A Survey of Damping in Control of Flexible Structures

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Abstract

This paper surveys the use of active damping in suppressing vibrations of flexible structures, in the sense that various uses of active damping are summarized. In addition, a comparison is made between active and passive damping in a simple configuration. Specifically, the loss factor of a layered damping treatment is compared to that of a piezoelectric sensor/actuator pair. Next, the use of active damping in several slewing control experiments is surveyed and examined. The nature of the interplay between active and passive damping is illustrated in both linear actuators (proof-mass actuator) and rotational actuators (electric motors). Several experiments as well as numerical simulations are used to illustrate the nature of active damping.

I. Introduction

The objective of this work is to encourage those vibration engineers expert in passive damping applications to consider active damping capabilities and limitations and to encourage those experts in active damping methodology to consider the use of passive damping as well. This is accomplished by making a theoretical comparison of the loss factor of a passively damped aluminum beam treated with a layered damping material and that of the same aluminum beam treated with an active piezoelectric feedback control system. This provides an example of an improvement in response performance provided by active damping.

One valid argument against the use of active control is the increased cost and loss of reliability involved in adding actuator and sensor hardware to the structure. In the case of slewing maneuvers however, the control hardware is already present so that active damping is available for "free." Section III of this paper discusses how damping is introduced by the slewing actuator and summarizes the amount of damping available from several reported slewing experiments. Section IV defines the interaction between a linear actuator and damping in the controlled structure and provides a case for the enhancement of active damping by use of passive damping.

II. Active Versus Passive Damping

It is difficult to make comparisons between two approaches in an attempt to decide that one method is better than another. Rather the attempt here is to make a comparison that illustrates that active control can under some circumstances provide larger damping rates than passive damping treatments for relatively the same increase in mass and geometric size. The compassion is made using the well accepted Ross-Kerwin-Unger equations[1] for the loss factor of an unconstrained-layer damping treatment. Let the untreated beam be a 1.22 meter x .028 mm x 3.18 mm piece of aluminum ($E_A = 10.3 \times 10^6$ psi, $\eta = .001$). The expression for the loss factor obtained by adding a layer of LD400 (Lord Corporation) damping material ($E_L = 1.5 \times 10^5$ psi) is computed from

$$\eta_c = \frac{e_2 h_2 (3 + 6\, h_2 + 4h_2^2 + 2e_2 h_2^3 + e_2^2 h_2^4)}{(1 + e_2 h_2)(1 + 4e_2 h_2 + 6e_2 h_2^2 + 4e_2 h_2^3 + e_2^2 h_2^4)}\ (.001) \qquad (1)$$

where $h_2 = H_2/(0.028)$ the ratio of the thickness of the added damping treatment to the thickness of the structure (beam) and $e_2 = E_2/E_A$ the ratio of elastic modulus of the damping treatment to that of the aluminum beam. The composite loss factor η_c is used as the measure of how effective the added damping, either passive or active, is.

The result of adding this passive damping treatment is compared to that of using active control. For the active control system a piezoelectric polymer (PVF_2) is used along with an accelerometer as described by Hubbard[2]. The PVF_2 material is layered on the aluminum beam in the same fashion as the LD400. In addition an accelerometer is placed at the top of the beam to close the feedback loop. Using equation (1) applied to the PVF_2 under velocity feedback control yields higher loss factors for the active system. If the passive and active system are required to have the same thickness, the active loss factor is five times that of the passive case. If the two systems are required to have the same weight then the active system produces a loss factor three times larger then that of the passive system.

This comparison shows a substantial advantage in using active control over using passive control. However, active control still requires a voltage source and computational device. If these are not already available as they are in many spacecraft, then passive damping may be the only available solution. The following two papers (HBB and HBC) present logical mixtures of using passive and active damping. The following sections present some uses of active damping.

III. Damping in Slewing Maneuvers

An example of a situation where active damping can be applied without the need for additional components is in the slewing control of a flexible structure. Such systems usually consist of an electric motor with a beam attached to its shaft (see HBB for an alternative example) as depicted in figure 1. Here a control system actuator (i.e., an electric motor) is already present to provide the pointing motion of the beam. The sensors and motor can also be used to feedback the velocity of the beam at some point and hence, provide increased damping.

The damping added to the structures by the actuator depends upon the motor's torque and generator constants, the motor's electrical resistance, the gear ratio and the structures frequency. The motor back emf is used by the feedback control to provide increased damping.

Many slewing control experiments have been performed. Juang[3] et al illustrates an increase in damping from 2% to 17.5% in the first mode of a steel beam and to 15.57% in the first mode of a slewing solar panel. This increased damping allows the slewing maneuver to be performed faster than without active damping.

A variation of the slewing maneuver is sketched in figure 2. In this case the motor is used as a hinge to connect two beam segments, one of which is cantilevered the other free to rotate. Figure 3 shows the step response of the second mode of the combined beam and motor system. Note that the second mode damping is increased from .04 to .18 as reported by Cudney[4], et at. Unfortunately, the fist mode damping ratio increases very little. The reason for this is that the hinge is close to a node of the first mode of the combined structure and hence has difficulty adding damping to that mode. Hence, it seems plausible that a passive damping material could be used in combination with the active system to enhance the closed loop systems behavior.

