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NOVEL METHODS AND SERVICES FOR MICROPHONE CALIBRATION AT INFRASOUND FREQUENCIES

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ABSTRACT

The calibration of microphones has been the basis of reliable acoustic measurements and traceability for many decades. All the sensors used in a reliable measurement are to be individually calibrated, and a well-established service system is available in Europe. This, however, only holds true for audible frequencies. At low frequencies and for infrasound, no calibration infrastructure exists. To improve this situation, two novel calibration techniques were established at the Physikalisch-Technische Bundesanstalt (PTB), the national metrology institute of Germany. There is a primary method that exploits the change of barometric pressure with altitude by moving the device under test (DUT) on a vertical circular orbit and subjecting it to a periodic pressure change. A secondary calibration technique produces a homogeneous sound field in a large, closed tube, where reference sensors and DUTs can be mounted side by side for a simultaneous measurement. This allows the calibration of a wide range of sensors, including microbarometers, sound level meters and microphones. Recently, this calibration technology has become one of PTB's metrological services, and it is offered to customers all over the world.

Keywords: *microphone calibration, infrasound, traceability,*

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1. INTRODUCTION

Noise measurements play a key role in the determination of environmental noise exposure to humans. Since the proliferation of green energy generation has been accompanied by serious concerns about low-frequency noise and infrasound emission, reliable and traceable sound measurements are an important issue for legitimating and improving the acceptance of installed energy converters. The calibration of sensors is one of the basic elements for the traceable and reliable quantitative characterization of a noise situation on site. For low frequencies and infrasound applications, however, there is no established calibration infrastructure. This is because calibration methods and techniques have not yet been developed or only exist at an experimental stage at present.
Two novel calibration methods to be applied in the low-frequency or infrasound-frequency ranges are described in this paper. A recently developed primary method is able to calibrate microphones under free-field conditions and uses a completely different measurement principle to well-established techniques that are mainly in the audible frequency range. Since it can only be applied to specified and particular measurement microphones, a secondary technique was developed, which is able to transfer the primary calibration results to nearly all practically relevant sensors.

2. PRIMARY CALIBRATION: THE "CAROUSEL" METHOD

A primary calibration has been defined as an operation that establishes a relation between the quantity values with measurement uncertainties provided by a measurement standard and corresponding indications provided by a measuring device under test (DUT) [1]. The widely established and common reciprocity technique uses a sophisticated method for this purpose to link the acoustic values to electrical SI variables. Alternatively, a reference with pressure values determined from basic principles could be used, for example, the static pressure values of ambient air. These values can be calculated from the gravity g and the density of the air ρ for an altitude h. Moving on a vertical course in the gravitational field changes the altitude h and thus the barometric pressure. If this induced pressure change is time-dependent or even periodic, the resulting dynamic pressure can be interpreted as sound pressure. The simplest way to implement this idea is to mount a sensor, such as the microphone under test, on a rotating disc, producing a sinusoidal waveform of pressure [2]. For altitude amplitudes below 10 m, linear conditions can be assumed, and the pressure is obtained by

$$\Delta p(t) = -\rho \cdot g \cdot \Delta h(t) \qquad (1)$$

Although this concept is quite obvious, its realization is technically challenging. Evaluating Eqn. (1) shows that even small changes in altitude lead to large acoustic pressure values. Thus, a sufficient signal strength can easily be obtained, but the mechanical construction is likewise challenging. The rotation axis has to be adjusted so that it is exactly horizontal, and vibrations have to be mitigated by carefully balancing the complete system.

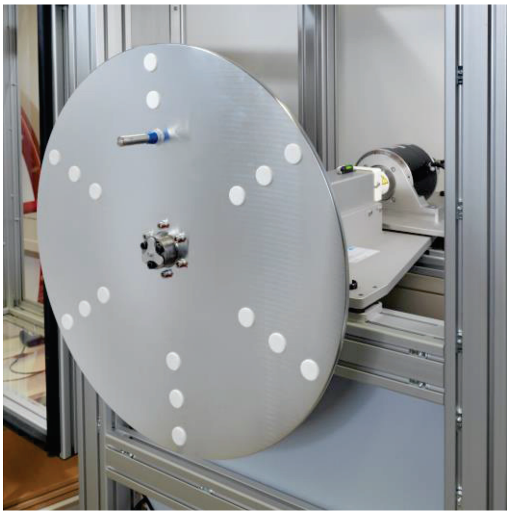

Figure 1. Photograph of the primary calibration setup that was developed showing the rotating disc with the microphone mounted.

