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Phase sensitivity microphone calibration

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Abstract

Measurement microphone calibration usually involves determine its modulus sensitivity as a function of frequency, however, in last years, demand for its phase sensitivity information has increased. In view of that, phase measurement was included in primary calibration of measurement microphones and international comparisons of that calibration have been performed. In order to allow the dissemination of the primary calibration to the end user, the secondary calibration of measurement microphones was investigated. This study comprises a phase measurement of a half-inch laboratory standard microphone and of a set preamplifier plus half-inch laboratory standard microphone by the comparison method.

Keywords: calibration, microphone, phase sensitivity, pressure sound field, coupler.

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1. INTRODUCTION

In last years, demand for phase sensitivity of measurement microphone has increased and, aware of this situation, phase information was included (on demand) in primary calibration of microphones by the reciprocity method in pressure sound field. In order to allow the dissemination of that primary calibration to the end user, secondary calibration of microphones phase sensitivity by the comparison method in pressure field was investigated. This paper summarizes the primary calibration of measurement microphones by reciprocity, presents the secondary calibration by comparison and shows the results of a microphone calibration.

2. PRIMARY CALIBRATION

Primary calibration of measurement microphones usually is performed by the reciprocity method in pressure sound field or free sound field [1], but the phase measurements have been commonly measured in pressure field [2]. In concept, free-field reciprocity calibration appears to be simpler than pressure calibration, but, in practice, it is far more difficult [3].

The reciprocity calibration of microphones may be carried out by means of three microphones or by means of an auxiliary sound source and two microphones, but the procedure using three microphones is the most used. According to this procedure, two microphones are acoustically coupled, and using one of them as a sound source and other as a sound receiver, the electrical transfer impedance between the microphones and the acoustic transfer impedance of the system are measured. When both impedances are known, the product of the sensitivities of the two-coupled microphones can be determined. Using pair combinations of the three microphones, three such mutually independent sensitivity products are available, from which an expression for the sensitivity of each of the three microphone can be derived [4, 5].

In pressure field calibration, the pressure sound field is obtained connecting the pairs of microphones by couplers, which, together the microphones, creates small closed cavities. Figure 1 shows pictures of a half-inch laboratory standard microphone (LS2), a plane wave coupler and a pair of microphones connected by a coupler.

Figure 1: At left, above, a picture of a half-inch laboratory standard microphone; at left, bellow, a picture of a plane wave coupler for half-inch microphones; and at right, a picture of a pair of half-inch microphones connected by a coupler.

It should be noted that, the phase sensitivity of the same microphone is different in pressure and in free sound fields [6]. That is expected because of the same two phenomena that produce differences in modulus responses: diffraction and radiation impedance [7]. Figure 2 illustrates the phase of the free-field correction of LS1 (one-inch laboratory standard) and LS2 microphones based on Barrera-Figueroa et al [6]. Notice that, in both cases, corrections are non-null at the typical diaphragm resonance frequency (determined by a 90^{o} phase lag relative to the phase at low frequencies), at 8,5 kHz and at 23 kHz for the calibrated LS1 and LS2 microphones types. This is not expected, as the diaphragm resonance frequency is a characteristic of the microphone (determined by its diaphragm system stiffness and mass [8]) and independent of the sound field where it is calibrated. A reason for this could be the use of microphones of different diaphragm resonance frequency to determine a correction, which leads different free-field corrections and, consequently, a non-suitable average correction. Therefore, use of these free-field corrections could bring inaccuracy to results, for example, for two LS1 microphones, one with diaphragm resonance frequency at 8 kHz and another at 8,9 kHz (actual values), the applied corrections will be zero and around -5^{o} respectively. Another example, for two LS2 microphones, one with diaphragm resonance frequency at 21 kHz and another at 23 kHz (actual values), the applied corrections will be around -10^{o} and around -13^{o} respectively, i.e., the corrections, that should be null, will be around dozens of degree. Hence, that issue should be investigated. A proposed solution (that needs to be checked) for this contradiction would be establish a correction as a function of the diaphragm resonance frequency. In this way, the correction curves would be normalized at the resonance frequency and the correction value would be always zero at the resonance frequency.

In order to check the reciprocity calibration of microphone phase sensitivity in pressure field, a key comparison on that calibration, using LS1 microphones and conducted by the Consultative Committee for Acoustics, Ultrasound and Vibration (CCAUV) of *Bureau International des Poids et Mesures* (BIPM), was performed in 2011-14 [9]. Beyond this comparison, a supplementary comparison, using LS2 microphones and conducted by Intra-Africa Metrology System (Afrimets), was performed in 2013-15 [10] and another key comparison, also using LS2 microphones and conducted by the CCAUV, is in progress [11].

