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Making pressure calibration easier – strategies for implementing a simple system for pressure comparison calibration of measurement microphones

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ABSTRACT

The implementation of pressure comparison calibration is described in the international standard IEC 61094-5. Some calibration environments are described: a coupler for simultaneous comparison (up to 10 kHz), a calibration jig placed in a test box (that could be used up to 20 kHz), and a coupler for sequential calibration. Different realisations of the calibration jig method were discussed in an earlier paper: placing the jig in a text box, as described in the standard, placing the jig in a reverberation room, and placing the jig in an anechoic room. That paper concluded that the two latter realisations provide the better results while the test box may not be very recommendable. Not much discussion about the use of comparison couplers has been published but experiences shared informally indicate that commercially available couplers may only be used in the full frequency range when the microphone under test and the reference microphone have the same geometry and similar impedance. This can be achieved in some cases using adapters; however in most cases, the microphone under test has to be calibrated with the grid on. The presence of the grid will limit the frequency range and therefore the calibration carried out as a combination of a coupler calibration covering the low frequency range, and using a rig either in a free field or a diffuse field for the mid and high frequency range. It would be very desirable to have a single calibration setup covering the full frequency range, or a calibration environment that may substitute the reverberant or the anechoic room. In this report proposals of alternative coupler designs and open calibration rigs are given and discussed.

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1. INTRODUCTION

Acoustic measurements play an essential role in many human activities ranging from measurement of industrial noise and its effects on workers to hearing assessment, sound quality in room acoustics, monitoring of environmental noise, and even climate change and highly dynamic events such as earthquakes, weapon testing. It is also important that acoustic measurements in these fields should be traceable to the base units of the International System of units (SI). This traceability is achieved by establishing an continuous line of calibrations referred to measurement standards up to the above mentioned SI base units.

Acoustic measurement systems and devices may take several forms, sound analysers, sound level meters and so on. However, measurement microphones are the element of the measurement system that transducers the acoustic signals to electrical signals that can be analysed further along the measurement chain. Thus, calibration of the microphone is fundamental for the establishment of the traceability chain. The relevance of microphone calibration has resulted in a series of international standards focused on the specification of measurement microphones (electro-acoustical and geometrical), and their calibration under different sound fields. The first document of the series, the standard IEC 61094-1 contains the specification of *Laboratory Standard* (LS) microphones, and the basis of a notation for differentiating microphone sizes and whether it is designed to work under pressure or free-field conditions [1]. Laboratory Standard microphones are intended to be calibrated using primary techniques that yield their absolute sensitivity, that is, without the need of another reference microphone; this calibration technique is known as the reciprocity technique and it is described in the IEC standard 61094-2 for the pressure condition [2]. Figure 1 shows examples of LS microphones.

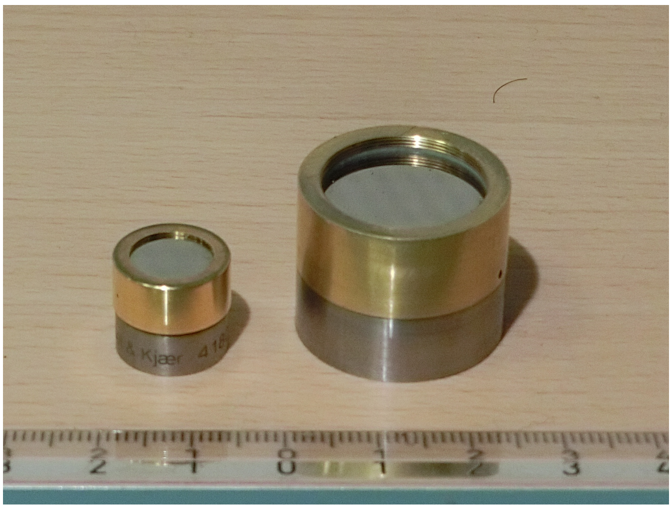

Figure 1: Laboratory standard microphones. On the right a type 1 (LS1). On the left a type 2 (LS2)

