Prediction of the Loudspeaker Total Harmonics Distortion Using Comsol Multiphysics

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Abstract: For automotive applications, simulation methods are used to optimize the position and orientation of speakers to get the best acoustic performance. Because a loudspeaker is a non linear device, the sound pressure in the vehicle includes harmonics. These harmonics are mainly created by the force factor, suspension stiffness and voice coil inductance of the speaker. The goal of this study is to simulate those non linear components using Comsol Multiphysics. Two different methods were used for validation. First of all, simulation data was compared with measurement delivered by a measurement system. Secondly, Total Harmonics Distortion was predicted based on Comsol and measurement system datasets. The comparison shows similar results. It is shown that measurement tools can be successfully replaced by non linear Comsol speaker simulations and the optimization of non linear behavior of a loudspeaker can be realized in the virtual domain.

Keywords: Loudspeakers, Harmonics, Prediction, Comsol

1. Introduction

The development of a speaker for an automotive or a home entertainment system considers the speaker sensitivity, the size of the speaker, the weight and the cost. The speaker optimization can end up with a non ideal transducer design. The use of the speaker with a powerful amplifier drives the speaker into a non linear behavior. Sound pressure measurement shows that additional harmonics and intermodulation components are generated. This explains why loudspeakers which sound alike at small voltage behave fully different at high amplitude. The harmonics will modify the tone of the musical instruments. The harmonics are created by non linear speaker components. For the speaker motor, the force factor and the voice coil inductance are not constant for all voice coil positions. This non constant behavior is also noticed for the stiffness of the speaker suspension (including the spider and the surround used for guiding the voice coil into the motor gap). The force factor, suspension stiffness and voice coil inductance can be predicted using numerical methods[1][2]. Our approach allows to simulate these non linear speaker components and to predict and validate the amplitude of the harmonics in the sound pressure.

2. Governing Equations

The amplitude and the phase of the harmonics can't be predicted using equivalent linear speaker models where constant parameters of the lumped elements are used. Displacement varying parameters have been introduced in the equivalent circuit to describe time-variant and nonlinear mechanisms[3].

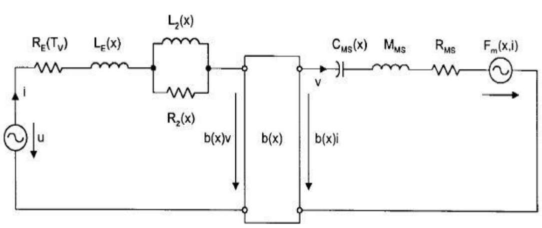

Figure 1: non linear equivalent circuit

The resulting model leads to a nonlinear differential equation[3] where:

- x is the speaker displacement
- b(x) is the instantaneous force factor of the motor defined by the integral of the magnetic flux density B over voice coil length l
- C_{ms} (x) is the compliance of driver suspension including the air load (the inverse of stiffness)
- L_e(x) is the part of voice coil inductance which is independent on frequency

$$u = R_e i + \frac{d(L(x)i)}{dt} + b(x)\frac{dx}{dt}$$
$$b(x)i = m\frac{d^2x}{dt^2} + R_m\frac{dx}{dt} + k(x)x + L_x(x)\frac{i^2}{2}$$

These differential equations can be solved using different mathematical approaches[4]. They allow to predict the fundamental and the harmonics for a speaker loaded by any air volume, measured on an infinite baffle and in an anechoic room.

3. Numerical Model

3.1 Simulation of the Force Factor and Voice Coil Inductance

To support a Harman speaker development for an automotive research project, a 5 inches automotive speaker was used for the simulation. The motor includes a ferrite and a neodymium buckling magnets. The diameter of the coil is equal to 25 mm. The geometry and the mesh were build using the import of a .dxf file. A 2D axisymmetric model including shell elements were used to optimize the calculation time. The Comsol AC/DC solver was used to perform the electromagnetic study.

