2.004 Lab Project: Tall Building Control **Fall 2013**

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Introduction

Vibrations in tall buildings are dangerous to high-paying clients. In this experiment, we will build a controller to reduce the effect of wind on a model of a skyscraper to make profit from non-seafaring businessmen. Two useful techniques are passive and active damping. Both consist of a large mass placed near the top of the building. In passive damping, the mass alone reduces a great deal of the oscillations caused by wind. With active damping, an actuator moves the mass, and in turn minimizes the vibrations even further.

System Model

We simplified the complex skyscraper into elements whose dynamics are well-known, creating a lumped parameter model of the uncontrolled system. The system consisted of a mass, spring, and damper. Using the model itself (without any added damping) the course staff provided a plot of the system's impulse response. From this, we determined the important coefficients of the uncontrolled system.

Parameters	Mass (kg)	Damping coeff (Ns/m)	Spring constant (N/m)
Building	5.12	0.731	2014

Passive Damping Model

Then the course staff created a passive damping subsystem. This subsystem also consists of a mass-spring-damper system; for this part of the experiment, the damping subsystem is attached in series with the building model, although all measurements assume the building is stationary. We use the impulse response of the damping subsystem to determine its important coefficients.

Parameters	Mass (kg)	Damping coeff (Ns/m)	Spring constant (N/m)
Damper	0.87	8.20	70.43

At this point, we can describe a lumped parameter model of the passively-damped building since we know all the elements' parameters and how they are all attached. That means we can derive the system's transfer function, G, which is described as follows:

$$G(s) = \frac{m_2 s^3 + B_2 s^2 + K_2 s}{m_1 m_2 s^4 + (m_1 + 2m_2)B_1 s^3 + \left((m_1 + m_2)K_2 + m_2 K_1 + B_1 B_2\right)s^2 + (K_1 B_2 + K_2 B_1)s + (K_1 + K_2)}$$

Once the passive-damped system was fully defined, we looked at its impulse response, and compared it to that of the undamped system. We developed the Impulse Response using Simulink. We invoked the 2.004 Building Model Subsystem, defined each necessary parameter, and connected an Impulse (we used the derivative of a step) to the Fwind input. To simulate a passive-damping system, Fact was set to 0. The important output was vm1, which represents the velocity of the building.

As seen in Figure 1, our simulink model behaves in a very similar manner to the experimental set-up.

