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Active Tuned Mass Damper: Sky-hook synthesis

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ABSTRACT

The association of a feedback control strategy with tuned mass dampers appears as an efficient way for enhancing the capability to damp structural vibration. Recently, several strategies have been proposed, which are targeting specific features, like multi-mode control, selective mode control. This study presents a new control law for hybrid vibration attenuation called hybrid SkyHook mass damper. Mechanical analogy and power flow formulation, shows that it enables the synthesis of an active skyhook damper, associated with an optimal passive Tuned Mass Damper. The improvement of performance is also accompanied by a fail-safe behavior. The hyperstability property is theoretically ensured, which means that the stability of the controlled system is guaranteed. Performances are illustrated by experiments.. It shows that this hybrid device has remarkable properties in term of vibration attenuation on the whole frequency range as expected for SkyHook device. No response amplification or specific drawbacks are observed.

Keywords: *Hybrid mass damper, Sky-hook Damper, active control.*

1. INTRODUCTION

Usual vibrations control approaches are passive or active [1-4]. Recently many hybrid devices, combining the advantages of passive and active systems have been developed [5-9]. This paper presents a new hybrid device. It illutrates how to use power flow formulation and equivalent mechanical impedance to design a specific control law for this HMD. The resulting system synthesizes a Skyhook damper parallel to this optimal TMD and presents hyperstable behaviour. Stability, performance, and robustness are analyzed through numerical simulations. Finally, experimental results validate the proposed hybrid device.

2. HYBRID MASS ABSORBER

This section illustrates the principle of the HMD and its equivalent mechanical analogy. A typical linear hybrid system is shown in Fig. 1.a. It is composed of a primary system indexed 1, associated with a TMD indexed 2. Fig. 1.b. represents the equivalent mechanical system when the controller is adequately tuned to synthesize a skyhook damper as proposed in this paper.

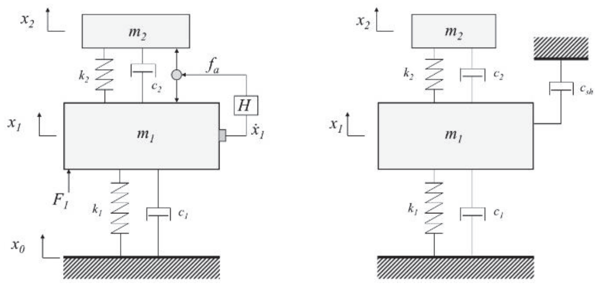

Figure 1. Schematics of the control unit model. a) Hybrid Tuned Mass Damper, b) Passive system (Tuned Mass Damper and Skyhook Damper).

3. SKYHOOK SYNTHESIS

3.1 Power flow formulation

It is known that the internal power generation mechanisms are only linked to the power flow generated by the actuator driven by the controller and its control law *H(s)*. Considering the parameters defined in Fig 1, the function *G(s)* that represents this dissipating mechanism can be written in the Laplace domain as follows:

$$G(s) = -F_a s(X_1 - X_2) \tag{1}$$

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with F_a=-sX_1*H, the force generated by the velocity feedback controller. On the other hand, one can easily show that the power dissipated by a mechanical Skyhook damper (as represented
in Figure 1(b) with a damping value of c_{sh}) is:

$$G(s) = (sX_1)^2 c_{sh} \tag{2}$$

To obtain an equivalence between these equations, one can define the control law *H(s)* as [10]:

$$H(s) = \frac{g}{s^2}\left(s^2 + \frac{sc_2}{m_2} + \frac{k_2}{m_2}\right) \tag{3}$$

Where *g* is the gain of the feedback loop and will be equal to synthesized skyhook damping.

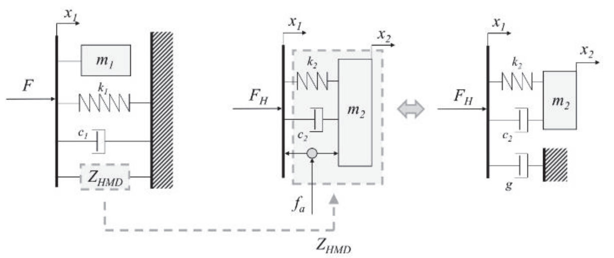

Figure 2. (a) Parallel representation of the global system, (b) Schematic of the hybrid device and (c) its equivalent mechanical model.

3.2 Mechanical impedance analysis.

For a single degree of freedom, the mechanical impedance can be defined as the ratio between the applied force and the resulting velocity:

$$Z(s) = F/(sX) \tag{4}$$

Figure 2(a) shows a representation of the global system, illustrating the fact that the impedance of the primary structure is in parallel with that of the hybrid absorber. Figure 2(b) isolates the absorber. One can compute the resulting force F_H generated by the device at its interface as follows:

$$F_H(s) = (k_2 + sc_2)(X_1 - X_2) + F_a \tag{5}$$

Then, by introducing the proposed control law *H(s)* defined in eq.(3), the resulting mechanical impedance of the proposed device is:

$$Z_{HMD}(s) = \frac{F_H}{sX_1} = \frac{sm_2(k_2+sc_2)}{s^2 m_{2+}k_2+sc_2} + g \tag{6}$$

As predicted in previous part, one can identify the mechanical impedance of a purely passive TMD in parallel to skyhook system with a damping value *g*. The resulting mechanical analogy is illustrated in Figure 2(c).

