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Innovative Hybrid Mass Damper for Dual-Loop Controller

S. Chesné [a,*], G Inquieté [b], P. Cranga [b], F. Legrand [a], B. Petitjean [c]

[a] Université de Lyon, CNRS INSA-Lyon, LaMCoS UMR5259, F-69621 Villeurbanne, France
[b] Airbus Helicopters, Marignane airport, 13725 Marignane Cedex, France
[c] Airbus Group Innovations, Team of Vibroacoustics and Dynamics, F-92150 Suresnes, France

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ABSTRACT

The paper presents a new dual transducer and its associated control law. It aims to increase the efficiency of a traditional passive damped electromagnetic resonator by controlling its mass response actively. The design aspects of the so-called Dual-Loop Controller (DLC) for Hybrid Mass Damper (HMD) are presented and discussed. The control law attempts to modify a Tuned Mass Damper (TMD) to use it as an Active Mass Damper (AMD), with the objective of combining the best of the two technologies by actively increasing the performance of the passive device. Based on an optimally tuned passive device, the resulting system is fail-safe. The conception of the new dual transducer used as an HMD, designed specifically for this control law, is detailed. The hybrid device is experimentally validated both on a laboratory setup and on a real helicopter.

1. Introduction

Vibrations problems are mainly related to structural resonances or important harmonic loads. If the frequency of a harmonic load matches the resonance frequency of a structure, dynamic amplification can create a vibration of huge amplitude. This amplification is linked to the internal damping of the structure. To reduce these resonance-based vibrations, structural damping can be increased by passive or active means. The Tuned Mass Damper (TMD) is a passive device tuned to a targeted mode (leaving the other mode unchanged), or a well-known harmonic perturbation (the device is then called a Dynamic Vibration Absorber (DVA) [1]). The Active Mass Damper (AMD) is fully active and can be efficient on all the controllable modes; usually it requires an absolute velocity (or acceleration) measurement as input [2]. In [3], the authors study the link between the tuning frequency of the AMD (called Inertial Actuators in the study) and their relative performance in comparison to TMD.

Recently, a new generation of dampers has appeared. It attempts to accomplish various objectives at the same time, combining the behavior of an optimal TMD and of the active damping devices. These devices are usually named Hybrid Mass Damper (HMD), or Hybrid Vibration Absorber (HVA). Depending on the application, the objectives can vary. It could be: to increase the performance, to reduce the power consumption, to reduce the stroke of the moving mass, to reduce the embedded mass and to ensure fail-safe behavior, i.e. that the damper is still efficient when the controller is turned off.

Over the last decade many systems have been proposed. In [4] an optimal control is used to combine structural damping with a restricted stroke of the actuator to create a HMD. In [5], optimal control is used to minimize both the control effort

* Corresponding author.
E-mail addresses: simon.chesne@insa-lyon.fr (S. Chesné), guillaume.inquiete@airbus.com (G Inquieté), paul.cranga@airbus.com (P. Cranga), franck.legrand@insa-lyon.fr (F. Legrand), benoit.petitjean@airbus.com (B. Petitjean).

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and the response. In [6], FXLMS controller (Filtered-X Least Mean Squares) is combined with a resonant isolation system (SARIB©) to enhance the frequency range for helicopters applications. In [7,8], a pole placement technique is proposed to ensure performance and stability. In [9] a two degree of freedom system is used, which can behave as an AMD to suppress the vibrations induced by small earthquakes, and as a TMD to suppress the vibrations of a targeted mode of a building, excited by a bigger earthquake. One common feature (and drawback) of the aforementioned controllers is that they are model-dependent, as depicted in [10], contrary to the proposed control device in this paper. It results that the control law is usually complex to tune. And their performances against parameter variations in the primary system are not very high. The present study will show that the developed system is simple and robust face to structural uncertainties. One can also cite another class of hybrid system: Delay Resonators (DR). Delayed resonators use both the passive behavior of a resonator and an active control law [11,12] to efficiently reject an harmonic perturbation. Their main difference compared to a TMD is that these hybrid devices are mainly developed for harmonic perturbation rejection and thus can not be considered as fail safe. More recently, a hyperstable HMD control law has been proposed in [13–15]. It is based on the phase correction of a direct velocity feedback law applied to a TMD and appears to efficiently control the first mode of the primary structure. In summary, hybrid controllers are attempting to get the best of TMD and AMD with robust and simple control laws, while maintaining the usual objectives of increasing the performance and/or decreasing the control effort of the actuator.

The present paper validates the so-called Dual-Loop Controller (DLC) (only the concept was briefly introduced in [2]) for Hybrid Mass Dampers (HMD) and its dedicated innovative transducer. These control laws attempt to modify a Tuned Mass Damper (TMD) to use it as an AMD (Active Mass Damper), with the objectives of tacking the best of the two technologies by actively increasing the performance of the passive device. Based on an optimally tuned passive device, the resulting system is fail-safe. Two parallel loops are used. One to detune the HMD (negative stiffness feedback), and the second one to damp the main structure (direct velocity feedback). The developed transducer is an oscillating mass including two voice-coil systems at its extremities. One dedicated to the passive behavior of the HMD and the other one to the active vibration control. The proposed conception allows to apply both active and optimal passive control, with double magnet-coil systems on a unique mechanical degree of freedom. This conception leads to simplicity and robustness.

The paper is organized as follows: after this introduction, the principle of the proposed dual loop controller is explained. The third part details the conception of the innovative dual transducer used as an HMD, designed specifically for these control laws. The fourth part shows experimental results on a laboratory setup that validates the proper functioning of the control system. The last part briefly illustrates the very good performance measured on an helicopter.

2. Principle of the Dual-Loop Controller

Consider an initial structure simplified to a one degree of freedom system. This represents the main structure to control (Fig. 1). We fix a Tuned Masse Damper (TMD) to this structure, optimally tuned using Den Hartog's law [1], then the active control force (f_a) is introduced between the two masses. Classically, it can be a voice-coil actuator, the mass of the TMD is the moving part of the actuator (usually the magnets). The concept of this dual loop controller, briefly presented in [2], is to combine two control laws using two different inputs. The two loops are in parallel (Figs. 1 and 7) and act on the same transducer. Contrary to many dual loop controllers, there is no "inner" or "outer" loop and no accelerometers are needed on the TMD to measure its absolute acceleration or velocity. The two loops are presented successively for a better understanding.

The first one (in blue in Fig. 1) is a proportional-derivative controller fed by the relative displacement between the inertial mass and the main structure. The second one is a proportional controller fed by the absolute velocity of the main structure

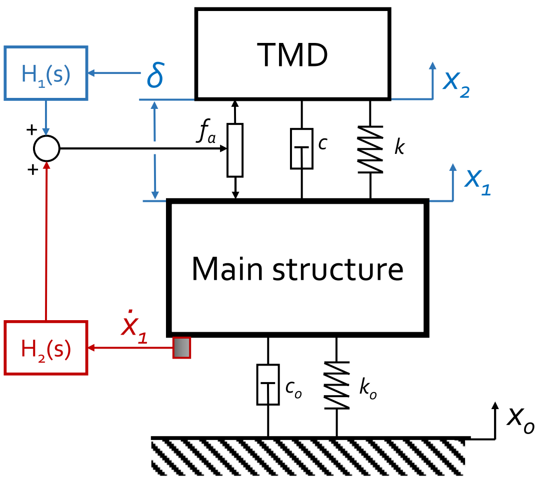

Fig. 1. SDOF of the main structure with an hybrid vibration absorber.