Emerging alternative to the well-known LS2P microphones

M Enge¹ and C Hof²

¹ Engineer, SPEKTRA Schwingungstechnik und Akustik GmbH, Dresden, Germany
² Laboratory Manager, Federal Institute of Metrology METAS, Bern-Waben, Switzerland

E-mail: ¹ maria.enge@spektra-dresden.com, ² christian.hof@metas.ch

Abstract. The usual primary method to determine the complex pressure sensitivity of laboratory standard microphones is the pressure reciprocity calibration method specified in IEC 61094-2. Up to now, this method has been applied around the world almost exclusively to calibrate laboratory standard microphones by the manufacturer Brüel & Kjær. Consequently, only Brüel & Kjær microphones are currently used as reference standard for the sound pressure. In this paper, microphones of the type G.R.A.S. 40AU-1 were evaluated as an alternative and calibrated according to the standard. The results of comparison measurements are shown in shortened fashion. Further research questions are given.

1. Introduction

The usual primary method of determining the complex pressure sensitivity of laboratory standard (LS) microphones is the pressure reciprocity calibration method (described in the IEC publication 61094-2 [1]). This method takes advantage of the fact that LS microphones are reciprocal transducers. This means that the microphone works both as sound receiver and sound source (transmitter). During calibration, two out of three microphones are coupled acoustically, one of which is receiver and the other is transmitter. The microphones are connected by a coupler (a small cylindrical cavity). For determining the sensitivity of each of the three microphones the electrical transfer impedance of the paired microphones has to be measured precisely. In addition to the electrical transfer impedance, the acoustic transfer impedance of the enclosed air volume between the microphones has to be modeled accurately. The acoustic transfer impedance is influenced by several factors including the microphone parameters.

In the past, this method has been applied almost exclusively to LS microphones manufactured by Brüel & Kjær – type 4160 and type 4180 – and the validity of the approach was approved by high effort of metrological investigation and with a large number of microphones.

Currently, comparable research to evaluate alternative types of microphones has not been published as yet. In this report, the results of a first investigation with LS microphones of the type 40AU-1 manufactured by G.R.A.S are presented.

2. Theory

Measuring microphones which are used for high-precision measurements or which are calibrated by the reciprocity method have to meet special specifications. These are described in the standard IEC 61094-1 [2]. The requirements address both the geometrical dimensions and the electroacoustic properties, especially the temporal stability. This includes the above-mentioned microphone parameter like the depth and volume of the front cavity and the acoustic impedance of the microphone.
The microphone parameters are specific for each individual microphone and may be subject to fluctuations over time. For that reason, it is important to determine the microphone parameters at each calibration. In the standard [1] some procedures are described. The front cavity depth can be determined by optical methods, whereas the front cavity volume as well as the acoustic impedance of the microphone are determined by acoustical methods or data fitting. The data fitting is a recognised methodology. This method is based on the fact that the sensitivity of the microphone is independent of the coupler which connects the microphones. So the calibration of the microphones is often carried out with three couplers of the same diameter but different lengths. Afterwards, the microphone parameters of each microphone are iteratively modified until a consistent set of frequency dependent sensitivity curves for each microphone is obtained independently of the coupler used. The iteration process is not standardised. For the implementation of the determination of the microphone parameters this leaves some room.

There are nominal reference microphone parameters for the well-known LS microphones by Brüel & Kjær, which are usually used as starting points for the data fitting. The reference microphone parameters are in the ballpark of the expected microphone parameters. As the consequence, the correct microphone parameter can be achieved by an automated data fitting. For other LS microphone such as the G.R.A.S. 40AU-1 the reference microphone parameters are not yet investigated.

3. Experiment

For the investigation three G.R.A.S. 40AU-1 were evaluated. The G.R.A.S. 40AU-1 is a new version of the G.R.A.S. 40AU. According to the supplier the manufacturing procedures, handling and ageing of the microphones has been improved with respect to the previous model.

Initially SPEKTRA examined the G.R.A.S. 40AU-1. Additionally the Federal Institute of Metrology (METAS) measured the microphones. After the transport to METAS, the microphones were calibrated again by SPEKTRA to monitor their stability. Each party was to determine the open-circuit sensitivity level of the microphones in a frequency range between 31.5 Hz and 20 kHz using their own calibration systems. The pressure sensitivities were determined at the reference environmental conditions (23 °C and 101.325 kPa) given in the standard [1].

