研 究 報 告

Bilateral comparison of pressure sensitivities of laboratory standard microphones between NMIJ and NIMT

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Abstract:

Bilateral comparison between two laboratories, the National Metrology Institute of Japan (NMIJ) and the National Institute of Metrology (Thailand), NIMT, was organized by NMIJ and carried out for the pressure sensitivities of laboratory standard microphones for accreditation of NIMT. Two LS1P microphones were prepared as traveling standards and calibrated in a frequency range between 20 Hz and 8 kHz. NMIJ used the reciprocity calibration system developed by NMIJ, including a large-volume coupler. NIMT used a Brüel & Kjær reciprocity calibration system with two plane-wave couplers.

The comparison showed that the *En* value was less than 1.0 for the entire frequency range, demonstrating that NIMT has sufficient calibration and measurement capability.

Based on experimental evidence, the small difference in measured pressure sensitivity between the two laboratories is possibly related to the respective coupler correction factor used to calculate the pressure sensitivity.

1. INTRODUCTION

In 1998, the National Institute of Metrology (Thailand), NIMT, was founded for the establishment of national measurement standards. Since then, the National Metrology Institute of Japan, NMIJ, has promoted the accreditation of NIMT as a reliable national metrology institute.

In the field of acoustics, NMIJ organized a bilateral comparison between NMIJ and NIMT in 2003 to confirm the calibration and measurement capability (CMC) of NIMT for the pressure sensitivities of laboratory standard microphones.

Comparison results showed good agreement between the two laboratories, proving the eligibility of NIMT for accreditation.

2. TECHNICAL PROTOCOL

As the pilot laboratory for this bilateral comparison, NMIJ prepared two LS1P microphones [1)] (Brüel & Kjær, type 4160) to be calibrated, and designed the technical protocol. Summary of the protocol is as follows.

The two microphones (A and B) were transported between the two laboratories by using an international delivery service as a trial to lower transport costs compared with the currently used method of hand-carrying the microphones. Microphones were packaged in an aluminum box padded with cushioning material and containing small holes in the outside casing to avoid sudden shocks and to minimize extreme changes in temperature or pressure, which could cause an irreversible change in the pressure sensitivity or degrade the stability of the pressure sensitivity. The microphones were calibrated again to monitor their stability after having been returned to NMIJ.

Each laboratory was to determine the pressure sensitivities of the two microphones by using a pressure calibration method described in IEC 61094-2 [2)]. Measurement frequencies were (a) 20 Hz, (b) nominal preferred octave frequencies from 31.5 Hz to 1 kHz, and (c) nominal preferred 1/3rd octave frequencies from 1.25 kHz to 8 kHz. The pressure sensitivities were corrected to the reference environmental conditions (23 ℃ and 101.325 kPa) given in

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IEC 61094-2.

The calibration results were reported by using a standard certificate that would be normally issued to a customer.

3. CALIBRATION SYSTEMS AND METHODOLOGIES

3.1. Calibration system and methodology at NMIJ

NMIJ uses a reciprocity calibration system that they developed for laboratory standard microphones [3), 4)]. In this system, firstly the voltage transfer function between an input terminal of a transmitter microphone and an output terminal of a receiver microphone is measured by using an insert voltage technique [2)]. Then the transmitter's capacitance is separately measured in comparison with reference capacitance. The electrical transfer impedance [2)] is determined using the voltage transfer function and the transmitter's capacitance.

In the system, a large-volume coupler [2)] (cavity volume of 19.62 cm^3) is used and gas in the cavity is exchanged from air to hydrogen in the frequency range above 1.6 kHz. The contacting surfaces between the microphones and the coupler are sealed with grease to prevent leakage of hydrogen and sound out of the cavity. Two capillary tubes [2)] are attached to the coupler to replace air with hydrogen and to equalize the static pressure inside and outside of the coupler. Each tube is 10 cm in length and 0.5 mmϕ in inner diameter.

3.2. Calibration system and methodology at NIMT

NIMT uses a commercially available reciprocity calibration system (Brüel & Kjær, type 5998)[5)]. In this system, the electrical transfer impedance is directly determined from the current through the transmitter and the output voltage of the receiver. The transmitter current is measured by using the voltage of the calibrated capacitance connected in series with the transmitter.

