COMPARISON OF THE METHODS TO CALIBRATE THE DIFFUSE FIELD SENSITIVITY OF LABORATORY STANDARD MICROPHONE

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Sensitivity of microphone is depended on the types of sound field. In case of the pressure and free-field condition, the method for the primary calibration of laboratory standard microphone is defined in IEC standards. However, the measurement standard to calibrate the diffuse field sensitivity is still not established. Two different methods, the reciprocity calibration in a reverberation chamber and the random incidence sensitivity measurement based on the directivity measurement had been proposed to calibrate the diffuse field sensitivity of microphone. In this study, these two different approaches are compared and investigate the detailed method to achieve stable and repeatable results. To this end, a scaled-reverberation chamber having un-parallel surfaces is designed for the reciprocity calibration and the directivity measurement system is designed for the random incidence sensitivity measurement. Commonly, both approaches are to implement sound field satisfying the definition of diffuse field and the results obtained by both methods should be same, in principle. Therefore, the difference between the results of two methods comes from the imperfection of field condition. For the reciprocity method with reverberation chamber, the method to improve diffusivity is investigated by increasing the reverberation time. For the directivity measurement, the effect of wave front shape is investigated to observe the difference from the ideal case of plane wave assumption in the definition of diffuse field.
Keywords: diffuse field sensitivity, standard microphone, random incidence sensitivity

1. Introduction

The primary standard of sound pressure is based on the sensitivity of laboratory standard microphone. The sensitivity of microphone is depended on the types of sound field. One of the representative classifications of sound field is the pressure field, free-field and diffuse field. In case of the pressure field and free-field sensitivity, the primary standard to determine the microphone sensitivity is defined in the IEC standards [1, 2]. However, the method to measure the diffuse-field sensitivity is not standardized yet.

As a parameter to define the characteristics of microphone, the pressure sensitivity is most widely used because of its stability. However, the pressure sound field is not usual condition in living environments. Most of practical situations, the sound fields in living environments are placed in between the free-field (outdoor) and diffuse-field (indoor). From this reason, the establishment of the measurement system for the free-field sensitivity has been progressed by several national metrology institutes. However, the propagation on the diffuse-field sensitivity is still limited.

Two types of methods were suggested to measure the diffuse field sensitivity. One is the reciprocity method in the small reverberation chamber [3, 4] and another is the random incidence sensitivity measurement based on the directivity measurement [5]. In this study, these two different approaches are compared and investigate the detailed method to achieve stable and repeatable results.

2. Method

In general, the definition of diffuse sound field is given by the sound field having equal probability of energy flow in all direction and the energy density is uniform in a volume [6, 7]. Based on these definitions, two different methods, the reciprocity method and the random incidence sensitivity method, were suggested to measure the diffuse field sensitivity.

2.1 Diffuse Field Sensitivity Measurement by Reciprocity Method

As a test facility to implement the diffuse field condition, the reverberation chamber is usually employed. The condition of qualified reverberation chamber is defined in the ISO Standard [8]. One of the important characteristics of diffuse field is uniform distribution of sound pressure level. From this reason, the sound pressure deviation in the chamber is observed as the specification of field.

In the diffuse field condition, the sensitivity of microphone can be estimated by the reciprocity relation as follows [3]

$$M_{d,1} = \sqrt{\frac{Z_{12}Z_{13}}{Z_{23}}\frac{J_{d12}J_{d13}}{J_{d23}}}. \tag{1}$$

Here, Z_{xy} means the electrical transfer impedance between two microphones, and J_d is called the reciprocity factor given by [3]

$$J_d = \sqrt{\frac{6}{\pi \log_{10} e}}\left(\frac{1}{\rho_0 f}\right)\sqrt{\frac{V}{cT_{60}}}, \tag{2}$$

where ρ_0 is the density of air, f is the frequency, c is the speed of sound, T_{60} is the Sabine reverberation time, and V is the volume of chamber.

To obtain the uniform distribution of sound pressure at low frequency range, the large volume of chamber is required. However, the sound power radiate from the microphone as a source is not sufficient to excite the full-scaled reverberation chamber used to measure the sound absorption and insulation. Therefore, the measurement in a full-scaled reverberation chamber has very large uncertainty [9]. From this reason, the scaled-reverberation chamber which the volume is about 2 m^3 were used [3, 4] as an alternative.

