

# Visualization and Analysis of Loudspeaker Vibrations

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## Abstract

The sound reproduction quality of loudspeakers is highly dependable on the vibration and radiation properties of the loudspeaker membrane. With the help of laser measurement techniques the movement of each membrane point can be determined. A new scanning technique performs a non-contact measurement of the mechanical vibration and the geometry data of cones, diaphragms, panels and enclosures. One rotational and two linear actuators ( $\varphi$ ,  $r$ ,  $z$ ) move a laser displacement sensor over a user-defined grid. At each measurement point the transducer is excited by a stimulus giving sufficient spectral resolution and high SNR in the measured response over the whole audio band ( $< 25$  kHz).

Dedicated analysis software supports visualization, animation of the mechanical vibration. Modern techniques of image processing are used for enhancing relevant information, suppressing noise and animating the vibration as a stroboscopic video. The sound pressure output in the far field and the directivity pattern are calculated and the contribution of each vibrating point on the vibrating surface is visualized. Novel decomposition techniques show radial and circular modes and vibrations components related with the SPL output. The analysis reveals the interaction between vibration and radiation, indicates critical vibration pattern and is the basis for FEA using the measured geometry and material parameters.

## Vibration Measurement

A new technique for scanning vibrometry is presented which is dedicated to loudspeakers, micro-speakers, headphones and other electro-acoustical or electro-mechanical transducers. The vibrometer uses a displacement triangulation laser sensor and other standard modules of the KLIPPEL Analyzer System such as the Distortion Analyzer DA2 and the Transfer Function Module (TRF) to excite the loudspeaker under test with a pre-shaped sweep and to perform the signal acquisition and spectral analysis. Special scanning hardware uses a turntable with two additional linear actuators and an control hardware to scan the target surface in polar coordinates, see figure 2.

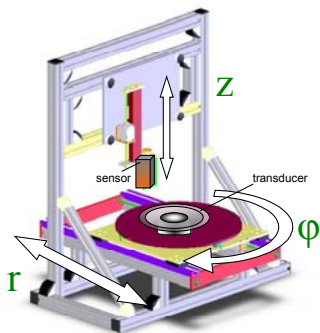


Figure 1: Vibration Scanner Hardware Setup

A displacement sensor based on Laser triangulation technique is a cost effective alternative to a velocity sensor ( $\rightarrow$  Doppler interferometry) but requires advanced signal processing to measure the break-up modes up to 25 kHz at sufficient signal to noise ratio. The decay of the

displacement above resonance frequency can be compensated by using a sinusoidal sweep as stimulus where the higher frequency components are emphasized inversely. Hence, the amplitude is not constant but rises by 9dB per octave up to 10 V rms at 25 kHz. Repeating the measurements with the same stimulus  $2n$  times and averaging the measured displacement responses will improve the signal to noise ratio by  $3*n$  dB.

The displacement sensor is capable of measuring the cone geometry at high precision. This may be useful for checking the variation of the cone shape in quality control and for investigating design choices by performing an FEA using  $E$  modulus and loss factor of the cone material measured by a dynamic method [3].

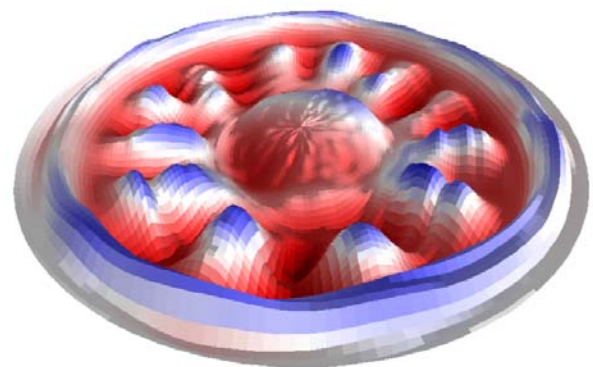


Figure 2: 3D Animation of a Loudspeaker Cone Vibration

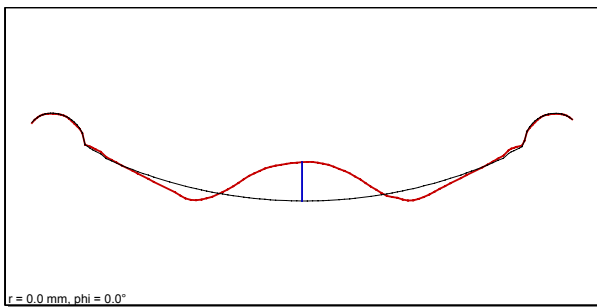
## Visualization

Special analysis software is developed for the visualization of the vibration data. Incomplete measurement data is filled up by an appropriate interpolation while applying an

adequate error recognition and correction. Noise in the vibration data can be suppressed by an adjustable two-dimensional Gaussian smoothing.

