A new scanning apparatus for the dissemination of the unit Watt in airborne sound

Spyros Brezas[1], Christian Bethke[1],Volker Wittstock[1]

[1] *Physikalisch-Technische Bundesanstalt , 38116 Braunschweig, E-Mail:spyros.brezas@ptb.de*

Introduction

Sound power calibration measurements in PTB's hemianechoic room are performed utilizing the spiral method, which follows the free field assumption allowing the sound power to be determined by averaging the sound pressure over an enveloping surface [1]. The rotation of the source during measurement and the quarter-circle microphone path which is identical for all measurements are main disadvantages of the method. Within the scope of a European Metrology Research Programme, a scanning apparatus has been developed and tested at PTB. The apparatus is designed for the dissemination of the unit Watt from primary sound power standards to transfer standards.

Apparatus description

The new scanning apparatus enables the sound pressure measurement of a stationary sound source over a physical hemisphere in PTB's hemianechoic room. On the contrary, the spiral method covers a virtual hemisphere, due to the quarter circular microphone path and the simultaneous rotation of the sound source. The new apparatus consists of a hemi-circular stainless steel arc, where up to 24 microphones can be mounted and a motor, which tilts the arc onwards and backwards over the source under measurement, which is placed at the centre of the hemianechoic room. The scanning movement settings, including duration, are controlled by a software.

There are two arcs of different radius available enabling measurements at different distances to the source. Both arcs can be easily removed from the hemianechoic room. Figure 1 shows both arcs of the scanning apparatus. The spot in the centre of the hemi-circles delimited by the arcs is the location, where the primary and the transfer standards are positioned during measurements.

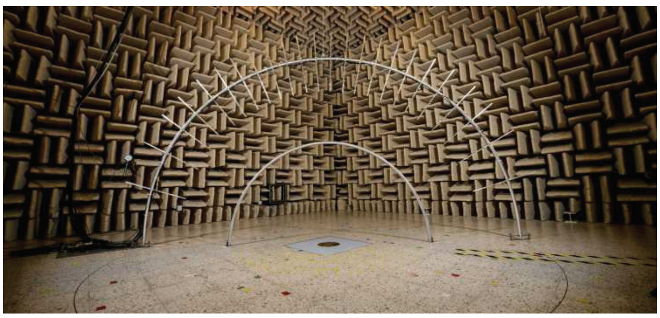

Figure 1: PTB's scanning apparatus.

The position of each microphone along each arc is a compromise between equal angles (preferred for directivity measurements) and equal partial surface areas from the floor (preferred for sound power measurements). As it can be seen in figure 1 the microphones are attached to 70 cm long acrylic glass rods, which can be manually fixed at different measurement radii. These variations provide measurement results at different distances to the sources.

Background noise considerations

A mainly desired feature of the scanning apparatus is a low background noise. The driving motor of the apparatus is located on the outer side of a hemianechoic room sidewall. Between the motor and the wall, a concrete mass has been placed in order to prevent vibration excitation of the wall. The arc is connected to the motor by wire rope and rope. A spring is used to decouple motor vibrations from the arc. Figure 2 shows the sound pressure level of the background noise (scanning apparatus operating) along with the sound pressure level of primary and transfer standards for both one-third octave and FFT (3.125 Hz resolution) frequency analysis, since the application of the apparatus for sound power measurements is aimed for both broadband and narrow band analysis. The primary standard is a vibrating piston embedded in the floor of the hemianechoic room and aerodynamic reference sound sources were used as transfer standards.

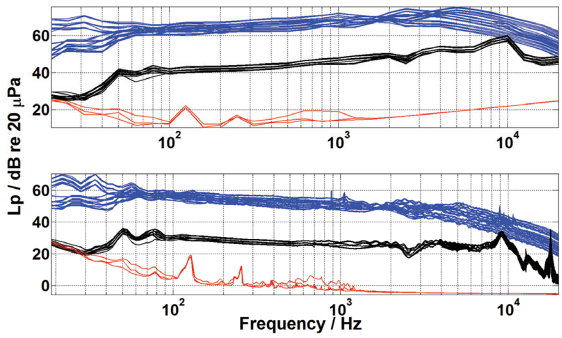

Figure 2: Sound pressure level of primary standard (black), transfer standards (blue) and background noise (red). Top: one-third octave band analysis. Bottom: FFT analysis (3.125 Hz resolution).