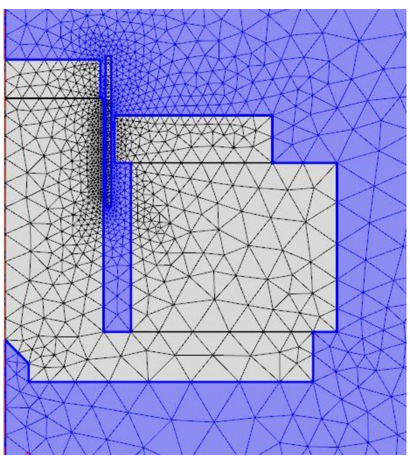

Figure 2: mesh for the AC/DC solver

3.2 Simulation of the Suspension Stiffness

The same speaker is used for the prediction of the suspension stiffness. The Structural Mechanics solver is used for the prediction.

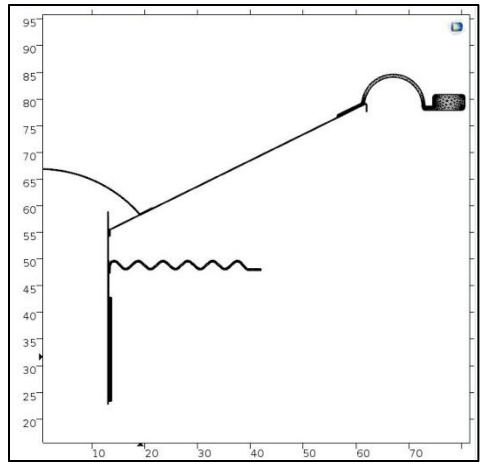

Figure 3: mesh for the Structural Mechanics solver

4. Loudspeaker Measurement

4.1 Large Signal Measurement

For the speaker measurement, a professional measurement analyser is used[5]. The speaker is in free air and excited by a broad band signal. The speaker displacement delivered by a laser sensor and the current in the coil are measured. Connecting the non linear equivalent circuit in parallel to the driver/sensor system, the speaker parameters are adaptively adjusted to minimize the error between the measured output and the predicted output delivered by the non linear circuit (use of a LMS algorithm).

Figure 4: Large signal measurement system

4.2 Total Harmonics Measurement

For the harmonics measurement, the speaker is measured in an anechoic room. The speaker is mounted on a 10 liters box inserted on an infinite baffle. A sound pressure measurement is performed (on axis microphone, distance 1 meter between the speaker membrane and the microphone). For each frequency where the Total Harmonics Distortion is measured, a pure sine with a RMS voltage equals to 20 volts is applied on the speaker terminals.

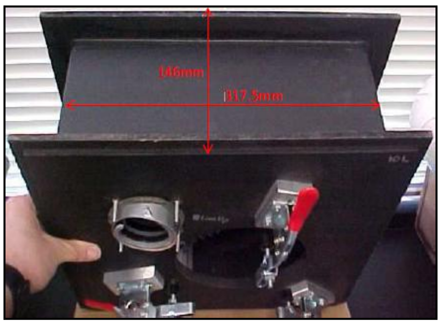

Figure 5: speaker box for the measurement

5. Prediction of the Total Harmonics Distortion

Using the 2 non linear equations (see Governing Equations), Engineers at Harman developed a non linear speaker simulation tool to predict, in the time domain:

- the non linear membrane speaker displacement and velocity
- the non linear sound pressure generated by the speaker
- the non linear current in the coil

For this prediction tool, input data are:

- non linear data as the force factor, the voice coil inductance and the stiffness of the suspension
- linear data as the Dc resistance of the coil, the moving mass of the speaker membrane, the volume of the speaker enclosure, the mechanical Q factor, …

6. Results

To validate the simulation of the force factor, suspension stiffness and voice coil inductance delivered by Comsol, two different methods were used. First of all, simulation data was compared with the speaker data measured by the large signal measurement system. Secondly, total Harmonic Distortion (THD) was predicted based on Comsol and measurement system datasets. These predicted THD were compared to the THD delivered by the anechoic measurement.

6.1 Comparison with Large Signal Measurements

The figures 6, 7 and 8 show the comparison between the prediction and the measurement for the force factor, the voice coil inductance and the stiffness of the suspension. The comparison shows that the prediction and the measurement are similar (tolerance +/- 10% for the force factor and the voice coil inductance, tolerance +/-12% for the voice coil inductance).