Figure 3 shows typical expanded uncertainty, reported by Inmetro, for sensitivity phase of LS2 microphone calibration by reciprocity in pressure field.

3. SECONDARY CALIBRATION

Secondary calibration of measurement microphones is usually performed by the comparison method (simultaneously or sequentially) or by the electrostatic actuator method [12, 13]. While the comparison method is more accurate and provides results direct related to a sound field, the electrostatic actuator method is faster and cheaper. The comparison method could be applied in pressure, in free or, even, in diffuse sound field. In this investigation it was used the sequential comparison method in pressure field and the reference microphone was a LS2 microphone calibrated by reciprocity.

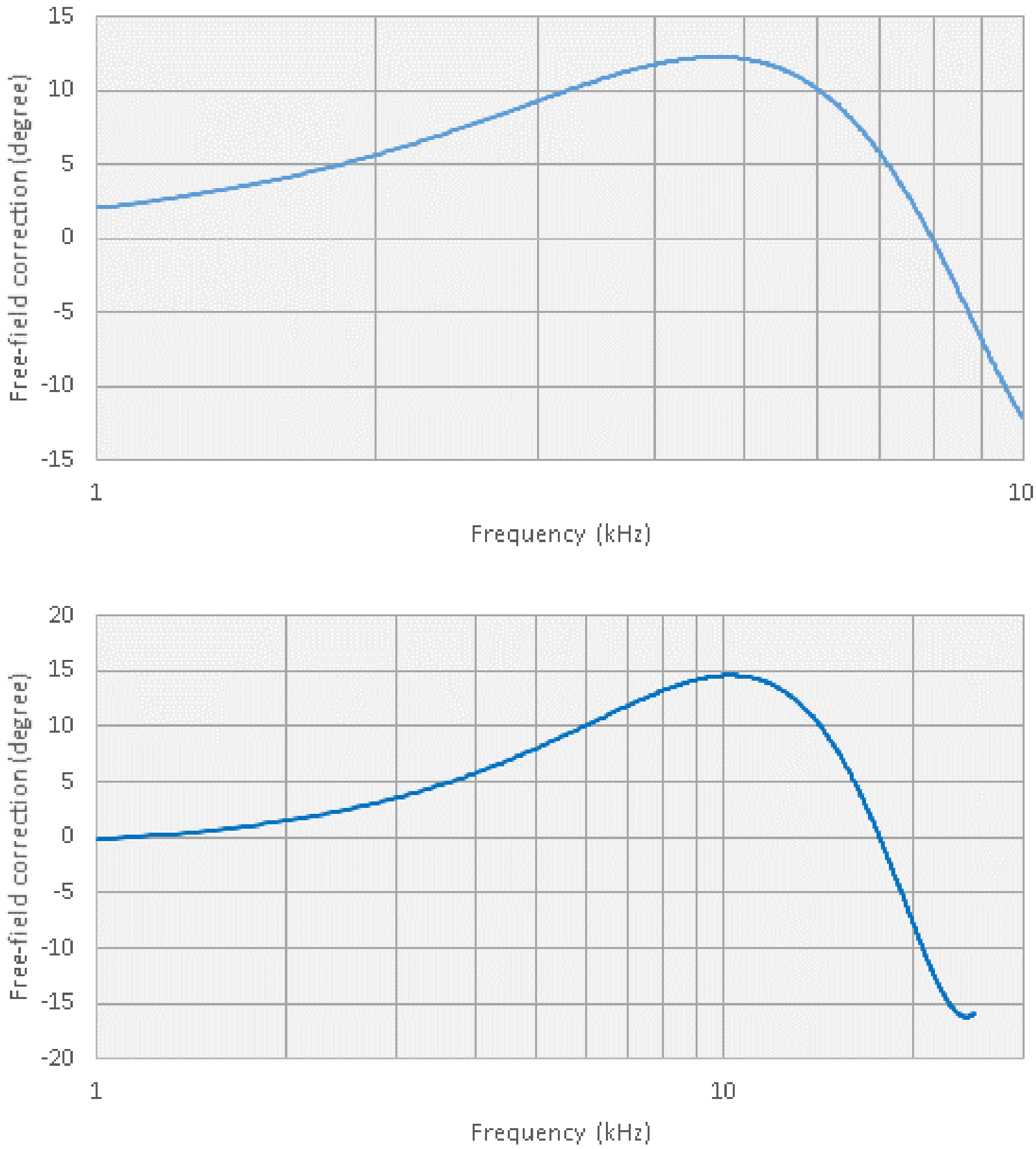

Figure 2: Above, an illustration of phase of the free-field correction of one-inch laboratory standard microphone; bellow, an illustration of phase of the free-field correction of half-inch laboratory standard microphone based on Barrera-Figueroa et al [6].

