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Instability of the voltage transfer function for an MR103 microphone in a coupler calibration technique

Ryuzo Horiuchi*, Takeshi Fujimori, Sojun Sato

Acoustics and Ultrasonics Section, Acoustics and Vibration Metrology Division, National Metrology Institute of Japan (NMIJ), AIST Tsukuba Central 2, Tsukuba 305-8568, Japan

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Abstract

MR103 microphones are commonly used laboratory standard microphones in Japan. When the pressure sensitivity of MR103 is calibrated by using a coupler calibration technique, higher accuracy is difficult to achieve due to deviations in the measured voltage transfer function. These deviations are peculiar to MR103, but not to B&K4160, which is also a commonly used laboratory standard microphone throughout the world. Such deviations occur even when the measurements are done consecutively under the same measurement conditions, such as polarization voltage, temperature, and static pressure.

This study experimentally and theoretically considered one of the possible reasons for this deviation. The results reveal that (a) this deviation can be explained by changes in the microphone's parameters, such as the distance between a microphone's membrane and back-plate, and the tension of the membrane, (b) grease used to prevent leakage of gas and sound out of the coupler might be one of the reasons for this deviation, and (c) insertion of polished sapphire spacers between the microphones and the coupler might help diminish this deviation.

1. Introduction

Pressure sensitivities of laboratory standard microphones are calibrated by using an absolute calibration technique called the coupler calibration method [1,2]. In the National Metrology Institute of Japan (NMIJ), the coupler calibration system has been improved to reduce the uncertainty in the calibrated results [3,4]. Measurement uncertainty generated by the electrical circuit composed of an attenuator and amplifiers is reduced in this improved system, and therefore accuracy related to the acoustical pass from a transmitter microphone to a receiver microphone

*Corresponding author.

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through an acoustic coupler can be studied in detail. Using this system, NMIJ has calibrated pressure sensitivities of two types of LS1P microphones, MR103, which is a commonly used type in Japan, and B&K4160, which is also a commonly used type throughout the world [1]. The calibration results show that MR103 has much larger deviation in the measured parameter called the voltage transfer function (VTF) than does B&K4160, even when the measurements are done consecutively under the same measurement conditions, such as polarization voltage, temperature, and static pressure.

In this study, one of the possible reasons for this VTF deviation was investigated and then a solution to diminish this deviation was suggested.

2. Coupler calibration method [4]

The coupler calibration method uses two microphones, one as a transmitter and the other as a receiver, that are set into a large-volume coupler as shown in Fig. 1. These microphones are acoustically connected through a small cavity in the coupler. The large-volume coupler has an advantage of realizing more precise calibration than a plain wave coupler because the corresponding coupler correction value is relatively small [2]. The contacting surfaces between the microphones and the coupler are sealed with grease to prevent leakage of gas and sound out of the cavity. At a higher frequency range, gas in the cavity is exchanged from air to hydrogen to increase the speed of sound within the cavity.

An AC signal is applied to the transmitter, and the VTF between an input terminal of the transmitter microphone A and an output terminal of the receiver microphone B is measured. This VTF, called T_{AB}, is related to the pressure sensitivities of the two microphones as follows:

$$T_{AB} = 20\log\frac{\gamma P C_A K_A K_B}{V}, \tag{1}$$

where γ is the ratio of specific heats of the gas, P is the static pressure, V is the volume of the cavity, C_A is the capacitance of microphone A, and K_A and K_B are pressure sensitivities of microphones A and B, respectively.

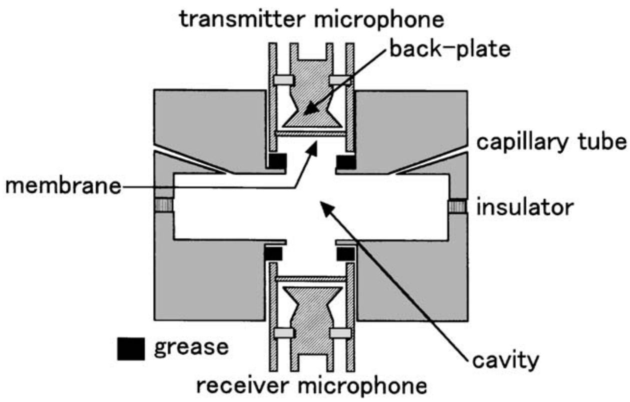

Fig. 1. Schematic of microphones set into a large-volume coupler with grease.

