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Effects of Atmospheric Pressure Variation on Temperature and Humidity Measurement Using Ultrasonic Probe

超音波プローブを用いる温湿度計測における気圧変動の影響

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1. Introduction

Ultrasonic probes for air temperature measurement are commercially available and widely used. Temperature and humidity measurements by an ultrasonic probe have been proposed by the authors[1)]. In this technique, an ultrasonic probe measures the sound velocity and attenuation coefficient in air, and the temperature and humidity can be estimated from the measured sound velocity and attenuation coefficient. This technique has advantages that the temperature and humidity can be measured instantaneously, and the measurements are not affected by thermal radiation because the air itself is used as a sensing element[2)]. This technique can be used in the chambers such as an incubator whose inside air pressure is constant. However, the atmospheric pressure varies outside the chambers, and the atmospheric pressure variation may cause temperature and humidity estimation errors on this technique because sound velocity and attenuation coefficient also depend on atmospheric pressure.

In this paper, the effects of atmospheric pressure variation on temperature and humidity measurement using the ultrasonic probe are evaluated. After that, to achieve the temperature and humidity measurements by the ultrasonic probe when the atmospheric pressure varies, the system composed of an ultrasonic probe and an atmospheric pressure sensor is proposed. The system can compensate the effects of atmospheric pressure variation by measuring the atmospheric pressure sensor. Therefore, the system can measure air temperature and humidity accurately when the atmospheric pressure varies, and can be extend the applicable fields such as air conditioning management in rooms. Temperature and humidity are measured by the proposed system to verify the measurement accuracy improvement.

2. Principle of Measurement

The ultrasonic probe is composed of a pair of ultrasonic transducers and a propagation path whose length, L, is known. The ultrasonic probe measures sound velocity and attenuation coefficient in air between the transducers by a burst signal[1)].

According to theoretical equations[3)], the sound velocity c_{th} and attenuation coefficient α_{th} depend on temperature T, humidity H_{R}, and atmospheric pressure p_{a} when the sound attenuation at the single frequency is focused on. For example, the sound velocity and the attenuation coefficient at 400 kHz in the atmospheric pressure change are shown in **Fig. 1** (a) and (b). The pair of temperature T_{est} and humidity H_{Rest} that minimize the evaluation function defined as eq. (1) can be determined by an optimization method, from the measured sound velocity c_{mes} and attenuation coefficient α_{mes}.

$$(T_{\mathrm{est}}, H_{\mathrm{R\,est}}) = \underset{T,\,H_{\mathrm{R}}}{\operatorname{argmin}} \left\{ \begin{array}{l} |c_{\mathrm{th}}(T, H_{\mathrm{R}}, p_{\mathrm{a}}) - c_{\mathrm{mes}}| \\ + |\alpha_{\mathrm{th}}(T, H_{\mathrm{R}}, p_{\mathrm{a}}) - \alpha_{\mathrm{mes}}| \end{array} \right\} \quad (1)$$

In the previous works, it is assumed that the atmospheric pressure p_{a} is constant at the standard atmospheric pressure calibrated initially[1)]. Then, the estimation error of temperature and humidity by atmospheric pressure change are shown in Fig. 1 (c) and (d). According to the figures, it is considered that temperature estimation errors caused by atmospheric pressure variation are within permissible accuracy ±0.5 K, while humidity estimation errors are not within permissible accuracy ±5%RH. Therefore, it is required to compensate eq. (1) by always measuring the atmospheric pressure p_{a} for humidity measurement with practical accuracy.

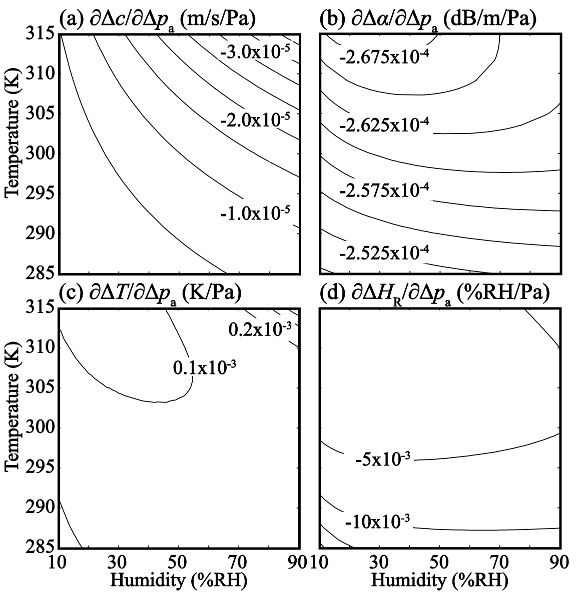

Fig. 1 Effects of atmospheric pressure variation:
(a) Sound velocity change, (b) Attenuation coefficient change at 400 kHz, (c) Estimated temperature change, and (d) Estimated humidity change.

