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An acoustic impedance measurement technique using one cardioid microphone in a tube

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Abstract

The mechanism of a cardioid microphone is recognized as the combination of a sealed (omnidirectional) and an open (figure-eight) microphone. The sealed and open microphones can obtain the signal of sound pressure and particle velocity, respectively. Therefore, the specific acoustic impedance, defined as the ratio of sound pressure to particle velocity, could be obtained from the multiple signals measured by cardioid microphones. To take advantage of this, we tried to measure the impedance of absorptive material in a tube. Prior to performing the aforementioned measurement, the characteristics of a cardioid microphone—the gain ratio of sound pressure to particle velocity—were measured in the tube that had a rigid terminal. The obtained characteristics were used as corrective values for the impedance measurement. Subsequently, an absorptive material was installed in that tube and the signals were measured twice using the cardioid microphone. The impedance was calculated from the obtained signals and the corrective values. Compared to the conventional transfer function method, it was also measured using two omnidirectional microphones. Different lengths of impedance tubes were also used for verification. As a result, the impedance values obtained from the cardioid microphone showed good agreement with those from the transfer function method at the whole frequencies in any tubes.

Keywords: cardioid microphone, absorption coefficient, impedance measurement.

1 Introduction

The PU-Probe produced by Microflown [1] is widely known as a sensor of sound pressure and particle velocity. This sensor is of significant value to sound intensity or acoustic impedance measurement. On the other hand, some reports—the PU sensor is affected by temperature and humidity [2, 3] and needs calibration on each measurement day [4, 5]— suggested that this sensor is significantly sensitive.
The goal of this study is to develop a new robust sensor of sound pressure and particle velocity using a pair of cardioid microphones. We reported in the past that the possibility of in-situ measurement and normal impedance acoustic impedance measurement in a tube using cardioid microphones [6–8]. It is revealed that the characteristics of a cardioid microphone—the gain ratio of sound pressure to particle velocity— must be obtained as the correction factor before impedance measurements [9].
It has not however been known that the correction factor can be obtained from any tubes. Therefore, the correction factors of three cardioid microphones were measured using two different lengths of impedance tubes for verification. Additionally, the absorption coefficient of material was measured to check the effect of these

correction factors. This paper explains the basic theory of how to measure reports these results mentioned above.

2 Basic theory

2.1 Surface impedance measurement using a cardioid microphone in a tube

The measurement condition is shown in Figure 1. The signal $M^{+}(x)$ is recorded at position x with the directivity of a cardioid microphone heading to the specimen, and the signal $M^{-}(x)$ is done with directivity heading to the loudspeaker (180 degrees opposite from the specimen). The receiving signals consist of both sound pressure and sound velocity, so that receiving signals M^{+} and M^{-} are described with complex constant α, β as followings:

$$M^{+}(x) = \alpha\, p(x) - \beta\, \rho c\, u_x(x), \tag{1}$$

$$M^{-}(x) = \alpha\, p(x) + \beta\, \rho c\, u_x(x). \tag{2}$$

Thus, the spacific impedance Z at position x equals

$$Z(x) = \frac{p(x)}{u_x(x)} = \frac{M^{+}+M^{-}}{M^{-}-M^{+}} \cdot \frac{\beta}{\alpha} \cdot \rho c. \tag{3}$$

Therefore, the reflection coefficient r is expressed with the distance l from the microphone position to the specimen:

$$r = \frac{Z(x)-\rho c}{Z(x)+\rho c}\, e^{2jkl}. \tag{4}$$

The surface impedance $Z(L)$ can be obtained as following:

$$Z(L) = \rho c \frac{1+r}{1-r}. \tag{5}$$

The value of β/α in Equation (3) is necessary to obtain the surface impedance. We named β/α as the correction factor. The correction factor is microphone-specific value.

