Fast Measurement of Motor and Suspension Nonlinearities in Loudspeaker Manufacturing

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Introduction

Automatic testing at the end of the assembling line is performed to find loudspeaker defects caused by parts or manufacturing process. Measurements of 2nd-order, 3rd-order and total harmonic distortion reveal symptoms of nonlinearities inherent in the loudspeaker. However, those measurements are difficult to interpret: For example, the 2nd-order harmonic component is caused by an asymmetrical nonlinearity but it is not clear whether it is caused by a nonlinear force factor Bl(x) or inductance L(x) of the voice coil in the electro-dynmical motor or by the nonlinear stiffness $K_{ms}(x)$ of the mechanical suspension. The nonlinearities can directly be measured by using a nonlinear system identification technique which becomes a standard in loudspeaker development. This technique uses an adaptive nonlinear filter and provides precise data after 5 min learning time. This technique is not fast enough for quality control on 100% of the units supplied to the customer. In addition to that the quality control prefers single-valued parameters which are subject of statistical analysis and are more easy to interpret.

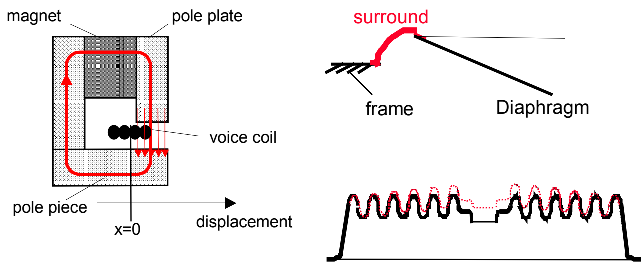

Figure 1: Dominant causes for loudspeaker nonlinearities caused by manufacturing: Offset in the voice coil rest position (left) and asymmetry in the suspension (right)

Measurement Principle

The MSC is based on a system identification technique based on a lumped equivalent model considering the dominant loudspeaker nonlinearities. The loudspeaker is excited by a multi-tone signal of sufficient bandwidth and amplitude. Only electrical signals (voltage and current) are measured at the terminals of the transducer. The output parameters of the MSC are calculated by exploiting the nonlinear information found in the current signal. The MSC assumes a 2nd-order mechanical system comprising a stiffness, moving mass and losses. Additional acoustical resonances (as caused by a vented enclosure) should be removed. The technique is patent protected.

Results

The large signal parameters (coil offset, suspension asymmetry, …) measured with the MSC are not nonlinear curves but single-valued parameter expressed in mm and percent. However, those parameters can be compared with the data measured by the regular Large Signal Identification (LSI). single-valued parameters

Voice coil offset X_{offset}

The voice coil offset X_{offset} is defined as the symmetry point $x_{sym}(x_{ac})$ in the Bl-curve which is the centre point between two points on the Bl-curve producing the same Bl-value

$$Bl(X_{sym}(x_{ac}) - x_{ac}) = Bl(x_{sym}(x_{ac}) + x_{ac}) \quad (1)$$

which are separated by $2x_{ac}$. The symmetry point is measured at a high value of X_{ac} ($X_{ac} > X_{Bl}$) to assess the symmetry at the steep slopes of the Bl-curve.

The compliance limited displacement X_C is a useful characteristic for finding a defect suspension part such as a spider or surround causing excessive harmonic distortion (THD). However, harmonic distortion is not a unique symptom of suspension problems but may also be caused by a voice coil offset. X_C considers symmetrical and asymmetrical variation of the suspension nonlinearity only.

Minimal or maximal QC limits may be applied to check X_C and to make a PASS/FAIL decision.

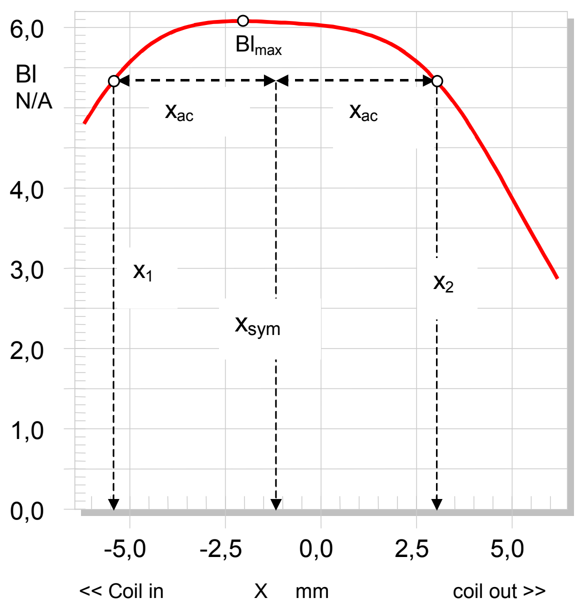

Figure 2: Reading the voice coil offset X_{offset} from the symmetry point in the nonlinear Bl(x) curve (conventional technique which requires complete identification)