As it can be seen in figure 2, the level differences between transfer sources and the scanning apparatus background noise is large for the entire frequency range in both analyses. For the case of the primary standard, the low and high end frequency characteristics of the source should be improved so that the corresponding level difference is enlarged. Apparently, the scanning apparatus background noise does not affect the sound power measurements to a great frequency extent. The major background noise sources are other than the scanning apparatus.

Scanning speed monitoring

The movement of the apparatus must be uniform and adjustable during the scanning to provide various measurement durations. The latter can be set using the software that controls the motor. The scan angular velocity can be monitored via a potentiometer, which is connected to an arc end and rotated by the moving arc. From the slope of the voltage output signal, the velocity can be extracted. Figure 3 shows the potentiometer output voltage for both onwards and backwards movement of the scanning apparatus and the scan speed of such signals recorded during sound power measurements. The measurement duration was 1200 s and the slope was calculated for 10 s time intervals.

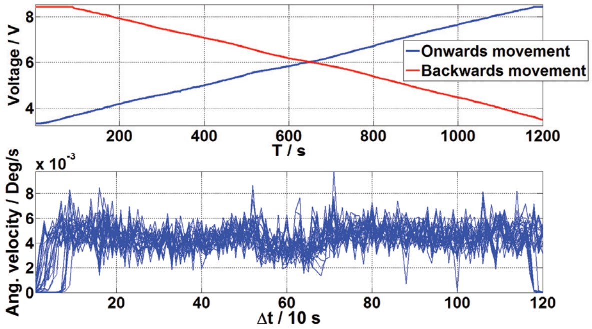

Figure 3: Potentiometer output voltage for both possible scanning paths (top) and angular velocity of corresponding voltage data collected during sound power measurements (bottom).

Figure 3 reveals that the scan speed is approximately 0.005 deg/s for the majority of the scan duration, except for the beginning and the end of the movement and the middle of the scan. The zero angular velocity values can be attributed to the connection of the arc to the potentiometer. This is made using a small plastic tube, whose flexibility makes the start of the arc tilting and the potentiometer rotation not simultaneous. In the middle of the scan, the angular velocity is decreased as the motor slows down while the arc reaches its maximum position.

For the validation of the scan speed as described by figure 3, the repeatability of the sound pressure level averaged over time and surface was calculated for both primary and transfer standards in terms of standard deviation. The measurements represent different radii and both one-third octave band and FFT frequency analysis. Figure 4 shows the standard deviation. The large standard deviation values for the primary standard measurements are attributed to its frequency response, while for the transfer standards to the tonal characteristics exhibited by some of the sources. The initial angular velocity values suggest that further investigation should be performed to achieve a more uniform scan.

Measurements at different radii

The use of the scanning apparatus is intended to enable measurements at different radii, which may be used to extend the usable frequency range towards lower frequencies. For this reason, measurements at various radii from 0.60 m to 2.75 m were performed. For the better quantification of the effects related to the different measurement distances, the sound power level differences between each radius and the largest radius (2.75 m) were calculated and are presented in figure 5 concerning a transfer standard. For the measurements, microphone wind shields were used.

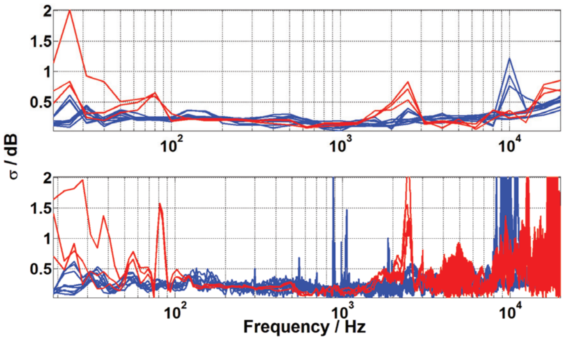

Figure 4: Standard deviation of average sound pressure levels for different measurement radii and sources. Blue: transfer standards. Red: primary standard. Top: one-third octave band analysis. Bottom: FFT analysis (3.125 Hz resolution).