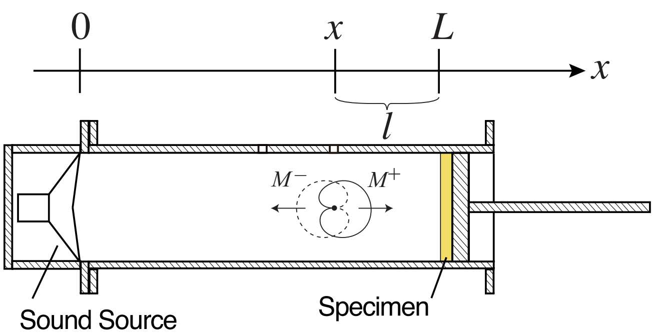

Figure 1 – Impedance measurement setting in a tube.

2.2 Correction factor β/α

The impedance tube which has a rigid terminal, shown in Figure 2, is used to obtain the correction factor β/α of a cardioid microphone. Sound pressure and particle velocity at the position x in a tube are expressed as

$$p(x) = A\left(e^{-jkx} + e^{jk(x-2L)}\right), \quad (6)$$

$$u_x(x) = \frac{A}{\rho c}\left(e^{-jkx} - e^{jk(x-2L)}\right). \quad (7)$$

The specific impedance $Z(x)$ at the position x is also expressed as

$$Z(x) = \frac{p(x)}{u_x(x)} = -j\,\rho c\,\frac{\cos(kl)}{\sin(kl)}. \quad (8)$$

The correction factor β/α is calcurated from Equations (3) and (8):

$$\frac{\beta}{\alpha} = -j\,\frac{(M^- - M^+)}{(M^+ + M^-)}\,\frac{\cos(kl)}{\sin(kl)}. \quad (9)$$

Equation (9) tells us that the correction factor can be obtain form two recorded signals M^+ and M^- in a tube which has a rigid terminal and that the upper limit frequency is decided according to $l < \lambda/4$.

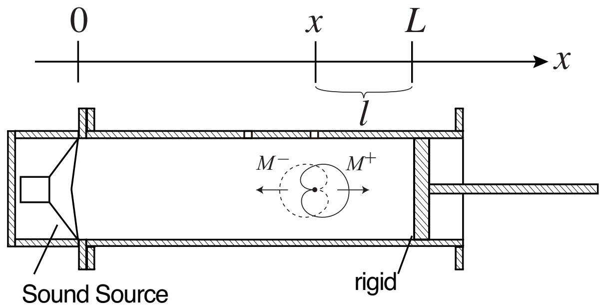

Figure 2 – Measurement setting of correction factor in a tube.

3 Measurement of correction factor β/α

There is no proof that the proper correction factors can be obtained from any tubes. Therefore, a verify test was conducted with three cardioid microphones and two impedance tubes.

3.1 Test condition

Three cardioid microphones ISOMAX-IIC produced by Countryman (CM_A, CM_B, and CM_C) and two wooden impedance tubes (long tube and short tube) which have 100 mm squared sections and different lengths were ready for the test. The specifications and test conditions of the impedance tube are shown in Figure 2 and Table 1. The target frequency range is from 140 to 1275 Hz. The distance l from the microphone position to the rigid terminal edge was varied according to frequency (Hz) to keep $l < \lambda/4$. Pinknoise were exposed from the loudspeaker for about 30 seconds and were recorded twice to obtain M^+ and M^- with 24bit/48kHz sampling. The recorded signals were calculated every 16384 data (about 0.34 seconds) and the window were shifted with 8192 data (half overlap). The calculation results were averaged in the frequency domain.

Table 1 – Specification and measurement condition of two tubes.

	Material	Section shape	Thick (mm)	Target frequency (Hz)	Entire length (mm)	Distance *x* (mm)	Distance *l* (mm)
Long tube	MDF board	100×100 mm squared	15	140 – 1275	1050	900	120 ($f \leq 500$ Hz) 60 ($500 < f \leq 1000$ Hz) 30 ($f > 1000$ Hz).
Short tube					900	570	120 ($f \leq 500$ Hz), 30 ($f > 500$ Hz)

3.2 Results

The measurement results of correction factor β/α are shown in Figure 3, 4, and 5. The left figure shows the ratio of amplitude (ideal value: 1.0) and the right figure shows the phase difference (ideal value: 0.0) in each figure. As these figures indicate, the values of the long tube and the short tube were almost the same throughout the frequency range. It was found from the results that the correction factors can be obtained from any tube. See the detail of these figures, two lines were separated from 700 Hz in the amplitude figures and separated from 400 Hz in the phase figures. We could not judge which line was better at this stage. This judgment was postponed to the next session.

