# Static and Dynamic Measurement of the Nonlinear Force Factor Characteristic of Loudspeakers

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## Introduction

The magnetic flux density in the magnetic gap and the geometry of the moving coil determine the force factor Bl which is an important parameter of the electro-dynamical transducer. The manual measurement is time consuming and an exact positioning of the sensor at defined points difficult. The paper presents a new measurement technique for scanning the flux density B(z, φ) on a cylindrical surface within and outside the magnetic gap using a Hall sensor and robotics changing the position of the sensor versus vertical position z and angle φ. The two-dimensional data collected from this measurement require new derived characteristics which simplify the interpretation. Those tools make new kinds of diagnostics on the motor structure possible. Finally the limitations of the measurement and prediction (BEM) of the static field are discussed which neglect the ac field generated by the voice coil current.

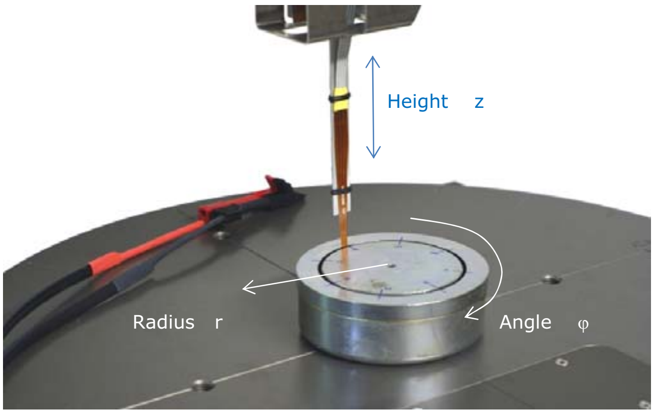


**Figure 1:** Measurement of the magnetic flux density in the gap by using a hall sensor and a mechanical scanning system.

## Scanning Grid

The scanning process provides the radial component of the flux density

$$B(z_i, \varphi_k, r_0) \quad \begin{cases} i = 1,...,N_z \\ k = 1,...,N_\varphi \end{cases} \qquad (1)$$

at points defined by vertical coordinate $z_i$ and angle $\varphi_k$ in cylindrical coordinates distributed in a particular grid depending on the thickness and position of the pole plate. Experiments have been performed to find a scanning grid giving sufficient resolution and keeping the measurement time as short as possible. A sufficient angular resolution requires 4 … 10 points equally distributed over the circumference. About 5 … 10 vertical measurement points are required to measure the rapid decay of the B field at the upper and lower side of the pole plate. The vertical resolution may significantly be reduced below and above the gap and in the middle part where the B is relatively constant. Measurements at multiple radii are not required because the variations are less than 1 % as confirmed in additional experiments (details see [1]) using radii varying by 0.2 mm limited by the gap width W. A useful scan of the B field requires at least 100 measurement points in total.

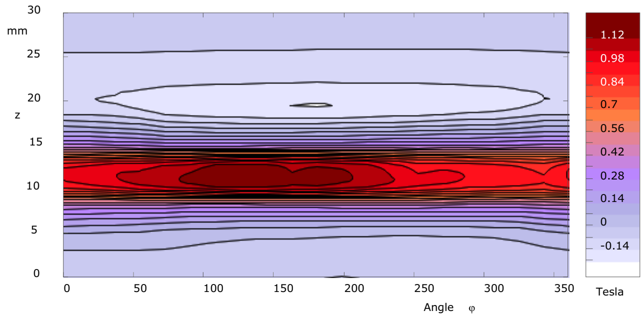


**Figure 2:** Contour plot of the magnetic flux density of an example loudspeaker having a distinct field asymmetry.

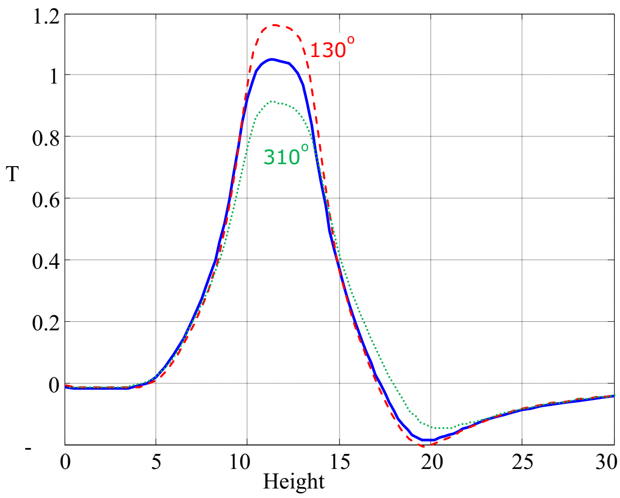


**Figure 3:** Mean value $\overline{B}^{\varphi}(z)$ (solid line) and values of the magnetic flux density at selected angles 130 degree (dashed line) and 310 degree (dotted line) versus vertical coordinate z of example loudspeaker A.

## Flux Density

The flux density on the scanned cylindrical surface is presented as a contour plot in Figure 2 for a small example loudspeaker having a coil diameter of 35 mm and a gap depth of 3 mm. Figure 3 shows magnetic flux density versus vertical height z for two selected angles and the mean value

$$\overline{B}^{\varphi}(z) = \frac{1}{2\pi}\int_{0}^{2\pi} B(z,\varphi)d\varphi$$
$$\overline{B}^{\varphi}(z_i) = \frac{1}{N_{\varphi}}\cdot\sum_{k=1}^{N_{\varphi}} B(z_i,\varphi_k) \qquad (2)$$

calculated by integrating B(z,φ) over 2π or by calculating the mean value over all angles equally distributed on the circumference.