3. Experimental Procedure and Results

The sound velocity and attenuation coefficient of moist air were measured in the thermostat and humidistat chamber (SH241, Espec). In this chamber, narrowband ultrasonic transducers (MA400A1, Murata) whose center frequency was 400 kHz were set up as shown in **Fig. 2**. The atmospheric pressure was measured by a pressure sensor (TR-73U, T&D). The experiment is performed when the atmospheric pressure p_a was 1,003 hPa, which is lower than the standard atmospheric pressure of 1,013 hPa. Temperature was 293 K, and Humidity was varied at 50 to 90%RH at 10%RH intervals in the chamber. In each condition, sound velocity and attenuation coefficient was measured 10 times. The measurement signal was a sinusoidal burst signal at 400 kHz of 0.5 ms. The applied voltage was 44.8 V peak to peak, and the standard sensitivity of transducers was 10 V/Pa. The sampling frequency was 1 MHz. The signals were generated and processed by a computer. The transducers were connected to the computer via A-D converter (USB-5133, National Instruments) and amplifiers. The computer extracted sound velocity and attenuation coefficient. The references were measured by the wet-dry hygrometer.

Measurement results of sound velocity and attenuation coefficient were shown in **Fig. 3** (a) and (b), and the measured sound velocity and attenuation coefficient almost agreed with the theoretical curves at 1,003 hPa. Estimation results of temperature and humidity were shown in Fig. 3 (c) and (d). The measurement accuracies by the proposed system were 0.04 K and 0.94%RH, and the accuracies by the previous system were 0.12 K and 6.79%RH. Thus, the accuracy improvement was confirmed.

4. Conclusions

In this paper, the effects of atmospheric pressure variation on temperature and humidity measurement using the ultrasonic probe were evaluated. So, it was considered that compensation of atmospheric pressure was necessary for humidity measurement with practical accuracy. Then, the system which compensated the atmospheric pressure was proposed to improve the measurement accuracy by the ultrasonic probe when the atmospheric pressure varied. As the experimental results, the improvement of air temperature and humidity measurement accuracy by the proposed system was confirmed, and the practical accuracies were achieved.

Acknowledgement

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References

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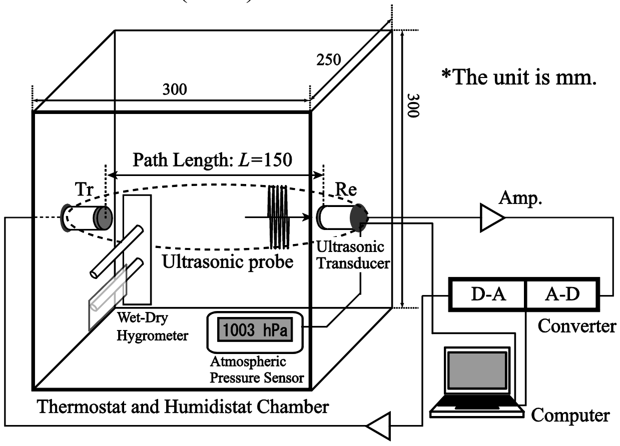

Fig. 2 Experimental setting.

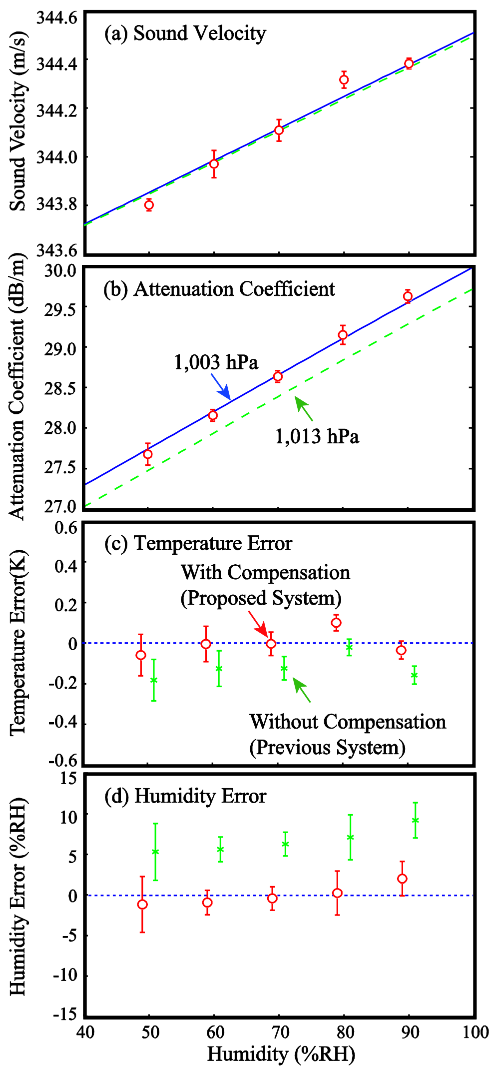

Fig. 3 Measurement results:
(a) Sound velocity, (b) Attenuation coefficient, (c) Temperature error, and (d) Humidity error.