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Nonlinear Stiffness Influence Analysis of a Loudspeaker Through Computer Simulations

Flávio P. Reis[1], Roseli F. da S. Ribeiro[2], Filipi G. Cardoso[3], José Flávio S. Feiteira[4]

[1] *(PGMEC, Escola de Engenharia Industrial de Volta Redonda, Brazil.)*
[2] *(PPGEM, Escola de Engenharia Industrial de Volta Redonda, Brazil.)*
[3] *(EEIMVR, Escola de Engenharia Industrial de Volta Redonda, Brazil.)*
[4] *(PGMEC, Escola de Engenharia Industrial de Volta Redonda, Brazil.)*

ABSTRACT
Given the fact that loudspeakers have several nonlinearities during operation, one of the biggest challenges when designing systems for audio transmission is to ensure that the input signal will be properly reproduced, free of noise and free of spurious frequencies. This paper presents a model that incorporates the main nonlinearities of a loudspeaker in order to provide reliable results for the sound system design in low frequencies. The proposed model considers an acoustic system and also an electrical system that, coupled, represent the functioning of a general loudspeaker. The acoustic system is solved by the Finite Element Method. The electrical system is divided into two parts, one representing the electrical elements of the loudspeaker, and other representing the mechanical part of it.

Keywords: effective stiffness, loudspeaker, nonlinearity, resonant frequency

I. INTRODUCTION

One of the higher indicative of the loudspeaker nonlinearity stands on the dependency which its behavior shows in function of the vibration amplitude. For small amplitudes, it has linear transference functions, which describe, with fidelity, the information emitted by the source. With the increase of the amplitudes, it can be observed the arising of additional spectral components (not contained in the excitation signal), that can be interpreted in the form of sound signal distortion.

The more scathing nonlinearity in the low frequencies regime, focus of this work, is the suspension stiffness $k(x)$. Considering intrinsic factors, as the elasticity of the material that forms the components of suspension and diaphragm systems, is convenient adopt the effective stiffness concept, which covers the rigidity of the entire assembly; it is named $k_{eff}(x)$. Recent studies, [1], [2], [3] et al., show the relation between the significant elastic deformations in these components and the nonlinearities of $k_{eff}(x)$, suggesting the existence of a chaotic dynamic in loudspeaker system as an important source of distortions in the original sound.

II. METHODOLOGY

The "Acoustics – Pressure Acoustic - frequency domain" and "AC/DC - Electrical Circuit" modules of COMSOL Multiphysics 5.0 software were used. The model represents a voice coil loudspeaker, in which the mechanical and electric parameters are grouped in analogous circuits. These circuits are coupled to an axisymmetric 2D model of acoustic pressure that describes the surrounding air domain [4]. The coupling between the acoustic portion (evaluated by Finite Elements Method) and the electric circuits is given by the acting force on the (F_D) diaphragm, described by the equation:

$$F_D = \int (\Delta p . n_z) dA \quad (1)$$

(Where Δp is the variation of pressure in the diaphragm and n_z is the axial component of the normal vector to the cone surface).

Table 1 shows the Thiele-Small parameters used on the simulations, extracted from the measurement report of [5].

Table 1. Basic parameters *Thiele-Small*.

Para meter	Value	Description
M_{md}	103.23 [g]	Moving mass
C_{ms}	0.36 [mm/N]	Mechanical compliance
R_{ms}	1.86 [Kg/s]	Mechanical resistance of driver suspension losses
L_E	0.31 [mH]	Voice coil inductance
R_E	6.1 [Ω]	Voice coil resistance
βl	10.37 [Wb/m]	Force factor
S_D	0.0232 [m^2]	Driver equivalent area

The mechanical compliance is the main parameter of this work, because it can be understood as the inverse of effective stiffness:

$$C_{ms} = \frac{1}{k_{eff}(x)} \qquad (2)$$

The simulations were conducted considering two conditions. In the first case, *condition A*, it was used the compliance provided by the producer (constant, with value 0,36 mm/N) and, in the second case, condition B, the compliance was obtained from equation (2), taking into account the nonlinear stiffness curve (measured by [5] – fig.1). Both of them consider the loudspeaker mounted in an infinite *baffle*, that can be understood as a panel large enough to isolate the waves created from frontal and posterior parts of the loudspeaker.