From the measured geometry a three-dimensional representation of the cone is created and the vibration at each measurement point is illustrated as an offset superposing the pure cone geometry.

By rotating the vibration phase around the unit circle at each measurement point a continuous animation of the cone motion is created. The amplitude of the superposing offset can be manually increased to visually emphasize small vibrations.



**Figure 3:** Cross-sectional cut through the loudspeaker

Also a two-dimensional plot of the vibration amplitude distribution on the cone is created. There the location of nodal lines and vibration maxima can be easily determined. Finally, also a cross-sectional cut through the loudspeaker geometry, see figure 3, superimposed with the vibration can be animated and the measured displacement transfer function at each measurement point can be regarded.

## Vibration Analysis

### Sound Radiation Modelling

Using the geometry and the vibration data the SPL response is predicted in the far-field at the point  $r(r_o, \phi, \theta)$  on the basis of the Rayleigh integral equation. Critical frequencies for the sound radiation can be easily found and analyzed.

The sound pressure modelling can also be used to evaluate the directivity of the sound radiation. For a certain selected frequency the total sound pressure at certain points on a hemisphere over the cone is determined and displayed in a polar plot.

### Vibration Decomposition

The cone vibration can be separated into single components by using novel data decomposition techniques. In a first method the total vibration is divided into a radial component and a circumferential component and each of them can be analyzed separately, see equation (1).

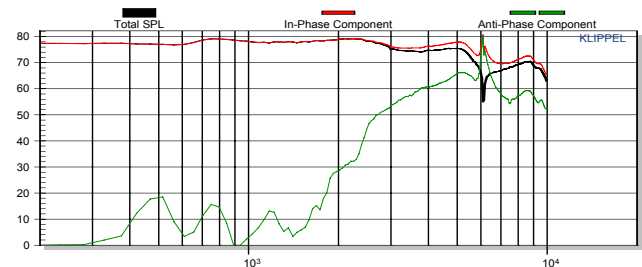
$$\bar{x}_{total} = \bar{x}_{rad} + \bar{x}_{circ} \quad (1)$$

Also the sound pressure produced by the respective component can be regarded independently.

A second decomposition technique, compare equation (2), is capable of separating vibration components according to their contribution to the total sound pressure at a certain listener position  $r(r_o, \phi, \theta)$ .

$$\bar{x}_{total} = \bar{x}_{in} + \bar{x}_{anti} + \bar{x}_{out-of} \quad (2)$$

The in-phase component of the vibration contributes to the sound pressure at the listening point. The anti-phase component of the vibration reduces the sound pressure output. The out-of-phase component produces positive and negative volume velocity which cancels out in the near field and will not contribute to the total sound pressure at the listening position.



**Figure 4:** The SPL frequency response of the total output can be compared with the in-phase and anti-phase component.

The dashed anti-phase component in figure 4 above produces a very low SPL output before the cone breaks up ( $< 2$  kHz). At 6 kHz the anti-phase component almost equals the in-phase component causing a dip in the total SPL output at the listener position.

## Literature

- [1] Schlechter, J.: Visualization of Vibrations of Loudspeaker Membranes. TU Dresden, October 2006.
- [2] Klippel, W., Schlechter J.: Measurement and Visualization of Loudspeaker Cone Vibrations, presented on the 121th Convention of the Audio Eng. Soc., San Francisco, October 2006, Preprint 6882.
- [3] Material Parameter Measurement, Manual of the MPM module of the KLIPPEL Analyzer System, [www.klippel.de](http://www.klippel.de).
- [4] Scanning Vibrometer, Specification of the module, KLIPPEL Analyzer System, [www.klippel.de](http://www.klippel.de)