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SOUND FIELD CORRECTIONS FOR SECONDARY PRESSURE CALIBRATION OF MEMS MICROPHONES

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ABSTRACT

For accurate pressure calibration of MEMS microphones by the comparison method, it is important to evaluate the frequency response corrections associated with non-uniform sound fields occurring into typical couplers or jigs used in the calibration apparatus. In fact, since the comparison is carried out by a reference condenser microphone of significantly larger diaphragm diameter with respect to the MEMS microphone size, non-uniform sound fields in the cavity between transducers may produce different values of acoustic pressures actually sensed by reference and under test microphones. In this work, we present a numerical model for the evaluation of the sound field corrections due to non-uniform acoustic fields inside pressure comparison couplers or jigs, and its validation against the corrections provided by the Standard IEC 61094-5 for pressure comparison between microphones of different sizes.

Keywords: *MEMS microphones calibration, pressure comparison calibration, sound field corrections.*

1. INTRODUCTION

The rapid growth and improvements of MEMS microphones technology are opening new opportunities of application of acoustic sensors for noise monitoring and measurement. The miniature size, low cost and low power consumption put this kind of microphones in a privileged position for the development of acoustic sensors networks, and other interesting applications like sound sources localization and mapping by acoustic cameras.

The improved metrological performances of MEMS microphones, together with the advantages in terms of cost and power consumption, are suggesting their possible use as measurement microphones, e.g. as integrated acoustic transducers in new types of sound level meters. Such a potential application of MEMS microphones makes it necessary to ensure the metrological traceability of the acoustic measurements provided by these sensors, to the International System of Units SI. Along this line, it is important to develop proper measurement systems and methods for the calibration of MEMS microphones, in order to provide their acoustic characterization in terms of sensitivity in the frequency range of interest, with the associated measurement uncertainties.

2. PRESSURE CALIBRATION OF MEMS MICROPHONES BY COMPARISON

A possible way to characterize the metrological performances of MEMS microphones is by secondary pressure calibration by the comparison method. In this method, the pressure sensitivity of the MEMS microphone is obtained, in the frequency range of interest, from the pressure sensitivity of a reference microphone (known by primary pressure reciprocity calibration), providing that both the MEMS and the reference microphone are exposed to approximately the same acoustic pressure. However, even considering the simultaneous acoustic excitation of both microphones, placed face-to-face with a small gap between their diaphragms in order to realize pressure field conditions in the frequency range of interest, a uniformly distributed acoustic pressure in the space between microphones cannot be achieved particularly at high frequencies. This is a problem when microphones of

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different sizes are compared, since the smaller microphone diaphragm is exposed to only a part of the sound field compared to the larger microphone [1]. The higher the differences in the diaphragm size, the greater the impact of the sound field non-uniformity on calibration results. For such a reason, a method to evaluate the corrections for acoustic pressure non-uniformities in comparison calibration is needed, particularly concerning the calibration of miniaturized transducers, like MEMS microphones. The evaluation of sound field corrections can be performed by the numerical modelling of the acoustic field in the space between microphones, as discussed in the following sections.

3. SOUND FIELD CORRECTIONS MODELLING

The mathematical model describing the acoustic field $p(\boldsymbol{x},t)$ produced by a sound source is given by the wave equation:

$$\frac{\partial^2 p}{\partial t^2} - c^2 \Delta p = 0 \tag{1}$$

where c is the speed of sound in the acoustic propagation medium. The solution of the wave equation has the form:

$$p(\boldsymbol{x},t) = \Re e[p_{ac}(\boldsymbol{x},k)\, e^{j\omega t}] \tag{2}$$

where ω is the angular frequency, $k = \omega / c$ is the wave number, $p_{ac}(\boldsymbol{x},k)$ is the spatial distribution of the acoustic pressure, $\Re e$ indicates the real part of the complex number, and j is the imaginary unit. Substituting the expression of the solution into the wave equation, the Helmholtz equation yields:

$$\Delta p_{ac} + k^2 p_{ac} = 0 \tag{3}$$

which can be solved numerically by the Finite Element Method (FEM) to evaluate the spatial distribution of the acoustic pressure, by considering appropriate boundary conditions (BCs), i.e. infinite acoustic impedance BCs for “sound hard boundaries”, finite impedance BCs for vibrating boundaries (microphones’ diaphragms), and source boundary conditions where sound is emitted.