According to the comparison method, the reference microphone (usually calibrated by a primary method) and the microphone under test are exposed to the same sound pressure, either simultaneously or sequentially, and their open-circuit output voltages are measured. Then, the phase of the sensitivity of the microphone under test can be calculated from the known sensitivity of the reference microphone [14, 15] from

$$\Phi_{\mathrm{m,t}} = \Phi_{\mathrm{m,r}} + \Phi_{\mathrm{ocov,t}} - \Phi_{\mathrm{ocov,r}}, \qquad (1)$$

where $\Phi_{m,t}$ and $\Phi_{m,r}$ are the phases sensitivity of microphone under test and reference microphone in degree, and $\Phi_{ocov,t}$ and $\Phi_{ocov,r}$ are the phases of the open-circuit output voltage of microphone under test and reference microphone in degree.

The principle of this method also allows the microphone under test to be attached to a measuring equipment, for example a particular preamplifier, and the sensitivity phase may be referred to the unload output of that measuring

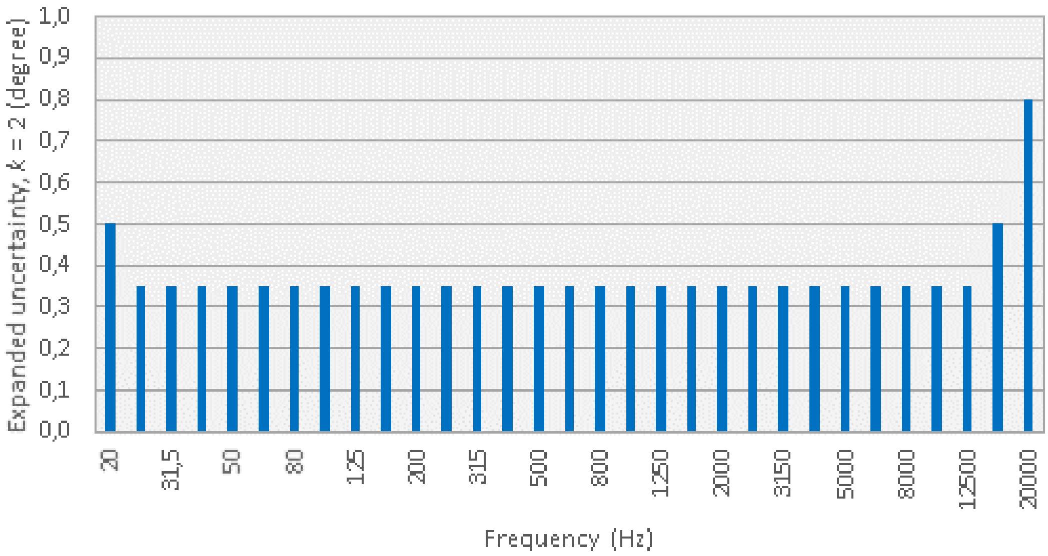

Figure 3: Typical expanded uncertainty (k = 2), reported by Inmetro, for sensitivity phase of half-inch laboratory standard microphone calibration by reciprocity in pressure field.

equipment [14, 15] from

$$\Phi_{m,t} + \Phi_{p,t} = \Phi_{m,r} + \Phi_{uop,t} - \Phi_{ocov,r}, \quad (2)$$

where $\Phi_{p,t}$ is the phase gain of preamplifier under test in degree, and $\Phi_{uop,t}$ is the phase of the unload output of preamplifier under test in degree.

Equations (1) and (2) highlight that, for measuring the phase response of a microphone (or a set of preamplifier plus microphone), it is required to separate the phase response of the microphone from that of the amplifiers, filters, analyzers or other instruments [16].

As in primary calibration, in secondary calibration it was commonly used couplers to obtain the pressure sound field. Figure 4 shows a picture of a half-inch microphone connected by a coupler.

Figure 5 shows the obtained phase of pressure sensitivity (as a function of frequency) of a LS2 microphone manufactured by Brüel & Kjaer, type 4180, by the sequential comparison method. The behavior at lower frequencies occurs because a positive pressure produces a negative change in the distance from the diaphragm to the backplate of the microphone and the output voltage of the microphone is proportional to this displacement. As this microphone is an externally polarized microphone (and power supplies apply positive charges), a positive pressure creates a negative output voltage. However, if the microphone was

Figure 4: Picture of a half-inch microphone connected to a sound source (another microphone) by a coupler.