Microphones used for measurement purposes are known as *Working Standard* microphones (WS). Electro-acoustic and geometrical specifications are described in the standard IEC 61094-5 [3]. Working Standard microphones are not necessarily suited for being calibrated using the method described in the standard IEC 61094-2. Secondary (comparison) methods for calibrating WS microphones under uniform pressure conditions are described in the standard IEC 61094-5 [4]. Figure 2 shows

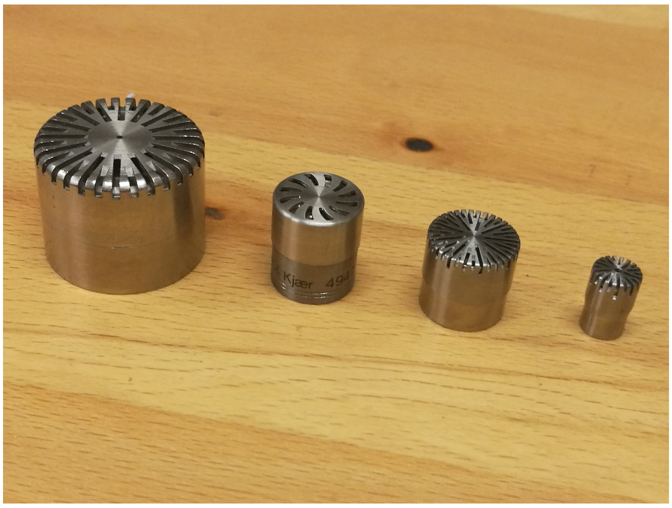

Figure 2: Working standard microphones. On the left a type 1 (WS1). On the center two examples of type 2 (WS2). On the right a type 3 (WS3)

examples of WS microphones. It could be argued that the pressure sensitivity of WS microphones can be determined using the electrostatic actuator response [5] and a the pressure sensitivity at a single frequency determined by means of a sound calibrator or a pistonphone. However, there are differences between pressure and actuator response that should eventually be taken into account. It can also be argued whether the actuator response is actually traceable to the SI.

An earlier paper [6] investigated some practical implementations of the standard 61094-5. These implementations placed most emphasis on the simultaneous comparison approach implemented in an open sound field, that is, when both the reference microphone and the microphone to be calibrated are subjected to the same sound pressure at the same time. The open sound field implementations discussed are a measurement rig in a regular reverberant room, and another in a small free-field. These open spaces seem to be appropriate for the purpose, and several aspects of the calibration such as microphone separation were tested.

The experiences from this study serve as starting point for this project. This paper describes the implementation in open spaces and in couplers that differ from that paper. Two types of open spaces are sketched: a small reverberant room, and a plane propagating wave tube. For the coupler solutions, some alternative designs are sketched, and a more complex solution directly based on reciprocity is discussed.

2. COMPARISON TECHNIQUE

The generic comparison method is based on the assumption that a microphone under test (DUT) is subjected to the same sound pressure as a reference microphone either sequentially or simultaneously. The result of this comparison is the ratio of open-circuit output voltages of each microphone. Because the open-circuit output voltage is proportional to the sensitivity of the microphones, it follows that the sensitivity of the DUT, $M_{p,DUT}$, can be determined by multiplying the ratio of the output voltages of DUT and reference microphone, R_M, and the pressure sensitivity of the reference microphone,

$M_{p,REF}$:

$$M_{p,DUT} = M_{p,REF} R_M, \tag{1}$$

$$R_M = \frac{u_{DUT}}{u_{REF}}. \tag{2}$$

This can also be expressed in terms of levels as

$$L_{p,DUT} = L_{Mp,REF} + \Delta_M, \tag{3}$$

$$\Delta_M = 20 * \log_{10} \frac{u_{DUT}}{u_{REF}}. \tag{4}$$

Changes in environmental conditions will affect the sensitivity of different microphones in different ways. However, because it is likely that the environmental coefficients of the DUT microphone may be unknown, typically its sensitivity will only be calculated at measurement conditions. Hence it is only needed to apply a correction on the sensitivity of the reference microphone to measurement conditions. This correction can be determined using:

$$\Delta_{Env} = \delta_p(p_s - p_0) + \delta_t(t_s - t_0) \tag{5}$$

where δ_p is the static pressure coefficient in dB/kPa, δ_t is the temperature coefficient in dB/K, p_s and t are the static pressure and temperature at measurement conditions, and p_0 and t_0 are the reference static pressure and temperature.

