Identification of Damping from Structural Vibrations

Reliable predictions of the dynamic loads and the lifetime of structures are influenced by the limited accuracy concerning the level of structural damping. The mechanisms of damping cannot be derived analytically from first principles, and in the design of structures the damping is therefore based on experience or estimated from measurements. This thesis consists of an extended summary and three papers which focus on enhanced methods for identification of damping from random structural vibrations. The developed methods are validated by stochastic simulations, experimental data and full-scale measurements which are representative of the vibrations in small and large-scale structures.

The first part of the thesis presents an automated procedure which is suitable for estimation of the natural frequencies and the modal damping ratios from random response of structures. The method can be incorporated within existing time domain Operational Modal Analysis (OMA) techniques to automatically select the most representative time lag in the correlation function and model order of the system, by fitting a cluster of estimated frequencies and damping ratios to the dynamic response data. The procedure is applied to stochastic simulations of the tower accelerations of an 8 MW offshore wind turbine generator during downtime. This is a scenario in which a limited amount of damping is expected to be available. Therefore, it may be significant for the next generation of wind turbines for which estimates from field measurements may be applied for design optimization. The expected level of error in the estimates of damping computed by stochastic simulations is validated by real vibration measurements of an offshore wind turbine in non-operating conditions. The best bias-variance error trade-off in the damping estimates is obtained by the covariance driven stochastic subspace (COV-SSI) identification technique in combination with the automated method. It has been estimated that the average damping in the fundamental fore-aft mode is 42% lower than the damping in the side-side mode and the scatter is within the expected standard deviation. It is notoriously difficult to separate the magnitude of the multiple sources of damping in offshore wind turbine generators. The magnitude of energy dissipation depends on the vibration amplitude and is associated with a spatial location which can be described by the non-classical viscous damping matrix.

The second part of the thesis demonstrates how the spatial location of damping can be obtained by a derived explicit expression of the non-classical damping matrix. The modal parameters without a specific scaling are required in the expression as well as the mass distribution. This expression can be incorporated into an output-only system identification technique as well as in traditional experimental modal analysis techniques. The identified damping matrix is of high accuracy and yields a real-valued symmetric matrix from simulations. It is furthermore shown, by measurements of a model-scale five-story shear building, that the estimated complex-valued mode shapes are reproducible and their convergence concerning the measurement duration validates that the non-classical damping matrix can be re-constructed robustly by estimating the complex-valued modal parameters of dynamic structures.

In the last part of the thesis a method for identification of damping in hysteretic systems is presented. The method extends the post-processing of the estimates obtained by the classical COV-SSI technique. Hysteresis is modeled by the Bouc-Wen model which is represented by an equivalent linear relaxation model. The linear relaxation model is related to the Bouc-Wen model by explicit expressions of the relation between the model parameters obtained by harmonic averaging. These expressions are incorporated in the identification procedure and they depend on the identification of a cluster of non-oscillatory poles, the root-mean-square of the displacement response and the resonance frequency. Synthetic data provided by a benchmark challenge on identification of single-degree-of-freedom (SDOF) systems with hysteresis is used for validation. The displacement response from random excitation of a hysteretic system is contained in the data set, by which it is shown that the model parameters identified by the method can predict the response at both low and high-levels of excitation amplitudes.

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