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Time Assessment on Sensor Stability for Sound Absorption Measurement

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ABSTRACT

In previous study, humidity consistency had been proven as significant contributor to the stability of sensor in measuring absorption coefficient of acoustical material. This phenomenon becomes critical as method of *in-situ* measurements naturally involve environmental variables, where temperature and humidity may vary. This research applies two similar pu-sensors (pu-1 and pu-2) in series of calibration and EA-method measurement sets then comparing both results on absorption characteristics through standard deviations, each in various controlled humidity. In every of four measurement sets, both sensors behave in similar trend in responding different humidity changes, Δ¨. The higher the humidity difference, Δ¨between measurement sets, the bigger deviation of results occurred. To confirm this humidity effects on sensors' stability on measurement of absorption coefficient by EA-method, further investigation were performed by statistical correlation between humidity levels and the time of measurements (4 sets of separated time). Environment humidity manually controlled in ranges of 30 - 60% by set of fans and humidifiers throughout set of measurement, while deeper understanding on the resulted deviations were discussed by evaluation on the sensors working principles and how its sensibility may effected by humidity in the environment. Based on time and humidity difference, Δ¨ statistical simulation, correlation between sensor's calibrations and their responses in 4 separated time of experiments had emphasized the above phenomenon. No significant differences on both sensors' deviation in each of the experiment time sets, leaving humidity as the deviation source with less correlation to time of measurements.

Keywords:Time assesment, Pressure-velocity sensor, Relative humidity, Sound absorption measurement.

1. INTRODUCTION

The influence of relative humidity on the stability of the pu-sensor was investigated through experiments in a reverberation room with humidity level controlled from 35%–60%. The humidity influence on sensor's stability was identified by the increasing deviation of correction values (C_H). The author using an impedance tube to calibrate the pu-sensors. As is illustrated in Figure 1, the tube has the length of *L* and its end is terminated with a hard wall. A reference microphone preliminary calibrated using a piston phone, or by some other way, is set on the hard wall. Next, absorption coefficients of material were measured through Ensemble Averaged method (EA-method) as shown in Figure 2.

This C_H value directly affected by the increasing differences of humidity between sensor's calibrations and sensor's measurements. The influence was confirmed by two identical pu-sensors and application of ensemble average method (EA-method) [1]. To reassure the phenomenon, functional and theoretical assessments on pu-sensor's stability are constructed, following by time analysis on the results of sensor's measurement taken from four (4) sets of experiments within 390 days.

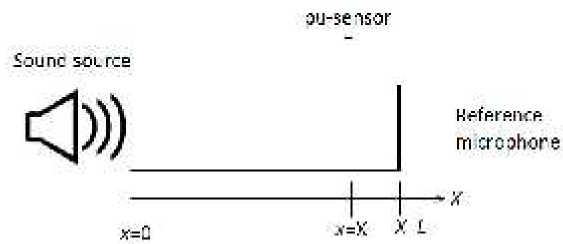

Figure 1. Schematic diagram of pu-sensor calibration in an impedance tube

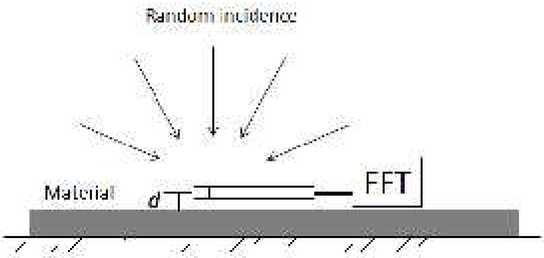

Figure 2. Schematic diagram of the measurement set up with pu-sensor

2. Examination Of Sensor Mechanism And Sensitivity

A.Quantitative Model of Sensor Sensitivity

Figure 3 depicts the cross section of a Microflown sensor, consists of two silicon nitride wires, spaced by 350 «m as the main the part of its functional principle [2].

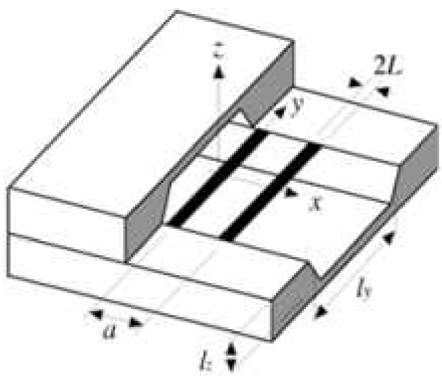

Figure 3. Cross section of microflown and the coordinate system
Source: V. B. Svetovoy and I. A. Winter

The wires regarded as electrical resistors dissipating electrical current power P_e. Resistance increases linearly by temperature and heat convection around the resistors, define the sensor sensitivity through the relative differential of the resistances:

$$\frac{\Delta R}{R} = \propto \Delta T \,, \qquad (1)$$

Where, *R*, Δ*R*, ~, and Δ*T*, respectively denote electrical resistance, resistance differences, temperature coefficient, and the temperature difference of resistors [3].