Eq. (1) can be solved for the pressure sensitivities by using a third microphone, C. The VTF is measured for each of the three pairs of transmitters and receivers, namely, (A, B), (A, C), and (B, C), as follows:

$$T_{AC} = 20 \log \frac{\gamma P C_A K_A K_C}{V}, \tag{2}$$

$$T_{BC} = 20 \log \frac{\gamma P C_B K_B K_C}{V}, \tag{3}$$

where C_B is the capacitance of microphone B and K_C is the pressure sensitivity of microphone C. Unknown sensitivities K_A, K_B, and K_C are calculated from Eqs. (1)–(3) as follows:

$$20 \log K_A = \frac{1}{2}(T_{AB} + T_{AC} - T_{BC}) - 10 \log \frac{\gamma P C_B}{V} + 20 \log \frac{C_B}{C_A}, \tag{4}$$

$$20 \log K_B = \frac{1}{2}(T_{AB} - T_{AC} + T_{BC}) - 10 \log \frac{\gamma P C_B}{V}, \tag{5}$$

$$20 \log K_C = \frac{1}{2}(-T_{AB} + T_{AC} + T_{BC}) - 10 \log \frac{\gamma P C_B}{V}. \tag{6}$$

To calibrate K_A, K_B, and K_C precisely, each VTF must be measured with high accuracy. Therefore, in this study, a possible reason for the deviation in the VTF was examined.

3. Coupler calibration system [3,4]

Fig. 2 shows the coupler calibration system for measuring the VTF by using an insert voltage technique [2]. The system was designed to reduce the electrical noise and the cross-talk. The noise

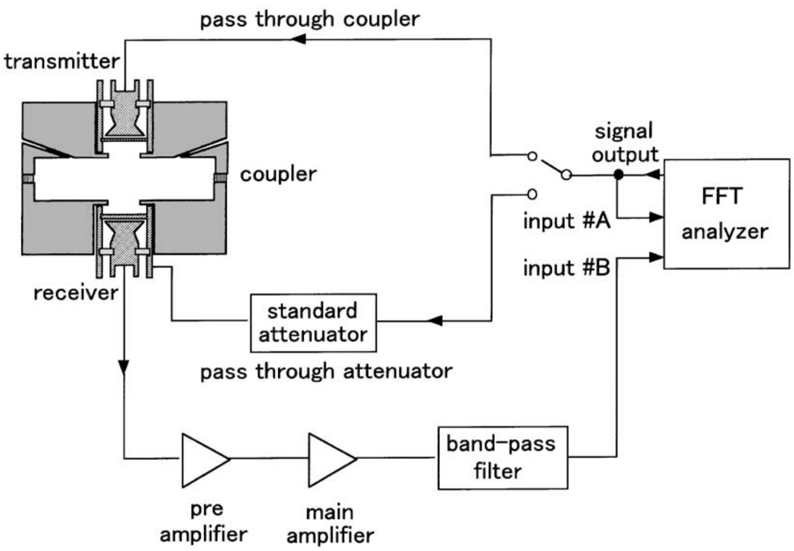

Fig. 2. Schematic of a coupler calibration system.

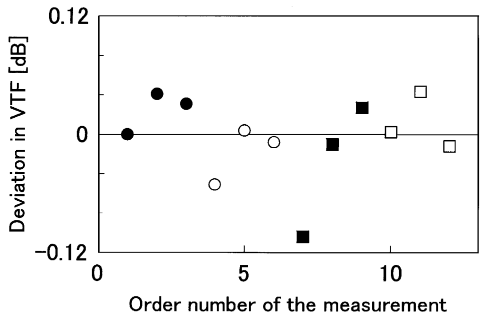

Fig. 3. Deviation in VTF. Each set of symbols corresponds to a different measurement day.