In the system, two plane-wave couplers [2)] (cavity volumes of 3.098 cm^3 and 5.135 cm^3, respectively) filled with air are used for all the measurement frequencies. Microphones are set into the coupler without using grease, because leakage of sound is assumed negligible. A needle bung [5)] is used instead of a capillary tube to equalize the static pressure inside and outside the coupler.

4. RESULTS

4.1. Microphone parameters and temperature and pressure coefficients of pressure sensitivity

Tables 1 and 2 list the microphone parameters reported by NMIJ and NIMT for microphones A and B, respectively. Table 3 shows the frequency dependence of the temperature and pressure coefficients in the pressure sensitivity reported by NMIJ and NIMT. Both laboratories reported the same values for the coefficients, which were derived from the same reference paper [6)].

4.2. Pressure sensitivity

Figs. 1 and 2 show the frequency dependence of the difference between NMIJ and NIMT in the pressure sensitivity for each microphone and the pressure sensitivity difference measured by NMIJ before and after transport of the microphones. These figures indicate relative differences from a reference pressure sensitivity that was calibrated by NMIJ before transport of the microphones.

Both microphones showed similar characteristics (Figs. 1 and 2); Fig. 3 shows the average difference for both microphones. For all the frequency ranges, the day-to-day difference in the measured pressure sensitivity was less than 0.01 dB (marked as •), proving that the microphones were sufficiently stable during this bilateral comparison. Although further monitoring of the stability of calibrated microphones is necessary, Fig. 3 suggests that a delivery service might be used instead of carrying the microphones by hand in the passenger cabin of an aircraft.

The maximum difference between the two laboratories (marked as ○ in Fig. 3) was 0.04 dB. To assess the calibration proficiency of NIMT, an E_n value [7)] defined as follows was used:

$$E_n = \frac{M_{lab} - M_{ref}}{\sqrt{U_{lab}^2 + U_{ref}^2}} \qquad (1)$$

where M_{lab} is the averaged pressure sensitivity for both microphones reported by NIMT, M_{ref} is that calibrated before transport of the microphones reported by NMIJ, and U_{lab} and U_{ref} are the expanded uncertainties [8)] of the pressure sensitivities declared by NIMT and NMIJ, respectively (coverage factor k was 2). Table 4 summarizes the uncertainty budget for U_{lab} and U_{ref}, and Fig. 4 shows the calculated E_n value.

Table 1 Microphone parameters for microphone A

Laboratory	NMIJ	NIMT
Front cavity volume (mm^3)	533	543.0
Front cavity depth (mm)	1.96	1.952
Equivalent volume (mm^3)	152	130.5
Resonance frequency (Hz)	8200	8200
Loss factor	1.05	1.05

Table 2 Microphone parameters for microphone B

Laboratory	NMIJ	NIMT
Front cavity volume (mm^3)	529	550.0
Front cavity depth (mm)	1.95	1.957
Equivalent volume (mm^3)	151	125.6
Resonance frequency (Hz)	8200	8200
Loss factor	1.05	1.05

Table 3 Frequency dependence of temperature and pressure coefficients in pressure sensitivity for microphones A and B. Both NMIJ and NIMT reported the same values for the coefficients.

Frequency (Hz)	Temperature coefficient (dB/°C)	Pressure coefficient (dB/hPa)
20	-0.003	-0.002
31.5	-0.003	-0.002
63	-0.003	-0.002
125	-0.003	-0.002
250	-0.003	-0.002
500	-0.003	-0.002
1000	-0.003	-0.002
1250	-0.003	-0.001
1600	-0.003	-0.001
2000	-0.004	-0.001
2500	-0.006	-0.001
3150	-0.007	-0.001
4000	-0.010	-0.001
5000	-0.014	0.000
6300	-0.018	0.000
8000	-0.016	0.000

For all the frequency ranges, the absolute E_n value was less than 1.0 (Fig. 4). The pressure sensitivities reported by NIMT were therefore regarded as satisfactory, according to the recommendation described in ISO/IEC Guide 43-1 [7].