The quantitative model of sensor is reported by Svetovoy and Winter [4], presentingΔ*T* as

$$\Delta T = v_0 \frac{P_e}{Dk} A\left(\frac{\omega}{\omega_0}, \frac{a}{l_z}, \frac{2l_z}{l_y}, \frac{L}{l_z}\right)\cos(\omega t + \varphi) \,. \qquad (2)$$

k denotes thermal conductivity of air, *A* and ~denote amplitude and phase, and v_0 is the particle velocity of sound wave with an angular frequency μ, defined by

$$v_0 = \frac{\delta p}{\rho(T_r)c} \,. \qquad (3)$$

¢*p*, *c*, and°(T_r) are the sound pressure, sound speed and air density at room temperature T_r, respectively, where the substrate is assumed to be T_r ≈ C. Thermal diffusion *D* and frequency scale μ₀ in constant pressure given the values of $D \approx 1.9\times1$ m²/s and $\rho(T_r)c \approx$ kg/m². Through Eq. 1 and Δ*R* obtained from measurement, then particle velocity can be determined.

B. Examination of Sensor Sensitivity by Moist Air Theory.

The aforementioned quantitative model explained the sensor sensitivity as in proportion to a*T*, simplified into

$$\frac{\Delta R}{R} = \propto \Delta T \propto \frac{v_0 P_e}{k^2} \,. \qquad (4)$$

Thermal conductivity of air k was generally assumed to be independent of humidity [2] , but in the moist air theory, k is examined as humidity dependence [5]. As the thermal conductivity of dry air $k_d \approx 0.023807 + 7.1128 \times 10^{-5}$, water vapor $k_v \approx 0.015606 + 7.1128 \times 10^{-5}$.

Then the moist air $k$were approximated by

$$k_a \approx k_d \left[1 - \left(1.17 - 1.02 \times \frac{k_v}{k_d}\right) \times \frac{\varphi}{100}\right]. \qquad (5)$$

¨denotes relative humidity, in respect to $k_a$and T are shown in Figure 4. The linear relation appeared for ¨= 0 case, as higher ¨should differsmore k_a value. Humidity might also possible to influence °(Tr) or c parameters, but requires more complicated techniquesof moist air theory, hence experimental examinations were conducted as quantitative modeling.

3. MEASUREMENT CONDITIONS

Prior to measurements, sensor requires prerequisite calibration, which in this study applied by standing wave tube. In the practical calibration of the measurements, we used an impedance tube with the inner dimensions of 10 cm x 10 cm and with L = 70 cm, and the pu-sensor positioned at point X = 68 cm. Pink noise was emitted by a loudspeaker at the opening edge of the tube (x=0).The resolution of the two-channel FFT (RION SA-78) unit is set to 1.25 Hz and a Hanning window of duration 0.8 s is employed. Linear averaging in the frequency domain is performed N = 150 times.

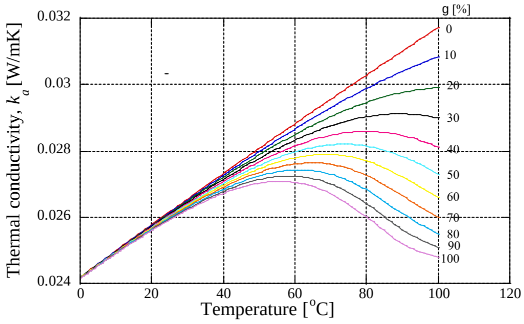

Figure 4. Thermal conductivity of moist air k_a in respect to temperature T and relative humidity ¤

Two sets of pu-sensors named pu-1 and pu-2 were calibrated by using impedance tube (see Figure 1) to compare the results each other. Examination of humidity effects onto each of pu-sensor calibration were conditioned in sixrelative humidity, φ, levels ranging from 35% to 60% with 5% step.

The calibration is conducted in a reverberation room of 168 m^3 with non-parallel walls, located at Information Center of Oita University. In the room, we also conducted the measurement by EA-method. Temperature and relative humidity are controlled and measured by thermo-hygrometer (A&D AD-5640A).

Figure 2 shows a schematic diagram of the measurement set up of EA-method with pu-sensor. The pu-sensor is positioned at the centre of 0.9 m x 0.9 m material. The distance, d, is 1 cm above material surface. Glass wool (GW50) with 32 kg/m^3 density and 50 mm thickness is used. The same settings of two-channel FFT are applied. Here, the thermo-hygrometer is positioned 1m away from the sensor.

