Optical Linear Position Measurements of the Speaker Membrane Displacement

A New, Cheap and Easy Way to Characterise the Speaker Behaviour with High Accuracy

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Introduction:

Manufacturers of speakers characterize the properties of chassis with the Thiele/Small parameters [1], which are calculated from the electrical impedance. The influence of the mechanical parameters is largest at the mechanical fundamental resonance of the membrane displacement. In this paper it will be shown that the parameters of a speaker can be calculated with more accuracy by measuring the transfer function of the membrane displacement.

In addition to the mechanical resonance there are natural resonances of the membrane that influence the quality of the speaker at higher frequencies. All mechanical resonances of the speaker membrane oscillations are detected as electrical impedance peaks, but at higher frequencies the mechanical natural vibrations of the speaker membrane are concealed by eddy current effects and the speaker voice coil impedance. Therefore, it is difficult to calculate the mechanical displacement Δx from the electrical impedance at higher frequencies. But the behavior of the membrane is fundamental to the sound pressure propagation. Until today most developers measure only the mechanical resonance of the speaker to characterize all speaker properties.

When a Position Sensitive Detector (PSD) [2] is used, it is possible to measure the real displacement with high linearity, a large dynamic range and a high signal to noise ratio. Up to 90 dB are obtained even at high frequencies.

The electrical impedance (figs. 4,5)

$$Z_{el}(s) = R_e + s L_e + \frac{M^2 s \left(1 + \frac{m_s}{k_s} s\right)}{D_m \left(1 + \left(\frac{k_m}{D_m} + \frac{m_s}{k_s}\right) s + \left(\frac{m_m}{D_m} + \frac{k_m m_s}{D_m k_s} + \frac{m_s}{D_m}\right) s^2 + \frac{m_m m_s}{D_m k_s} s^3\right)} \qquad (1)$$

can be calculated with the lumped element model (fig. 6).

Electrical parameter (R_e: voice coil resistor, L_e: inductivity of the voice coil, M: the force factor), mechanical parameter of speaker membrane (m_m: mass constant, D_m: spring constant, k_m: damper constant), mechanical parameter of sound field (k_s: damper constant, m_s: mass constant), s: complex frequency variable.

The electrical impedance

$$Z_{el}(s) = R_e + s L_e + M \left(\frac{s}{c_i c_s}\right) F(s) \qquad (2)$$

can be also solved from the voice coil displacement transfer function F(s) (fig. 1)

$$F(s) = \frac{\Delta x}{I} = c_s c_i \frac{M}{D_m} \frac{\left(1 + s \frac{m_s}{k_s}\right)}{1 + s\left(\frac{k_m}{D_m} + \frac{m_s}{k_s}\right) + s^2\left(\frac{m_m}{D_m} + \frac{k_m m_s}{D_m k_s} + \frac{m_s}{D_m}\right) + s^3 \frac{m_m m_s}{D_m k_s}} \qquad (3)$$

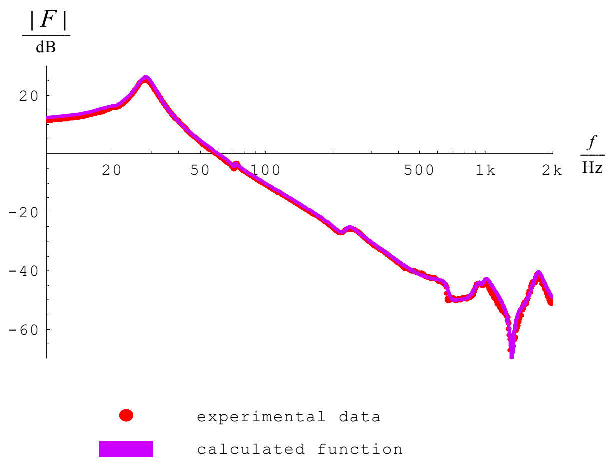

Fig. 1 shows the absolute value of speaker membrane displacement transfer function F measured in an anechoic room. The corrected model function corresponds well with the experimental data.

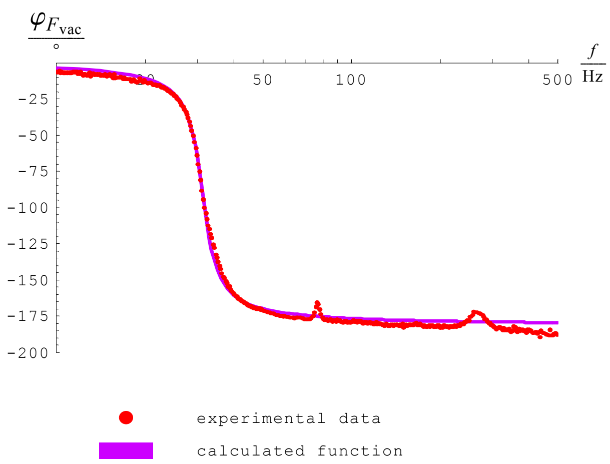

Fig. 2 shows the phase of vacuum speaker membrane displacement F_{vac} measured in a vacuum chamber.

(c_{se}: transfer function of the optical sensor system, c_I transfer function of the voltage controlled current source).

