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TOWARDS LOW CONSUMPTION SMART DAMPERS

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ABSTRACT

Combining a feedback control strategy with tuned mass dampers is an efficient way for enhancing the capability to damp structural vibration. Several strategies have been proposed in the literature, which are targeting specific features, like multi-mode control, selective mode control. However, a comparison of these concepts based on objective criteria is missing, although very important for detecting shortcomings, and limitations in practical implementations. The objective of this study is to investigate an extensive comparison of three concepts of active damper, namely the dual loop controllers, Alpha-HMD and Hybrid-Double-TMD. This comparison will encompass criteria like stability margins, bandwidth, transducer stroke, maximum force, or power consumption.

1. INTRODUCTION

Tuned Mass Dampers (TMD) or Dynamic Vibration Absorber (DVA) are well known devices, appended to a structure to dissipate the vibrational energy at a specific resonance. Usually they are used in a passive way. Since their first invention in 1909 [1], they have found numerous applications ranging from civil structures to precision engineering. The most popular design is the so-called equal peak design [2]. On the other side, Active Mass Damper (AMD) is an inertial actuator and is used to actively control a structure. Contrary to TMD, which is passive, the resonance frequency of the actuator is much lower than the fundamental resonance frequency. Direct velocity feedback is an efficient control law, usually used for these actuators. However, for large values of the control gain, stability is no more guaranteed. And the fail-safe behavior in case of failure is not ensured.

Recently, a novel class of damper (called Hybrid Mass Dampers) has appeared which are trying to combine the best of passive and active devices [3-7]. This paper studies and try to compare three systems developed by the authors [3,6]. These systems are simple feedback controller and they do not use a model of the main structure.

Globally these compensators aim to correct the relative phase between the damper and the control law or to modify the dynamical behavior of the device itself in order to ensure stability and to absorb and dissipate energy. As many systems exist, we propose here to compare fairly three of them with some practical consideration as stability, stroke, maximum force, or power consumption.

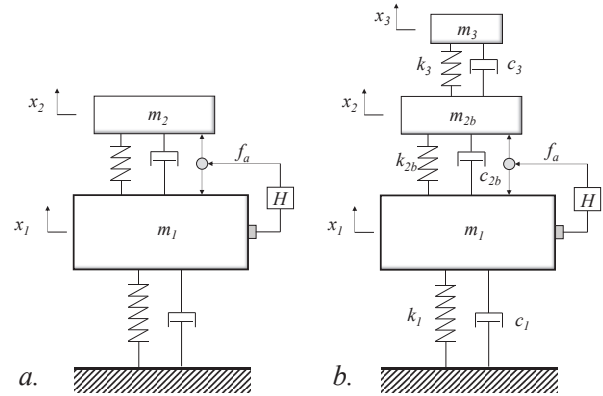


Figure 1. Mechanical model of the hybrid TMD and double hybrid TMD

2. SYSTEMS DESCRIPTIONS

Fig. 1 shows the systems under study, which includes a main oscillator to control with a mass m_1 and a stiffness k_1 and a damper c_1 . Fig 1.a shows the control device using a single TMD. Fig 1.b shows the control device using a double TMD in series. Note the added mass is the same for both system ($m_2 = m_{2b} + m_3$) and it represents 1% of the mass m_1 . In the hybrid version of these systems, a control force f_a is added between two degrees of freedom. A velocity sensor is placed on the main structure and is used to feed control laws $H(s)$ defined in the next part of the paper.

3. DEDICATED CONTROL LAWS

3.1 Dual loop controller

The concept of this dual loop controller, presented in [6], is to combine two control laws using two different inputs. The two loops act in parallel on the same transducer. The first one actively reduces the stiffness k_2 of the TMD in order to increase its stability margins. It uses the relative displacement of the transducer, it can be done with a second collocated voice-coil transducer as in [6] or by using self-sensing technic [9]. The second one introduces the desired damping as a classical AMD would do using the velocity of the main structure. In the Laplace domain the resulting control force can be written:

$$f_a = g_{DL1}(x_2 - x_1) + g_{DL2}\dot{x}_1 \quad (1)$$

3.2 α controller

The α control law is a revisited direct velocity feedback. Two zeros are added to the controller to interact with the poles of the plant and to correct the phase of the open-loop transfer function. This controller has been studied in [tt]. In the Laplace domain, the resulting control force can be written:

$$f_a = g_\alpha \frac{(s + \omega_\alpha)^2}{s^2} \dot{x}_1 \quad (2)$$

Where ω_α is a tuning parameter, usually equal to the resonant frequency of the main structure.

