

Factors that affect the sound power emitted by reference sound sources

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Introduction

To establish traceability for the quantity sound power, a Joint Research Project in the frame of the European Research Programme is implemented. The project consists of three major parts, the second of which focuses on the dissemination of the unit Watt and constitutes the basis for this paper. It is intended to use aerodynamic reference sound sources as transfer standards. It is therefore necessary to investigate how the sound power of these sources depends on the operating conditions and what the directivity of these sources is.

Directivity measurements

The determination of the sound power level of noise sources according to [1] or other methods requires sound pressure measurements on an enveloping surface. The directivity of the source under test, but also of a possible transfer standard, is then an important quantity for the assessment of the uncertainty of the surface averaged sound pressure. Therefore, a scanning apparatus has been constructed at PTB as shown in figure 1. It consists of a hemi-circular arc (one out of two available) on which 24 microphones can be mounted in a way that enables different measurement radii to be used. The arc can be tilted over the measured source with the use of an external motor.

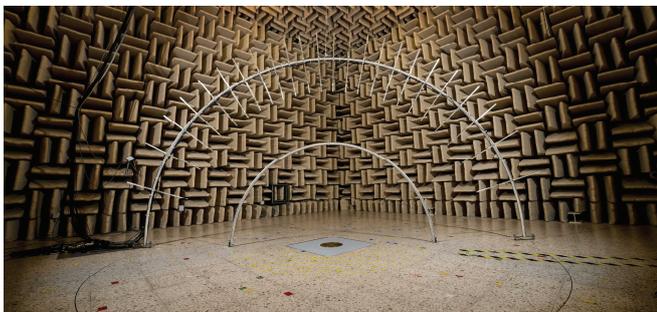


Figure 1: Scanning apparatus in PTB's hemianechoic room.

Figure 2 shows two different directivity plots, both corresponding to a measured reference sound source (RSS). The quantity depicted in these plots is the directivity index, which is calculated according to the following equation

$$DI_i = L_{pi} - \bar{L}_p \quad (1)$$

where L_{pi} is the sound pressure level at the i -th position and \bar{L}_p is the sound pressure level averaged over the measurement surface [2]. According to figure 2, the RSS exhibits directional characteristics, which should be taken into consideration for the dissemination process.

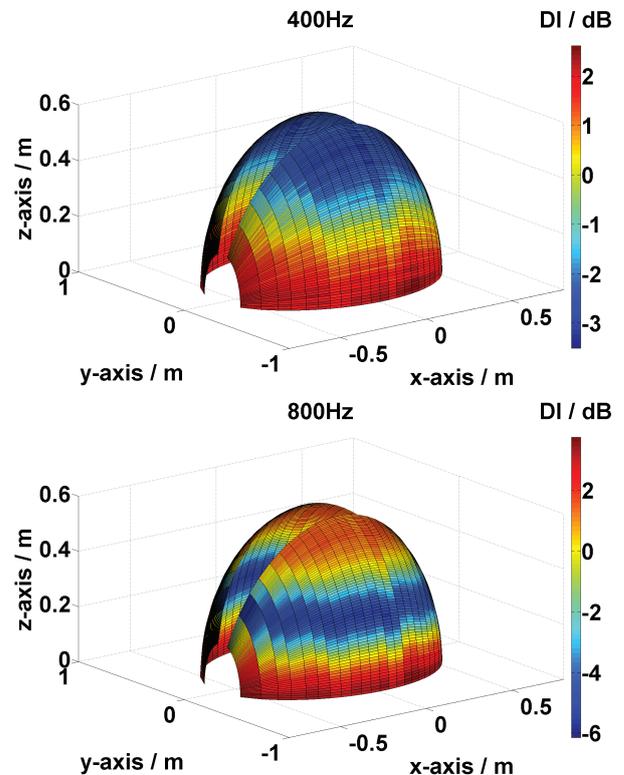


Figure 2: Directivity plots of a reference sound source at 400 Hz (top) and 800 Hz (bottom).

