Combined measurement of cone vibration and 3D sound pressure output of transducers

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Introduction

As discussed in [1] the 3D sound pressure output of an electroacoustic transducer can be determined by using a holographic measurement technique. When performing such a measurement in normal non-anechoic rooms, the loudspeaker need to be at the same position in the room during the scanning process to separate the sound radiated from the device from room reflections, which requires a special robotics. Anyway, combining the acoustic measurement of the sound pressure output with a scan of the mechanical vibration is an attractive alternative to minimize the setup time and increase the amount of measurement data.

As shown in Figure 1, by adding a second z-axis with a microphone to the Scanning-Vibrometer (SCN) both cone vibration and the sound pressure in the near field can be measured automatically using the same hardware. During the measurement, the loudspeaker is shifted by the R-axis and rotated by the Phi-axis to collect the measurement data on the hemisphere in the near field.

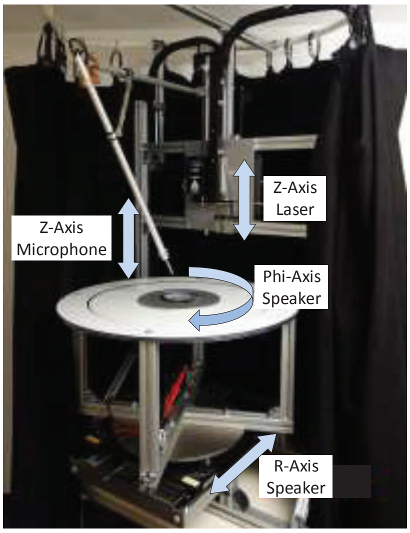

Figure 1: Scanning-Vibrometer (SCN) with additional microphone

Measuring with this setup has limitations. The loudspeaker is moved, so room effects cannot be separated, because the excitation of the room is not constant during the measurement process. However, the acoustic short-cut and the distinct diffractions from the circular baffle can be removed by field separation. Also the near field measurement gives a high level of direct sound compared to the room reflections which may provide sufficient accuracy of the measured sound field. This paper will discuss the particularities and limitation of this measurement with the modified Vibrometer hardware based on the measurement of a 10cm transducer.

Reference Measurement with Near Field Scanner (NFS)

The 10cm woofer was measured on the near field scanner to determine a reference for the further research. For this measurement, the microphone is move along hemisphere in front of the speaker while the DUT is staying at a fixed position. As shown in the picture the transducer is mounted in a circular baffle which has a diameter of 72cm.

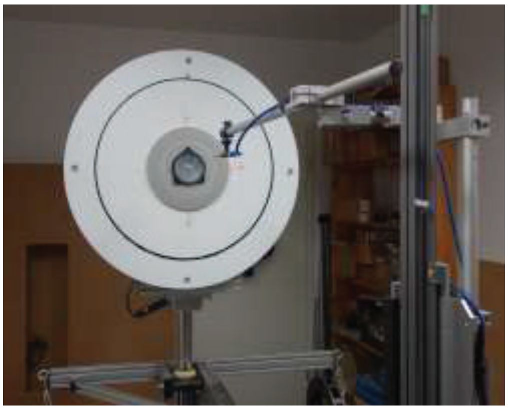

Figure 2: Reference Measurement with Near Field Scanner (NFS)

As shown in the equations (1), (2) and (3) the measured data can be decomposed into spherical waves as the sum of outgoing waves p_{out} and incoming waves p_{in}. This decomposition requires a scanning on two layers to get sufficient measurement information. By using the spherical wave expansion, these terms can be expressed as a weighted sum of spherical harmonics $Y_n^m(\phi,\theta)$, which describes the angular behavior and Hankel function of the 1st kind $h_n^{(1)}(kr)$ representing incoming waves and 2nd kind $h_n^{(2)}(kr)$ for outgoing waves. The coefficients $C(\omega)$ weights the individual elementary sound sources.

$$p(r,\phi,\theta,\omega) = p_{out}(r,\phi,\theta,\omega) + p_{in}(r,\phi,\theta,\omega) \quad (1)$$

$$p_{out} = \sum_{n=0}^{N} \sum_{m=-n}^{n} C_{n,m}^{out}(\omega) \cdot h_n^{(2)}(kr) \cdot Y_n^m(\phi,\theta) \quad (2)$$

$$p_{in} = \sum_{n=0}^{N} \sum_{m=-n}^{n} C_{n,m}^{in}(\omega) \cdot h_n^{(1)}(kr) \cdot Y_n^m(\phi,\theta) \quad (3)$$

As shown in figure 3 the sound field separation can decompose the direct sound from reflections and resonances from the room as well as the effects from baffle.