3.3 Hybrid double TMD controller

This news controller use the same principle that the α -controller. But the phase drop of the double TMD open loop transfer function being higher than for a simple one, the order of the control law has to be increased.

$$f_a = g_{\alpha'} \dot{x}_1 \frac{(s + \omega_{\alpha'})^4}{s^2} \quad (3)$$

Where $\omega_{\alpha'}$ is a tuning parameter, usually equal to the resonant frequency of the main structure.

4. PERFORMANCE AND ANALYSIS

4.1 Vibration attenuation

Obviously, the three gains g_{DL} , g_α or $g_{\alpha'}$ are not choosen equal. They are tune in order to reduce by 60% the H2-norm of the response of the structure when a perturbation is applied on the main mass.

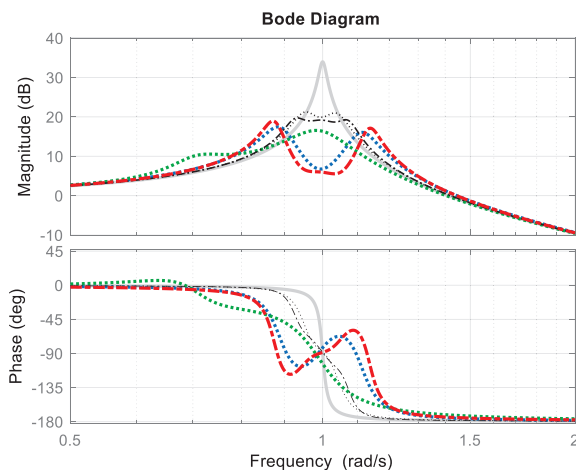


Figure 2. Frequency response function x_1/f_{ext}

The frequency response function x_1/f_{ext} are plotted in fig 2. The continus grey line corresponds to the main structure

alone. The black lines corresponds to the response of the passively controlled system (dotted: single TMD, Dashed-dotted: double-TMD). The green, blue and red lines correspond respectively to the dual loop controller; the α -controller and the hybrid double TMD. Very different behaviors can be observed, depending on the ability of the control law to damp the poles or to reduce the vibration amplitude at the nominal frequency by moving away the initial poles. These analyses are completed by the observation of the root locus.

4.2 Stability

The figure 3 illustrate clearly how each controller behave and explain the resulting FRF. One can observe the hyperstable property of the α -controller and the hybrid double TMD. One can also see the limitation of the dual loop controller in term of gain. For these simulations, the detuning loop has been tune in order to reduce by a factor 2 the stiffness k_2 and to multiple by 2 the damping c_2 .

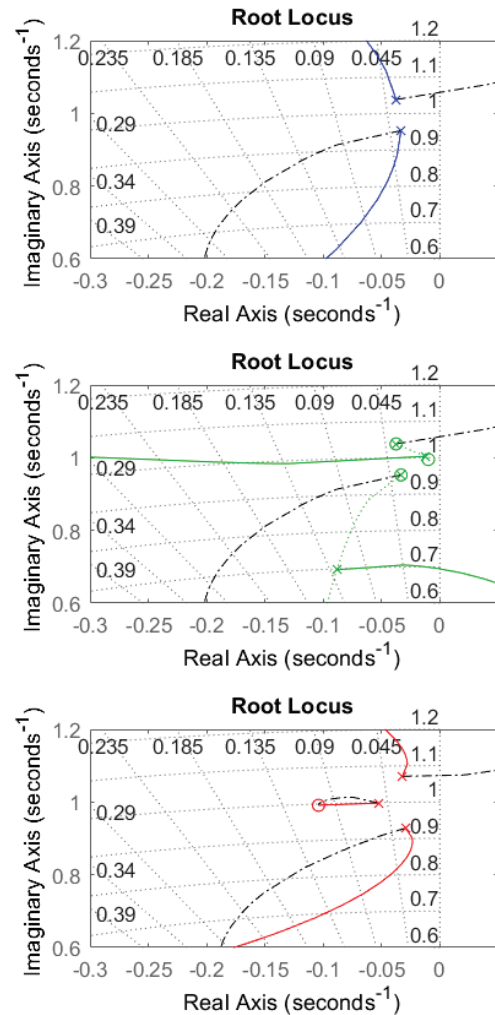


Figure 3. Rootlocii blue: α -controller, green: dual loop controller, red: hybrid double TMD. Black line: Direct velocity feedback.