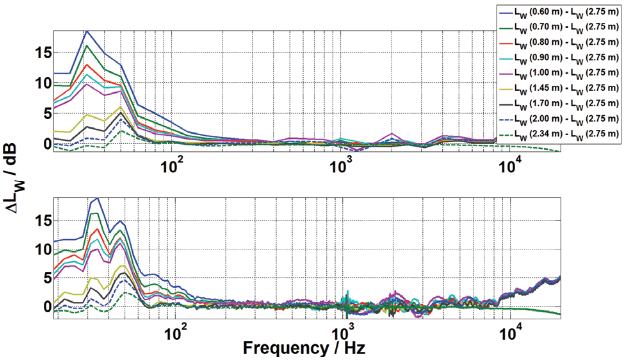

Figure 5: Sound power level differences between measurements at different radii. Top: one-third octave band analysis. Bottom: FFT analysis (3.125 Hz resolution).

The largest level differences can be found at the lower frequencies in figure 5, which can be related to near field effects, room reflections and remaining wind influences, since it is assumed that the wind produced by the rotating fan of the reference sound source was not fully suppressed by the wind shields. At frequencies between 1 and 2 kHz, the reflections from the arc increase the sound power level differences. The differences at frequencies above 8 kHz are attributed to the acoustic shadow of the arc, because for the two largest radii, the microphones diaphragm was oriented outwards.

Arc reflections

The use of the arc leads to reflections. Figure 6 shows the sound pressure level (FFT analysis) of the primary standard measured at 2 m for the spiral method and 1.91 m for the arc method. Both distances correspond to the same distance between the microphones and the measurement equipment. As it can be seen in figure 6, both methods are influenced by reflections.

The calculation of the sound power level of a source using the scanning apparatus is intended to be based on the substitution method, which is described by:

$$L_{W,TS} = L_{W,PS} + \overline{L}_{p,TS} - \overline{L}_{p,PS} \qquad (1)$$

where and $L_{W,PS}$ is the sound power level of the transfer and primary standard respectively. Accordingly, $\overline{L}_{p,TS}$ and $\overline{L}_{p,PS}$ is the time and surface averaged sound pressure level of the transfer and the primary standard [2].

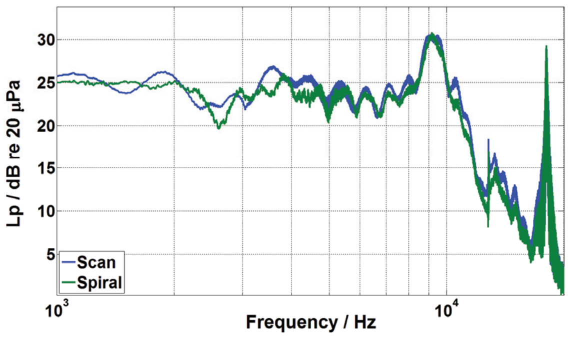

Figure 6: Sound pressure level of the transfer standard at the same distance from the microphone mounting equipment for arc (blue) and spiral method (green). FFT analysis (3.125 Hz resolution).

The latter two levels are expected to provide a compensation for the arc reflections. To examine the efficiency of the compensation, measurement results of different radii were used. The standard deviation of the originally measured data was calculated. The sound pressure level subtraction as described by equation 1 was performed for the measured data, after being referred to the same radius. The standard deviation of the level differences was also calculated. The comparison of the two deviations can be seen in figure 7.

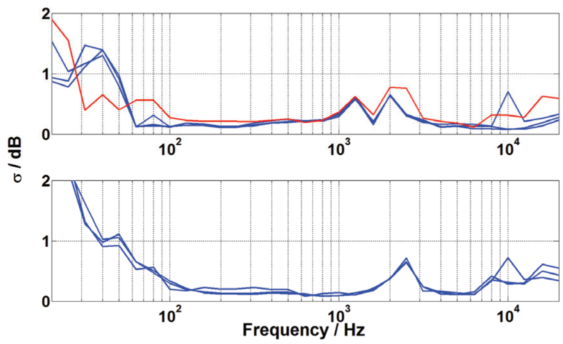

Figure 7: Standard deviation of sound pressure levels at different radii (top) for different sound sources (blue: transfer standards, red: primary standard). Bottom: Standard deviation of sound pressure levels according to substitution method.