2.2 Random Incidence Sensitivity

One more important characteristics of diffuse field is uniform probability of wave incoming from whole direction. In terms of this characteristics, the diffuse field can be defined by the field consists of infinite number of plane waves with random phase from uniformly distributed direction [6]. With this definition, the superposition of plane wave having same power can make the same condition to the diffuse field [5]. Therefore, the diffuse field sensitivity can be converted into the summation of the directional response along the whole direction and it can be described by the directivity index of microphone as follows

$$M_d(f) = M_p(f) + RI_{cor}(f), \tag{3a}$$

$$\text{where } RI_{cor}(f) = FF_{cor}(f) - DI(f),$$

$$M_d(f) = M_f(f) - DI(f). \tag{3b}$$

where M_p is the pressure sensitivity of microphone, FF_{cor} is the free-field correction factor, DI means the directivity index and the M_f is the free-field sensitivity of microphone.

3. Measurement Result

3.1 Diffuse Field Sensitivity Measurement by Reciprocity Method

To apply the reciprocity method, the scaled reverberation chamber is designed as Fig. 1. The volume of chamber is 2.8 m^3 and each wall has un-parallel surfaces to the others. The inside wall of chamber is made by aluminium and the measured reverberation time is shown in Fig. 2. The transmission loos of the chamber is about 35 ~ 40 dB for the 0.1 ~ 10 kHz range.

Figure 3 shows the data acquisition system to measure the electrical transfer impedance. The basic configuration is same to the system for the free-field calibration system [2]. The steady-state response is measured by the system and the results are averaged on the 10 independent combination of position for the transmitter and microphone.

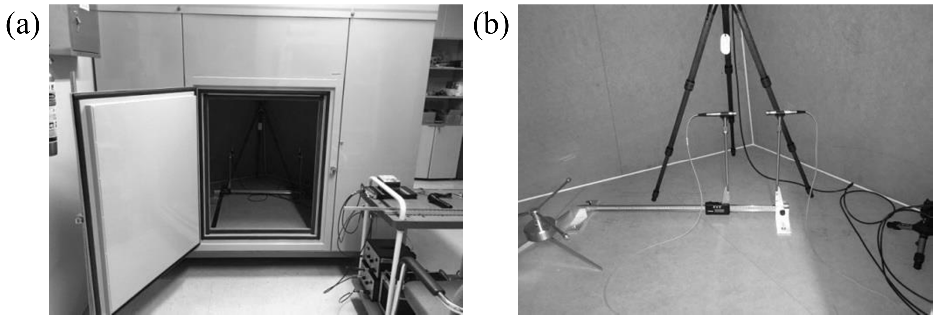

Figure 1: (a) The scaled reverberation chamber, (b) inside of chamber.

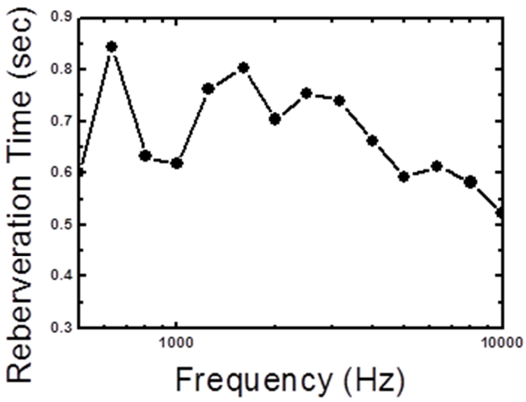

Figure 2: Measured reverberation time of the scaled reverberation chamber.

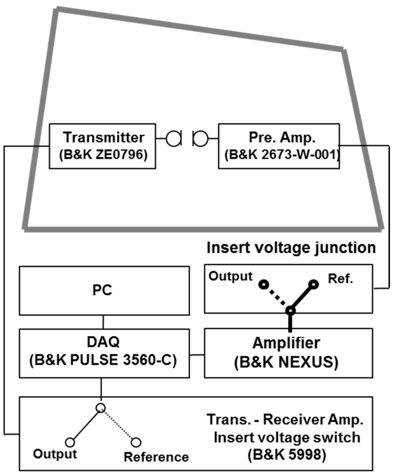

Figure 3: Configuration of measurement system for the reciprocity method.