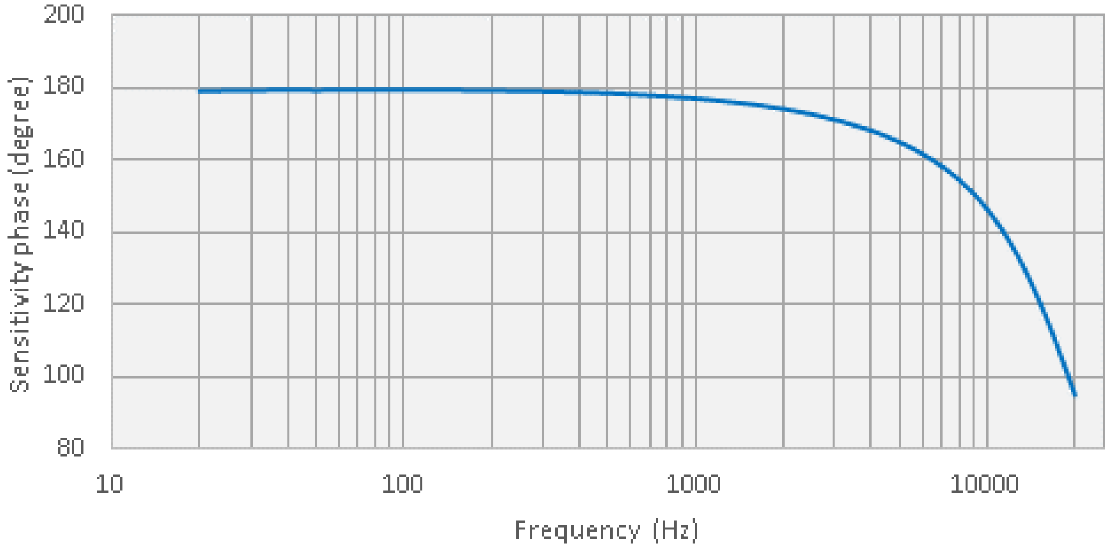

Figure 5: Phase of pressure sensitivity of a half-inch laboratory standard microphone manufactured by Brüel & Kjaer, type 4180.

a prepolarized microphone (and have a negative charge applied to the electret), a positive pressure would lead a positive voltage, i.e. the two types of microphones' frequency responses differ by 180°. At higher frequencies, the behavior is due to the stiffness and mass of the diaphragm system and to the diameter and damping resistance of the diaphragm. The 90° phase lag relative to the phase at low frequencies determines the diaphragm resonance frequency [8]. As per convention, phase sensitivity is reported as positivity values [9-11].

Figure 6 shows the obtained phase of pressure sensitivity of a set preamplifier (Brüel & Kjaer, type 2673) plus LS2 microphone (Brüel & Kjaer, type 4180) by the sequential comparison method. The increase at lower frequencies (compared with the frequency response presented in Figure 5) is due to the preamplifier and microphone characteristics. It is determined by the preamplifier input resistance and microphone capacitance [8].

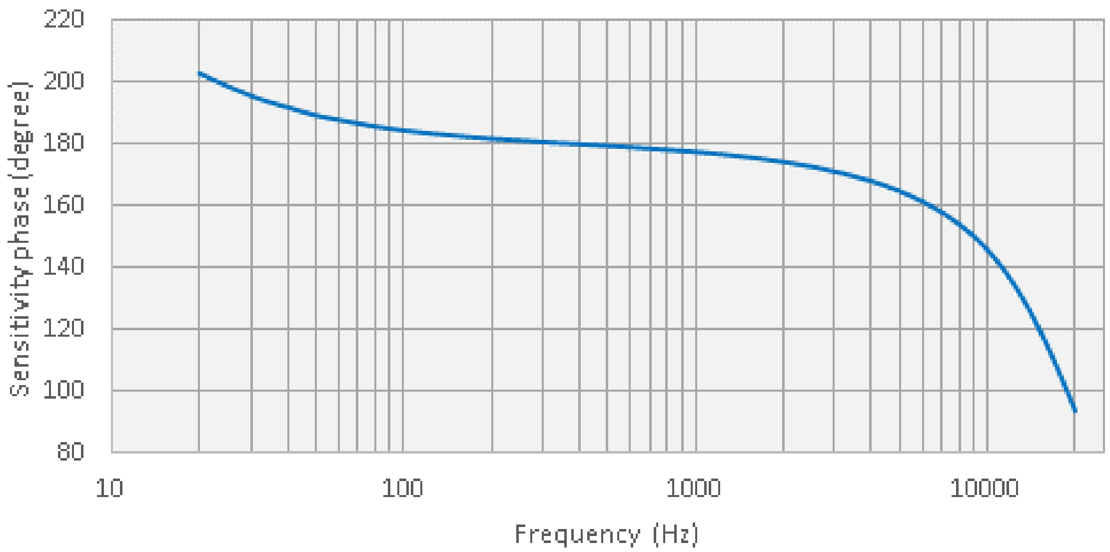

Figure 6: Phase of pressure sensitivity of a set preamplifier (Brüel & Kjaer, type 2673) plus a half-inch laboratory standard microphone (Brüel & Kjaer, type 4180).