The influences of the reflections, which are apparent at 1.25, 1.6 & 2.0 kHz at the upper graph of figure 7 are compensated in the lower part of the figure. The peak at 2.5 kHz after implementing the substitution is attributed to the low repeatability of the primary standard at this frequency (see figure 4).

Arc – spiral path results comparison

A comparison between results for transfer standards obtained by the arc and the spiral method was performed. Figure 8 shows the absolute sound power level difference between scan method measurements at 1.45 m from the source and the spiral method (2 m from the source).

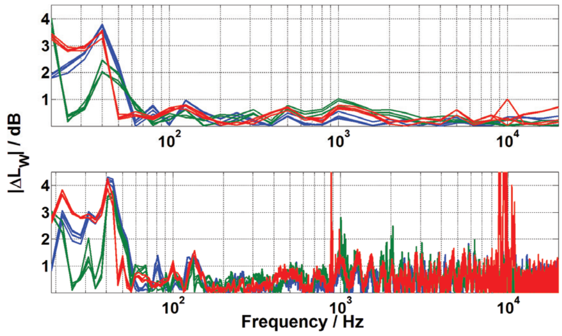

Figure 8: Absolute sound power level differences between arc (1.45 m measurement radius) and spiral method (2 m measurement radius). Top: one-third octave band analysis. Bottom: analysis FFT (3.125 Hz resolution).

The influences on the spectra that were revealed by the measurements at different radii, are also apparent in figure 8. The availability of sound power level measurements over a period of more than 20 years using the spiral method enabled the calculation of the standard deviation of these results. The standard deviation of the results obtained by the arc method for three different measurement radii has also been calculated and plotted against the standard deviation of the spiral method. All results correspond to the same reference sound source specimen.

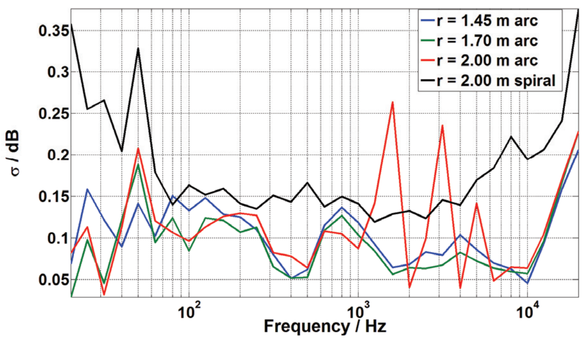

Figure 9: Standard deviation of sound power levels of various measurement radii and methods for the same reference sound source specimen and one-third octave band frequency analysis.

The comparison of the measurement methods based on figure 9 reveals that in overall the scanning apparatus results provide less deviated sound power levels compared to the spiral method, except for the frequency region between 1 kHz and 4 kHz. These measurements have the closest distance to the arc and thus, arc reflections are prominent. The decrease in the standard deviation is more profound in both frequency ends.

Conclusions

A newly developed scanning apparatus has been tested at PTB. The background noise of the moving apparatus has been found to be sufficiently low to avoid detrimental effects on targeted sound power measurements. The movement of the arc has been suffiently uniform to provide repeatable results. Further improvements are expected to provide a more uniform angular velocity. The use of the arc imposes reflections, similar to those observed with the spiral method. Contrary to the latter, the former are expected to cancel out during the sound power level calculation procedure according to the substitution method. The scanning apparatus has enabled sound power measurements at different radii to extend the valid sound power level measurement frequency range below 100 Hz. Finally, the sound power levels based on the scanning apparatus have a smaller standard deviation than the values obtained by the spiral method. The absolute level differences between the two measurement methods are believed to cancel out after a more thorough evaluation of the scanning apparatus results.

This work was carried out within the EMRP Joint Research Project SIB56 SoundPwr. The EMRP is jointly funded by the EMRP participating countries within EURAMET and the European Union.

Literature

[1] ISO 3745:2012, Determination of sound power levels and sound energy levels of noise sources using sound pressure - Precision methods for anechoic rooms and hemi-anechoic rooms

[2] ISO 3743:2010, Determination of sound power levels and sound energy levels of noise sources using sound pressure - Engineering methods for small movable sources in reverberant fields - Part 1: Comparison method for a hard-walled test room