3.2 Random Incidence Sensitivity Measurement

To measure the random incidence sensitivity of microphone, the directivity measurement system is designed as shown in Fig.4. Basically, the fundamental system configuration is similar to the set-up to the free-field calibration by comparison method [10] and the rotator is added to change the arrival directional of wave front. The microphone diaphragm position is adjusted at the centre of rotating axis. To minimize the effect of reflection induced by structures, the rod supporting the microphone is hanging on the rotator by wire. As a sound source, the omni-directional source is placed at the 3 m distance from the microphone. To monitor the deviation of source level, the monitor microphone is placed at the front of the loudspeaker. Figure 5 shows the measurement system installed in the anechoic chamber. The responses are measured along the half circle with 5^{o} spacing and the directivity index is estimated with these directional responses.

The measured directivity index of LS1 and LS2 microphones are shown in Fig. 6. In case of LS1 microphone, the measured value of 3 different microphones are averaged and 6 for LS2 microphones. Because the directivity is closely related to its geometrical shape and design, the deviation between same types of microphones is relatively small. Here, the major cause of deviation between same types of microphone and fluctuation according to frequency is the instability of supporting structure of microphone and rotator. If the data is collected with the sufficient number of samples by using the stabilized system, the directivity index can be used as the diffuse-field correction factor, as similar to the free-field correction [11].

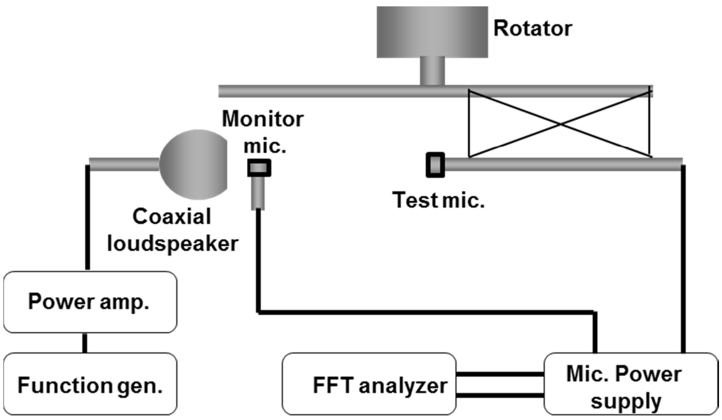

Figure 4: Basic configuration of the measurement system for the random incidence sensitivity of microphone:

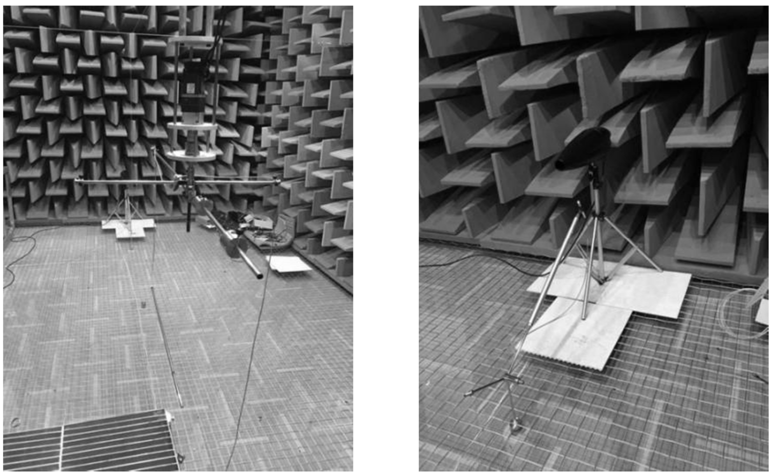

Figure 5: Measurement system for the random incidence sensitivity of microphone: (a) microphone rotator, (b) omni-directional sound source.