Another example of active damping is provided by a proof-mass actuator.[5] This solenoid like device is a self contained space realizable actuator capable of providing velocity feedback at its mounting point. As shown by Zimmerman[5] et al, this actuator increases the damping in a meter long beam from 1% to 9.4% as illustrated in figure 4.

Again, as in the case of the slewing control experiments, situations often arise with feedback control systems that can benefit by the combined use of both active and passive damping. This has been recently discussed by Miller and Crawley[6] for inertial mass or proof-mass actuators.

IV. Conclusions

It is shown that active damping is capable of yielding larger loss factors per same geometric shape and mass than passive damping treatments in some cases. Often both passive and active added damping are needed to provide the best response. The results of several active damping experiments were summarized. There exists a need for more comparisons between active and passive damping as well as for design criteria to be established. Combined design of active and passive damping is encouraged.

V. References

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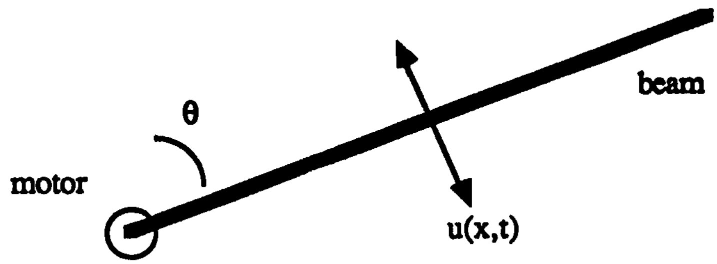


Figure 1. Schematic of a slewing maneuver.

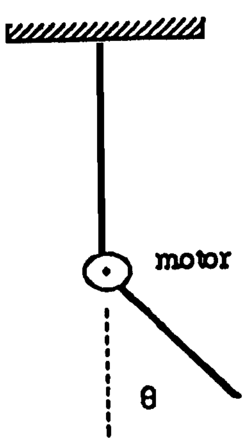
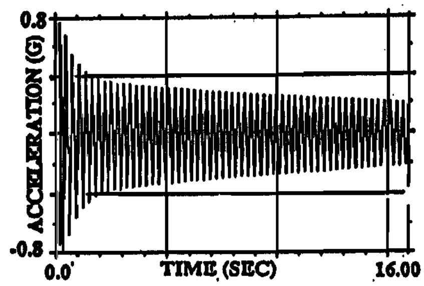


Figure 2. A two beam, or hinged beam slewing control.

o **Uncontrolled Structure**



o **Controlled Structure**

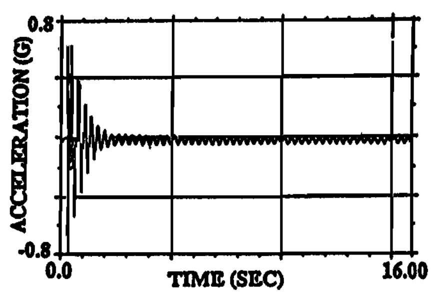


FIGURE 4

Figure 3. Comparison of active damping obtained with proof-mass actuator.

TRANSIENT RESULTS

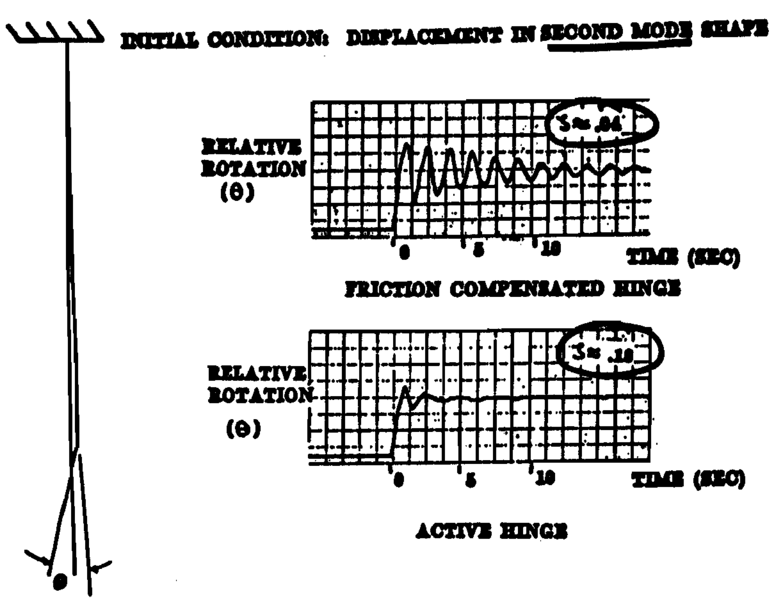


Figure 4. Damping for controlled (bottom) and uncontrolled (top) hinge.