Besides the standard microphone combinations, other microphone combinations were measured to estimate the reciprocity of the microphones. Furthermore, primary calibrations with one or two G.R.A.S. 40AU-1 and one or two known Brüel & Kjær 4180 were carried out. The Brüel & Kjær 4180 were used as known test standard to verify the calibration method.

In this section, the descriptions of the measurement systems and the methodology used for the microphone parameters determination by the parties are included. Preliminary results are also given.

3.1. Measurement equipment

SPEKTRA developed its own reciprocity calibration system according to the current standard [1]. It includes three air-filled sapphire plane-wave couplers, a microphone fixture and a pressure chamber. The microphones are connected to a vibration control system SRS-35 by SPEKTRA via a microphone transmitter unit Brüel & Kjær ZE0796 and a microphone preamplifier unit Brüel & Kjær 2673. Furthermore, the software CS18 that controls the SRS-35 and a MATLAB script for the calculation of the sensitivities are included. The MATLAB script contains all approaches for determining the sensitivities of the standard [1]. It is possible to compare the approaches and to validate the calculation systematically. The MATLAB script and the calculation program by METAS were compared in advance. The difference by the calculation is up to 1.3·10⁻⁵ dB (10⁻⁶ dB on the average).

The pressure reciprocity calibration set-up operated at METAS was initially based on the commercial calibration system Brüel & Kjær 9699 [3]. But it has over the years been gradually modified to improve the calibration uncertainty, to allow for phase calibration of microphones and to increase the speed of the data acquisition. METAS is still using the manually pressurized bell-jar and microphone fixture Brüel & Kjær UA 1412, the reciprocity apparatus Brüel & Kjær 5998, the microphone preamplifier unit Brüel & Kjær 2673 as well as the transmitter unit Brüel & Kjær
ZE 0796. Major modifications concern a set of four sapphire plane-wave couplers without capillary tube manufactured by METAS, which are routinely used for LS-microphone pressure reciprocity calibrations. To perform the measurement of the electrical transfer impedance of pairwise acoustically coupled microphones as required by the standard [1], the original Brüel & Kjær signal generator, band pass filter and hp 3458A digital voltmeter were replaced by an NI 4461 DAQ-card. The data acquisition is performed by a LabVIEW program, which excites the transmitter microphone with quasi-stationary sinusoidal signals. The data acquisition is based on the sine-approximation method. The insert-voltage method to determine the open-circuit sensitivity of the microphones is used.

3.2. Methods for obtaining microphone parameters

SPEKTRA measures the front cavity depth of the microphones using a laser distance sensor. Initially, the front cavity results from the measured front cavity depth and the reference front cavity diameter. Subsequently, the front cavity volume and a reference equivalent volume have been optimized in a frequency range between 200 Hz and 2 kHz, to minimize the difference between the pressure sensitivities using three couplers. A reference resonance frequency together with a reference loss factor was determined by a least square fit in a frequency range between 1 kHz and 20 kHz.

At METAS the microphone parameters required for the calculation of the acoustic transfer impedance were determined using the same procedure, which is routinely applied for Brüel & Kjær LS microphones: the front cavity depth and volume were determined by the dimensional laboratory at METAS. The resonance frequency \( f_0 \) and the loss factor \( l \) describing the frequency response of the acoustic impedance \( Z_a \) were determined in an iterative process by fitting the microphone sensitivity \( M_p \sim \frac{1}{Z_{a,iw}} \) to the following equation (1):

\[
M_p = \frac{M_{p,0}}{\left(1 - \left(\frac{f}{f_0}\right)^2\right) + i\left(\frac{f}{f_0}\right)l} \quad [4]
\]

For LS2-microphones, METAS normally performs the fit for this relation over a frequency range from 1 kHz to 25 kHz.

3.3. Preliminary Results

Figure 1 shows the pressure sensitivities measured by METAS and SPEKTRA (before and after transport of the microphones).