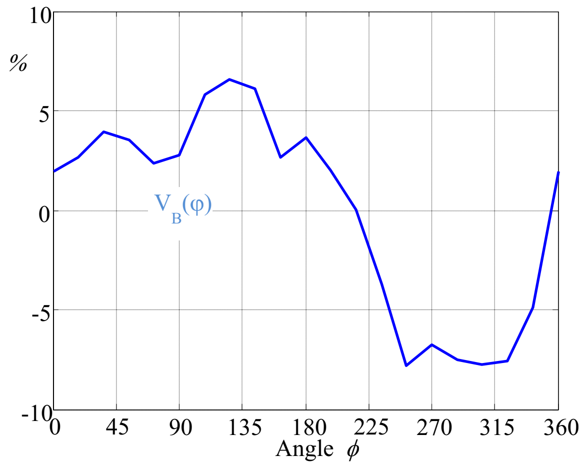


**Figure 4:** Relative variation of the flux density versus angle φ of the example loudspeaker A

The scanning of the magnet field seems to be the only way for detecting irregularities of the magnetic field such as axial asymmetries caused by partial magnetization, material inhomogeneity and failures in manufacturing. The scanning results of loudspeaker A reveal a 15 % higher value of the flux density at angle 310° inside the gap compared to the diametrical point at 130° as shown in Figure 4. The relative variation of the flux density

$$V_B(\varphi) = \frac{\overline{B}^{z}(\varphi) - \overline{\overline{B}^{\varphi}}^{z}}{\overline{\overline{B}^{\varphi}}^{z}} 100\% \qquad (3)$$

is calculated by using the mean value of the flux density

$$\overline{B}^{z}(\varphi) = \frac{1}{N_z}\sum_{k=1}^{N_z} B(z_k,\varphi) \qquad (4)$$

averaged over all vertical scanning points at particular angle φ and the overall mean value

$$\overline{\overline{B}^{\varphi}}^{z} = \frac{1}{N_z}\sum_{k=1}^{N_z} \overline{B}^{\varphi}(z_k) \qquad (5)$$

averaged over all measurement points.

Loudspeakers having irregularities in the magnetic field density have an electro-dynamical driving force which is not equally distributed over the voice. This excites rocking modes as illustrated in Figure 5 which is a major cause of voice coil rubbing on the pole tips resulting in a permanent damage eventually.

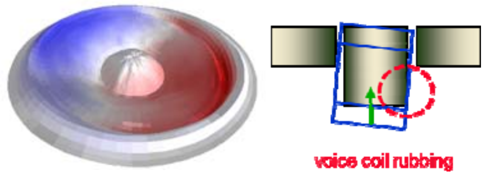


Figure 5: Rocking mode excited by an asymmetrical field

## Conclusion

The flux intensity measured at the position of the voice coil gives valuable information about the magnet system of the transducer. It is the basis for verifying the result of magnetic FEM and to predict the nonlinear force factor

$$Bl(x) = m\int_{-N_w\pi}^{N_w\pi} B(x+\frac{\varphi}{2\pi}D+z_r,\varphi)\cdot rd\varphi$$
$$\approx m2\pi r\sum_{i=-N_w}^{N_w} \overline{B}^{\varphi}(x+\frac{iD}{2}+z_r) \qquad (1)$$

as a function of the voice coil displacement x from the rest position $z_r$ by integrating the flux density versus wire length l (corresponding with angle φ and windings $N_w$). The parameter m considers the number of layers and D stays for the diameter of the wire considering the insulation and winding space.

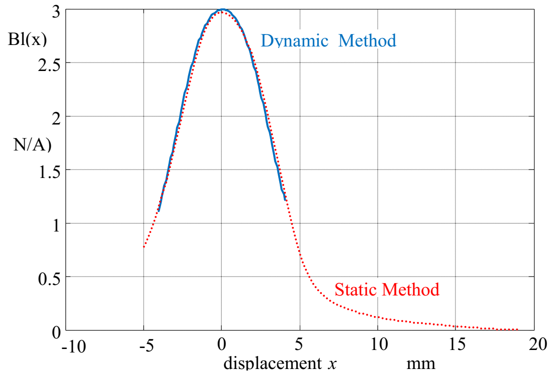


**Figure 6:** Force Factor Bl(x) versus voice coil displacement x of loudspeaker B calculated from scanned flux density and directly measured by dynamic method (large signal identification).

Figur 6 shows a good agreement between the nonlinear force factor Bl(x) calculated from the static B field measured after removing the voice coil and the effective Bl(x) curve measured by a dynamic identification technique operating the loudspeaker at high amplitudes and monitoring the electrical current and voltage at the terminals.

References:


[1] Klippel, W.: Scanning the Magnetic Field of Electro-dynamic Transducers, presented at the 130th Convention of Audio Soc. , May 13-16, 2011, London.

[2] Loisos, G., Moses, A.J., "Critical evaluation and limitations of localized flux density measurements in electrical steels," IEEE Transactions on Magnetics, July 2001, Volume: 37 Issue:4, pp. 2755 – 2757.