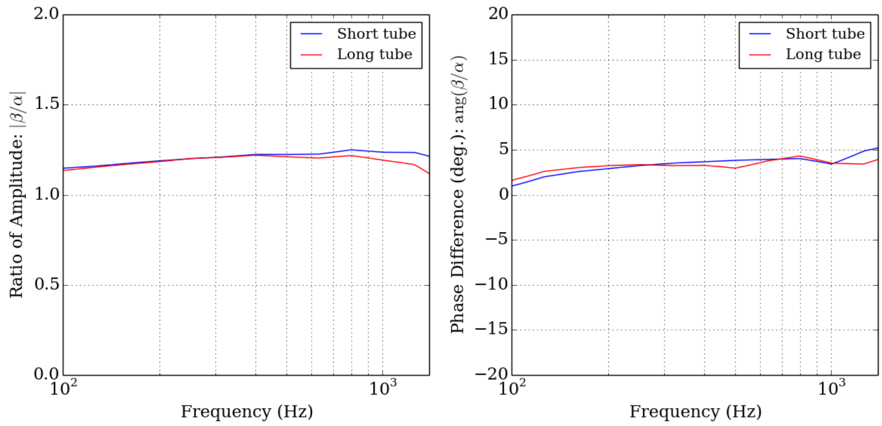

Figure 3 – Correction factor of cardioid microphone CM_A.

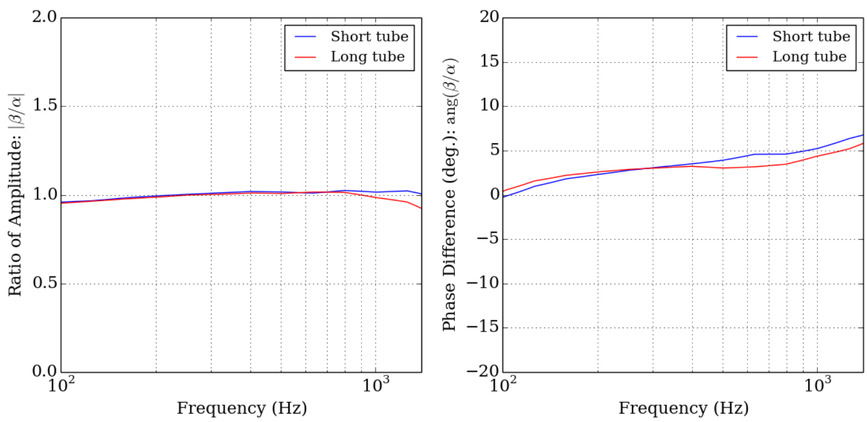

Figure 4 – Correction factor of cardioid microphone CM_B.

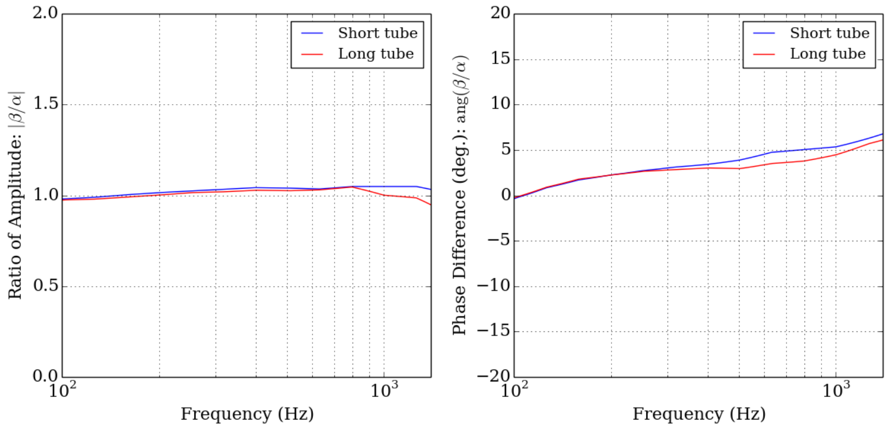

Figure 5 – Correction factor of cardioid microphone CM_C.