The distance from the rotation axis is to be carefully determined so that the correct pressure can be applied. To simultaneously ensure a high test-retest repeatability, self-centring structures were constructed for mounting the microphones. A photograph (Fig. 1) shows the novel setup. The periodically changing pressure caused by the disc's rotation is detected by the microphone, converted into an AC-voltage, amplified, and detected by an analogue-to-digital converter [2]. Fig. 2 depicts an example for a frequency of 0.2 Hz. The Fourier spectrum in Fig. 3 shows that the signal amplitude at 0.2 Hz can be determined with a high signal-to-noise ratio and disturbances have only marginal effect on the performance.

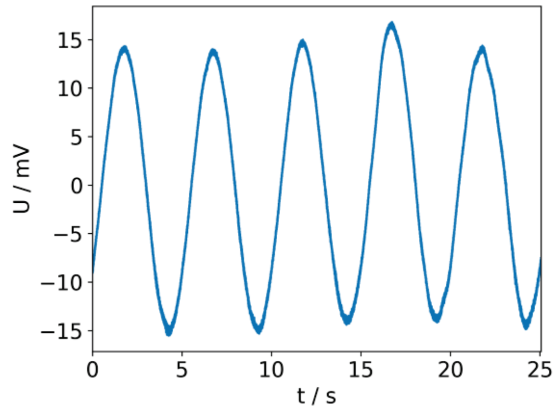

Figure 2. Signal voltage versus time for a calibration frequency of 0.2 Hz

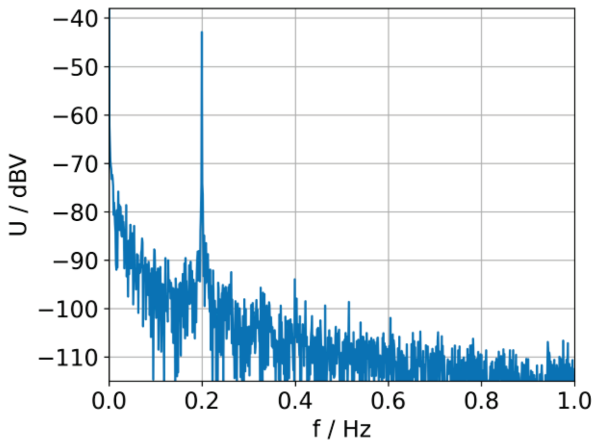

Figure 3. Fourier spectrum of a signal for a calibration frequency of 0.2 Hz, signal length 1000 s,

resolution bandwidth 1 mHz, rectangular window function applied.
The technique was successfully applied to microphones with vent openings on the front. A typical result is depicted in Fig. 4. Reliable values could be obtained with an uncertainty better than 0.2 dB. To validate the novel method, a first comparison was carried out with a pistonphone setup available at Laboratoire National de Métrologie et d'Essais (LNE) [3]. The agreement found was better than 0.1 dB in the frequency range between 0.1 and 5 Hz.

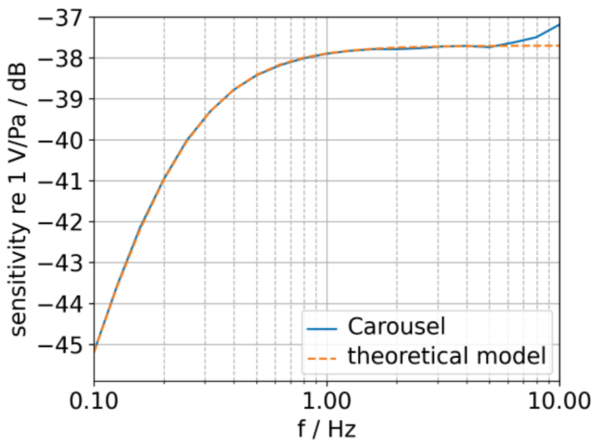

Figure 4. Result of a primary calibration using the carousel method. The DUT is a ½" microphone set specifically designed for infrasound measurements. The theoretical model is based on the specifications published by the manufacturer.

3. SECONDARY CALIBRATION TECHNIQUE: THE SOUND TUBE

The described primary technique can only be applied to particular measurement microphones. What is most critical is the orientation of the vent, which should ideally be oriented towards the front of the microphone. To allow the transfer of the primary calibration results to a great variety of practically relevant sensor systems, a secondary calibration setup was developed. It was based on the comparison principle, and all the DUTs were mounted in a well-known sound field and positioned beside the primarily calibrated reference.