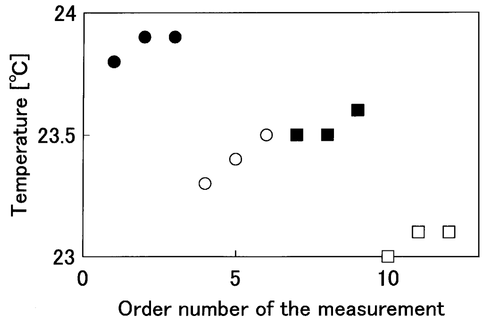

Fig. 4. Fluctuation in room temperature. Each set of symbols corresponds to a different measurement day.

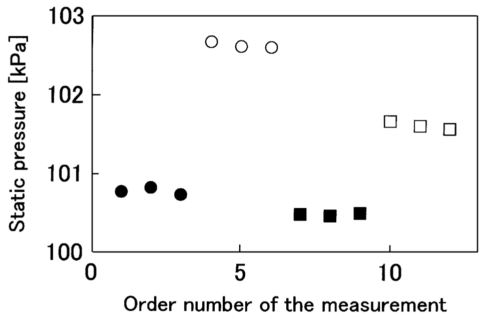

Fig. 5. Fluctuation of static pressure. Each set of symbols corresponds to a different measurement day.

is mainly due to the thermal noise of the input resistance of a pre-amplifier and the cross-talk is chiefly due to a signal bypassing the ground loop. The signal-to-noise ratio was significantly improved by using a synchronous averaging technique in an FFT analyzer and the cross-talk was also reduced by careful design of the electrical circuit.

In this system, measurement uncertainty related to the electrical circuit was less than 0.003 dB for a frequency range between 50 Hz and 20 kHz.

4. Deviation in VTF

The VTF measurements were done as follows using MR103 as a type LS1P microphone. For the LS1P microphone calibration, a large-volume coupler (19.62 cm^3) filled with air was used. A 1012.5 Hz sine wave with a peak amplitude of 1 V was applied to the transmitter. This frequency was selected to exclude the measurement uncertainty caused by the use of hydrogen and by the harmonics of the power supply. When the signal was detected in the FFT analyzer, the sampling frequency was set to 5.12 kHz; the number of sampling points was 4096 and the average number of signals was 60.

A pair of MR103 microphones was used to detect the deviation in the VTF. As shown in Fig. 3, the VTF was measured three times a day for four different days during a 1-month period. The horizontal axis is the order number of the measurement, and the vertical axis is the difference in VTF from the first measured VTF value. Because the temperature and static pressure of the laboratory fluctuated ($\pm 0.5^\circ C$ and ± 1.5 kPa, respectively), the measured VTF was corrected to the reference environmental conditions ($23^\circ C$ and 101.325 kPa) by using the temperature and pressure coefficients of the pressure sensitivity. The corrected VTF deviation was within a range of ± 0.1 dB (Fig. 3) and was independent of fluctuations in temperature and static pressure (compare Figs. 4 and 5 with Fig. 3).

Such deviation is peculiar to MR103 but not to B&K4160. Here, MR103 was examined to explore the possible reasons for this VTF deviation.

5. Instability of a microphone

A possible reason for VTF deviation was evaluated by measuring the frequency dependence of this deviation, in the high-frequency range between 1.5 and 8 kHz, and by using hydrogen within the large-volume coupler [2]. Increase in the measurement uncertainty caused by using hydrogen was assumed negligible. The test signal was a multi-sine wave composed of eight frequencies: 1512.5, 2012.5, 2512.5, 3162.5, 4012.5, 5012.5, 6312.5, and 8012.5 Hz. When the FFT analyzer detected the signal, the sampling frequency was set to 51.2 kHz; the number of sampling points was 4096 and the average number of signals was 200.

Before the measurement, the microphones were set into the coupler and left untouched for about 2 h to allow the system to reach thermal equilibrium (during handling, heat from the operator's hands is inevitably transferred to the microphones and the coupler). In this frequency range, such careful treatment is necessary because the temperature coefficient of the pressure sensitivity is relatively high. The measurements were repeated five times during a 1-month period.