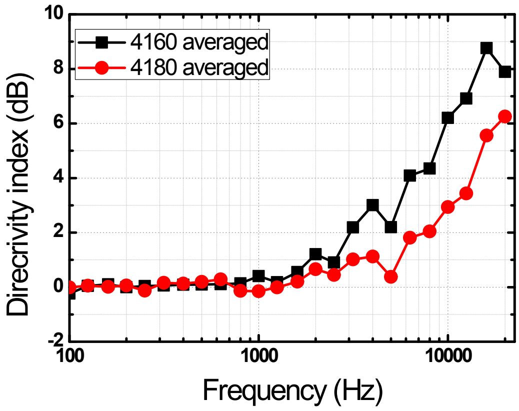

Figure 6: Measured directivity index.

3.3 Result Comparison and Discussion

The measured sensitivities of the LS2 microphones are compared in Fig. 7. The pressure sensitivity is measured by the reciprocity method [1] and the free-field sensitivity is estimated with the free-field correction factor [11]. In case of the random incidence method, the directivity index of individual microphone is applied to estimation.

In this result, it is observed that the both results of diffuse-field sensitivity estimated by the different methods are placed in between the pressure and free-field sensitivity. This is reasonable result because the pressure type microphone including LS microphone has the highest sensitivity at the frontal direction. In principle, both results have to show same results if the condition of sound field is successfully implemented satisfying the condition of diffuse field. Although, the scaled reverberation chamber is applied, it is still difficult to achieve the uniformly distributed sound pressure and the large number of measurement is needed for sufficient averaging. To overcome the small sound power of source and reduce the required number of measurement points, the diffusivity inside of chamber should be increased and it can be achieved by increasing the reverberation time with diffusers [4]. Moreover, the method to estimate the representative value of reverberation time and the volume of irregular shaped chamber should be considered to remove the bias of measured value.

In case of the random incidence sensitivity measurement, the mechanical instability of measurement system is mentioned as an important cause of error. Another cause making difference from the exact definition of diffuse field is the assumption of plane wave incidence. Actually, to obtain the plane wave front, the distance of source should be large and the directional characteristics of source also become a problem especially in the high frequency region. From this reason, an investigation on the method to compensate with the other types of general wave front is required.

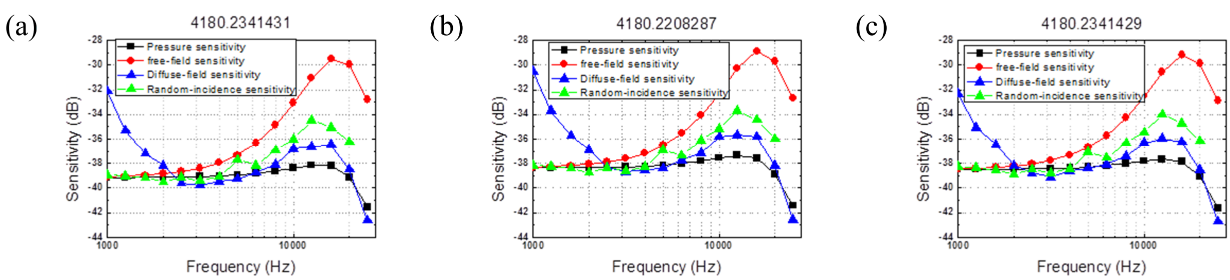

Figure 7: Comparison of the measured sensitivity of LS2 microphone according to the types of sound field: (a) 4180.2341431, (b) 4180.2208287, (c) 4180.2341429.

4. Conclusion

Two types of systems to measure the diffuse field sensitivity of microphone are established and the measured sensitivities are compared each other and the sensitivities of the other types of sound field. A scaled-reverberation chamber having un-parallel surfaces is designed for the reciprocity calibration and the directivity measurement system is designed for the random incidence sensitivity measurement. Commonly, both approaches are to implement sound field satisfying the definition of diffuse field and the results obtained by both methods should be same, in principle. Therefore, the difference between the results of two methods comes from the imperfection of field condition. For the reciprocity method with the scaled reverberation chamber, the method to improve diffusivity is investigated by increasing the reverberation time. For the directivity measurement, the effect of wave front shape is investigated to observe the difference from the ideal case of plane wave assumption in the definition of diffuse field.

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