Nonlinear System Identification, Reduced Order Modeling, and Model Updating of the Effects of Mechanical Joints on Structural Dynamics

Keywords: mechanical joints, nonlinear system identification, finite element model updating

Summary: Mechanical joints are present in nearly every structure, device, or vehicle in operation today. As these become ever more complicated the need for the classification and understanding of the nonlinear effects on structural dynamics grows ever more critical. I propose to apply recently developed nonlinear system identification methods, reduced order modeling and model updating techniques to characterize and model these nonlinear effects. The outcome of this research will be the development of models for use in standard finite element (FE) methods that capture the nonlinear effects of mechanical joints.

Literature Review: Several techniques exist for the identification of joint parameters, but these methods require extensive instrumentation and measurements that may not be practical and rely on frequency response functions that are assumed to be linear [1]. Yet the current FE model updating techniques necessitate accurate modal parameters and often produce results that differ greatly from experimental results [1]. A recently developed nonlinear analysis methodology with broad applicability can be applied to alleviate these issues by characterizing the nonlinearities and developing reduced order models for use in standard FE codes.

The proposed method relies on the assumption that the application of Empirical Mode Decomposition [2], a time-domain based signal decomposition method, results in nearly orthogonal components, called Intrinsic Modal Functions (IMF), characterized by 'fast' oscillations controlled by 'slow' changing amplitudes [3-5]. The IMFs result in local nonlinear interaction models [6] that portray the local dynamics through sets of intrinsic modal oscillators (IMO). The IMOs are able to reproduce the measured times series while completely capturing the effects of the nonlinearities.

The global dynamics are determined by superimposing the wavelet transform (WT) of the original time series in the energy-frequency domain with the frequency-energy plot (FEP) [7] of the representative Hamiltonian system. By assessing the global dynamics an understanding of the energy dependence of the nonlinear normal modes [7] of the system can be developed. This method was recently applied to a beam with a bolted lap joint to identify the damping nonlinearities and the effects on the structural dynamics [8]. This research aims to continue that study and extend the results into FE model updating.

Hypothesis: Through the application of recently developed nonlinear system identification, reduced order modeling, and model updating techniques the nonlinear effects of mechanical joints on structural dynamics can be classified and incorporated into standard FE models.

Research Method: In order to study the effects of mechanical joints, steel beams will be constructed that incorporate bolted, riveted, and welded connections. "Monolithic" steel beams without any connections, but with holes, bolts, rivets, etc. will be used as experimental control beams for the analysis. The beams will be constrained in various positions to model the most common structures: cantilever, fixed-fixed, fixed-pinned, and similar configurations. Accelerometers will be attached using adhesives at evenly spaced points across the beams. Two cases will be studied: 1) free vibration characteristics induced by impact forces and 2) forced vibration characteristics induced by an electrodynamic shaker.

Linear modal analysis in addition to the proposed nonlinear analysis will be applied to both the "monolithic" systems and the systems comprised of mechanical joints. This will allow me to verify that the nonlinear analysis is able to reproduce both the linear and nonlinear effects as well as e the deficiencies of the linear modal analysis. EMD will be applied to the measured time series to decompose them into nearly orthogonal IMFs. The extracted IMFs will be used to develop IMOs that capture the local dynamics. The global dynamics will be characterized by superimposing the Hamiltonian FEP with the WT of the measured time series in the energy-frequency domain. A FE model consisting of two linear beams connected by a nonlinear element will be used to compute the Hamiltonian FEP and will serve as the basis for the model updating.

By characterizing both the local and global dynamics, I will be able to develop a reduced order model of the nonlinearity for each particular configuration. These reduced order models will be used to reproduce the dynamics of the measured systems and predict the dynamics of unmeasured systems. Finally, the models will be incorporated into standard FE methods for use in a broad range of applications.

Anticipated Results: 1) The application of the proposed nonlinear analysis methodology will fully capture the linear and nonlinear effects of mechanical joints on the structural dynamics. 2) Reduced order modeling techniques will be developed that can be incorporated into standard FE methods that account for the nonlinear modal interactions produced by mechanical joints.

Broader Impacts: This research aims to apply recently developed techniques to characterize the nonlinear effects of mechanical joints and to incorporate these effects into standard FE models. These models will made available for use in a broad range of applications in fields such as aerospace, automotive, heavy industrial equipment, turbo machinery and structural engineering. As this research progresses, I will present my findings at technical conferences such as the International Modal Analysis Conference and in technical journals such as the Journal of Sound and Vibration and Mechanical Systems and Signal Processing. Furthermore, this research will lay the foundations for developing further methods aimed at understanding nonlinear effects and incorporating them into standard FE analysis methods.

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