Mitigating vibration levels of mistuned cyclic structures by use of contact nonlinearities

Samuel Quaegebeur*, Benjamin Chouvion** and Fabrice Thouverez *

**Ecole Centrale de Lyon, LTDS UMR 5513, 69130 Ecully, France*

***Centre de recherche de l'école de l'air, Ecole de l'air et de l'espace, 13661, Salon-de-Provence*

Abstract. In cyclic systems, manufacture tolerances and possible wear of the structure lead to small random variations (also called random mistuning) of the nominal (tuned) cyclic-symmetric mechanical system. Most of the time, these imperfections result in systems with vibration levels higher than the tuned one, and are thus detrimental. Friction non-linearities are used in the nominal design as a damping mechanism to dissipate the vibrational energy. The aim of this paper is to show that they can also mitigate the negative influence of random mistuning. This result is achieved through statistical studies on a high-fidelity nonlinear finite-element model of a bladed-disk. In order to restrain the numerical cost of deterministic simulations, state-of-the-art nonlinear reduction methodologies are employed.

Introduction

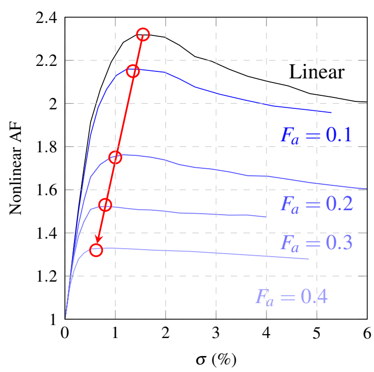
Computing the vibrational displacement of a structure is of the utmost importance to design the system and predict its potential failure. Although numerical tools are accurate in a deterministic way, manufacture tolerances and possible wear of the structure create discrepancies between the simulations and the real-life system. These slight differences may severely impact the expected system dynamics.

For linear systems, researchers have developed reduced-order model (ROM) to decrease significantly the size of the system while keeping an accurate prediction of its dynamics. Applying these ROMs with an accelerated Monte-Carlo method, Castanier et al. have been able to quantify the amplification factor (AF) of a bladed-disk FE model [1].

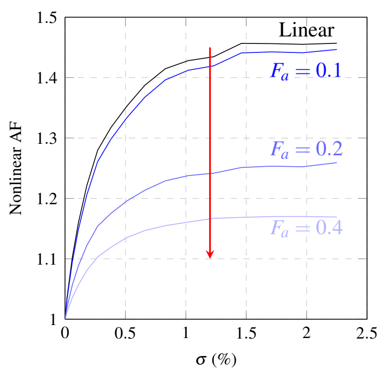
The purpose of this work is to apply a recent nonlinear ROM [2] to study the impact of mistuning on a high-fidelity FE model (approximatively 700,000 degrees of freedom) of a bladed-disk with contact nonlinearities. This original contribution focuses on computing the nonlinear AF of a randomly mistuned bladed-disk for different types of harmonic excitation. A particular attention is paid to the level of energy in the structure because, unlike in the linear case, it strongly impacts the AF.

Results and discussion

While linear mistuned systems can exhibit a vibration level 120% higher than the nominal system (see black curve in Figure 1a), this value can be decreased to 30% in the presence of a nonlinearity strong enough. Similar behaviour is observed for another kind of harmonic force exciting different dynamics of the system (see Figure 1b). Such a result is of the utmost importance for turbomachines engineers and will facilitate the future design of engines.



(a) Excitation wavenumber = 1.



(b) Excitation wavenumber = 3.

Figure 1: Parametric study conducted for different levels of nonlinearity (F_a) and mistuning (σ). The curves illustrate the AF below which 95% of the maximum amplitudes of vibration are situated.

Contact nonlinearities act as a damping mechanism and have the beneficial effect of reducing the level of vibration and thus extending the lifespan of mechanical systems. Our study shows another beneficial feature, namely that contact linearities also tend to mitigate the detrimental effect of mistuning.

References

[1] Castanier, M. P. and Pierre, C. (2006) Modeling and analysis of mistuned bladed disk vibration : status and emerging directions. *J. Propuls. Power* **22**: 384-396

[2] Quaegebeur, S., Chouvion, B., Thouverez, F. (2021) Nonlinear cyclic reduction for the analysis of mistuned cyclic systems. *J. Sound Vib* **499**: 116002