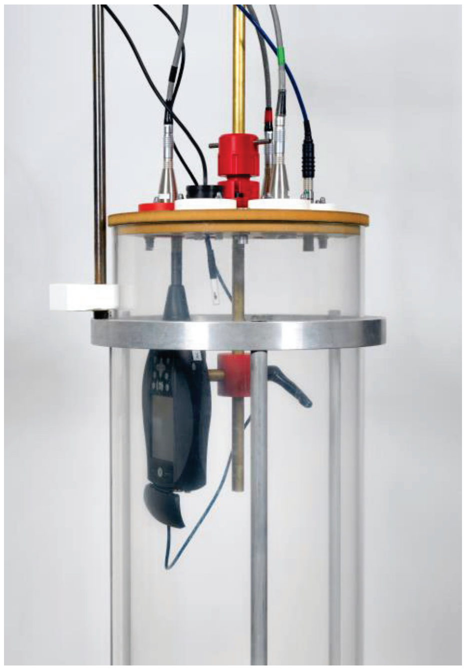

Figure 5. Photograph of the active sound field area of the secondary calibration setup with reference microphones and DUTs.

For this purpose, the sound field should favourably be quite homogeneous in the region of interest. This requirement could mostly be accomplished by a sound tube with a large diameter (30 cm), a length of about 1.1 m and a subwoofer as a sound source at the bottom of the tube. The sound field was numerically modelled using a finite element technique and the design was optimized to realize a sufficient wide homogeneous sound field. This was accomplished in the frequency range between 0.5 Hz and 100 Hz, and the system provides enough space for a variety of sensors now, such as microphones and sound level meters, see Fig. 5. Even microbarometers can be calibrated.
Many calibrations have already been undertaken using the secondary method. As an example, the result of the calibration of a microbarometer (CEA/DASE MB2005) is shown in Fig. 6. Microbarometers of this type are deployed in the infrasound stations belonging to the International Monitoring System (IMS) of the Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) which are distributed around the world and need a careful calibration and traceability to national standards.

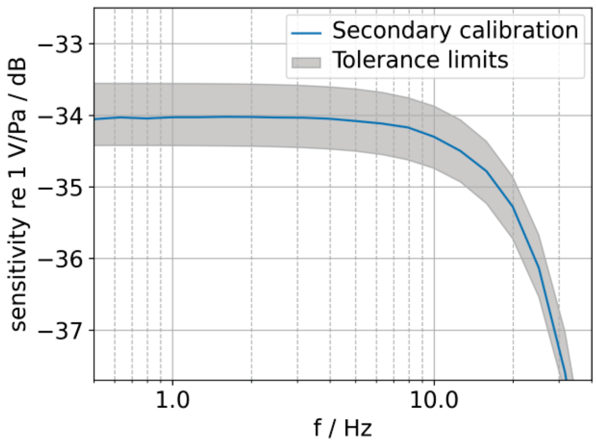

Figure 6. Result of a secondary calibration using the sound tube. The DUT is a MB2005 microbarometer. The tolerance limits (shaded in grey) are given by the manufacturer.

The setup, including all the analysis methods, has been evaluated with several comparisons and internal checks using a variety of sensors and sensor combinations, and it will be employed as a formal calibration service of PTB from now on.

4. DISCUSSION

A novel primary and a secondary calibration method were developed for applications in the low-frequency and the infrasound ranges between 0.1 Hz and 5 Hz, and from 0.5 Hz to 100 Hz, respectively. Uncertainties down to below 0.2 dB can be reached, which is suitable for all applications in environmental noise measurements.

The upper frequency limit of the primary carousel technique is currently 5 Hz. It is mainly determined by the noise induced by the air stream at the microphone tip which inevitably accompanies the method because of the movement of the microphone. A limit of 5 Hz is, however, sufficient for establishing a sound pressure standard without gaps between 0.1 Hz and the audible frequency range because the carousel results can easily be combined with a common reciprocity calibration. Such a calibration is available down to 2 Hz. To widen the overlap, the influence of streaming and other impacting factors on the carousel method are under investigation to increase the upper limit of the exploitable frequency range of the novel method.

The sound tube plays a major role in disseminating the calibration results. Its internal volume allows nearly all the practically relevant sensors to be managed. Currently deployable down to 0.5 Hz, improvements regarding the sealing of the tube are to decrease this limit to about 0.1 Hz in the near future.

The newly developed calibration facilities are enabling the establishment of the complete traceability chain from infrasound to audible sound. They are also allowing reliable and most notably traceable measurements in the complete frequency range, which is particularly relevant for environmental investigations. Furthermore, they form the objective basis for noise exposure determinations, for example, at sites with renewable energy converters. The methods have recently become part of PTB's metrological services, and such calibrations are thus being offered to customers all over the world.

5. ACKNOWLEDGMENTS

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