4. EXPERIMENTAL VALIDATION

4.1 Set-up

The control system and the setup are represented in Figure 3. It is a cantilever steel beam (58x10x1cm). The hybrid absorber is mounted on the beam at 48 cm from the base. This electromagnetic system is a Micromega product (ADD-5N), originally designed for purely active control. Never the less, its dynamical properties correspond to a passive TMD for this system. The passive response (without and with TMD) of the beam are shown in figure 4.

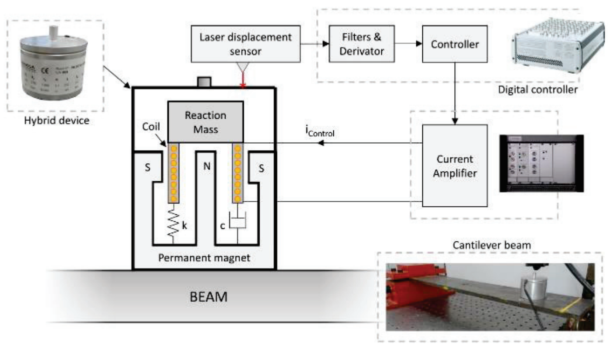

Figure 3. The control system, its feedback loop, and the experimental setup.

4.2 Results

The performance of the control device is observed in terms of the displacement response at the actuator location. Figure 4 shows the displacements of the beam without a TMD (gray line), with a passive TMD (green line), and with the hybrid device using different gains in red (continuous line: g = 60, dotted line: g = 180). The initial passive TMD almost verifies the equal peak property. One can observe the effect of the hybrid device on the first mode. It can reach a huge attenuation compared to the passive device, cancelling the dynamical amplification of the two resulting modes.
The red curves are under the green one over a very wide frequency band. This is one of the main particularities and advantages of the sky hook behavior.

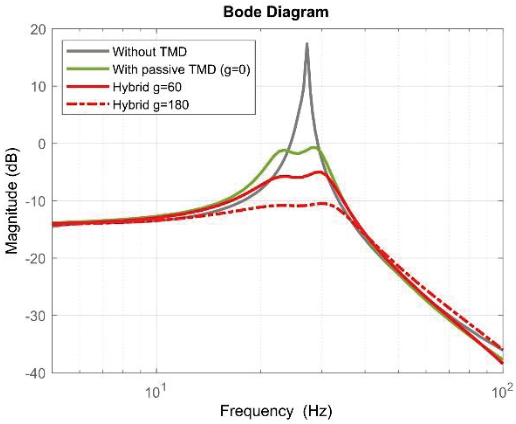

Figure 4. Frequency response function in term of displacements without TMD (grey line), with passive TMD (green line) and with the HSHMD using different gains in red (Continuous line: g = 60, dotted line: g = 180).

Figure 5 shows the root locus for various values of the gain compared with the simulated system. The initial state is represented by the gray crosses and has been experimentally identified. This figure shows a good correlation between a simulated control and an experiment. These curves also illustrate the hyperstable property of the proposed control law.

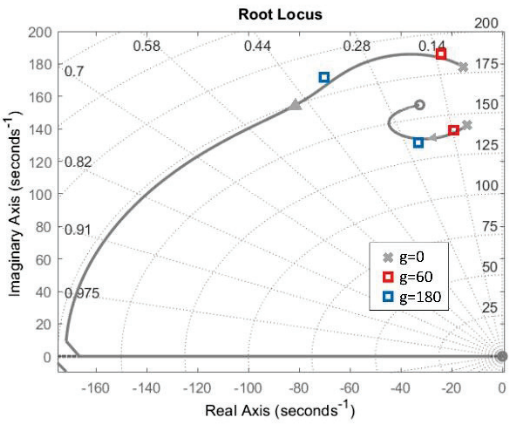

Figure 5. Root locus of the hybrid controller as a function of the control gain. Square: Experimental results.

5. CONCLUSION

This study presents a new control law for hybrid vibration attenuation called hybrid skyHook mass damper. Mechanical analogy or a power flow formulation, shows that it enables the synthesis of an hybrid skyhook damper. With this active-passive device using the TMD as an inertial actuator, the system can be considered as *fail-safe*. The hyperstability property is theoretically ensured, which means that the stability of the controlled system is guaranteed. Experimental application validates the concept. Contrary to many hybrid controllers, no response amplifications are observed. More details are given in [10].

6. REFERENCES

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