III. RESULTS AND DISCUSSIONS

Figure 2 shows the impedance curves. It can be seen the decreasing of resonant frequency (indicated by the peak of impedance curve), that falls from 25.6 *Hz* to 18.2 *Hz;* Figure 3 exhibits the resonant frequency in function of the cone displacement, measured by [4].

Both simulations were performed to small input signals (1 Volt), obtaining small displacements. It can perceive the coherence of the simulated value in the *condition B* with the value measured by [5] in the region of small displacements ($\pm 5\ mm$).

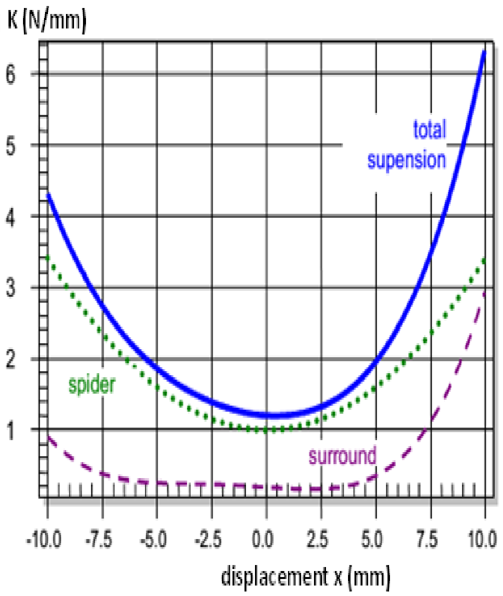

Figure 1. Effective stiffness curve.[5]

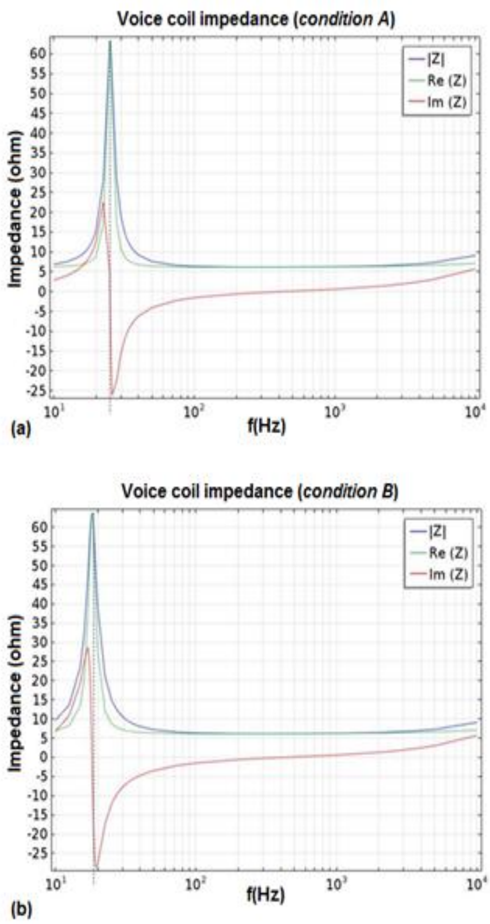

Figure 2. Impedance curves in *conditions A* (a) and *B* (b).

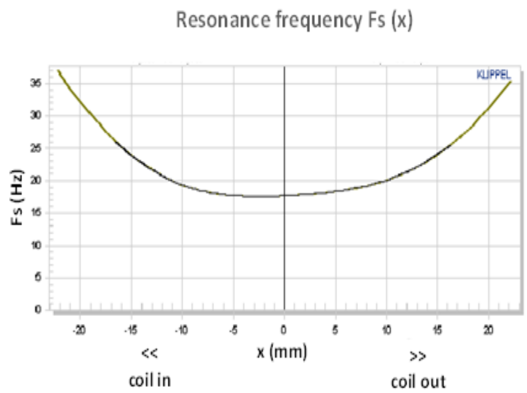

Figure 3. Resonant frequency versus cone displacement.

Figure 4 shows the efficiency curves of simulations under conditions A and B. The "Efficiency (Comsol)" curves are that evaluated by Finite Elements Method, considering the cone geometry very close to reality. On the other hand, the "Efficiency (piston model)" curve, called *efficiency of reference*, considers the loudspeaker as a piston (scheme used a lot for low frequencies).