Considering the case where the acoustic pressure distribution is evaluated in the space between condenser microphones’ diaphragms under pressure comparison calibration, the sound field correction δ, which should be applied for the determination of the pressure sensitivity to compensate possible differences in acoustic pressures sensed by microphones, is calculated as:

$$\delta = 20\log_{10}(\tilde{p}_{ac,1}/\tilde{p}_{ac,2}) \tag{4}$$

where $\tilde{p}_{ac,1}$ and $\tilde{p}_{ac,2}$ are the mean acoustic pressures over the microphones’ diaphragms, averaged according to the general radial dependence of the sensitivity across the diaphragm, as given by [1]. The numerical solution of Eqn. (3) can allow evaluating sound field corrections due to non-uniform acoustic fields for particular mounting configuration of microphones and sound source, or inside pressure comparison couplers or jigs, considering the appropriate BCs for the boundary surfaces. In particular, the numerical model can be applied to the evaluation of sound field corrections in secondary pressure calibration by comparison between microphones of different sizes.

4. MODEL VALIDATION

In this section, the results of the validation of the numerical model against the analytical model described by Barham et al [1], for the evaluation of sound field corrections for secondary pressure calibration of condenser microphones by comparison, are presented. Two validation cases are discussed: i) the pressure comparison of a ¼” diameter Working Standard microphone (WS3 type, without protection grid) against a reference ½” diameter Laboratory Standard microphone (LS2 type), and ii) the pressure comparison of a ½” diameter Laboratory Standard microphone (LS2 type, without cavity ring) against a 1” diameter Laboratory Standard microphone (LS1 type).

For both the validation cases, the microphones mounting configuration considered for pressure comparison calibration is shown in Fig. 1.

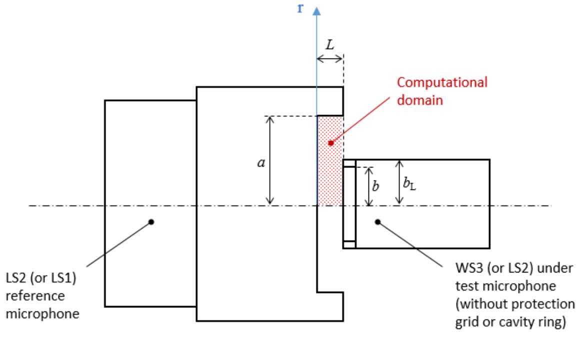

Figure 1. Microphones configuration considered for the evaluation of sound field corrections in pressure comparison calibration.

Microphones are placed with their diaphragms face-to-face, coaxial between each other and with the sound source, so that the acoustic pressure distribution can be reasonably assumed as circularly symmetric. The separation distance between the diaphragms is equal to the front cavity depth of the larger microphone, and the source velocity at the annular open space (source boundary) around the smaller microphone is assumed to be circularly symmetric as well, and described as a Fourier Bessel series as given by [1].

The numerical model consists in the solution of the Helmholtz equation given by Eqn. (3) by the FEM method, considering the same source velocity distribution at the source boundary as used in the analytical model, and finite impedance BCs at microphones' diaphragms, whose acoustic impedances are calculated from the values of resonance frequency, equivalent volume and loss factor of microphones. Furthermore, in the evaluation of the acoustic impedance, the "effective" diaphragm surface is considered, i.e. the base surface of the equivalent cylindrical rigid piston that displaces the same volume of air as the microphone diaphragm at its maximum deflection (centre diaphragm displacement). The effective surface is evaluated from the radial distribution of the diaphragm displacement when it is exposed to a uniform acoustic pressure [2-3], and depends on frequency; this leads to an approximation of the problem, since the diaphragm displacement actually depends on the distribution of the acoustic pressure. Finally, for "sound hard boundaries", infinite acoustic impedance BCs are assumed.

4.1 Comparison of WS3 *vs* LS2 microphones

The input parameters related to condenser microphones WS3 (without its protection grid) and LS2, considered in the evaluation of sound field corrections, are listed in Tab. 1. The separation distance *L* between diaphragms is equal to 0,5 mm, and coincides with the front cavity depth of the LS2 microphone.

