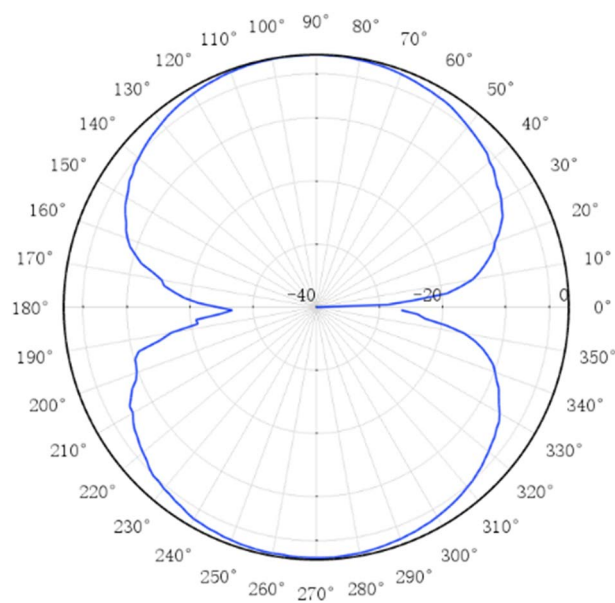
**Figure 3** shows the state and dynamic temperature field of Pt wires where  $u_0 = 2.4$  mm/s,  $f = 250$  Hz,  $l = 100$   $\mu\text{m}$ . Then the particle velocity is measured from Equation (4).

## 2.2. Directivity of PVS

In the plane of the Pt wire, when the acoustic is incident in the direction perpendicular to the wire, the generated temperature difference will reach maximum and the voltage output will be the maximum correspondingly. When the acoustic is incident in the direction parallel to the wire, the airflow will result a consistent temperature change. There is no temperature difference and the voltage output is the minimum. When the acoustic is incident perpendicular to the wires plane, the voltage output is the minimum as well. Therefore, the PVS naturally has the figure-of-eight directivity pattern, showing in **Figure 4**. It is different



**Figure 3.** The state and dynamic temperature field of Pt wires (*The superimposed temperature disturbance is amplified 200 times*).



**Figure 4.** The figure-of-eight directivity pattern for PVS.

from the pressure sensor, which has an omnidirectional response. This feature makes PVS is suitable for noise measurements in reverberation environments and reducing the noise contributions from certain directions.

### 2.3. Pressure-Particle Velocity Probe

As shown in **Figure 5**, the research team has integrated the measurement of particle velocity and sound pressure, and developed the P-U probe, which allows the direct measurement of sound intensity and acoustical impedance. The probe is processed by MEMS technology, which realizes the synchronous and co-point measurement of particle velocity and sound pressure in a very small size. **Table 1** shows the parameters of the probe from physical, measurement, operating environment and electrical.

## 3. Experimental Evaluation

### 3.1. Experimental Details

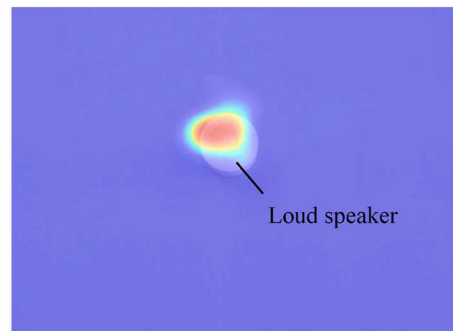
An experiment was arranged to scan and map the sound source in this part by using the scan-based acoustic-imaging instrument. A loud speaker box was used to produce a stationary acoustic excitation. Single frequency sound was used in



**Figure 5.** The P-U probe.

**Table 1.** The parameters of P-U probe.

Content	Characteristics	Parameters
Physical	Diameter	12.7 mm (1/2 inch)
	Length	100 mm
	Weight	38.5 g
Measurement	Frequency range	10 Hz - 20 kHz
	Sensitivity	55 mV/Pa for sound pressure 60 V/(m/s)@250 Hz for particle velocity
Operating Environment	Pressure	Atmosphere
	Temperature	-10 - 70°C
Electrical	Excitation voltage	12 VDC



**Figure 6.** Acoustic imaging of the single sound source.

order to excite noises. A 20 - 40 seconds scanning measurement was undertaken, moving the probe across an area of 0.5 meters by 0.5 meters approximately 0.1 meters from the plane of the loudspeaker box. The scanning speed was set as 0.05 meters per seconds.