Influential parameters

The sound power produced by a RSS is described by:

$$P = K \left(B / B_0 \right)^{exB} \left(T / T_0 \right)^{exT} \left(\omega / \omega_0 \right)^{ex\omega} \quad (2)$$

where K is a constant, B is the atmospheric pressure, T the ambient temperature, ω the fan rotation speed of the RSS and exB , exT , $ex\omega$ factors related to the aforementioned influential quantities [3]. The quantities with the index 0 are reference values which may be chosen arbitrarily. By using eq. 2 to relate the sound power level in situ to the sound power under calibration conditions, the following equation is derived:

$$L_{W, in situ} = L_{W, cal} + 10 exB \lg \left(\frac{B_{in situ}}{B_{cal}} \right) \text{dB} + 10 exT \lg \left(\frac{T_{in situ}}{T_{cal}} \right) \text{dB} + 10 ex\omega \lg \left(\frac{\omega_{in situ}}{\omega_{cal}} \right) \text{dB} \quad (3)$$

It can be concluded from eq. 3 that the factors exB , exT and $ex\omega$ must be determined to calculate the in situ sound power level. For this reason, measurements were performed where one influential parameter was changed whereas the other two were kept as constant as possible. For the influence of the atmospheric pressure, measurements at

PTB's hemianechoic room were performed allowing atmospheric pressure changes of 5%. Outdoor measurements took place for the influence of ambient temperature providing changes of 46% compared to manufacturers' proposed operating temperature intervals, while measurements for the influence of the fan rotation speed by changing the input voltage allowed changes of 22%.

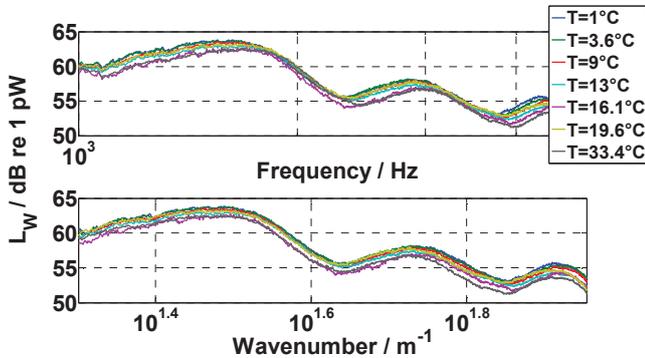


Figure 3: Frequency shift in sound power level due to temperature changes. Sound power level against frequency (top) and against wavenumber (bottom).

Changes in atmospheric pressure result in common changes of the whole frequency spectrum of the sound power level. On the contrary, this is not the case for changes in temperature and fan rotation speed. For this reason, a compensation must be performed. Figure 3 shows the frequency shift in sound power level due to changes in temperature along with the same level plotted against wavenumber. Another factor that influences the spectra in figure 3 is the interference from the ground. For this reason it is possible to observe regions of maximum change due to temperature changes (e.g. 1500 Hz) and regions of minimum change (e.g. 2000 Hz) in the upper graph of figure 3.

Similarly, a compensation for the frequency shift is needed for changes in the fan rotation speed of the RSS. In figure 4, the sound power level corresponding to different rotation speeds is plotted against frequency and against frequency divided by the rotation speed. Measurements have been performed for different electric current alternating frequencies (blue – 50 Hz, red – 60 Hz). Each line corresponds to one value of the rotation speed.

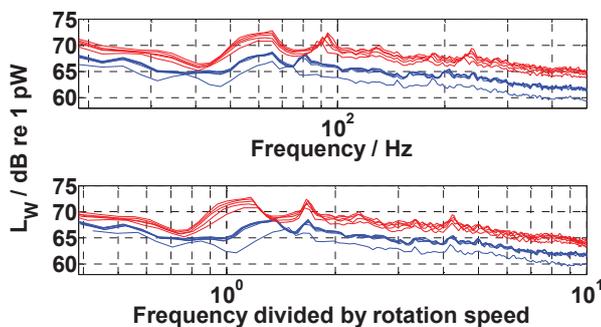


Figure 4: Frequency shift in the sound power level due to changes of the fan rotation speed. Sound power level against frequency (top) and against frequency divided by rotation speed (bottom).

