Study on High-sensitivity Measurement of Binary Gas Concentration Variation Using Ultrasound

Wei Lin, Zhemin Zhu, Changming Gan & Yifeng Yuan

State Key Laboratory of Modern Acoustics & Institute of Acoustics Nanjing University, Nanjing, 210093, P.R.China

linwei_nju@hotmail.com

Abstract

Ultrasound velocity in binary gas is the function of gas concentrations. But the measurement sensitivity is decreased by variation of temperature or pressure. In the present paper, a frequency-difference measurement system which is composed of double-channels delay line oscillator: an airproof channel and a non-airproof channel which probe the variation of gas component is suggested. The measurement sensitivity of the binary gas concentration variation is better than 8 ppm after eliminating the affect of temperature or pressure by means of difference. The corresponding relation of sensitivity and frequency of space delay oscillator is also achieved by study on the phase condition of generating and maintaining oscillation.

1. Introduction

Sound velocity, acoustic attenuation and reflection are important acoustical parameters. They are widely applied to make acoustical NDT system such as ultrasonic flaw detector and so on. But acoustic attenuation and reflection in material are caused by acoustic impedance incoherent. And acoustic impedance is function of Sound velocity. So sound velocity is more important acoustical parameter of material than other. Furthermore the measurement sensitivity of acoustic attenuation isn’t more than 10-3, but the measurement sensitivity of sound velocity can achieve 10-5 to 10-7. In gas analysis, sound velocity of gas (\( v \)) is \( \sqrt{\frac{RT}{M}} \) if the analyzed gas is binary gas. In this formula, \( \bar{v} \) is average specific heat rate of the binary gas, \( \bar{M} \) is the average molar mass of the binary gas. They are function of the proportion of each gas contents. Furthermore sound velocity of gas (\( v \)) is function of \( \bar{M} \), so it is possible to compute the binary gas concentration change by measurement the change of \( \bar{v} \). Micro-change of gas can be measured by high-precision measurement of gas sound velocity. It is a high-sensitivity ultrasound measurement apparatus.

2. Theory

It is frequency-difference method when the output of difference-net behind double-channels is signal of frequency difference.

In figure 1, 1&2 are two air delay channels; 3 is amplifier; 4 is double channel frequency differentiator; 5 is low-pass filter (LPF). In this system, one channel is airproofed in locale not to touch the micro-change gas, the other isn’t airproofed. The temperatures in each channel are same, so the temperature responds are also same. Those two signals are subtracted by different circuit. The out signal only images the information of change of gas concentration and the influence of temperature is restrained.

The key part in frequency-different system is air delay oscillator. Figure 2 shows its schematic diagram. It consist transmitting transducer, air delay channel, receiving transducer and feedback amplifier. The
oscillating frequency is decided by the sound transmission time (τ).

![Diagram of Air Delay Oscillator](image)

The air delay channel is the sound transmutation space between the transmitting transducer and receiving transducer. There is filled the measured material (liquid or gas) in the airproof channel which is the sensitive part of sensor. The time of its transmission (τ ) is decided by sound velocity of material. If only one material fills in it, 

τ = l/v . And τ = l/ v ( v is average velocity) if mix material in it. It is that the change of sound velocity of material causes the sound transmission time change, therefore causes the oscillating frequency change.

This method of oscillation of a single frequency continuing wave differs from usual method of acoustic measurement system. It was got by reference the theory of SAW high stabilization signal generator. Compare with this method, the sound impulse ring method which is usually mentioned in normal document is a kind of oscillation which is excited by impulse. It is a wide-bandwidth oscillation . So its measurement precision was influenced by bandwidth of transducer and quality of the exciting impulse in oscillating process.

3. Measurement precision

If the distance between the transmitting transducer and receiving transducer is l and delay time is t, then

\[ l = v \tau = (v + dv)(\tau + d\tau) \]

\[ = v\tau + vd\tau + \tau dv + dv \cdot d\tau \]

For the change of velocity is very little, so:

\[ dv \cdot d\tau \rightarrow 0 \]

\[ vd\tau + \tau dv = 0 \]

\[ \frac{dv}{v} = -\frac{d\tau}{\tau} \]

Based on the phase condition of generating and maintain oscillation,

\[ \varphi_A(f) + \varphi_{tra}(f) + \varphi_{air}(f) = 2n\pi \]

\( \varphi_A \) is the phase difference of amplifier; \( \varphi_{tra} \) is the phase difference caused by impedance of transducer and peripheral circuit connected. Since the frequency change is very little, so it is considered that \( \varphi_A \) and \( \varphi_{tra} \) don’t change. \( \varphi_{air} \) is the phase difference of ultrasound wave transmitting.

\[ \therefore \varphi_{air} = \frac{2\pi fl}{v} \]

\[ \therefore \varphi_A(f) + \varphi_{tra}(f) + \frac{2\pi fl}{v} = \varphi_A(f) + \varphi_{tra}(f) + \frac{2\pi (f + df)l}{v + dv} \]

\[ \therefore \frac{2\pi fl}{v} = \frac{2\pi (f + df)l}{v + dv} \]

\[ \therefore \frac{df}{f} = \frac{dv}{v} \]

If the 125 kHz ultrasound transducer and cymometer which precision is 1Hz are used, the theoretical precision of measurement of sound velocity is:

\[ \frac{dv}{v} = \frac{df}{f} = \frac{1Hz}{125kHz} = 8 ppm \]

4. Conclusions

In the present paper, a gas concentration micro-change measurement system using frequency-difference method is suggested. It is actually a measurement system of micro-change of ultrasound velocity. Its precision can get 8 ppm in theory computation.

5. References