Table 1. Input model parameters for WS3 and LS2 microphones.

	WS3	LS2
Overall radius (b_L) / mm	2,975	-
Diaphragm radius (b, a) / mm	2,065	4,650
Resonance frequency / kHz	100	22
Equivalent volume / mm^3	0,25	9,30
Loss factor / -	1,1	1,1

The results of the validation of the numerical model are reported in Tab. 2, in the frequency range from 2 kHz to 20 kHz, expressed as deviations of sound field corrections δ obtained by the numerical model, with respect to the ones calculated by the analytical model δ_{an}, given by [1] and considered in the IEC 61094-5 Standard [4]. For this configuration, sound field correction values become significant especially for frequencies above 8 kHz, ranging from about -0,3 dB up to approximately -1,4 dB at 20 kHz.

Table 2. Results of the validation of the numerical model for WS3 *vs* LS2 comparison.

Frequency f / kHz	Deviation $\Delta\delta = \delta - \delta_{an}$ / dB
2	$1{,}0\cdot10^{-4}$
4	$5{,}2\cdot10^{-4}$
8	$1{,}5\cdot10^{-3}$
10	$2{,}5\cdot10^{-3}$
16	$7{,}1\cdot10^{-3}$
20	$1{,}2\cdot10^{-2}$

4.2 Comparison of LS2 *vs* LS1 microphones

The input parameters related to condenser microphones LS2 (without its cavity ring) and LS1, considered in the evaluation of sound field corrections, are listed in Tab. 3. The separation distance *L* between diaphragms is equal to 1,944 mm, and coincides with the front cavity depth of the LS1 microphone.

Table 3. Input model parameters for LS2 and LS1 microphones.

	LS2	LS1
Overall radius (b_L) / mm	6,0	-
Diaphragm radius (b, a) / mm	4,650	9,30
Resonance frequency / kHz	24	8,48
Equivalent volume / mm^3	9,60	132,0
Loss factor / -	1,27	1,08

The results of the validation of the numerical model are reported in Tab. 4, in the frequency range from 0,5 kHz to 8 kHz, expressed as deviations of sound field corrections obtained by the numerical model, with respect to the ones calculated by the analytical model given by [1]. For this configuration, sound field correction values become significant especially for frequencies above 4 kHz, where corrections of approximately -0,7 dB are expected around 8 kHz.

Table 4. Results of the validation of the numerical model for LS2 *vs* LS1 comparison.

Frequency f / kHz	Deviation $\Delta\delta = \delta - \delta_{\mathrm{an}}$ / dB
0,5	$4{,}2 \cdot 10^{-5}$
1	$1{,}7 \cdot 10^{-4}$
2	$6{,}9 \cdot 10^{-4}$
4	$3{,}1 \cdot 10^{-3}$
6,3	$9{,}0 \cdot 10^{-3}$
8	$1{,}6 \cdot 10^{-2}$

5. CONCLUSIONS

The numerical model presented in this work for the evaluation of sound field corrections has proven to be an effective tool to reduce the measurement uncertainty associated with secondary pressure calibration by the comparison method between microphones of different sizes. The numerical model has been validated against the sound field correction values calculated analytically for a reference mounting configuration of microphones, according to the Standard IEC 61094-5. The numerical sound field correction values have been observed to be within 0,02 dB with respect to the analytical ones, for the both the comparison of ¼" *vs* ½", and ½" *vs* 1" condenser microphones.

The numerical model is particularly suitable for being applied to the pressure calibration of MEMS microphones by the comparison method, because of its ability to describe and deal with complex geometries, like cavities and acoustic ports/holes resulting from MEMS microphones mounting on typical PCB evaluation boards, acoustic impedances of boundary surfaces, and particular source boundary conditions. Although the numerical model could be applied to the evaluation of the sound field corrections also for pressure comparison inside couplers or jigs, the use of a similar microphones mounting configuration as described for the validation cases is advisable to obtain repeatable and reliable measurement results. Such a configuration can be realized, for instance, inside an anechoic chamber using a sound source coaxially aligned with microphones, and cylindrical mounts for MEMS microphones that mimic the shape of Laboratory Standard microphones (preferably with removable cavity ring) or Working Standard microphones without protection grid.

6. REFERENCES

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