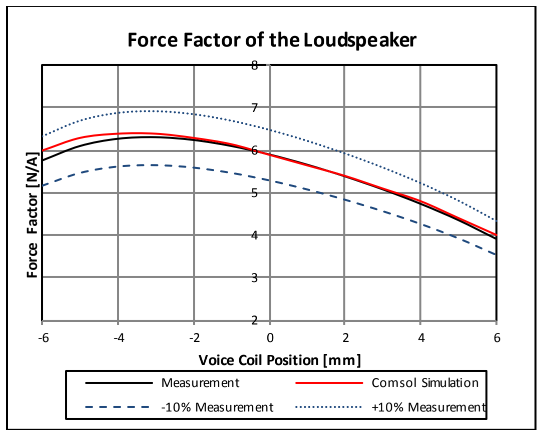

Figure 6: predicted/measured force factor

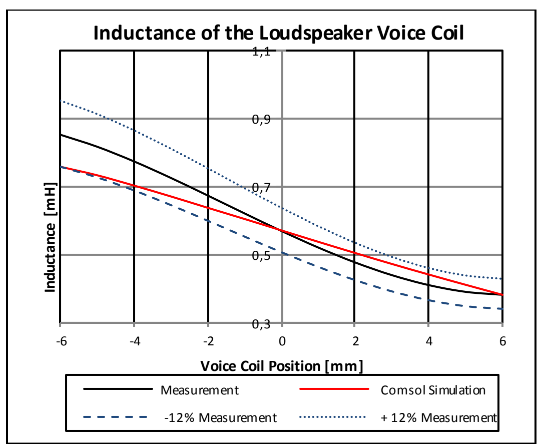

Figure 7: predicted/measured voice coil inductance

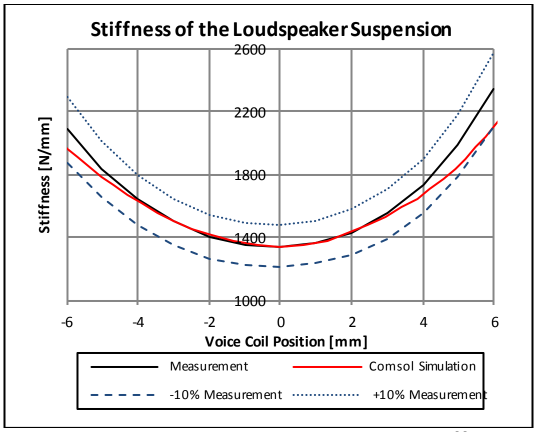

Figure 8: predicted/measured suspension stiffness

6.2 Comparison with Measured Total Harmonics Distortion

Total Harmonic Distortion (THD) was predicted based on Comsol and measurement system datasets. The comparison of the simulated THD below 1 kHz using the loudspeaker simulation and measurement shows similar results.

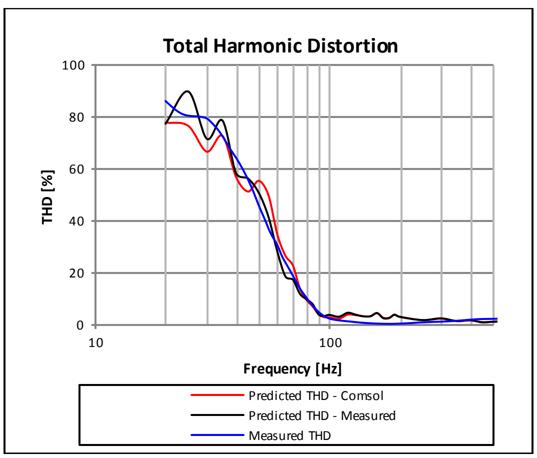

Figure 9: predicted/measured THD

10. Conclusion

In this paper, it is shown that professional measurement tools can be successfully replaced by non linear Comsol speaker simulations. It is also demonstrated, that the optimization of the non linear behavior of a loudspeaker can be realized in the virtual domain. This allows to reduce development times and costs and to have more freedom in loudspeaker design decisions to optimize any car audio system.

11. References

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12. Acknowledgements

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