When analyzing the sound pressure level of a measurement point at 15cm in front the speaker, it is visible that the measured sound for very low frequencies $f < 100$ Hz is about

2 to 3 dB below the direct sound radiated from the transducer. Even though that the measurement is performed in the near field, the effect of the acoustic short cut is reducing the sound pressure measured in front of the driver.

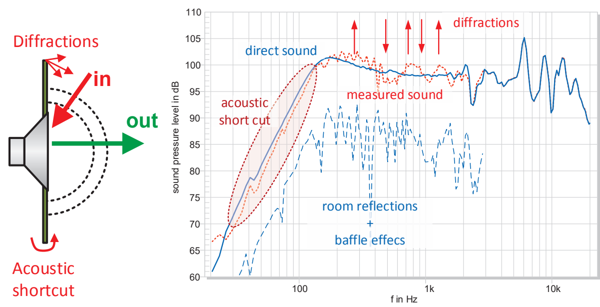

Figure 3: Decomposition of measured sound (dotted line) into direct sound (solid line) and room reflections and baffle effects (dashed line)

Above 200Hz the difference between measured and direct sound show a very distinct pattern which is typical for diffractions at the baffle’s edge. E.g. by assuming a point source in the middle of the 72 cm baffle, the on-axis measurement should show cancellation effects at 480 Hz, 950 Hz and 1.4 kHz and constructive interferences at 240 Hz, 715 Hz and 1.2 kHz, which matches approximately with the measurement of the 10cm woofer. After the room reflections and baffle effects are removed the data can be extrapolated to the far field, providing accurate free field data.

Acoustic Measurement with SCN-Hardware

The measurement of the same loudspeaker mounted in the same baffle was repeated on the SCN-hardware. The measurement was performed in a normal office room which is insufficiently damped and has distinct room modes. To minimize these effects the scanner was surrounded by curtain and the ceiling reflection was damped by using absorbing materials.

For high frequencies $f > 1$ kHz, time windowing can be used to separate the direct sound from reflections so both measurements show the same results. The critical frequency range for the measurement with the SCN is below 1 kHz, which will be discussed in the following.

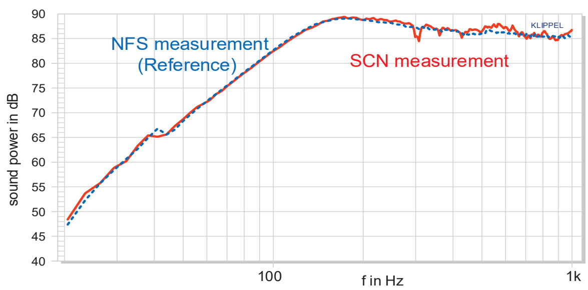

Figure 4: Radiated sound power (far field) of the reference measurement with the Near Field Scanner (dashed line) and the measurement with the Scanning Vibrometer (solid line)

When comparing the measured sound power of both measurements, there is an agreement for very low frequencies, so the acoustic short cut was removed. In the lower mid frequencies from 300Hz to 1 kHz there are mismatches between both measurements. In this frequency range the room effects cannot not be neglected and these disturbances cannot be removed by the holographic field separation, since they are caused by the measurement setup. The loudspeaker is moving which changes the room response for each speaker position. Anyway, the field separation method can be used to detect critical frequency by comparing the apparent power in the near field of the incoming and outgoing sound. If a room mode disturbs a specific frequency this cannot be described by an internal sound source, so some energy will be distributed to both basic function of the model. For example the room modes at 300 Hz is disturbing the measurement but this can be detected.

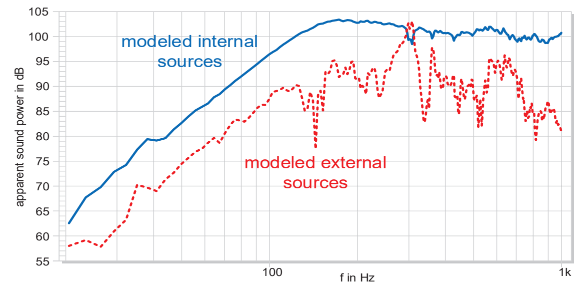

Figure 5: Apparent Sound Power of modeled internal (solid line) and external (dashed line) sound sources in the near field of speaker

Conclusion

It is very beneficial to perform two different measurement with the same hardware automatically. The example measurement has shown that the holographic near field measurement with the SCN hardware can provide the same accurate 3D sound field data for low frequencies below 100Hz and for high frequencies above 1 kHz. Measuring in the near field reduces room problems and some simple acoustic treatment around the scanning hardware can damp reflections. When measuring in small environment, room modes may become critical and they cannot be removed. But by using the field separation approach the critical frequencies can be detected. So the system can automatically check the accuracy of the final results and can help to optimize the measurement room by improving the treatment for the critical frequencies.

References

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