The comparison pressure sensitivity is then realised by determining Δ_M as indicated in equation (3) and applying the correction defined in equation (5) to obtain the pressure sensitivity of the DUT microphone. Finally, the above procedure can be applied at any frequency where there is a reference microphone with a traceable calibration (potentially from 2 Hz and up to 31.5 kHz for LS2 microphones). Each realisation may have a limited frequency range of application.

3. POSSIBLE IMPLEMENTATIONS

3.1. Calibration in couplers

3.1.1 Comparison coupler

There are very few commercial comparison couplers that can be used for calibration purposes. One of the most used can be used with LS2 and WS2 microphones. The coupler is basically a small cavity that allows to put the microphones about 1.5 mm from each other. In the space between microphones there is an inlet for the sound generated by a piezoelectric ring loudspeaker. The main limitation is that the coupler only allows WS microphones with the grid mounted on, or with an adapter that fits in the outer cavity. The presence of the grid will change the pressure response as the frequency increases, degrading the uncertainty that can be obtained during the calibration. If an adapter can be put on the microphone this problem is mitigated but not fully.

A possible solution is to have the microphone stops removed and a small clearance added around the microphones. In order to hold the microphones in place and seal the cavity, o-rings can be put around the microphone-preamplifier bodies. Figure shows an scheme of the existing coupler, and the proposed one 3

As with any coupler, resonances can be a limiting factor, and care must be take to ensure that these are either outside the frequency range, or somehow damped. Strong resonances may emphasize positioning differences of the microphones within the coupler.

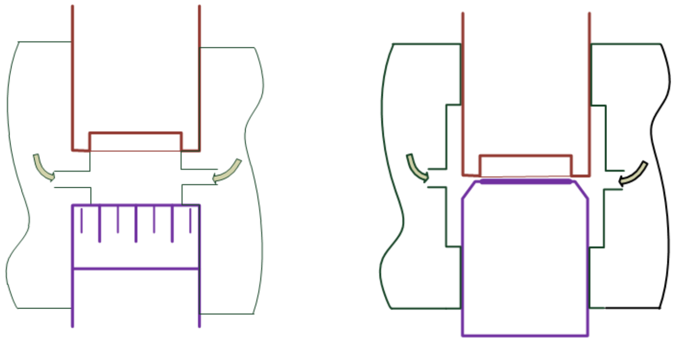

Figure 3: Sketch of the microphone configuration. On the left an example of a commercial coupler. On the right, the proposed solution

3.1.2 Plane-wave coupler and reciprocity

This method is based in a variation of the reciprocity method used for calibration LS microphones [3]. In this method, the product of the sensitivity of two microphones coupled in a cavity is defined as

$$M_{p,1}M_{p,2} = \frac{u_2}{i_1}\frac{1}{Z_{a,12}}, \tag{6}$$

where $M_{p,1}$ and $M_{p,2}$ are the sensitivities of the two microphones, u_2 is the output voltage of the receiver microphone, and i_1 is the current flowing through the terminals of the transmitter microphone. $Z_{a,12}$ is the acoustic transfer impedance of the coupled cavity. The sensitivity of an unknown microphone may be determined by means of the above equation. If it is assumed that the sensitivity of one of the microphones is known, the determination of the sensitivity of the other is straightforward providing that the ratio u_2/i_1 can be measured accurately, and the acoustic impedance of the coupled system can be determined by analytical means.

