ABSTRACT

Accurate identification of stiffness and damping is essential for reliable dynamic analysis and vibration-based Structural Health Monitoring (SHM), particularly for composite structures where material heterogeneity and damage cause spatially non-uniform stiffness and energy dissipation. This work presents a unified SHM framework for Glass Fibre Reinforced Polymer (GFRP) plates that integrates experimental modal analysis with sensitivity-based Finite Element Model Updating (FEMU) using the Inverse Eigen-Sensitivity Method (IEM) to identify both stiffness and damping parameters. The study first examines the influence of exponential window functions in impact hammer testing. Although windowing reduces spectral leakage, it introduces decay-rate-dependent numerical damping that biases damping estimates, especially for lower modes. A two-stage IEM methodology is developed to correct this. In the first stage, stiffness parameters are updated from measured natural frequencies and mode shapes to establish an undamped baseline. In the second stage, modal damping ratios are identified from measured frequency response functions. The approach recovers unbiased damping even without unwindowed reference data and under modal and spatial sparsity. The framework is then extended to non-proportionally damped systems with complex mode shapes. Window-induced numerical damping appears as a diagonal term in modal space and translates into a mass-proportional damping term in the physical domain. This increases diagonal dominance, weakens intermodal coupling, suppresses imaginary components, and reduces modal complexity, thereby masking true non-proportional behaviour. A hybrid strategy combining first-order perturbation with IEM restores the distorted complex modes and recovers the intrinsic non-proportional characteristics. Finally, complex modal characteristics are used for damage identification. A generalised non-proportional damping model assigns distinct stiffness and spatially varying Rayleigh coefficients to damaged and undamaged regions. The resulting modal complexity indices vary monotonically with damage severity and show higher sensitivity than frequency-based indicators. A sequential two-stage procedure identifies stiffness reduction from the real components and damping increase from the imaginary components, with updated parameters closely matching the imposed damage. Overall, the combined use of complex modal analysis, modal complexity measures, and sequential updating of elastic and damping parameters provides a physically interpretable and robust framework for damping identification and vibration-based SHM of composite structures.

Keywords: *Vibration-based structural health monitoring; GFRP composite plates; Damping identification; Non-proportional damping; Complex modes; Modal complexity indices; Finite element model updating; Inverse eigen-sensitivity method; Exponential window functions; Damage detection.*