4 Impedance measurement with correction factor β/α

The impedance measurement of glass wool (50 mm thick, 32 kg/m^3 density) was conducted using these three cardioid microphones, two omnidirectional ones, and the long tube.

4.1 Measurement condition

Three cardioid microphones ISOMAX-IIC produced by Countryman (CM_A, CM_B, and CM_C) and two 1/2-in. class 1 omni-directional microphones MI-1231 + MI-3110 produced by ONO-SOKKI were ready for the test. The distance l was changed into 60, 180, and 240 mm (three patterns) when the cardioid microphones were used. The omnidirectional microphones were used to obtain the reference data according to the transfer function method (ISO10534-2 [10]). The long tube shown in Table 1 were chosen for the test. The detail of microphone position and the distances are shown in Table 2.

Table 2 – Microphone types and conditions for impedance measurement.

Microphone type	Distance *x* (mm)	Distance *l* (mm)	Distance of two mics. (mm)
Cardioid (CM_A, CM_B, CM_C)	570	60, 180, 240	-
Omnidirectional	570	60	120

4.2 Results

The measurement results are shown in Figure 5 and 6. Figure 5 consists of nine figures; the left three figures show the result of three cardioid microphones without correction data and that of omnidirectional microphones (PP, transfer function method). These figures indicated that the data of cardioid microphones are essential to be corrected. Three figures of the centerline show the corrected results of cardioid microphones with the correction factor from the long tube. Three figures on the right line show the corrected data from the short tube. The corrected results of cardioid microphones converged on the omnidirectional microphone line from about 200 Hz to 1400 Hz. These six figures indicated that both correction factors from the long tube and short one worked to good advantage at any distance *l* and any cardioid microphones. Focusing on over 800 Hz, the results of the short tube are a little more fitting than that of the long one. From the point of view of easy and stable measurement, the short tube may be better to obtain a correction factor.

Figure 6 shows nine (3 distances × 3 cardioid microphones) corrected results and the results of omnidirectional microphones. All results display with 1/3 octave band data. The error bars represent the standard deviation. The maximum difference between the value of the cardioid microphone and the omnidirectional microphone is 0.047 at 160 Hz. The maximum difference between two cardioid microphones is 0.007 at 160 Hz. The maximum standard deviation is 0.027 at 200 Hz. From this result, the absorption coefficient can be measured using a cardioid microphone and the correction factor of the microphone with any length of the tube is essential for correct measurement.

