Attempt to improve the pressure reciprocity calibration of microphones

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Introduction

The determination of the pressure sensitivity of Laboratory Standard Microphones is performed by the reciprocity calibration method [1]. For the last decades analytical and experimental works have been done to improve techniques and methods (even to find new ones) to calibrate microphones, especially concerning the thermal boundary layer effects.

The present paper gives a summary of the analytical calculation methods currently in use, discusses their validity, and then, through an analytical investigation, suggests means to improve the accuracy of calibration results.

Reciprocity calibration method: models in use

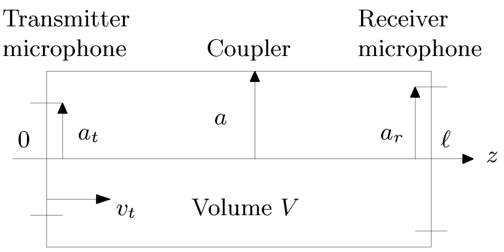

Figure 1: Geometry of coupler and microphones.

Two microphones to be calibrated are acoustically connected by a coupler, one being used as a transmitter and the other as a receiver (Figure 1), their pressure sensitivity being denoted M_{pt} and M_{pr} respectively. The product of their sensitivity is given by [1]:

$$M_{pt}M_{pr} \approx \frac{u_{r0}}{i_t}\,\frac{q_t}{p_r} = Z_E Y_T\,, \tag{1}$$

where

$Z_E = u_{r0}/i_t$ is the electrical transfer impedance defined as the ratio of the open-circuit voltage u_{r0} of the receiving microphone to the current i_t through the transmitting microphone,

$Y_T = q_t/p_r$ is the acoustical transfer admittance defined as the ratio of the volume velocity q_t of the diaphragm of the transmitting microphone to the sound pressure p_r on the diaphragm of the receiving microphone.

At low frequencies the acoustic field is assumed to be uniform in the cavity and the acoustical transfer admittance is given by

$$Y_T = j\,\omega\,\frac{VC_{TH}}{\gamma P_0} + Y_t + Y_r\,, \tag{2}$$

where

Y_t, Y_r are the acoustical admittances of the transmitter and receiver microphones respectively,

P_0 is the static pressure and γ the specific heat ratio at measurement conditions,

ω is the angular frequency,

and where C_{TH} is the heat-conduction correction factor, calculated by Gerber [2] and suggested by Jarvis [3] and Rasmussen [4] to be normalized. This correction factor will be discussed below.

At higher frequencies, plane-waves propagate in the cavity, and the transmission line theorie applies. Then, the acoustical transfer admittance Y_t is given by [1]

$$Y_T = \left(Y_c + \frac{Y_tY_r}{Y_c}\right)\sin(k_0\ell) + (Y_t + Y_r)\cos(k_0\ell)\,, \tag{3}$$

where

$Y_c = \rho_0 c_0/(SC_{TH})$, is the characteristic admittance and $S = \pi a^2$ the cross-section area of the coupler,

ρ_0 is the density of the gas enclosed, c_0 the adiabatic speed of sound in the gas, and $k_0 = \omega/c_0$ is the wavenumber of sound waves in the gas.

This expression assumes both that the diaphragm of the microphones behave as rigid pistons and that they have the same diameter as the coupler. But none of these assumptions is really true in practice: a radial wave-motion takes place in such cavity. So Rasmussen suggests a correction to the plane-wave theory [5]: following a practical method he introduces this correction but shows that it is a little correction in calibration results only up to 5 to 10 kHz (depending of the length of the coupler and the diameter of the diaphragm). So it would be interesting to start future work to investigate the behaviour in the higher frequency range.

On the other hand, Rasmussen shows that the sensitivity level of a microphone is a linear function of the static pressure and temperature. Therefore he suggests pressure and temperature correction coefficients, which are semi-empirically determined, for different kinds of microphone [6], [7]. These coefficients are only little corrections and so introduce a neglectible uncertainty on calibration results.

Heat-conduction correction: model to be used

According to Gerber [2], the acoustical admittance of a cavity, in which the sound pressure is uniform, takes two forms denoted Y_V and Y_P, which correspond to a pure volume-velocity or pressure driving source respectively. For reciprocity calibration, the sound pressure is created by a microphone with a large impedance, and so close to a pure volume-velocity driving source. Then, according to Gerber, the normalized heat-conduction correction is derived from the first admittance Y_V [1].

But the model given by Gerber to obtain Y_V and Y_P lies on hypothesis which are not acceptable because it admitts that the acoustic pressure or the acoustic density can both act as external sources.

It appears that, instead of being the admittance of a cavity with a pure volume-velocity driving source, Y_V is the admittance of a cavity in which the density is uniform, but this assumption is inconsistent with a uniform sound pressure. Indeed, the density is a function of the sound pressure and the temperature variation which is not uniform in the boundary layers. Therefore the heat-conduction correction C_{TH} derived from Y_V, and chosen in the IEC Publication 1094-2 [1], is not appropriate to interpret the heat effects coupled to the acoustic motion.

On the other hand, Y_P is not the admittance of a cavity with a pure pressure driving source but the admittance of a cavity in which the sound pressure is uniform: it is the analytical investigation mentionned in the introduction that we have carried out for the purpose. A correction derived from the admittance Y_P would replace the normalized one.

Even if C_{TH} (eq. 2) is only a correction, the difference between the acoustical transfert admittances calculated with corrections derived from Y_V and Y_P can be larger than 0.08 dB (Figure 2). This difference is significant for reciprocity calibration of microphones and for measurements of input impedance like those of capillary elements and small cavities.

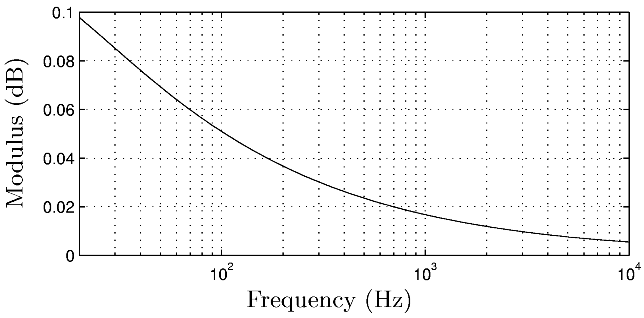

Figure 2: Difference between acoustical transfert admittances derived from the two solutions of H. Gerber for LS2P microphones.

Conclusion

Several ways can be considered to increase the accuracy of calibration results, especially through analytical investigations. Indeed the acoustic model in use nowadays appears to be analytically not fully appropriate. Then a revisited model could be suggested, which takes into account effects like viscous and thermal boundary layers (and even radial wave-motion) in a more consistent manner.

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