### 3.2. Results and Discussions

**Figure 6** shows the measurement results of single sound source (1 kHz) using a mapping of sound intensity. The sound intensity is directly calculated from the sound pressure and acoustic particle velocity using P-U probe. The normal particle velocity and sound intensity perform well in identifying noise source. The positions of the noise sources imaged on the nephograms are consistent with the real positions of the loud speaker, which indicates that the instrument is good at noise source identification. Experiments results also shows that the developed P-U probe and acoustic imaging instruments will play an important role in the field of industrial noise measurement, machine diagnostics, vibroacoustic characterization and sound radiation assessment in real-life conditions.

### 4. Conclusions

This paper introduced a sensor to directly measure the particle velocity. The one-dimensional P-U probe and scan-based acoustic-imaging instrument are developed based on the PVS. A series of experiments for single and double sound source measuring are performed using the instrument. The following conclusions can be drawn.

- 1) Sound pressure and particle velocity for air field can be directly measured by the P-U probe.
- 2) The P-U probe can be used for noise source near field measurement, identification and localization by simple and fast operations. The sound field can be directly imaged by scan-based acoustic-imaging instrument.
- 3) The P-U probe and scan-based acoustic-imaging instrument have widely application prospects.

### Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

## References

- [1] Lai, J.C.S. (1996) Some Applications of the Sound Intensity Technique to Noise Control in the Workplace. *International Journal of Occupational Safety and Ergonomics*, **2**, 1-15. <https://doi.org/10.1080/10803548.1996.11076332>
- [2] Du, G.H., Zhu, Z.M. and Gong, X.F. (2012) *Acoustic Basis*. 3th Edition, Nanjing University Press, Nanjing.
- [3] Vorländer, M. (2013) Acoustic Measurements. In: Müller, G. and Möser, M., Eds., *Handbook of Engineering Acoustic*, Springer, Berlin, Heidelberg. [https://doi.org/10.1007/978-3-540-69460-1\\_2](https://doi.org/10.1007/978-3-540-69460-1_2)
- [4] Bree, H.E., Leussink, P., Korthorst, T., Jansen, H., Lammerink, T. and Elwenspoke, M. (1995) The  $\mu$ -Flow: A Novel Device for Measuring Acoustic Flows. *Proceedings of the International Solid-State Sensors and Actuators Conference*, Stockholm, 25-29 June 1995, 536-539. <https://doi.org/10.1109/SENSOR.1995.717278>
- [5] Bree, H.E., Leussink, P., Korthorst, T., Jansen, H., Lammerink, T. and Elwenspoke, M. (1996) The  $\mu$ -Flow: A Novel Device for Measuring Acoustic Flows. *Sensors and Actuators A: Physical*, **54**, 552-557. [https://doi.org/10.1016/S0924-4247\(97\)80013-1](https://doi.org/10.1016/S0924-4247(97)80013-1)
- [6] Akal, T., Bree, H.E., Hans, E., Guerrini, P. and Maguer, A. (2008) Hydroflow: MEMS-Based Underwater Acoustical Particle Velocity Sensor. *Journal of the Acoustical Society of America*, **123**, 3006. <https://doi.org/10.1121/1.2932584>
- [7] Basten, T.G.H., Bree, H.E. and Sadasivan, S. (2008) Acoustic Eyes: A Novel Sound Source Localization and Monitoring Technique with 3D Sound Probes. *Proceedings of the Biennial ISMA Conference on Noise and Vibration Engineering*, Leuven, 15-17 September 2008.
- [8] Zhao, L.J., Feng, J., Feng, H., Zhou, Y. and Shi, Y.H. (2015) A Particle Velocity Sensor for Airborne Sound Measurement. *ACTA Acoustic*, **40**, 598-606.
- [9] Elwenspoek, M.C. (1999) Thermal Flow Micro Sensors. *Proceedings of the 1999 International Semiconductor Conference*, Sinaia, 5-9 October 1999, 423-435. <https://doi.org/10.1109/SMICND.1999.810580>