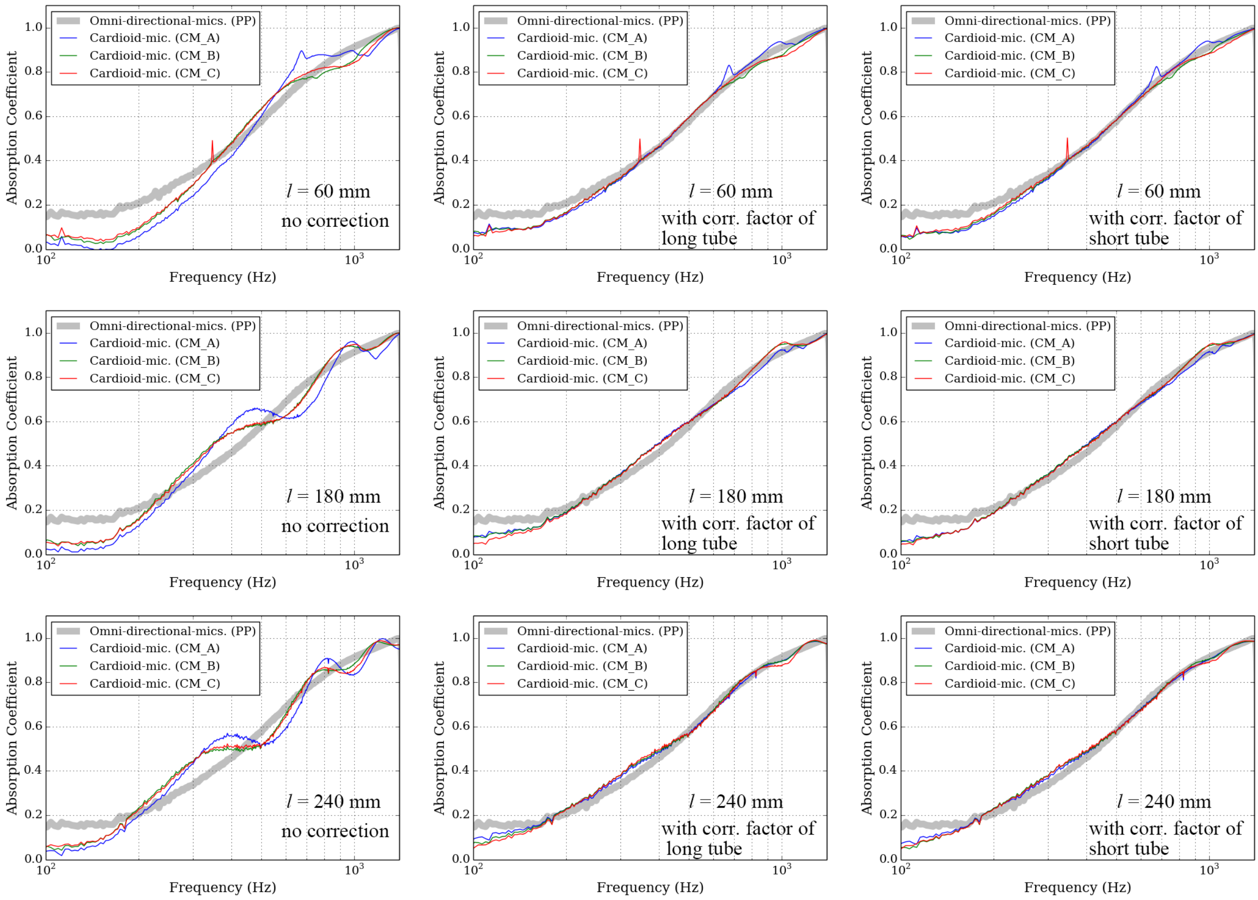

Figure 5 – Measurement results of absorption coefficient of 50-mm-thick glass-wool.

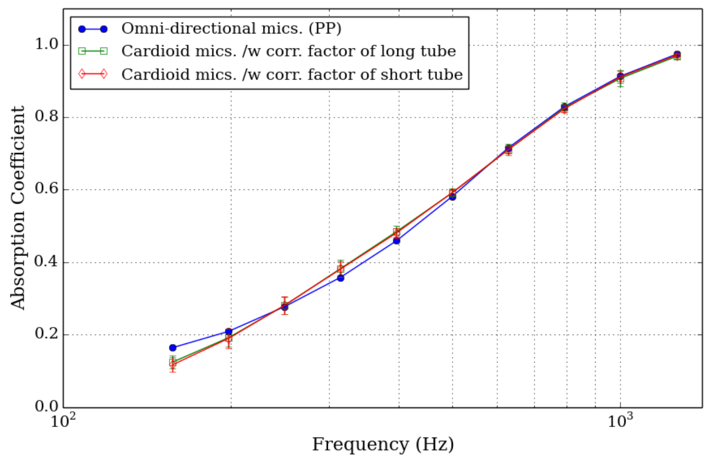

Figure 6 – Measurement results of absorption coefficient in 1/3 octave band.

5 Conclusions

To measure the acoustic impedance of material using one cardioid microphone, the correction factor β/α (complex gain ratio of sound pressure to particle velocity) of the microphone is necessary. However, it is doubtful that the correction factor β/α can be obtained from any impedance tubes. Therefore, the two different lengths of impedance tubes and three cardioid microphones (CM_A, CM_B, and CM_C) were used for verification. The almost same values of correction factor were obtained from the two tubes. The impedance measurement using three cardioid microphones was conducted to check the effect of correction factors. The results indicated that both correction factors of the long tube and short one worked well in any distance l from the microphone position to a specimen. The difference of absorption coefficient using cardioid microphones and omnidirectional microphones was less than 0.05 and the value of the cardioid microphone was stable (standard deviation was less than 0.03) with any correction factor throughout the target frequency.

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