Fig. 6 shows the frequency dependence of the deviation in the VTF (corrected for fluctuations in room temperature and static pressure), indicating relative differences from a reference VTF value. This reference was one of the five measured VTF values. This specific value was chosen as the reference because it showed simpler frequency dependence of the VTF deviation than the others. The deviations can be classified into three types: (1) deviations that changed sign at around 3.5 kHz as the frequency increased (marked as ● and □), (2) deviation that decreased as the frequency increased and finally reached zero at about 8 kHz (▲), and (3) deviation that was relatively independent of frequency (except at 8 kHz), compared with the other two types (■).

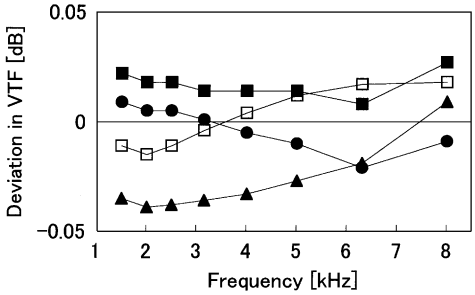

Fig. 6. Frequency dependence of deviation in VTF. Each deviation is a relative difference from one of the five measured VTF values. Each set of symbols corresponds to a different measurement.

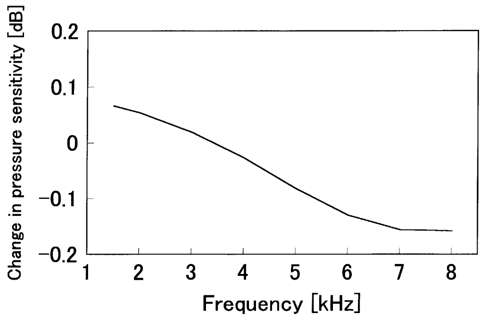

Fig. 7. Theoretical dependence of pressure sensitivity on the distance d between a microphone's membrane and back-plate. d is decreased by 1% from 20 μm.

The first and second types of deviations are possibly related to changes in the microphone's parameters; the first type to changes in the distance d between a microphone's membrane and back-plate, and the second to the tension T of the membrane. The theoretical dependence of the pressure sensitivity of the microphone on the microphone parameters d and T was calculated [5] and compared with the experimental deviation, as discussed in the next two sections (Sections 5.1 and 5.2). For the third type of deviation, further study is needed to determine the possible reasons.

5.1. *Effect of distance d on pressure sensitivity*

Fig. 7 shows the theoretical change [5] in pressure sensitivity when d is decreased by 1% from 20 to 19.8 μm. The sign of the change reverses at about 3.5 kHz, and the frequency dependence of the theoretical change in pressure sensitivity was similar to the first type of experimental deviations (● and □) shown in Fig. 6.

5.2. *Effect of tension T on pressure sensitivity*

The relationship between T and resonance angular frequency of the membrane ω_0 is as follows:

$$\omega_0^2 = \frac{j_{01}^2 T}{b^2 \sigma}, \tag{7}$$

where j_{01} is the zero point of a Bessel function, b is the radius of the membrane, and σ is its surface density. If the change in T is ΔT, then the change in ω_0 is $\Delta\omega_0$, defined as

$$\frac{\Delta\omega_0}{\omega_0} = \frac{1}{2}\frac{\Delta T}{T}. \tag{8}$$

Fig. 8 shows the theoretical change [5] in pressure sensitivity when T is increased by 0.6% from 2.9×10^3 N/m and ω_0 by 0.3% from 8000 Hz. The frequency dependence of the theoretical change in pressure sensitivity was similar to the deviation in the second type of experimental deviation (▲) shown in Fig. 6.

5.3. Correction of VTF

The frequency dependence of the first type of VTF deviation (● and □) shown in Fig. 6 was corrected by estimating the changes in d (+0.03 for data ● and −0.01 μm for data □), and that of the second type of deviation (▲) by estimating ΔT and $\Delta\omega_0$ (0.02×10^3 N/m and 20 Hz, respectively). No correction was made for the data marked as ■.

As a result of these corrections, both the frequency dependence of the VTF deviation and the VTF deviation itself significantly decreased, as shown in Fig. 9. This suggests that the VTF deviation might result in changes in the microphone parameters d and T (Fig. 6–9).

