Towards an efficient strategy for the optimal design of aerospace structures with local nonlinearities in vibration dynamics

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The design of aerospace structures must address strong constraints, such as mass reduction or size restrictions, in an environment of high mechanical stress. Multiple iterations are often needed during the design process to reach an optimal configuration. Numerical simulation provides effective solutions to circumvent lengthy and expensive experimental tests. In this regard, *INGELIANCE* develops advanced numerical tools to perform analyses in structural dynamics, such as the software *PRIMODAL* [1] co-developed with *TOP MODAL*. In vibration dynamics, employing a linear or linearized model allows very efficient computations. However, nonlinearities frequently manifest in complex structures, including phenomena like large deformations, materials with nonlinear constitutive law, contact or friction. Specifically, contact at joints gives rise to complex behaviors during testings which are challenging to analyze and cannot be accurately replicated using linear models [2]. To address these issues, the objective is to develop a robust strategy for the optimization of structures with local nonlinearities in vibration. The first challenge arises from the dynamic simulation of nonlinear structures. While most industrial finite element software programs include nonlinear dynamic solvers, they mainly rely on time integration methods that are computationally expensive. Moreover, these methods are not able to capture complex nonlinear phenomena such as bifurcations in the frequency responses or hysteretic behavior for instance. The second challenge comes from the optimization process. Classical optimization methods require numerous iterations which is not affordable with a nonlinear model.

The proposed strategy is based on a Bayesian Optimization (BO) process relying on the use of a dedicated nonlinear mechanical solver for the construction and enrichment of a Gaussian Process surrogate model. The mechanical solver is based on the Harmonic Balance Method (HBM) associated with an Alternating Frequency-Time (AFT) approach as well as a path following continuation procedure to compute the frequency responses with bifurcations [3]. The HBM [4] is a frequency domain method that allows the computation of steady state periodic solutions using a Fourier series expansion. The AFT process [5] is employed to compute the nonlinear terms in the frequency domain. Finally, the continuation procedure is carried out using a predictor-corrector method based on a tangent prediction and orthogonal (or pseudo-arclength) corrections [6]. For large-scale industrial structure with localized nonlinearities at the interface of linear substructures, a Craig-Bampton condensation is conducted prior to the dynamic resolution to reduce the model size. The described mechanical solver is efficient and robust for the computation of frequency responses with bifurcations which provide useful insight on the dynamical behavior of the studied nonlinear structures. In the past years, several studies have used the HBM with numerical continuation strategies and condensation strategies for the simulation of industrial scale structures (see for instance [7]). The BO strategy relies on the mechanical solver to evaluate the objective and constraint functions of the optimization problem, but aims at limiting the number of calls to the mechanical solver. For this purpose, initial surrogate models are built to provide an approximation of these functions using a limited number of samples. The models are then refined with an appropriate enrichment based on a decision criterion (also called acquisition function).

The whole BO strategy has previously been studied for the optimization of a gantry crane undergoing sporadic contact [8]. In this work, the focus is put on the use of the mechanical solver on a simple satellite truss structure that have to endure strong dynamic solicitations during the launch phase. The structure exhibits gaps at its joints resulting in sporadic contact phenomena under vibration. Frequency responses are computed with the nonlinear solver for different configurations of the structure which permits a better understanding of the dynamic behavior of the structure. Discussion is made on the performance of the studied solver in the light of optimization framework.

609 words.

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