1P2-9

Proceedings of Symposium on Ultrasonic Electronics, Vol. 30 (2009) pp. 33-34
18-20 November, 2009

Temperature Dependence of an Ultrasonic Hydrogen Sensor
超音波を用いた水素センサーの温度特性

Masashi Sonoyama[1‡], Hideaki Fujita[2], and Yoshimine Kato[1] ([1]Dep. Automotive Science, Kyushu Univ., [2]Oriimec corp.)
園山将士 [1‡], 藤田秀朗 [2], 加藤喜峰 [1] ([1]九州大 オートモーティブサイエンス, [2]オリイメック(株))

Abstract

A palm-sized hydrogen sensor using ultrasonics is demonstrated at temperatures from -10 to 50°C. The sound velocity of hydrogen is about 1310m/s and the sound velocity of dry air is about 344m/s. Therefore, it is possible to measure hydrogen concentration by measuring the change in sound velocity when hydrogen is mixed with the air. However, the sound velocity also changes with temperature. In this study, we show that it is possible to detect hydrogen concentrations even when the temperature is varied by compensating the temperature effect.

1. Introduction

Recently, using hydrogen as a new alternative fuel is important for a clean-energy society and a global reduction in emissions of CO_2, NO_x, hydrocarbon materials, etc. Especially, fuel cells and hydrogen gas vehicles are widely studied and developed. But there is a danger of explosion when the hydrogen concentration becomes more than 4% in the atmosphere. Therefore, a fast response hydrogen sensor that detects the hydrogen leakage below 4% is necessary. Currently, many kinds of hydrogen sensors have been developed and are used today. For example, solid state sensors [1], electrochemical sensors, catalytic sensors, thermoelectric sensors [2], etc, are commercially available or are being studied.

However, some of them use a closed resonator or a container that needs forced air flow which is not practical for fast detection and also needs power consumption to make the air flow. For the use of hydrogen sensors in automobile or related facilities, it is important to use a low cost, fast response, low-power consumption, small size sensor that operates without degradation of the sensing head material. The hydrogen sensor using ultrasonics in this study can meet these requirements.

2. Theory and experiment

For hydrogen mixed with dry air the sound velocity v_H can be expressed as

$$v_H = \sqrt{\frac{kRT}{28.96(1-\rho)+2.016\rho}} \qquad (1)$$

where k is the average specific heat ratio, R is the gas constant and T is the temperature and the hydrogen mass is 2.016 g/mol with a volumetric concentration ρ, and the dry air mass is 28.96 g/mol. Factors which change the sound velocity are temperature and hydrogen concentration (vol%). Therefore, if the temperature and sound velocity are known, the hydrogen concentration (vol%) can be calculated.

When the sound wave travels a distance x with velocity v in dry air, the traveling time is $t = x/v$. After hydrogen is introduced to the dry air, the sound traveling time decreases by Δt. Δt is measured as the sound traveling time difference between the dry air and the hydrogen/dry air mixture and can be expressed as

$$\Delta t = t - \frac{x}{v_H} \qquad (2)$$

Thus , the ρ can be expressed as

$$\rho = \frac{28.96}{26.94}\left\{1-\left(\frac{t-\Delta t}{t}\right)^2\right\} \qquad (3)$$

from eq.(1) and (2).

Figure 1 shows the calculated relation between the sound traveling time difference Δt and the hydrogen concentration ρ in dry air according to eq.(3). Figure 1 indicates that Δt and ρ have an almost liner relation around 0.0% to 4.0% hydrogen concentration. Therefore, it is simple to detect low concentrations of hydrogen by just measuring Δt, and converting Δt to ρ with a linear micro-processor.

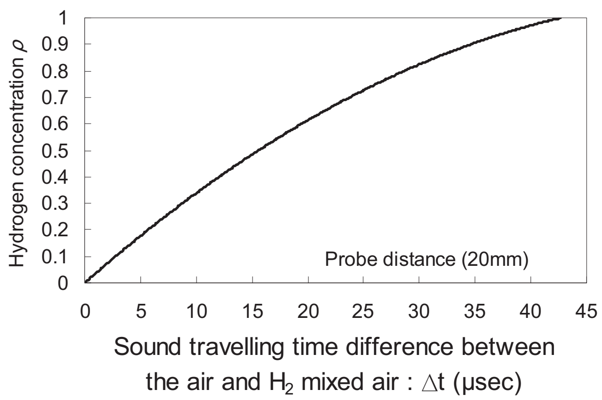

Fig.1 Relationship between the hydrogen concentration ρ in dry air and the traveling time difference Δt between the dry air and the hydrogen/dry air mixture according to eq.(3)

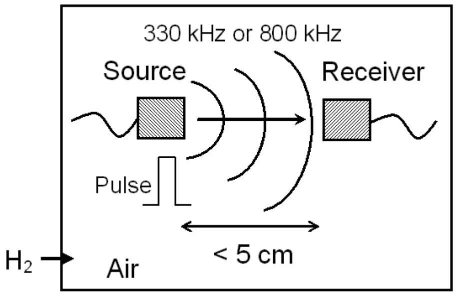

Fig. 2. Diagrammatic illustration of a device.