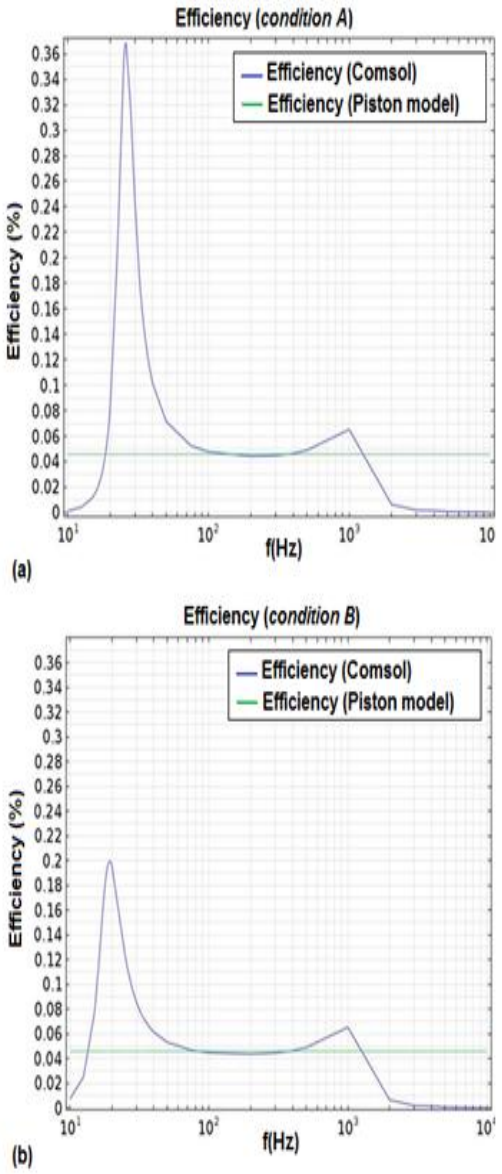

Figure 4. Loudspeaker efficiency: *condition A* (a) *and condition B* (b)

The decreasing of efficiency in the resonant frequency region also is an expected fact, when one considers the nonlinear stiffness. The efficiency is given by the ratio between radiated sound power and the input electric power. Knowing that, the higher the cone displacement, the greater the stiffness provided by the suspension, to achieve the same levels of sound pressure that those reached with the linear stiffness, it is necessary a higher input power.

Figure 5 exhibits the sensitivity curve (sound pressure level in function of the frequency) for the conditions described on the methodology (item II).

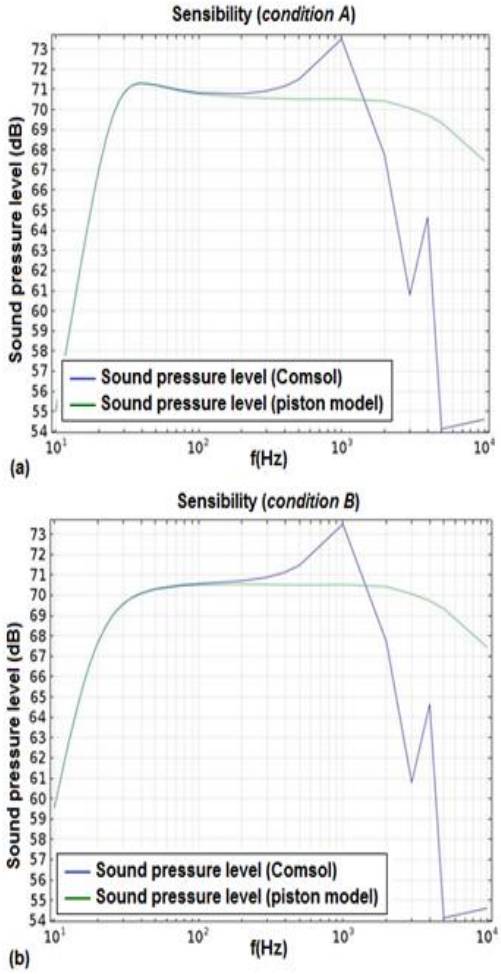

Figure 5. Sensibility curve: *conditions A* (a) and *B (b).*

It can be seen that the stiffness nonlinearity smooths the peak of the sensibility curve. In general, it is a favorable effect since the purpose of loudspeaker designs is to obtain curves as flat as possible.

IV. CONCLUSION

The model used in this work allows evaluating in a fast and practice manner the influences of a variation in the stiffness curve or in others loud-speaker parameters. Therefore, it becomes a very useful tool in the development of loudspeakers and acoustic boxes. Even to signals of small amplitudes, it can be perceived significant differences on the loudspeaker response.

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