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Hybrid Mass Damper Using Electromagnetic Resonator: Application to an Helicopter

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ABSTRACT

This work aims to illustrate how to increase the efficiency of an initial passive damped electromagnetic resonator by controlling the mass response actively. In aerospace and aeronautical engineering a fail-safe design for active systems is usually required. Hybrid Mass Dampers (HMD) tend to realize these objectives. Design rules and limitations of the so-called Hybrid Mass Damper (HMD) are discussed and analyzed. The main idea is to modify a DVA (Dynamic Vibration Absorber) to use it as an AMD (Active Mass Damper). Objectives are to take the best of the two technologies and increasing the performance of the passive device and/or decreasing the control effort of the actuator in comparison with a fully active system. A specific electromagnetic resonator is then designed and an appropriate control law is proposed. The methodology is illustrated and validated with an application to a helicopter. Theoretical and numerical results are completed by experimental validation.

Keywords: Mass Damper, Active and passive control.

1. HYBRIDIZATION PRINCIPLE

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 (fa) 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 (Fig 1) and act on the same transducer. These 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 (in red in Fig.1).

Figure 2 illustrates the pole locations of this device. In Fig2a, the initial pole of the main structure can be seen in grey. By adding an optimal passive TMD with equal peak design parameters, one can see the two new poles and the increasing of damping. In the Fig 2b the two control laws are added successively, starting with the optimal passive device.

It is known that direct velocity feedback associated with a TMD results in very poor stability margins (3). The purpose of the first control loop (H1) is to increase these margins. It aims to reduce the stiffness of the TMD and to add damping. It is shown by the blue root locus in fig 2b. One can observe that the low frequency pole, linked to the actuator, is moved away from the imaginary axis. The high frequency mode tends to return to the initial pole of the structure as the TMD is no more tuned to absorb vibrations. At this point the device behaves like a classical AMD.

The second step consists of applying a direct velocity feedback (red root locus in fig 2b). One can see that the two poles are moving to opposite directions. The gain of this controller appears as a

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tradeoff between the damping of the high frequency mode and the stability margins as explained if (4). These schemes show that this kind of dual loop controller, when adequately tuned, can in theory, yield high damping on both resulting modes with adequate stability margins.

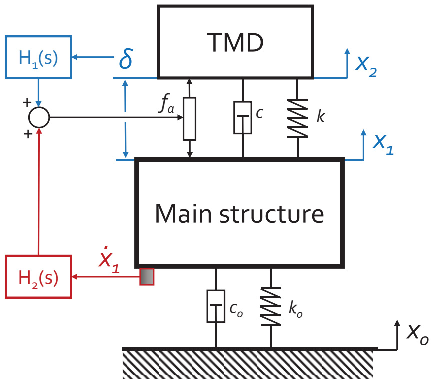


Figure 1 – SDOF of the main structure with an hybrid vibration absorber

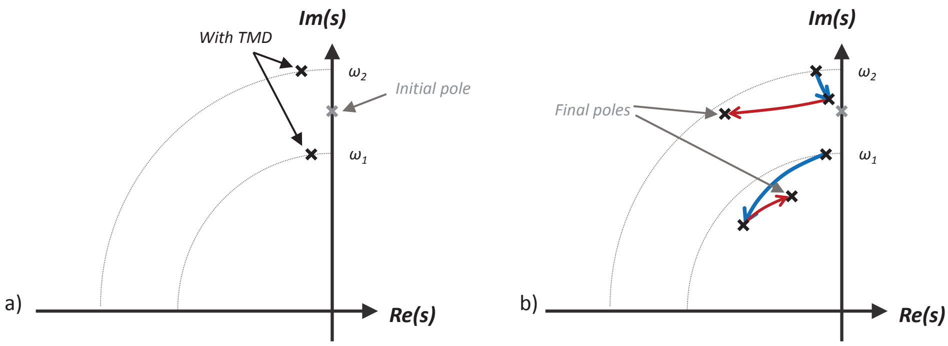


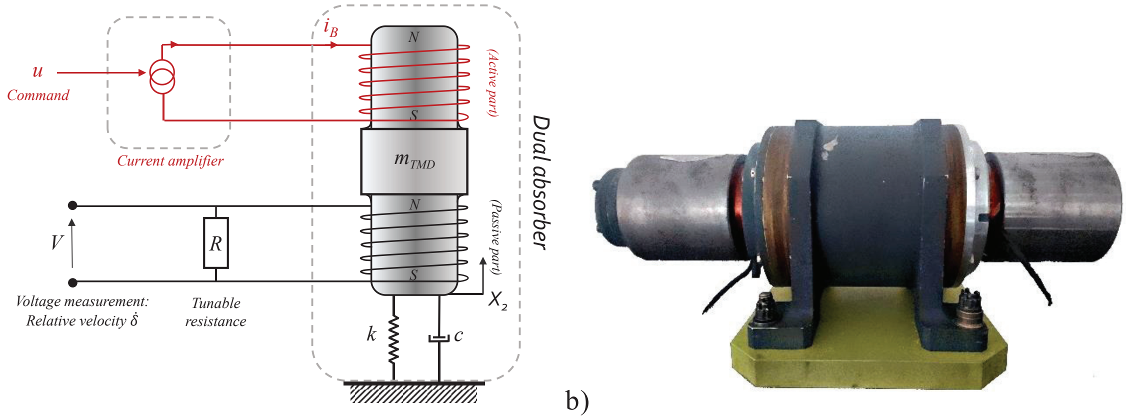
Figure 2 – a. Pole location of the passive devices (without and with TMD) b. Root locus of the Hybrid device by successively adding the H1 control loop (in blue) and the H control loop (in red).

