Improving correlation between uncertain experimental data and simulation predictions

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Abstract

This paper deals with the problem of improvement of correlation between uncertain experimental data and simulation predictions in the field of structural dynamics. The responses to be correlated are the natural frequencies of a disc brake calliper. Test campaign has been carefully planned and performed on a set of nominally identical callipers in order to estimate the uncertainty and variability content in the measurement data. The baseline Finite Element (FE) model of the test component has been built based on the available CAD geometry and nominal material properties. The goal was to update the numerical model in a way that would allow to reproduce numerically not only the mean of measured eigenfrequencies but also the scatter in the data. To solve the problem model updating approach has been applied that allows for adjustment of mean parameters and covariance matrix. The results of the procedure are summarized and discussed together with a comment on the sources of scatter in measured responses.

Keywords: modal analysis, model validation, uncertainty quantification, inverse problem

1. Introduction

Uncertainties and variability are inherent to experimental and simulation data and originate from various sources [1,2]. Uncertainty also referred to as 'epistemic uncertainty' is the reducible part or the lack of knowledge. It arises from the potential deficiency of knowledge about a test structure or the nature of physical phenomena involved and can be reduced as required information is gradually gathered. Variability also referred to as 'aleatory uncertainty' is the irreducible source of the scatter in the data. It arises from the manufacturing tolerances, natural fluctuations in material parameters, environmental conditions etc. Both uncertainty and variability contribute to the scatter in experimental data that is acquired on a structure. Simulation predictions are affected mostly by uncertainties that are due to modelling idealizations, parameter values taken from literature instead of test etc. Considering these factors the question of the credibility of numerical predictions in structural dynamics of vital imprtance. This paper addresses the problem of improvement of correlation between uncertain experimental data and simulation predictions in the field of structural dynamics considering uncertainty and variability content in the data.

2. Experimental campaign

Test structure was a disc brake calliper for a segment C passenger car. The calliper is the component of the brake that houses the brake pads and the piston in a disc brake. It is made of aluminium alloy AlSiMg07 and manufactured by permanent mould casting. After casting the specimen undergoes machining where internal channels are made and the surfaces that will be in contact with moving parts are machined. The callipers that are analyzed in this study were in the final stage after machining. There were 14 machined callipers of the same type in the measurement database.

Modal tests in the free-free boundary conditions have been performed using a single one axial accelerometer and modal hammer excitation [3]. Each specimen has been tested 29 times with identical test set-up. One Frequency Response Function (FRF) was produced from averaging over 8 runs. This kind of averaging is required in order to eliminate random measurement noise. The tests have been made by three different experimenters with use of the same measurement equipment. Detailed study on the sources of variability in measured natural frequencies can be found in [3].

3. Numerical model and analysis method

The baseline Finite Element (FE) model of the test component has been built based on the available CAD geometry and nominal material properties supplied by the manufacturer. FE model depicted in Fig. 1 was composed of 15 thousand nodes and 60 thousand elements. One component and one material property card had been defined in the model definition

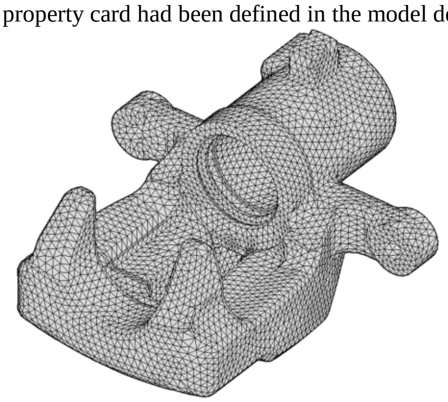

Figure 1: Numerical model of the analyzed disk brake calliper

Initial correlation between model predictions and measured natural frequencies was reasonably good but could not be accepted for two reasons. Firstly, for such a simple component with linear material properties and low damping better correlation has been expected. Secondly, the scatter present in the experimental data could not be reproduced with the baseline model.

Model updating approach that allows for adjustment of the mean parameters and the covariance matrix has been applied in order to improve the correlation between the experimental data and model predictions. The approach is based on perturbation theory where local sensitivity values (i.e. the first order partial derivatives of responses with respect to parameters) are used to model uncertainty. The implementation was based on the approach presented in [4]. It is a two step procedure where the vector of mean values and the covariance matrix are updated in parallel via the sensitivity-based approach.

The parameters chosen for model updating were the material properties of the aluminium alloy namely the: Young's modulus, Poisson's ratio and mass density. Responses that were taken into account were the first five natural frequencies of the calliper.

4. Results

As a result of the model updating procedure new values of the material constants have been computed together with respective variance coefficients. Fig. 2 presents the graphical representation of the results. Two clouds of points are superimposed representing measured values of natural frequencies (green circles) and model predictions (red stars). Points representing model predictions have been computed via the Monte Carlo analysis considering the updated values for mean values and variances of the parameters. Ellipses in Fig. 2 represent the 1σ, 2σ and 3σ levels.

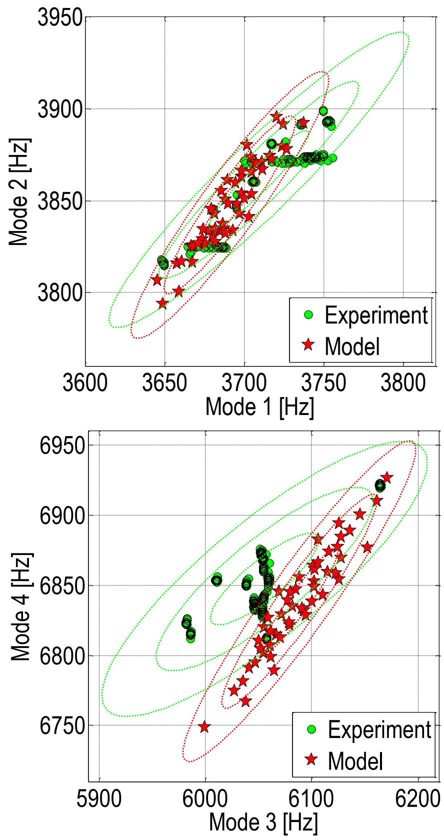

Figure 2: Numerical model of the analyzed disk brake calliper

As can be seen from the plots the correlation is acceptable but not perfect. There is a qualitative change with respect to the baseline model in the fact that the scatter in the data is now reflected in the numerical model. There is however some area for improvement. The analysis that has been presented was a first approach to the problem. The authors were aware of the simplifications that were made by choosing the global material properties as updating parameters. In reality the variability is most likely due to the variability in geometry of the calliper and spatial variability in material properties that are due to the manufacturing process. The purpose of the study was however to verify the possibility of improving the simulation predictions in engineering practice where there will be no possibility to perform a detailed study on uncertainty for every new design. Therefore beginning with simplified assumptions was fully justified.

5. Discussion

The question of the credibility of numerical predictions in structural dynamics is of vital importance. It has been shown that it is feasible to improve the correlation between the measurement data and simulation predictions by means of a model updating approach. Even in case of simplified assumptions about the sources of uncertainty in the experimental data it is possible to update the numerical model in a way that allows to mimic the real data reasonably well. The computational procedure that has been applied is relatively cheap in terms of computational time and there is a potential to apply it in more computationally demanding scenarios.

Acknowledgments

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