To produce the incidence condition close to random incidence, six loudspeakers

(Fostex FE-103) mounted in small boxes that radiate incoherent pink noise were placed in the reverberation room. Following the former papers [6-9], the pink noise is filtered to focus the frequency range from 100 Hz to 1200 Hz. A sub-woofer (JVC SX-DW77) is also installed to increase the low frequency energy, roughly below 200 Hz.

Each measurement set consists of sensor calibration (c) and EA-method measurement (m), then referred to as ***a pair*** ($c_x m_x$), x is humidity level. Each pair is taken at humidity difference Δ¨ = 0%, time duration of the calibration and the EA-measurement were 90 seconds each. Therefore environmental conditions (i.e constant temperature and ambient pressure) might not change significantly during the measurements. By 5% interval, level of relative humidity is gradually increased from 35% - 60%, resulting six pairs measurement of Δ¨ = 0% ($c_{35}m_{35}$, $c_{40}m_{40}$,…, $c_{60}m_{60}$). This complete pair is referred as ***one set*** measurement, usually took 1-2 days.

In this study, four sets were conducted independently over a period of 390 days. In each set, two identical pu-sensors were utilized in turn, labeled as pu-1 and pu-2. Assessment on humidity differences $\Delta\varphi$ were applied by pair combinations of calibration and measurement of different humidity level ($c_{35}m_{40}$, $c_{35}m_{45}$, …, $c_{60}m_{55}$). The step was repeated to all possible combination for six humidity differences ($\Delta\varphi$ = 0%, 5%, …, 25%) within one set measurement.

In this study, there were three limitations of the measurement conditions: Firstly, the humidity ranged from 35-60%, secondly, the maximum difference of temperature was 1.8^{o}C and thirdly, the maximum difference of atmospheric pressure was 0.7 kPa.

4. Results and Discussions

In the previous paper, the influence of relative humidity on pu-sensor utilizations were confirmed through series of quantitative models [1], which then compiled to ease the understanding as seen in Figure 3. Here, both pu-1 and pu-2 sensors had demonstrated comparable trends in every $\Delta\varphi$ throughout four measurement sets, where higher $\Delta\varphi$ comes with bigger deviation. Next, only the result of pu-2 was illustrated due to the space limitation. To examine whether the sensor sensitivity is affected by the time of measurements, the first step is to identify all pair combinations $c_x m_x$ for six Δ¨ within each, and then among four measurement sets. Next, combinations of pairs were classified based on the same Δ¨ of the whole sets. As quantitative analysis, standard deviations of absorption coefficients on each classified Δ¨ then visually presented, which expressed as

$$SD_{\Delta\varphi}(f) = \sqrt{\frac{1}{N_{\Delta\varphi}} \sum^{N_{\Delta\varphi}} \left(\alpha'_{CM,\Delta\varphi}(f) - \alpha'_{\Delta\varphi}(f)\right)^2} \qquad (6)$$

Here, CM denotes every possible pair combinations from the whole four measurement sets of the same Δ¨. $N_{\Delta¨}$ is the number of pair combinations within the group of Δ¨, for the whole sets. Calculation results then be presented by the group of Δ¨ in relation to the four groups of time simulation. The total number of analyzed data are 576. The number of data within the same $\Delta\varphi$ from the whole sets and its corresponding analyzed data are shown in Table 1. Moreover, the total pair combinations found to be 576 data which is based on time and pair combinations as simplified in Table 2.

Table 1. Number of analyzed data

Δφ (%)	Number of data
0%	96
5%	160
10%	128
15%	96
20%	64
25%	32
Total	576

Table 2. Time and Pair Combinations

Σt	□ pair combinations
t1	c set 1 (m set 1; m set 2; m set 3; m set 4)
t2	c set 2 (m set 1; m set 2; m set 3; m set 4)
t3	c set 3 (m set 1, m set 2; m set 3; m set 4)
t4	c set 4 (m set 1; m set 2; m set 3; m set 4)

Figure 6, show the average standard deviations of absorption coefficients (S̅) in relation to humidity difference (Δ¨) and combinations times. Each bar represents the average of pair combination of each Δ¨( ) while Σt is four group of measurement time combinations as shown in Table 1. The S̅ clearly shows an increasing tendency as the Δ¨ increased, repeatedly in all Σt. As discovered in each Σt, although combination pairs for each Δ¨ were the combination among four independent measurement sets, the result shows a similar tendency to the result obtained by combination pairs of single measurement set, where deviations of measurement results were proportional to the increasing Δ¨ (Figure 5 vs Figure 6). Thus it can be inferred that time criterion does not significantly affect the measurement results.