The application of the method described above requires that the test microphone can be fitted to the coupler by mechanical means, that is, an adapter *without the protection grid*. Typical reciprocity calibrations are performed in plane wave couplers. The geometry of this type of couplers is basically that of a cylindrical cavity with a radius equal to the radius of the membrane of the microphones, and ended by the front cavities and membranes of the coupled microphones. The fact that plane wave couplers are cylindrical cavities simplifies the process of determining the acoustic transfer impedance, $Z_{a,12}$, and other corrections up to a certain degree. Using different microphones with different acoustic characteristics may challenge this.

3.2. Calibration in open spaces

3.2.1 Small reverberant room

Barham *et al* concluded that small anechoic spaces (such as small test boxes) are not appropriate for comparison calibration due to the fact that oblique sound source relative to the axis along the microphones will excite non-symmetrical modes in the small cavity created by the closely placed microphones. However, it would still be very convenient to have such a bench-top test rig. A small reverberant space may solve the problem observed in the small anechoic space. Although the reverberant field implementation was only tested in a regular room, building a small reverberant space may be relatively

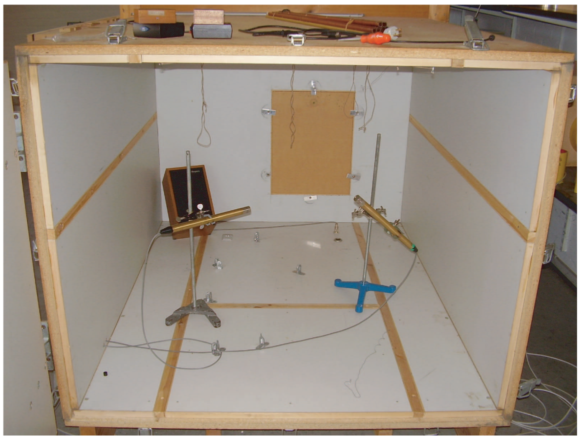

Figure 4: An example of a small reverberant room that can be used for microphone calibration

straightforward. There are some earlier solutions that have been used for microphone calibration [7, 8]. Figure 4 shows such an small reverberant space though not fully table-top.

Measurements in a diffuse field, or its approximated version may require that other signals than sinusoidal or sweeps are used. In any case, measurements in multiple places within the space may be necessary for averaging the frequency responses. Averaging in frequency bands is also necessary. However, it has to be considered that there is a difference between the pressure response averaged in wide frequency bands and the narrow frequency bands [6].

3.2.2 Propagating plane-wave tube

Another alternative is to put the microphone rig in a propagating plane-wave tube. There are some guidelines for the design of plane-wave tubes used in testing of audio compression drivers [9]. For driver testing, the most relevant characteristic is that plane wave tubes present the driver with a load similar to an infinite horn. This characteristic by itself is not the most relevant for microphone calibration. What may have a more important influence is the standing wave ratio which values are heavily depending on the quality of the anechoic termination of the tube. This may also imply that in order to take this into account, an inversion of the positions of the microphones may be necessary. Designing the anechoic termination is not trivial but the fact that the microphones to be measured are very close to each other, it may not be necessary to have a close-to-the-ideal termination but optimal for purpose.

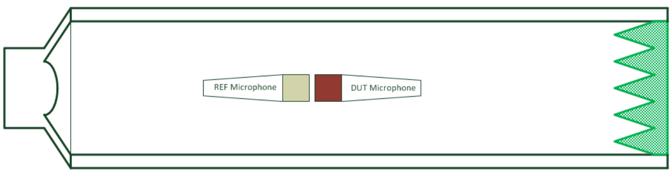

Figure 5: A sketch for the plane wave tube solution

4. FUTURE WORK

Some alternative realisations of the procedure and rig for the pressure comparison calibration have been sketched. Their potential advantages and disadvantages have been briefly discussed.

These realisations will be implemented experimentally and their merits and demerits assessed accordingly.

5. ACKNOWLEDGEMENTS

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