

Summary

Industrial facilities comprising of structures embedded with tanks and heavy machineries, long span pipelines supported on flexible racks and large steel tanks are highly vulnerable to extreme loadings such as earthquakes, hurricanes, etc. Also, prolonged exposure to high amplitude vibrations due to machineries, flow induced vibrations, etc., may lead to fatigue problems. Any damage to industrial structures apart from resulting in economic losses may have serious consequences such as release of hazardous chemical and nuclear materials, fire, explosions, etc. Thus, the safety of such structures is of prime importance. In this context, structural health monitoring to detect any impending damage and vibration control of critical parts are a necessity.

In vibration-based structural health monitoring, mode shapes expanded from the sparse sensor positions serve as an important damage indicator. Most conventional optimal sensor placement algorithms are based on making the modal displacements at the sensor position as linearly independent as possible. While the mode shapes expanded from such positions may be reliable under the absence of uncertainties such as measurement noise and modelling error, it is neither clear as how they perform in the presence of uncertainties nor any literature exists for placing sensors efficiently in these situations. Using Monte-Carlo simulations, it is shown that the quality of expanded mode shapes deteriorate rapidly in the presence of such uncertainties when using the conventional sensor configuration.

Subsequently, a novel measure for the quality of modal expansion is derived based on the mean normal distance between the expanded and actual mode shape. This quantity is minimized to obtain new optimal sensor configuration. It is found that, even with these new configurations, the quality of expansion decreases with an increase in measurement noise and modelling error. But this happens at a rate smaller than that of the conventional configuration. For a given measurement noise and modelling error, the quality of expansion can be enhanced by increasing the number of sensors. An industrial tower and a cantilever beam are taken as case studies. Using Monte Carlo simulations, reliability of this new measure is verified considering realistic modelling error scenarios. In case of the cantilever beam 40 % improvement in mode shape expansion is obtained while 60% is obtained for the industrial tower. The efficacy of genetic algorithm and sequential sensor placement methods in finding optimal configurations for this new metric is also evaluated. For the industrial tower considered, a sensor layout is then designed considering mode shape expansion and linear independence of mode shapes.

Analogous to how sensor placement is important in health monitoring, placement of actuators and sometimes sensors are critical in vibration control. The optimal sensor-actuator locations are chosen so as to maximize mode controllability and observability. This is achieved either using certain norms of the transfer function or from system gramians. Taking the cantilever beam as an example it is shown that the optimal configuration from both the transfer function and system gramians are identical. Further using a simply supported beam as a case study, the optimal actuator locations are determined for controlling the first four modes. The efficiency of these locations for the placement of tuned mass dampers (TMD) are verified by keeping them at each possible location of the beam and finding the response. A periodically supported pipeline which exhibits unique stopband and passband characteristics is further considered. Optimal actuator locations are determined to control vibrations in the first and the second passband. Based on these results, different passive vibration control strategies are designed using TMD. The possibility of using an already existing pipe in the pipe-rack structure to be used as a damper is also evaluated. Finally, another novel way of realizing a tuned mass damper using an elastomeric lattice which can be tuned using topology optimization strategies is also proposed.