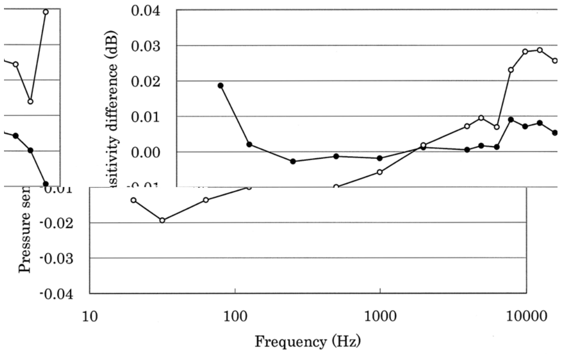

Fig.1 Frequency dependence of pressure sensitivity difference for microphone A calibrated by NMIJ after transport (●) and by NIMT (○). Relative difference from reference pressure sensitivity calibrated by NMIJ before transport is shown.

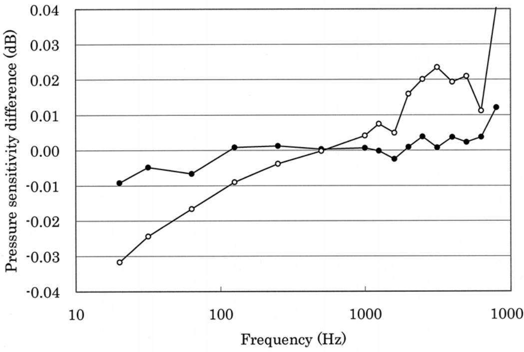

Fig.2 Frequency dependence of pressure sensitivity difference for microphone B calibrated by NMIJ after transport (●) and by NIMT (○). Relative difference from reference pressure sensitivity calibrated by NMIJ before transport is shown.

4.3. Difference in measured pressure sensitivity between NMIJ and NIMT

Based on Fig. 4, NIMT has sufficient calibration and measurement capability (CMC) for the pressure sensitivity of laboratory standard microphones. However, the difference in the measured pressure sensitivities between the two laboratories showed significant frequency dependence (Fig. 3). NMIJ suspected that this difference in measured pressure sensitivity might be due to the difference in the reciprocity calibration systems used by the two laboratories, namely, the system originally developed and used by NMIJ and the commercially available system, Brüel & Kjær type 5998, used by NIMT.

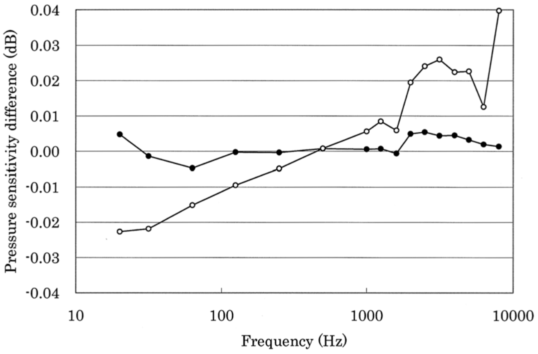

Fig.3 Frequency dependence of pressure sensitivity difference averaged for microphones A and B calibrated by NMIJ after transport (●) and by NIMT (○). Relative difference from reference pressure sensitivity calibrated by NMIJ before transport is shown.

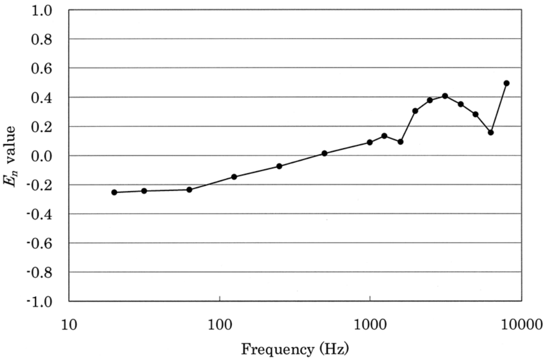

Fig.4 Frequency dependence of E_n value.

Table 4 Uncertainty budget for pressure sensitivity (coverage factor $k = 2$)

Frequency (Hz)	NMIJ (dB)	NIMT (dB)
20	0.04	0.08
31.5	0.04	0.08
63	0.04	0.05
125	0.04	0.05
250	0.04	0.05
500	0.04	0.05
1000	0.04	0.05
1250	0.04	0.05
1600	0.04	0.05
2000	0.04	0.05
2500	0.04	0.05
3150	0.04	0.05
4000	0.04	0.05
5000	0.04	0.07
6300	0.04	0.07
8000	0.04	0.07

To further clarify the reason for this difference in measured pressure sensitivity, NMIJ completed two more experiments. In the first experiment, NMIJ calibrated both microphones again by using a calibration system of the same model as used by NIMT, namely, type 5998. Fig. 5 shows the frequency dependence of the difference between two laboratories for the averaged pressure sensitivity of both microphones, indicating relative difference from a reference pressure sensitivity that was calibrated by NMIJ using type 5998.