The membrane displacement transfer function simplifies to

$$F_{vac}(s) = \frac{c_{Sensor} c_i M}{D_m} \frac{1}{1 + s \frac{k_m}{D_m} + s^2 \frac{m_m}{D_m}} \qquad (4)$$

if the sound field is eliminated in a vacuum chamber.

The inductivity of the voice coil is non linear [3]. To model the eddy current effects it is necessary to use the non linear transfer function of $L' \cdot s^{0.5}$. This non linear element is parallel to the linear impedance $L \cdot s$ (fig. 3) of the voice coil inductivity and gives a non-linear inductivity

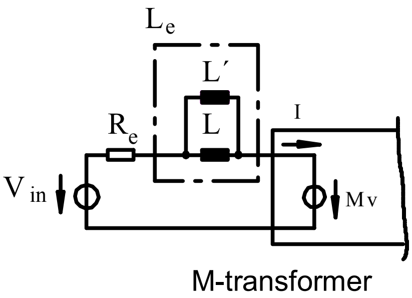

Fig. 3 shows the non linear effect of the eddy current which can be modeled as new lumped element.

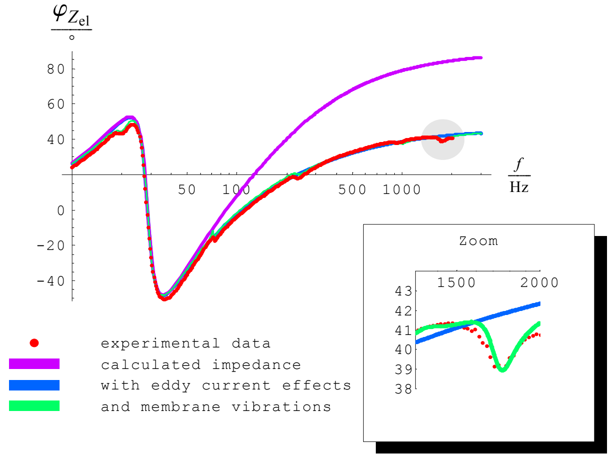

Fig. 4 shows the phase φ of the electrical impedance of a speaker. The eddy current effects and the voice coil inductivity cover additional vibrations. The zoom shows that the experimental data and the model data exactly corresponds.

$$L_e(s) = \frac{L}{1 + \frac{L}{L'}\sqrt{s}} \qquad (5)$$

(L: inductivity constant of the linear voice coil, L': inductivity constant of the nonlinear voice coil).

The membrane vibrations can be taken into account with a correction function

$$F_c(s) = \frac{a_1 s + b_1 s + 1}{c_1 s + d_1 s + 1} \times \ldots . \times \frac{a_n s + b_n s + 1}{c_n s + d_n s + 1} \qquad (5).$$

The existences of this vibrations is shown in [4].

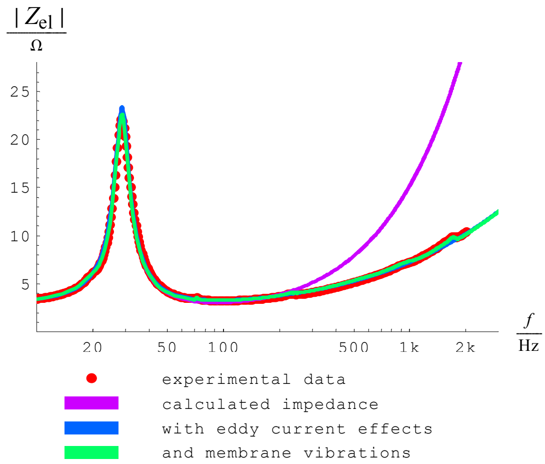

Fig. 5 Electrical impedance Z_{el} of the speaker.

The comparison of the calculated data with the measured electrical impedance shows an excellent correspondence. The sound pressure can be predicted from the mechanical displacement of the speaker membrane with a simplified lumped rigid piston model. The linearity of the measurement system makes it possible to control the speaker membrane displacement in a real time closed loop system [4].

References

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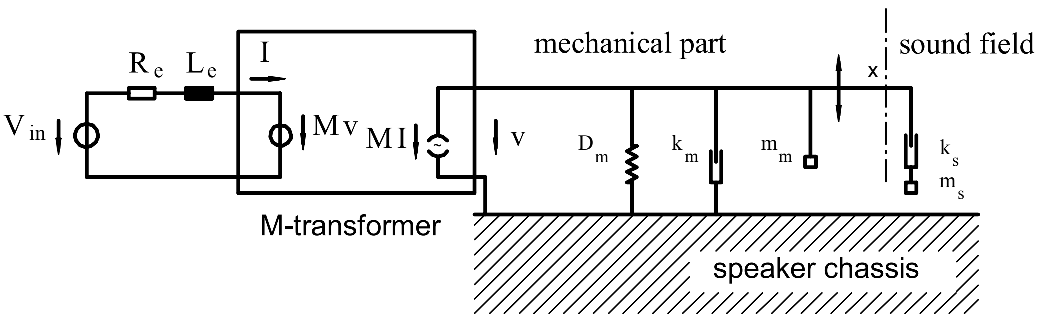

Fig. 6 shows the mechanical lumped element model connected to the electrical components. The feedback voltage from the mechanical elements depends on the velocity v of the membrane. The force of the mechanical elements is proportional to the current I of the electrical circuit and the force factor M.