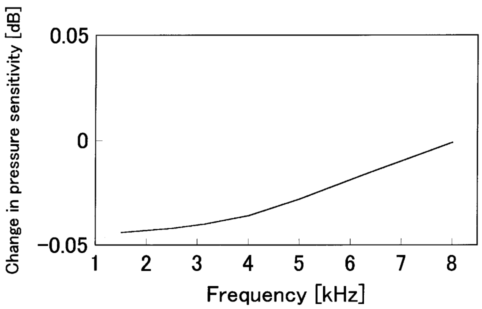

Fig. 8. Theoretical dependence of pressure sensitivity on tension T and resonance angular frequency ω_0 of a microphone's membrane. T is increased by 0.6% from 2.9×10^3 N/m and ω_0 by 0.3% from 8000 Hz.

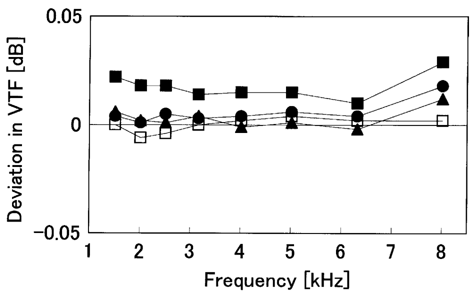

Fig. 9. Frequency dependence of deviation in VTF shown in Fig. 6, after VTF was corrected for changes in d, T, and ω_0.

6. Forces acting on a microphone

A change in d also causes a change in the microphone's capacitance. Therefore, one of the possible reasons for the VTF deviation related to the change in d was evaluated by measuring the deviation in the capacitance of the transmitter microphone.

6.1. Deviation in capacitance

First, an applied polarization voltage as an external force was examined to determine if it causes the deviation in the capacitance. In the capacitance measurement, the test signal was a 1012.5 Hz sine wave and the gas in the coupler was air. After two microphones were set into the coupler, three consecutive measurements were made with the polarization voltage off, on, and then off again, respectively. After these three measurements, both the microphones were completely removed from the coupler and then set into it again. This procedure was repeated 12 times over a 2-day period. Fig. 10 shows the deviation in the capacitance, indicating relative difference from the first measured capacitance values with the polarization voltage on and off. The uncertainty in the capacitance measurement was within 0.002 dB. The deviation was independent of the application of the polarization voltage, and therefore this applied voltage cannot be a cause of the capacitance deviation. (Fig. 10 does not indicate that the deviation with the polarization voltage on (marked as ○) was larger than that with the polarization voltage off (●) because each reference capacitance value was different.)

Then, the deviation in the capacitance was measured using the same procedure except that no grease was used when the microphones were set into the coupler. Comparison between the capacitance deviation with grease (Fig. 10) and without grease (Fig. 11) suggests that the use of grease is a possible cause of the capacitance deviation.

Finally, based on these results, the VTF was measured again, using the same procedure as described in Section 4, except without grease. The VTF was measured 12 times over a 4-day period. Comparison between the VTF deviation with grease (Fig. 3) and without grease (Fig. 12) suggests that grease is one of the causes of the VTF deviation.

6.2. Effect of polished sapphire spacers on deviation in capacitance

As described in Section 2, grease is indispensable for the microphone calibration. To possibly improve the measurement procedure, two polished sapphire spacers (1 mm thickness) shaped

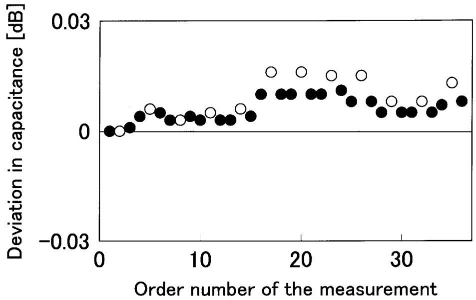

Fig. 10. Deviation in the capacitance of the transmitter with grease and with polarization voltage off (●) and on (○).