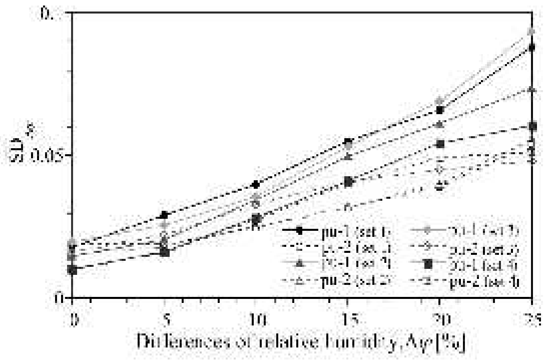

Figure 5. Standard deviation, $\overline{SD}_{\Delta\varphi}$ with respect to the difference of relative humidity,Δ¨from 0%- 25% obtained by pu-1 and pu-2

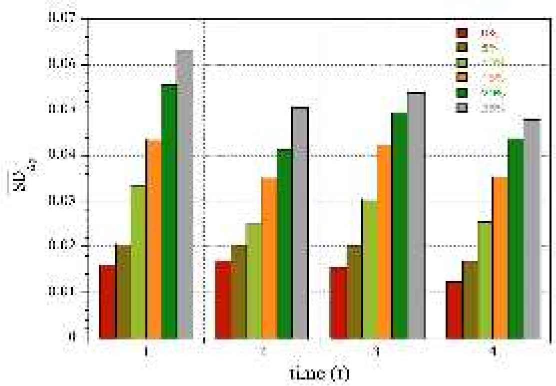

Figure 6. Standard deviation, S̅ with respect to the time criterion and humidity difference.

An examination on the deviation of absorption coefficients, resulted from measurements by using pu-sensor and time differences consideration was conducted. As stated in the previous paper [1], an investigation of humidity and other environmental factors (temperature and pressure atmospheric) were also applied by means of statistical approach. The results of experiments show that among environmental factors affecting the pu-sensor, humidity is still the most dominant factor to the deviation of the measurement result by EA-method application. The partial correlation results between the $\bar{S}$ of the absorption coefficient and the SD of the temperature (Δ*t*), atmospheric pressure (Δ*p*), and humidity (Δ¨), are shown in Table 3.

Table 3. Partial correlation

	Δφ	Δp	Δt
pu-1	0.955	0.521	-0.065
pu-2	0.959	[illegible]	-0.261

Both calculated results of pu-1 and pu-2 showed coefficient number > 0.95, which is explain a significant correlation of Δ¨ on the sensor stability. Up to this stage, Δ¨ has the most significant influence on $\bar{S}$ among other environmental factors. It should be noted that the investigation on these factors are limited within the range.

The present study confirms the previous findings and provides additional evidence of the humidity influences on the pu-sensor. Therefore, it is necessary to conduct sensor calibrations and measurements within similar humidity levels whenever measurements of absorption coefficients by using a pu-sensor is applied.

Further, comparison of mean value of $\bar{S}$ between the measurements result performed within the same measurement set, and the measurement result performed by different measurement sets (combination among four measurement sets) is presented. Figure 7 also confirms that there is no significant difference between them. Up to this stage, it can be inferred that the time criterion does not significantly affect the measurement results.

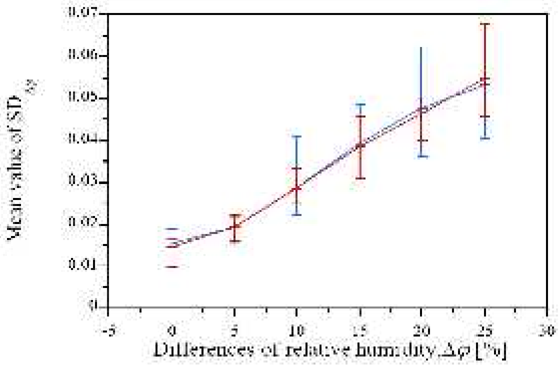

Figure 7. Mean value of $\bar{S}$ with respect to difference of relative humidity, Δ¨

5. CONCLUSIONS AND RECOMMENDATIONS

The influence of humidity level to the pu-sensor measurement was reconfirmed through quantitative modeling analysis, investigated by variation of humidity level during sensor calibration and EA-method measurement. Study results were also emphasized by the detail descriptions of moist air theory and time criterion assessment, revealed the less significance of measurement time to the pu-sensor measurement results, giving more credit the humidity influence. As the direct influence of humidity level to the sensor sensitivity has been discussed and reconfirmed in this study, consideration on humidity factor on pu-sensor sensitivity is worth for scientifically examination. Humidity of air may differ every now and then while the pu-sensor is applied in measurements. In particular, in countries where the climate is moist, humidity issue might be of great importance in precise measurements as well as in *in-situ* measurements using the Microflown.

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