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Sensitivity measurement of a laboratory standard microphone by measuring the diaphragm vibration

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ABSTRACT

As a method to determine the sensitivity of a laboratory standard microphone, the reciprocity method is employed as an international standard (IEC61094-2). This method is highly reliable and achieves high precision. However, three microphones are essentially required for this method. This procedure is complicated and takes a long time due to many combinations of microphone pairs and couplers. To overcome these difficulties, a novel method based on the measurement of vibration on the surface of a microphone using a laser Doppler vibrometer is proposed. It aims to obtain the sensitivity of a laboratory standard microphone. To this end, the relationship between the surface velocity of the diaphragm centre and acoustic volume velocity induced by the vibration of the diaphragm surface is investigated, and an empirical model is developed by measuring the distribution of the surface velocity. This paper used an empirical model of a 1-in. laboratory standard microphone estimated with 6 samples. The estimated sensitivity using this model has a difference of about 0.1 dB from the results of the reciprocity method applied to samples not used for estimating the empirical model.

1. Introduction

In accordance with the international standard for sound measurement, the sensitivity of the laboratory standard (LS) microphone [1] is employed as the reference sensor to maintain the traceability and equivalence of sound measurements. The method to measure the sensitivity of the LS microphone is the reciprocity method determined by IEC standard IEC61094-2 [2]. This method is highly reliable and achieves high precision. Therefore, many national metrology institutes state that their capability of measurement with uncertainties lower than 0.1 dB while using this method [3,4]. However, this method cannot be conducted with a single microphone; three microphones are essentially required. Moreover, the procedure is complicated and lengthy, because of the many combinations of microphone pairs and couplers used to create closed volumes between microphones to establish ideal pressure field conditions.

The reciprocity method is based on the concept that the characteristics of a transducer are identical when it acts as a receiver or as a transmitter. This implies that the relationship between the radiated sound and supplied electrical input to the microphone is determined by the sensitivity of the transducer. Therefore, if the relationship between the sound pressure and surface vibration of the diaphragm is known, the sensitivity can be derived by measuring the surface vibration and supplied electrical input.

In this paper, to overcome the complexity of the reciprocity method, a novel method based on the measurement of vibration on the surface of a microphone using a laser Doppler vibrometer (LDV) is proposed to obtain the sensitivity of laboratory standard microphones. For sensitivity measurement purposes, the vibration measurement on a diaphragm using an LDV was applied to a hybrid method using the numerical analysis of boundary element method, applying the measured surface vibration as the boundary condition [5]. However, this approach was applied to obtain the correction factors for free-field and diffuse-field sensitivity. For pressure sensitivity, the concept based on the distribution of surface vibration was mentioned but is not practical because of its required effort for complex and lengthy measurements, even when compared to the reciprocity method.

If the sensitivity measurement from the vibration measurement on a diaphragm is possible, the method that is proposed in this paper is capable of determining the sensitivity with one microphone. Moreover, it is also expected that a coupler is not necessary,

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because the signal-to-noise ratio (SNR) of the surface vibration is considerably higher than that of the acoustic radiation induced by a small area of the microphone's diaphragm.

Here, the process to determine the pressure sensitivity of LS microphone by measuring the surface vibration is proposed, and the relationship between the surface velocity of the diaphragm's centre and the acoustic volume velocity induced by vibration of the diaphragm surface is investigated to determine a value using single point measurements. Based on this relationship, an empirical model is developed by measuring the distribution of the surface velocity. The validation of the proposed method is conducted by comparing it with results obtained by the reciprocity method.

2. Theory

2.1. Reciprocity method (IEC 61094-2)

The sensitivity of a microphone has different values depending on the type of sound field, such as pressure, free-field, and diffuse-field. Among these, pressure sensitivity has been widely employed as a reference value because the high SNR induced by the small volume inside a coupler makes it suitable to realise an ideal pressure sound field.

The method to determine the pressure sensitivity of a LS microphone is the reciprocity method; its detailed procedure is well-defined in the IEC standard [2]. Three microphones are required for the measurement procedure. Fig. 1 shows the configuration, which consists of two of the three microphones and a coupler to measure the pressure sensitivity [2]. Only one microphone is used as a transmitter radiating sound and the other is a receiver. The process is repeated with three combinations of pairs by exchanging the microphones. The fundamental assumption of the method is that the sensitivity of a microphone as a receiver is equivalent to when it is used as a transmitter. For the reciprocal transducer, the following relationship is satisfied [2]:

$$\frac{p}{i} = \frac{U}{q}, \tag{1}$$

where p is the sound pressure on the receiver microphone, i is the current supplied to the transmitter microphone, U is the open circuit voltage output of the receiver microphone induced by p and q is the acoustic volume velocity induced by i. In the configuration of Fig. 1, the relationship between the input current and the output voltage can be defined by the electrical transfer impedance $Z_{e,xy}$ as follows:

$$Z_{e,12} = U_2/i_1. \tag{2}$$

Also, the relationship between the acoustic's volume velocity and the induced sound pressure can be defined by the acoustical transfer impedance $Z_{a,xy}$ as follows:

$$p_2 = Z_{a,12}q_1 = Z_{a,12}M_{p,1}i_1. \tag{3}$$

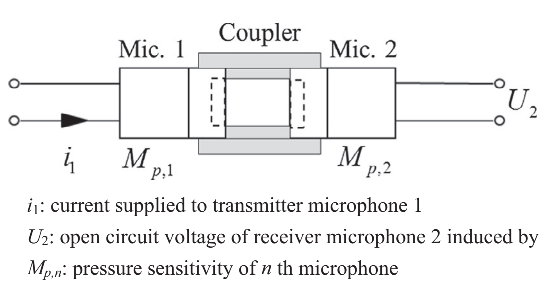

Fig. 1. Schematic configuration of the microphones and coupler for the reciprocity calibration [2].

By using Eqs. (2) and (3), the sensitivity of each microphone M_p and each transfer impedance can be described by [2]

$$q_1 = M_{p,1}i_1,\ U_2 = M_{p,2}p_2 = M_{p,2}Z_{a,12}M_{p,1}i_1, \tag{4a, b}$$

$$M_{p,1}M_{p,2} = \frac{1}{Z_{a,12}}\frac{U_2}{i_1} = \frac{Z_{e,12}}{Z_{a,12}}. \tag{4c}$$

The acoustical transfer impedance inside the coupler is estimated by [2]

$$\frac{1}{Z_{a,12}} = \frac{1}{Z_{a,v}} + \frac{1}{Z_{a,1}} + \frac{1}{Z_{a,2}} = j\omega\left(\frac{V}{\kappa P_S} + \frac{V_{e,1}}{\kappa_r P_{S,r}} + \frac{V_{e,2}}{\kappa_r P_{S,r}}\right), \tag{5}$$

where $Z_{a,v}$ is the acoustical impedance inside the coupler and $Z_{a,1}$ and $Z_{a,2}$ are the acoustical impedance of each microphone. Also, κ is the specific heat ratio. P_s is the atmospheric pressure at the measurement condition, V is the total geometric volume of the coupler, $V_{e,1}$ and $V_{e,2}$ are the equivalent volumes of each microphone, κ_r is the specific heat ratio at the reference condition, and $P_{S,r}$ is the atmospheric pressure at the reference condition. By using the three different combinations of microphones, three different descriptions of Eq. (4c) can be obtained and the sensitivity of the microphone can be estimated by [2]

$$|M_{p,1}| = \left[\left|\frac{Z_{e,12}Z_{e,31}}{Z_{e,23}}\right|\left|\frac{Z_{a,23}}{Z_{a,12}Z_{a,31}}\right|\right]^{1/2}. \tag{6}$$

This relation is assumed that the dimension of coupler is sufficiently smaller than wavelength. For the high frequency range, the acoustical transfer impedance inside the coupler of cylindrical shape having same diameter as the microphone diaphragms can be estimated as follows, based on the transmission line theory [2]:

$$\frac{1}{Z'_{a,12}} = \frac{1}{Z_{a,0}}\left[\left(\frac{Z_{a,0}}{Z_{a,1}} + \frac{Z_{a,0}}{Z_{a,2}}\right)\cosh\gamma l_0 + \left(1 + \frac{Z_{a,0}}{Z_{a,1}}\frac{Z_{a,0}}{Z_{a,2}}\right)\sinh\gamma l_0\right]. \tag{7}$$

where $Z_{a,0}$ is the acoustic impedance of the plane-wave coupler, l_0 is the length of coupler, and the γ is the complex propagation coefficient. Moreover, the heat conduction and capillary tube correction should be considered for the estimation process [2]. The final expression of the microphone sensitivity is given by [2]

$$|M_{p,1}| = \left[\left|\frac{Z_{e,12}Z_{e,31}}{Z_{e,23}}\right|\left|\frac{Z''_{a,23}}{Z''_{a,12}Z''_{a,31}}\right|\left|\frac{\Delta_{C,12}\Delta_{C,31}}{\Delta_{C,23}}\right|\right]^{1/2}, \tag{8}$$

where $Z''_{a,xy}$ is the acoustic transfer impedance corrected for heat conduction [2,6], and $\Delta_{C,xy}$ is the correction factor of capillary tube [2]. Also, the radial wave motion cannot be ignored for the high frequency range [7].

In this paper, the result obtained by the reciprocity method is used as the reference value to check the validity of the proposed method.

2.2. Relationship between diaphragm vibration and sensitivity

To determine the sensitivity of a microphone from the vibration measurement on its surface, the relationship between the acoustic pressure on the surface and surface vibration should be defined. In the case of the receiver, an additional sound source is required to excite the diaphragm and the exact amount of sound pressure arriving on the microphone diaphragm should be known. However, it is not straightforward and this is why the reciprocity method with a coupler has been applied. Therefore, it is preferable to use a microphone as the transmitter for the sensitivity measurement process. Moreover, the supplied electrical signal can be measured with relatively much higher precision.

Although these advantages, the process should be carefully conducted and the supplied voltage also restricted below 2 V because