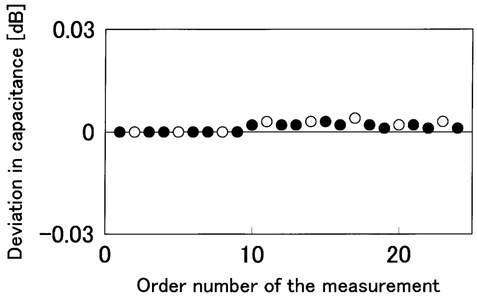

Fig. 11. Deviation in the capacitance of the transmitter without grease and with polarization voltage off (●) and on (○).

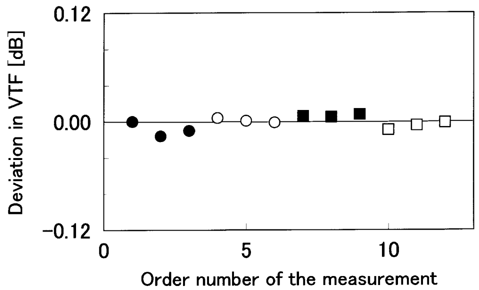

Fig. 12. Deviation in VTF without grease. Each set of symbols corresponds to a different measurement day.

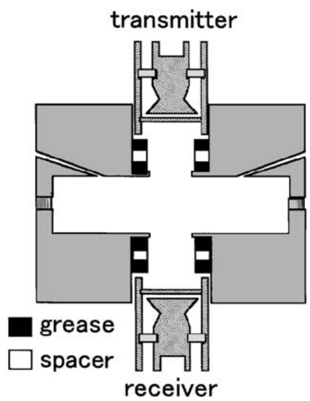

Fig. 13. Schematic of microphones set into a coupler with polished sapphire spacers and grease.

like washers were inserted between the contacting surfaces of the microphones and the coupler (Fig. 13).

The deviation in the capacitance was alternately measured with and without spacers. Based on the results discussed in Section 6.1, polarization voltage was not applied and grease was used between the microphones and the coupler.

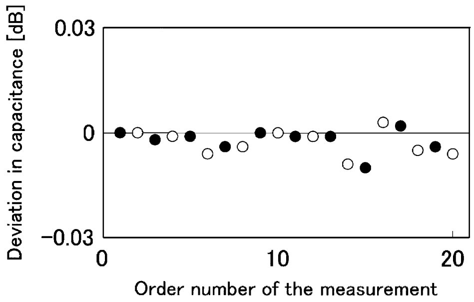

Fig. 14. Deviation in the capacitance of the transmitter with grease and without polarization voltage, with spacers (●) and without spacers (○).

Fig. 14 shows the measured capacitance deviation from the first measured capacitance values, with and without spacers. Observing the relative difference between two consecutive measurements, especially the three differences between 13th ● and 14th ○, 15th ● and 16th ○, and 17th ● and 18th ○, were greater than the others. These results imply that the deviation occurs when ○ data were measured, namely, when microphones were set into the coupler directly without spacers. On the contrary, such deviations could not be seen when ● data were measured, namely when microphones were set into the coupler with spacers. These results suggest that using polished sapphire spacers might decrease the deviation in the capacitance (Fig. 10–14).

7. Conclusion

This study examined one of the reasons for the deviation in the voltage transfer function of MR103 pair. Experimental and theoretical results suggested that (a) this deviation can be explained by changes in the microphone's parameters, such as the distance d between a microphone's membrane and back-plate, and the tension T of the membrane, (b) grease, which is used to seal the contacting surfaces between the microphones and the coupler, might be one reason for this deviation, and (c) inserting polished sapphire spacers between the microphones and the coupler might help diminish this deviation.

This study especially examined a possible reason and solution for the VTF deviation related to the change in d. Future study will include determining the cause related to the change in T.

The use of grease seems related to the deformation of the microphones because both MR103 and the coupler are made of titanium and their contacting surfaces are not polished sufficiently. Therefore, when MR103 is set into the coupler with grease, MR103 might be scraped against the coupler, thus changing its acoustic characteristics. VTF deviation is peculiar to MR103, but not to B&K4160, whose housing is gold-plated. Despite MR103 having the drawback of VTF deviation, pressure calibration of MR103 is an essential work requested by customers.

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