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Sweeping shunted electro-magnetic tuneable vibration absorber: Design and implementation

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ABSTRACT

This paper presents a study on the design and implementation of a time–varying shunted electro–magnetic Tuneable Vibration Absorber for broad–band vibration control of thin structures. A time–varying RL–shunt is used to harmonically vary the stiffness and damping properties of the Tuneable Vibration Absorber so that its mechanical fundamental natural frequency is continuously swept in a given broad frequency band whereas its mechanical damping is continuously adapted to maximize the vibration absorption from the hosting structure where it is mounted. The paper first recalls the tuning and positioning criteria for the case where a classical Tuneable Vibration Absorber is installed on a thin walled cylindrical structure to reduce the response of a resonating flexural mode. It then discusses the design of the time–varying shunt circuit to produce the desired stiffness and damping variations in the electro-magnetic Tuneable Vibration Absorber. Finally, it presents a numerical study on the flexural vibration and interior sound control effects produced when an array of these shunted electro–magnetic Tuneable Vibration Absorbers are mounted on a thin walled cylinder subject to a rain–on–the–roof stochastic excitation. The study shows that the array of proposed systems effectively controls the cylinder flexural response and interior noise over a broad frequency band without need of tuning and thus system identification of the structure. Therefore, the systems can be successfully used also on structures whose physical properties vary in time because of temperature changes or tensioning effects for example.

1. Introduction

Flexural vibrations of distributed structures is an important practical problem, particularly when it is associated to noise radiation into somewhat small enclosures such as the passenger compartments/cabins in cruise ships, trains, aircraft and cars [1–3]. Several materials, designs, mechanical treatments and control devices have been developed over the years to mitigate vibrations in thin walled structures, which for example include mass, stiffness and damping treatments, double wall constructions with sound absorbing materials, Tuneable Vibration Absorbers (TVA) and composite materials [4–11]. The selection and design of the most appropriate treatment for a given system is a complex process that often leads to non–ideal solutions to ensure a compromise between design constraints (e.g. structural requirements, weight limits, fabrication costs, maintenance costs, etc.) and the effectiveness of the remedy. For this reason, during the past thirty years, a big effort has been dedicated to the study and development of semi–active and

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active noise and vibration control systems that further enhance the control effects obtained with classical passive treatments [12–19].

This paper is focused on the implementation of semi–active TVAs on thin walled enclosures to reduce both the structural response of the walls and the interior acoustic field. Previous works in this area were focused either on the control of tonal disturbances [20–23] or the control of broad–band stochastic disturbances [24–28]. The study presented in this paper is dedicated to the latter application; more specifically to the implementation of time–varying TVAs aimed to reducing the broad frequency band resonant response of the flexible walls of somewhat small enclosures. Recent studies have shown that the vibration absorption produced by TVAs can be improved by varying the stiffness and damping parameters of the TVA during operation. In particular, the studies presented in Refs. [29–33], have investigated the implementation of switching laws where the stiffness and/or damping parameters of the TVA system are commuted from low to high values according to specific laws set to maximize the vibration absorption effect. The system considered here is instead based on the studies presented in Refs. [34–36], where the TVA natural frequency and internal damping are continuously varied within given ranges such that the TVA effectively absorbs flexural vibration energy from the hosting structure in a given broad frequency band. In particular, this paper investigates a practical sweeping TVA system, which is composed by a coil–magnet transducer, with the magnet mounted via soft springs to the case where the coil is rigidly fixed [37]. The coil is connected to a time–varying RL–shunt, which is designed in such a way as to independently produce stiffness and damping electro–mechanical effects [38]. More precisely, the RL–shunt is set to periodically vary the mechanical stiffness and damping of the TVA, so that the TVA fundamental natural frequency is continuously swept in a given frequency band whereas the TVA mechanical damping is adapted to maximize the flexural vibration absorption. The vibration control effectiveness of this semi–active TVA is then assessed considering an array of these TVAs mounted on a large, thin walled, cylinder. In particular, the structural–acoustic effects produced by two arrays of 12 and 18 sweeping TVAs are investigated considering both the spatially averaged flexural vibration of the cylinder and the spatially averaged sound pressure inside the cylinder.

In contrast to classical TVAs, the proposed time–varying shunted electro–magnetic TVA does not require precise tuning to the resonating response of a specific mode of the hosting structure. On the contrary, it blindly works in a wide frequency band encompassing the resonant responses of multiple modes of the hosting structure. Thus, it does not need a system identification initialisation procedure or an online tuning system. Besides, it can also work on structures and systems whose physical properties, and thus whose resonant responses, vary in time. These are rather interesting features, since the proposed TVA can be developed as a self–contained modular unit, which is characterised by a given operation frequency band and a given weight. In this way single or multiple units can be installed on a wide class of hosting structures and systems whose physical properties may vary during operation, due to changes of temperature or tensioning effects for example. For instance, small size and small weight units can be installed on lightweight structures such as thin panels and shells of transportation vehicles as for example aircraft, trains, cars, etc. Alternatively, large size and large weight units can be installed on heavy structures, such as shell structures of industrial plants, production machineries, frame structures of buildings, etc.

The paper is structured in five sections. Section two describes the thin walled cylindrical shell equipped with the time–varying shunted electro–magnetic TVAs and briefly revises the tuning laws and positioning criterion when a classical TVA is set to reduce the resonant response of a flexural mode of a cylindrical shell structure. It then presents the proposed electro–magnetic TVA system and provides the electro–mechanical analogies used to design the shunt circuit for the sweeping operation mode. Section three introduces the mathematical model and the state space and spectral formulations used to derive and depict the fully coupled structural–acoustic response when the cylinder equipped with the time–varying TVAs is exposed to a rain–on–the–roof stationary stochastic excitation. Section four presents the simulation results on the control effects produced by arrays of either 12 and 18 fixed and sweeping TVAs. Finally, section five summarizes the principal conclusions of the study.

2. Cylindrical shell with shunted electro–magnetic TVAs

2.1. Model problem

As depicted in Fig. 1, the system studied in this paper is composed by a thin walled aluminium cylinder, which is assumed to be simply–supported at the two ends and is connected to rigid cylindrical extensions, which form rigid baffles for the exterior unbounded air fluid. The interior cylindrical cavity is also filled with air and is bounded by rigid walls placed in correspondence to the circular edges of the flexible cylindrical wall.

The cylinder is exposed to a white noise rain–on–the–roof excitation [39], which, as shown in Fig. 1a, is approximated by a uniform grid of uncorrelated point forces oriented in radial direction (8 in the circumferential direction and 3 in the axial direction). This forcing field equally excites all flexural natural modes of the cylinder that resonate in the studied frequency band and thus can be conveniently used to assess the intrinsic effects produced by the proposed sweeping shunted electro–magnetic TVAs on the structural–acoustic response of the cylinder. As schematically shown in Fig. 1b, the cylinder is equipped with two arrays of either 12 or 18 shunted electro-magnetic TVAs, which are arranged in two groups, placed at 40% and 60% of the length of the cylinder and whose circumferential positions were chosen in view of the spatial criterion discussed in the following Section 2.2. The geometrical and physical properties of the thin walled cylinder and of the interior