For each measurement set, corrections for the other two influences were performed according to eq. 3, leading to an equation with only one influential factor. This equation was used to calculate the corresponding factors. The corrections were based on theoretical values of the factors, i.e. $exB = 1$, $exT = -2.5$ and $ex\omega = 5.5$ [4]. After the completion of the calculation, a new calculation was performed based solely on the calculated results. The factors that have been derived in both cases are shown in figure 5, where those derived by the former calculation are denoted with 1 and by the latter with 2 correspondingly.

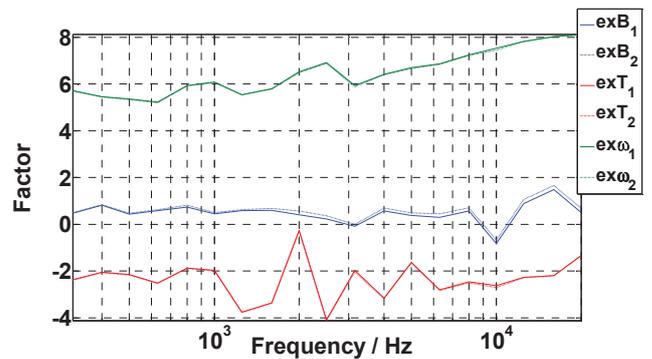


Figure 5: Correction factors for the relation of the in situ sound power to sound power under calibration conditions.

The differences between the two calculations for the factors are minor. The factor for the differences in atmospheric pressure (exB) has values close to the theoretical one ($=1$), but no robust conclusions can be drawn due to the narrow pressure spanning during the measurements. The factor concerning the ambient temperature changes (exT) has values near -2.5 , which is the theoretical one for a dipole behaviour [4]. The value at 2 kHz (close to 0) can be attributed to the destructive interference of the ground reflections. The factor describing the changes in fan rotation speed ($ex\omega$) exhibits a dipole behaviour with the values close to 6 and a quadrapole behaviour with values close to 8 at higher frequencies [4].

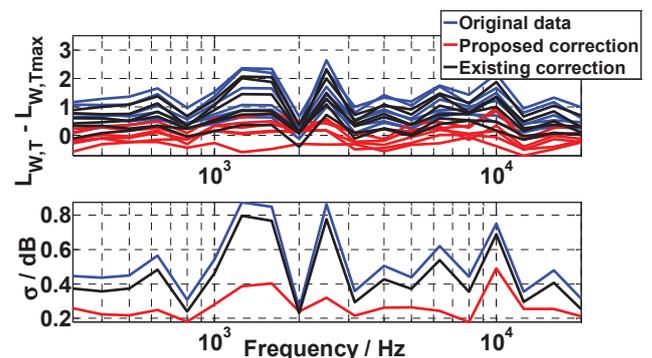


Figure 6: Difference between sound power level at a measurement temperature and sound power level at maximum temperature for original (blue), corrected according to proposed (red) and existing approach (black) data (top) and standard deviation of corresponding level sets (bottom).

Based on eq. 3 and the factors of figure 5, a correction was performed for a sound power level measurement set, related

to different ambient temperature values. An additional correction was performed based on an existing approach [5]. For all data sets, the difference between the sound power level at each temperature and at maximum temperature has been calculated. For the comparison of the two corrections, the standard deviation of each level set was also calculated. All level differences and standard deviations are presented in figure 6.

Conclusions

Scanning measurements have shown that the directivity characteristics of reference sound sources depend on frequency. The noise emission of this kind of sources is influenced by atmospheric pressure, ambient temperature and fan rotation speed. For the calculation of the in situ sound power level based on measurements under calibration conditions, correction factors must be determined. Measurements dedicated to the estimation of these factors have been performed and reveal a good agreement to theoretical values. According to these factors, the radiation behaviour can be explained. Finally, the proposed correction yields better results compared to an existing one.

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

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