Handling Uncertainties in Vibration Data for Damage Detection

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The excellent usage of vibration data to detect damage in engineering structures has been reported in several studies. This involved using numerical FE models, laboratory testing samples and real existing structures. In addition to damage detection, vibration data have been applied to verify and validate design, and predict dynamic responses due to loadings such as earthquake, wind and traffic. However, the use of vibration data to identify damage has been questioned (hindered) in terms of its reliability due to presence of uncertainties. In vibration data, there are two sources of uncertainties: FE modeling error and measurement noise. The existence of modeling error in FE is inevitable due to the inaccuracy of physical parameters, non-ideal boundary condition, finite element discretization, and nonlinear structural properties. This error may generate vibration data from a FE model that does not represent the exact dynamic behavior of the undamaged structure, thus leading to errors in damage detection. Uncertainties in measurement data normally occur during the testing phase and may lead to inaccurate damage identification. These uncertainties are associated with temperature, humidity, equipment calibration and external disturbances. Practically, as structures become larger and more complex, the inherent problems of uncertainties become more significant. These uncertainties are inevitable causing changes to the dynamic properties of the structure that can be equal to or greater than changes caused by damage, thereby leading to inaccurate damage diagnoses. The problems associated with uncertainties have triggered researchers to search for methods and indicators that are very highly sensitive to damage, so that the effects of uncertainties are reduced, and so that the uncertainties do not submerge the damage.

Researchers have proposed two main approaches namely probabilistic and non-probabilistic method to handle uncertainties in vibration data to enable accurate damage detection in structures. The Probabilistic approach to considering uncertainties in vibration data for damage detection was first presented back in early ‘90s. This approach accounts for variations in the modal properties of a structure. It involves perturbation of healthy eigenvalue problem to yield the relationship between the changes in eigenvalues and in the global stiffness matrix. This stiffness change is represented as a sum over every structural member by a product of a stiffness reduction factor and a stiffness sub-matrix. The determination of damaged stiffness statistics permits the comparison of probability density functions between the healthy and estimated damaged stiffness. A set of graphical and statistical probability damage quotients are applied to indicate a confidence level on the existence of damage. Researchers have applied this approach to propose several methods, i.e. Probabilistic Bayesian, ANN and fuzzy logic methods, to identify damage in various structures by using noisy vibration data. However, the Probabilistic approach is faces problem of assuming that the statistical distribution of uncertainties is known remains. In fact, the probability density function is difficult to acquire due to the complexity of uncertainty sources. In addition, experimental studies often do not provide adequate data, narrowing the chances of obtaining an unbiased probability density function. Furthermore, the probabilistic method requires long computation times due to the multiple data sets obtained through FE modelling.

In view of the problems encountered in the Probabilistic approach, several studies emphasized on the need for introduction of non-probabilistic interval analysis method. Unlike the conventional probabilistic approach, the non-probabilistic interval approach requires no assumptions regarding uncertainty distributions for estimating the Possibility of Damage Existence. Only the upper and lower bounds of the uncertain parameters are needed, thereby simplifying damage detection with noisy data, as well as reducing complex computation compared to the probabilistic approach. This approach has been applied to develop non-probabilistic fuzzy, non-probabilistic ANN and non-probabilistic wavelet transform methods.