Suspension Asymmetry $A_K(x_{peak})$

The asymmetry of the $K_{ms}(x)$-curve is the ratio

$$A_K(X_{peak}) = \frac{2\left(K_{MS}(-X_{peak}) - K_{MS}(X_{peak})\right)}{K_{MS}(-X_{peak}) + K_{MS}(X_{peak})}100\%, \qquad (2)$$

using the stiffness at the negative and positive limits $\pm X_{peak}$.

The stiffness asymmetry A_K is a useful characteristic for assessing the asymmetry of the suspension part which generates 2nd-order harmonic distortion. Stiffness asymmetry A_K only considers asymmetrical variation of the suspension nonlinearity separated from other nonlinearities. The stiffness asymmetry A_K should be close to zero. The sign of A_K corresponds with the sign of the d.c. displacement generated by an asymmetrical suspension.

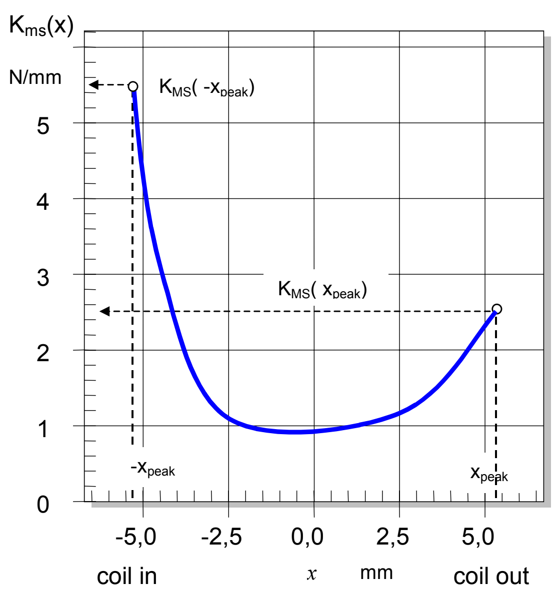

Figure 3: Reading the stiffness asymmetry A_K from the nonlinear $K_{ms}(x)$ curve (conventional technique which requires complete identification)

Diagnostic in Manufacturing

The QC- Motor and Suspension Check (MSC) satisfies the following requirements occurring under production condition:

- Objective and reliable detection of defects in motor and suspension is possible within the shortest possible measurement time (1 – 3 s).
- Although performing the measurement up to high amplitudes the MSC shall also provide the parameters at the rest position, such as Kms(x=0), which correspond with the small signal parameters (T/S).
- Large signal parameters are expressed as single values to support limit setting, statistics (cpk, ppk) assessing the process stability.
- The interpretation of the large signal parameters is simple and supports loudspeaker diagnostics. For example using a new batch of spiders may cause an offset of the voice coil position. Since the MSC measures this offset in mm this information can directly be used as a feedback to process control to correct coil position (see Figure 4 below).
- QC requires a robust and cost effective hardware solution. The MSC uses the Production Analyzer which provides already current and voltage sensors for small and high amplitudes. No additional sensor is required for MSC !
- The MSC dispenses with measurements of mechanical or acoustical quantities such as displacement or sound pressure. This gives high robustness of the measurement against ambient noise.
- Extremely short training period for the MSC.

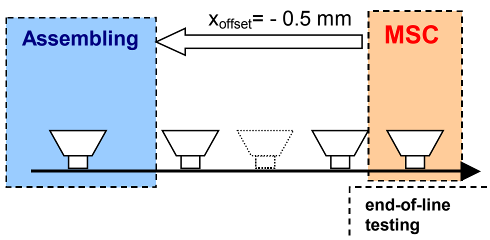

Figure 4: Measurement of the voice coil offset at the end-of-line testing and adjustment of the manufacturing process.

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