Two standard ultrasonic probes were used for transmitting and receiving the pulse inside a 10 liter container for example. (see **Fig.2**) For practical use these two probes can be just placed in the open air without a container. Different measured volumes of hydrogen were injected into the container to investigate a range of concentrations from 100 ppm to 3000 ppm. The air in the container was mixed with a fan after hydrogen injection. Next, the hydrogen concentration was varied from 0 to 1.4% with the temperature varying from -10 to 50°C. Values of Δt for each hydrogen concentration and temperature were measured. For determining Δt, the traveling time between source and receiver probes was measured.

3. Result and discussions

Figure 3 shows hydrogen concentration converted from the measured Δt according to eq.(3). The traveling time difference Δt between air and air containing hydrogen was able to be measured as small as 0.003 μsec by averaging the 5 to 10 wave data. In this case the hydrogen concentration was calculated to be about 100 ppm. The transmitting pulse was a single pulse and the distance between the probes was 50 mm. The transmitting ultrasonic frequency was 330 kHz. It was shown that it is possible to measure hydrogen concentrations accurately from

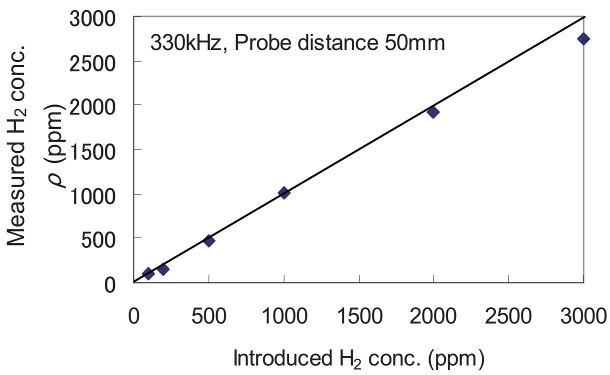

Fig.3. Measured hydrogen concentration derived from eq.(3) from the measured Δt: the traveling time difference between the air and the air containing hydrogen. The solid line is an eye guide for the one to one relation.

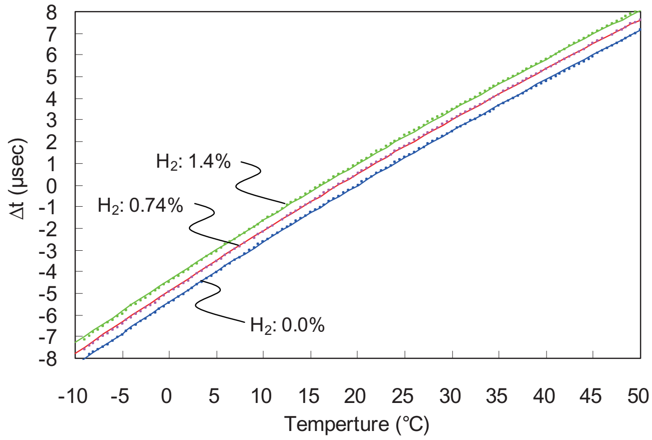

Fig. 4. Experimental and theoretical values of Δt for different temperatures. Solid lines are theoretical curves and dots are experimental data.

100ppm to 3000ppm.

Figure 4 is experimental and theoretical values of Δt for different temperatures. Δt is the traveling time difference between the dry air and the air containing hydrogen at the given temperature. Solid lines are theoretical curves and dots are experimental data. Looking at this data, the theoretical curves are well fitted to the experimental data all the way from -10 to 50℃. For this calculation, the specific heat ratio k is assumed to be constant, and the humidity variation is not considered yet. The good fit with the measured data indicates that for the range of atmospheric temperatures experienced on earth, the change in Δt with respect to temperature and can be calculated precisely. Therefore, it is possible to calculate the Δt change due to the hydrogen concentration change precisely. We will continue or investigations towards achieving more accurate concentration measurements including the above considerations.

4. Conclusion

In this study we have shown that it is possible to detect hydrogen concentrations over a practical operational range of temperatures by using an ultrasonic sensor. In addition, we have demonstrated that it is possible to make this sensor with lower cost and at palm size

Acknowledgment

The authors would like to thank M. Inoue, H. Baba, K. Ohira and P. Woodfield for their help in the experiment and discussions.

References

1. C. Christofides and A. Mandelis, J. Appl. Phys. 68, p. R1-R30 (1990).
2. Kazuki Tajima, Lionel Fabrice Houlet, Woosuck Shin, Toshio Itoh, Noriya Izu and Ichiro Matsubara, Jpn. J. Appl. Phys. 45: Part 1, p. 6186-6191 (2006).