The difference was around 0.01 dB (Fig. 5), and was independent of frequency, except at 8 kHz. Both laboratories operated the type 5998 in the same way, resulting in good agreement in the measured pressure sensitivity. The cause of the difference at 8 kHz remains unclear, but it is not a serious problem.

In the second experiment, NMIJ clarified the difference caused by the two methods for measuring the electrical transfer impedance. NMIJ method determines the electrical transfer impedance from the voltage transfer function and the transmitter’s capacitance, and type 5998 from the current through the transmitter and the output voltage of the receiver. In this experiment, the identical plane-wave coupler (cavity volume of 3.098 cm^3) with the needle bung was used for both methods. Fig. 6 shows the pressure sensitivity difference at NMIJ measured using the two methods, indicating a relative difference from the pressure sensitivity measured using the NMIJ method. Fig. 6 indicates that the measured pressure sensitivity were not significantly different between the two methods.

Based on the results of these two additional experiments, the difference in measured pressure sensitivity (Fig. 3) was not related to the differences in the characteristics between the reciprocity calibration systems in two laboratories.

The remaining difference between the two reciprocity calibration systems is only the coupler configurations. Two types of couplers, namely a large-volume coupler used by NMIJ and a plane-wave coupler used by NIMT, are designed based on a different idea. Therefore, the correction factor [2), 9)] to compensate for the difference of the acoustic condition within the respective coupler is different. It seems necessary to perform more detailed studies to solve this problem.

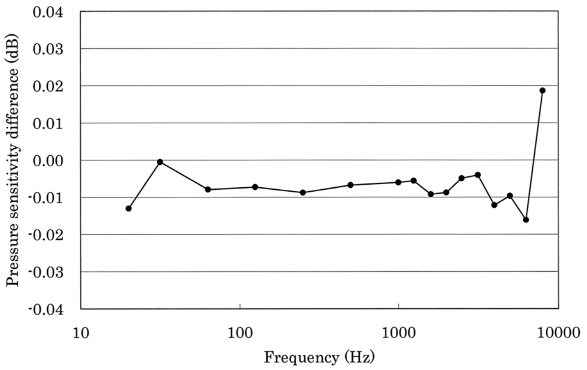

Fig.5 Frequency dependence of pressure sensitivity difference between NMIJ and NIMT by using Brüel & Kjær type 5998 (averaged for microphones A and B). Relative difference from reference pressure sensitivity calibrated by NMIJ by using the type 5998 is shown.

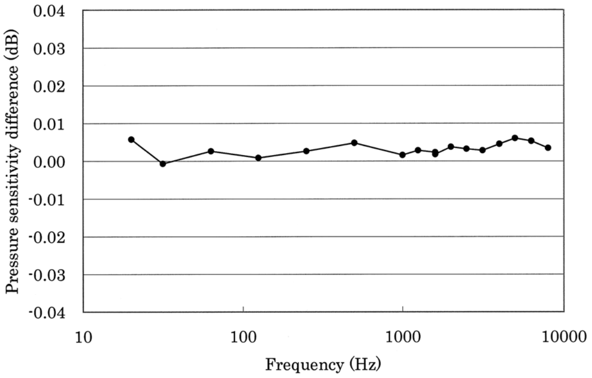

Fig.6 Frequency dependence of pressure sensitivity difference between the NMIJ method and the Brüel & Kjær type 5998. Relative difference from pressure sensitivity measured using the NMIJ method is shown.

5. CONCLUSION

A bilateral comparison was organized by NMIJ as part of a project to accredit NIMT for calibration of the pressure sensitivities of laboratory standard microphones. Calibration results revealed that NIMT could provide a reliable calibration service.

Experimental evidence showed that the two independent measurement systems used by the laboratories did not cause significant difference in the measured pressure sensitivity, and that the small difference was possibly due to the difference in the coupler correction factor used to calculate the pressure sensitivity by the two laboratories. NMIJ is currently further studying this possibility.

Experience gained through this comparison will be valuable for both laboratories when participating in future inter-comparisons planned in the Asia-Pacific Metrology Programme.

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