2. INNOVATIVE TRANSDUCER

For this project, a specific dual transducer has been designed and patented. Basically, it consists of a one mechanical degree of freedom system designed as a TMD.

The moving mass is guided by two set of flexible membranes. Two magnets are fixed at the extremities of the moving mass, contributing to the total mass of the moving part. Each magnet is surrounded by a coil. One magnet and coil is dedicated to the passive behavior of the TMD the other one to the active one. The principle is illustrated in Fig3.a (For better readability, the metal structures surrounding the magnet-coil systems for guiding the magnetic field lines are not shown on this scheme). The final prototype can be seen in fig 3.b.

Two parts can be clearly identified. The passive part (represented at the bottom of fig 3a) consists of a load (tunable resistance) and a system to measure voltage. The load is used to tune the damping of the TMD. The mechanical damping of the system is very low. To reach the optimal damping value, one uses the possibility of adapting the load to optimize damping of the coupled system. As the resulting voltage on the load is directly proportional to the relative velocity, this value is used to feed the first loop of the controller (H1). The active part (in red in fig 3a) uses a current amplifier in order to obtain a control force proportional to the command.



a) b)
Figure 3 – a) Schematic diagram of the dual transducer, b) the final prototype

3. FULL SCALE VALIDATION

The final aim of the project is to control a specific vibration mode on an helicopter. This section aims to illustrate the efficiency of the proposed device on a real structure for which the system has been designed. For confidentiality reasons, not all the data can be shown. This abstract only gives an insight of the potential applications. The helicopter used for the tests is shown in Fig 4.

Figure 4 – AH225 used for the tests

The transfer functions between a force sensor linked to the shaker located on the main rotor, and an accelerometer glued near the HMD are plotted in Fig 5. The responses of the passive systems are represented in black (helicopter alone), and in red (with the passive TMD). The effective modal mass of the mode to control is around 3 tons. In this case, the mass ratio is very low. The passive reduction is very small (around 2dB). No effects are observable at other frequencies.

Fig 5 shows two different tunings (in blue, continuous and dotted line). The continuous blue line uses a classical detuning (half of the passive stiffness) and high gain for the “H2 loop”. Two effects can be observed. The first one is a massive reduction of the vibration of the mode of interest, almost 8 dB in comparison with the passive system. The spectacular results are tarnished by the increase of the vibration of a lower frequency mode corresponding to the new frequency resonance of the HMD. A simple way to avoid this phenomena is to slightly change the detuning created by the “H1 loop”. The second tuning (light blue dotted line) shows that with a bigger detuning, this phenomena is avoided. The amplitude reduction on the mode of interest is around 5dB in comparison with the passive TMD, but a gain of 7.5dB is also observed on the previous low frequency mode. After the mode of interest, a global reduction of 2-3dB is observed. No high frequency spillover happens.

The tuning procedure of the various loops appears as a tradeoff between the modal repartition of the main structure, the stroke of the actuator and the stability margins. This tradeoff depends on the design of the transducer and the modal distribution of the main structure.

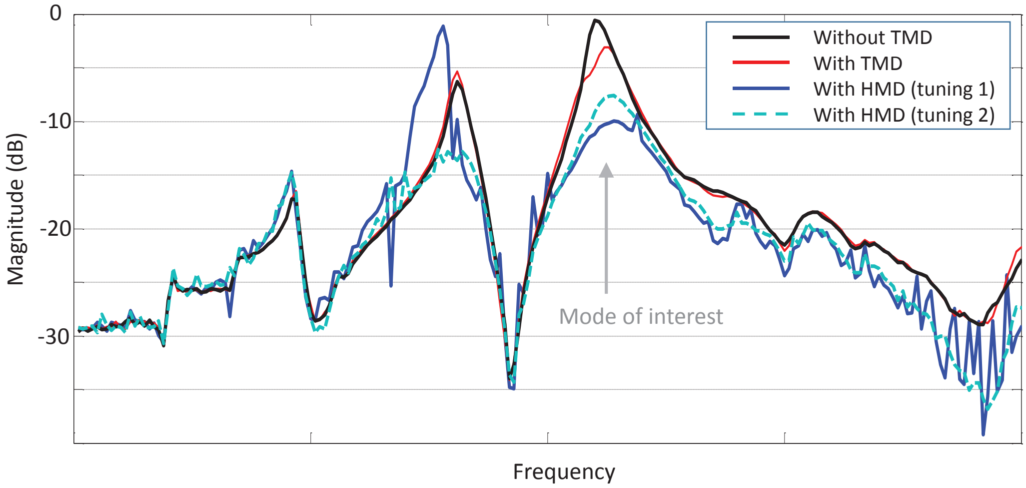


Figure 5 – Normalized transfer function without TMD, with TMD and with HMD using two different tunings. (For confidentiality reasons, the frequencies and the shapes of the mode are not given).

4. CONCLUSIONS

The study validates an innovative transducer dedicated to a dual loop controller. This transducer is a Hybrid Mass Damper, combining passive Tuned Mass Damper behavior and actuator capabilities for active vibration control. Sensing and actuating systems are linked to a single degree of freedom device constituted of two voice-coil systems, one dedicated to the passive damping and the other one to the active damping. The proposed control loops provide stable and efficient control. The resulting damping device is also fail-safe. In comparison to a classical optimal TMD, the damping performance is increased without adding any mass on the TMD. These aspects are very important for embedded applications. The proposed hybrid control device has been built at full-scale and successfully tested on both an academic bench and on an helicopter. Future studies will show that the power consumption of this kind of device is much lower than a full active system. More details can be found in (4).

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