Semi-Active Piezoelectric Tuned Mass Damper for Mitigation of Aerodynamic Vibrations in Aircraft Structures

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ABSTRACT

A semi active tuned mass damper (SATMD) is developed for the reduction of low-frequency aerodynamic vibrations in aeronautics structures. The SATMD entails a shunted piezoelectric actuator mechanism which provides the stiffness and also converts the stored elastic energy to electrical, and vice versa. The piezoelectric stack is also connected in series to an RL electric circuit. The baseline vibration reduction of the SATMD at a single frequency is provided by the tuned auxiliary mass. Additional robust vibration reductions over a frequency range are possible by dissipation of electric energy at the resistor, and by the introduction of electromechanical inertia by the inductor.

Initially, the theoretical model of the SATMD, including the equivalent electrical RL circuit, applied on a simplified system consisting of two structural modes is presented, and the fundamental equations of motion are formulated. The main capabilities of the SATMD to provide variable damping by changing the shunting resistance are first investigated. But more importantly, the capability to provide substantial frequency tuning and vibration reduction of the second mode by the introduction of a new coupled electromechanical mode via the electric inductor is analytically investigated. The optimal combinations of the parameters of the SATMD system are further explored.

Subsequently, the SAMTD concept is evaluated on a scaled-down simplified aircraft prototype developed and fabricated for this purpose. An equivalent electromechanical model of elastic frame structure and the piezoelectric stack was developed and correlated with the measured dynamic response of the actuator. The structural dynamics model of the aircraft structure was developed based on the modal superposition method and was coupled with the SATMD model at the physical domain. Modal characteristics of the prototype structure were predicted by modal analysis of a detailed Abaqus FEA model, which were subsequently correlated with experimental modal analysis data.

In parallel to the previous computational model, dynamic experiments were conducted on the lab scale prototype, using variable resistance and inductance elements, and frequency response functions (FRFs) were measured. Finally, the simulated FRF is correlated with the experimental measurements.

In summary, both experimental and numerical results, illustrate that by choosing an appropriate auxiliary mass for the SATMD a specific mode can be targeted and can be substantially damped using a properly tuned shunt resistor. Finally, by adding inductance to the SATMD, ‘virtual mass’ is added via the electrical circuit allowing to re-tune the SATMD to lower modal frequencies. The obtained results will be presented indicating capabilities to reduce the structural accelerance of the prototype up to 20dB.

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