In order to check the comparison calibration of microphone phase sensitivity in pressure field, the results obtained by this method for LS2 microphone were compared with the results obtained by the reciprocity calibration method using the E_n numbers [17]. This assessment indicated a satisfactory performance of the comparison calibration.

Figure 7 shows calculated expanded uncertainty for sensitivity phase calibration by sequential comparison in pressure field.

4. FUTURE INVESTIGATIONS

Next step of this investigation is extend it to working standard microphones. This will demand a suitable coupler that allows connect microphones with their protection grids without leakage. Results can be a little different (from that presented here) according to microphone and preamplifier characteristics (for example, microphone polarization voltage and preamplifier input resistance). Moreover, expanded uncertainty shall be higher (than that presented here) since it will no longer have the advantages that the reference microphone and the microphone under test are of the same type.

Another step is extend this investigation to free sound field calibrations.

5. CONCLUSION

Primary calibration of phase sensitivity of measurement microphone, currently, is performed by the reciprocity method in pressure field. Although modulus measurement is well known, phase measurement is relatively new. In order to check that calibration, a key comparison, using one-inch microphones, was performed and another key comparison, using half-inch microphones, is ongoing. Typical uncertainties, as a frequency function, for half-inch microphones varies from 0,35° to 0,80°.

Secondary calibration of phase sensitivity is under research and development. Following the primary calibration, this investigation was performed in pressure field by the sequential comparison method. A half-inch laboratory standard microphone and a set preamplifier plus a half-inch laboratory standard microphone were successfully calibrated. The calculated expanded uncertainties, as a frequency function, varied from 0,4° to 0,8°.

Future investigations should address calibration of phase sensitivity of working standard microphones fitted with their protection grid and calibration of phase sensitivity in free sound field.

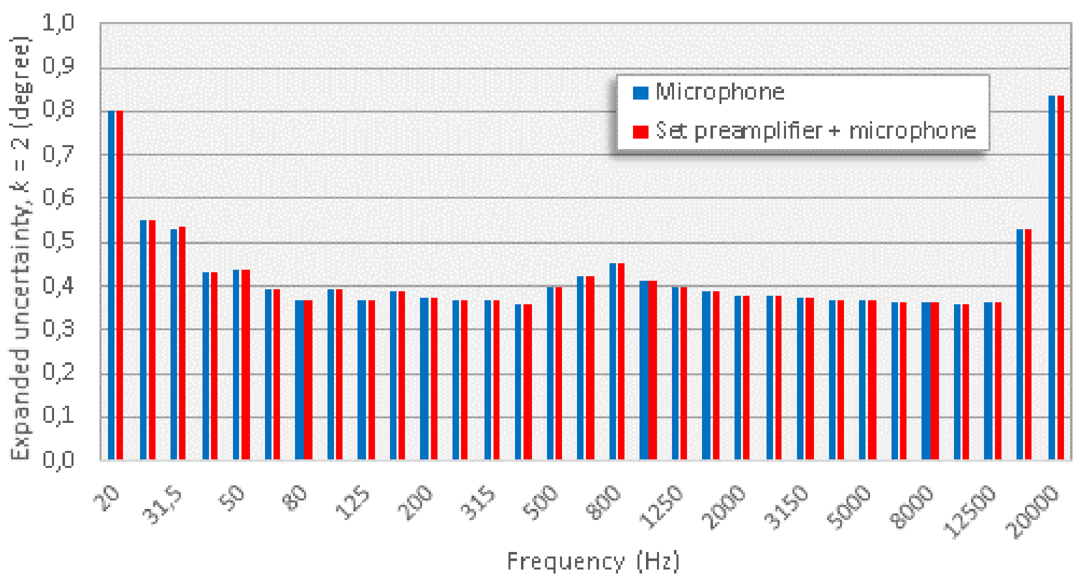

Figure 7: Calculated expanded uncertainty (k = 2) for sensitivity phase calibration by sequential comparison in pressure field.

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