![Figure 1. Pressure sensitivity determined by SPEKTRA (SPEKTRA I: before transportation, SPEKTRA II: after transportation) and METAS, exemplary for G.R.A.S. 40AU-1 285094](image)

Over a wide frequency range, the difference between the pressure sensitivities is less than 0.01 dB. In the worst case, the difference is 0.12 dB at 20 kHz. To assess the equivalence of the results, an \( E_n \)-value defined as follows was used:

\[
E_n = \frac{M_{\text{SPEKTRA}} - M_{\text{METAS}}}{\sqrt{u^2_{\text{SPEKTRA}} + u^2_{\text{METAS}}}} \quad (2)
\]
where $M_{\text{SPEKTRA}}$ is the pressure sensitivity reported by SPEKTRA after transport of the microphones, $M_{\text{METAS}}$ is that reported by METAS, $u_{\text{SPEKTRA}}$ and $u_{\text{METAS}}$ are the expanded uncertainties of the pressure sensitivities declared by SPEKTRA and METAS, respectively ($k = 2$). The absolute value of $E_n$ is less than 0.2 for the frequency range from 20 Hz to 10 kHz. In the worst case, the absolute value of $E_n$ is 0.56 at 20 kHz. The absolute value of $E_n$ being less than 1.0 indicates the equivalence of the results determined in the two laboratories.

Table 1 shows exemplary the associated microphone parameters of G.R.A.S. 40AU-1 285094 reported by SPEKTRA and METAS.

### Table 1. Microphone parameters determined by SPEKTRA and METAS, exemplary for G.R.A.S. 40AU-1 285094

| Parameter                        | SPEKTRA       | METAS        |
|----------------------------------|---------------|--------------|
| Front cavity volume [mm$^3$]     | 35.30 (fitted)| 30.87 (measured) |
| Front cavity depth [mm]          | 0.49 (measured)| 0.46 (measured) |
| Equivalent volume [mm$^3$]       | 9.20 (fitted) | 9.20 (reference value) |
| Resonance frequency [Hz]         | 22868 (fitted)| 24903 (fitted) |
| Loss factor                      | 1.12 (fitted) | 1.25 (fitted) |

In spite of differences in the proceedings for determining the microphone parameters and the measuring systems the results are highly comparable. Both parties using their own methods obtained for the G.R.A.S. microphones an equivalent frequency response behavior (with residuals strictly smaller than 0.01 dB up to 20 kHz).

The results obtained when combining a G.R.A.S. 40AU-1 with two Brüel & Kjær 4180 microphones were analyzed, too. The sensitivity curves of the microphones obtained when applying the pressure reciprocity technique to such a heterogeneous triplet were consistent with the results obtained when using only microphones of one type.

Finally, the reciprocity of the G.R.A.S. 40AU-1 microphones were checked by reversing the roles of the microphone acting as a transmitter and the one acting as receiver. The curves of the electrical transfer impedance were found to be consistent.

### 4. Discussion and Conclusions

After initial investigation on the G.R.A.S. 40AU-1, SPEKTRA and METAS are, hence, confident, that they are able to determine the microphone parameters and the pressure sensitivities of this new brand of microphones properly, using their respective procedures. The agreement between the pressure sensitivities reported by SPEKTRA and METAS was very good.

Nevertheless, further studies should be conducted to determine the influence of static pressure and temperature on the sensitivity of G.R.A.S. 40AU-1 as it has been done for Brüel & Kjær 4160 and 4180 [5]. Furthermore, the applicability of IEC TS 61094-7 [6] to determine the free-field sensitivity levels for G.R.A.S. 40AU-1 based on the pressure sensitivity levels should be re-examined. Finally, the stability of the G.R.A.S. microphones should be monitored over a longer period.

### References

[1] International Electrotechnical Commission IEC 61094-2 2009 Measurement microphones – Part 2: Primary method of pressure calibration of laboratory standard microphones by the reciprocity technique

[2] International Electrotechnical Commission IEC 61094-1 2000 Measurement microphones – Part 1: Specifications for laboratory standard microphones

[3] Frederiksen E and Christensen J I 1998 Pressure Reciprocity Calibration – Instrumentation, Results and Uncertainty Brüel & Kjær Technical Review N°1

[4] Brüel & Kjær 1996 Technical Documentation Microphone Handbook Vol. 1: Theory pp 2-30

[5] Rasmussen K 1999 The static pressure and temperature coefficients of laboratory standard microphones Metrologia 36 pp 265-273

[6] International Electrotechnical Commission IEC TS 61094-7 2006 Measurement microphones – Part 7: Values for the difference between free-field and pressure sensitivity levels of laboratory standard microphones