One understand that the control law can be chosen depending on the perturbation or the main structure, and if

the goal is to introduce damping or to reduce the amplitude o a specific frequency.

4.3 Mechanical and electrical considerations

Hybrid systems presents some practical issues, which have to be considered before experimental validations. The following results are plotted applying a perturbation force with unitary power spectral density.

4.3.1 Stroke

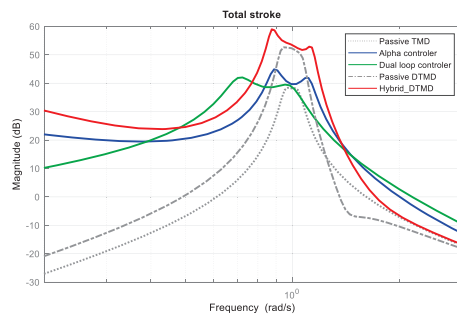


Figure 4. Total stroke of the control device

The figure 4 represents the total stroke of the devices. On can observe one main drawback of this kind of system. The strokes drastically increase versus the ones of passive systems. One can note that at the initial frequency, the strokes are almost the same as the passive systems. The passive behavior of the device is dominating the dissipation mechanism. At low frequencies, the integrators present in some control laws, generate high amplitude displacements that have to be counter using pass filters. Nevertheless, these modifications can generate instability or modify the performance [1]ref.

4.3.2 Active force

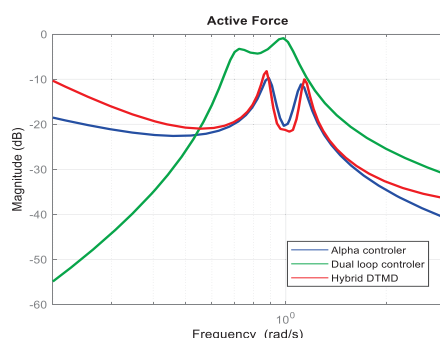


Figure 5. Active Force

Figure 5 shows the active force of the three hybrid devices. Here again, the main drawback of hypersatble control laws is linked to integrators. At very low frequencies, the active forces tend to infinity. High pass filters should be used, slightly altering the stability properties of the controllers. The problem for the dual loop controller is totally

different, in practice the detuning control law necessitate high forces to counter the natural behavior of the TMD.

4.3.3 Total power needed

The total power plotted in figure 6 represents the effective power (usually electrical) that the amplifier of the transducer should be able to deliver. Comparing with the two previous figures, similar observations can be made. Here again, the choice of the controller appears as a tradeoff depending on the perturbation, the damping of main structure and the capacities of the device.

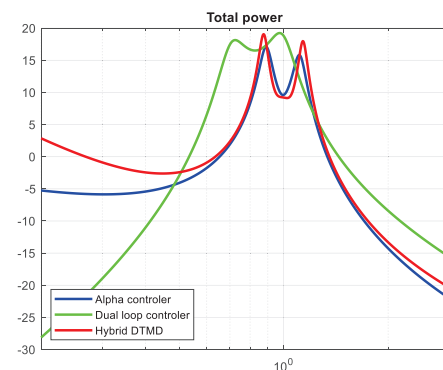


Figure 6. Total Power

5. COMMENTS AND CONCLUSION

Hybrid dampers appeared as a good opportunity to increase performance of classical damper. Depending of the chosen control law, some compromise have to be done. This study illustrates some aspect that have to be consider before the final design of the device. Many others development promising development around hybridization are under studies [8,10], opening the future of these kind of system to non linearities or to modify the system in the electrical domain. Nevertheless, stabilitiy appears as the critical issue for this kind of device.

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