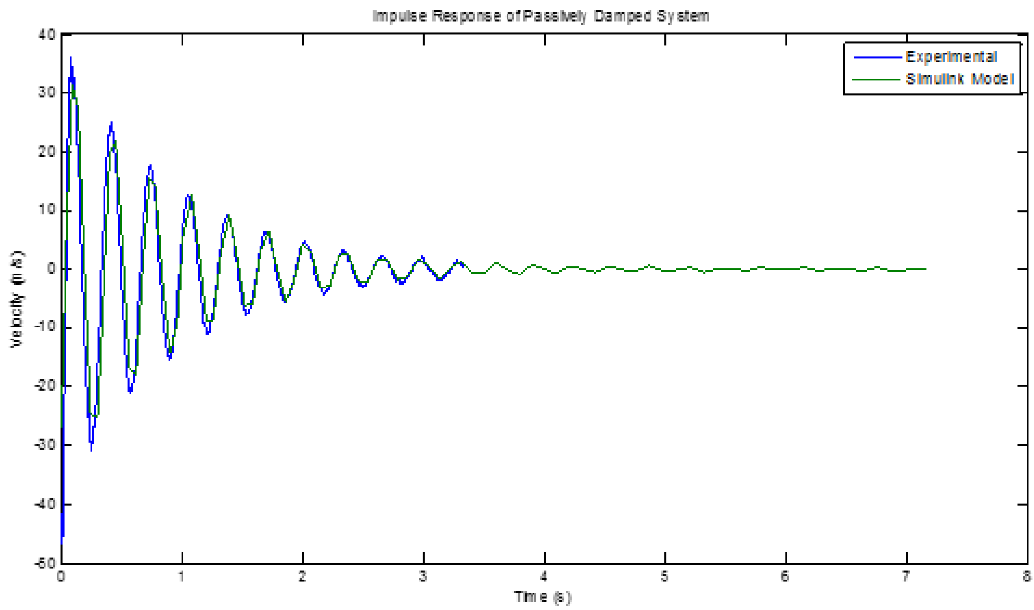

Figure 1: Undamped System Model Simulation vs. Experimental

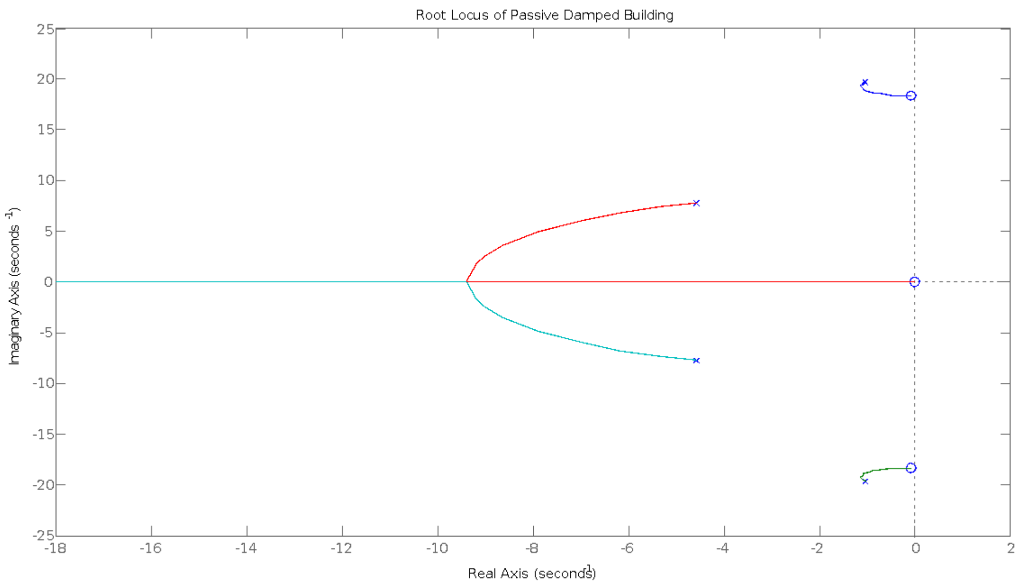

Figure 2: Passive Damped Root Locus

The Root Locus of the passive-damped system in Figure 2. Notice that the Root Locus for the Passive-Damped system is stable for all gain values, since all branches are to the left of the imaginary axis.

Control & Active Damping Model

Passive damping is an open-loop system. We were able to significantly reduce the oscillations and upset stomachs caused by wind simply by adding a passive damper to the building, but we can do even better. We can make measurements as the building moves and drive our damper to make it more useful. This process is known as feedback control, or closing the loop. The three objects we need to add to the system in order to make it closed-loop are: a measurement device for the building subsystem, a measurement device for the damper subsystem, and an actuator to allow for controllable relative velocity between the two subsystems.

Once we add these elements, we designed a gnarly controller, as seen in the Root Locus in Figure 3. We chose a PID controller, since it adjusted the root locus properly.

Ki = 1.6271

Kp = 0.0072

Kd = 0.0000457

The derivative control component is very small compared to the PI part.

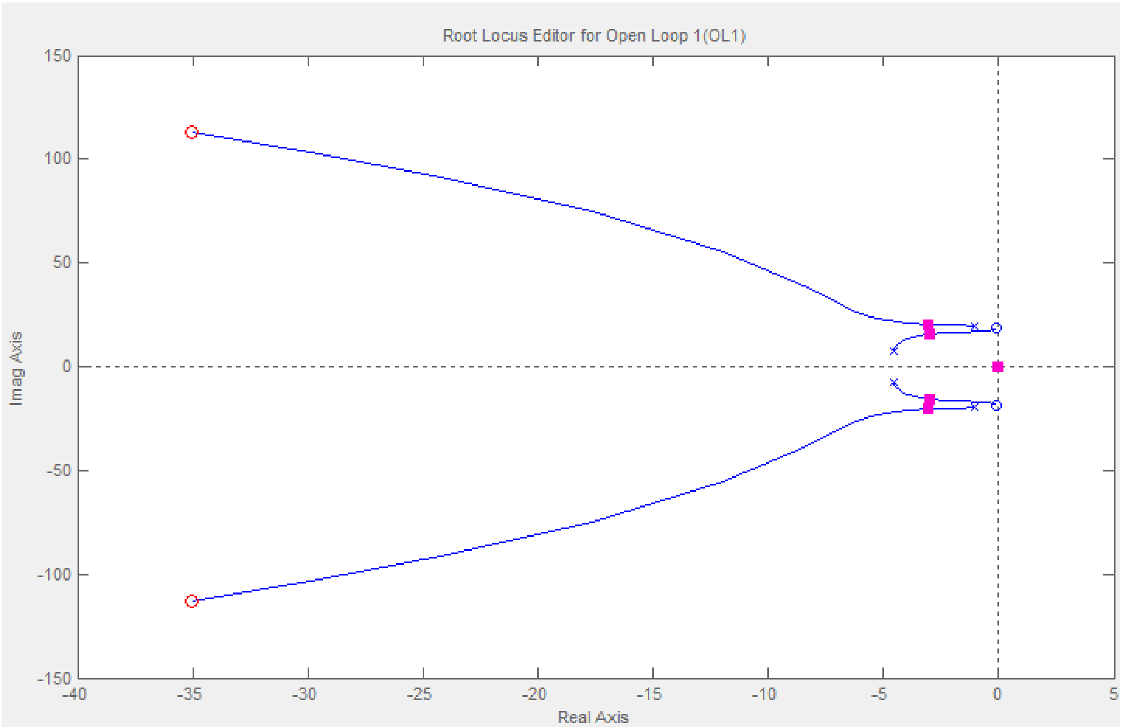

Figure 3: Active Damped Root Locus (PID Control)

Figures 4 and 5 show how the Active Damping system performed much better than Passive Damping in both the simulation and experiment.

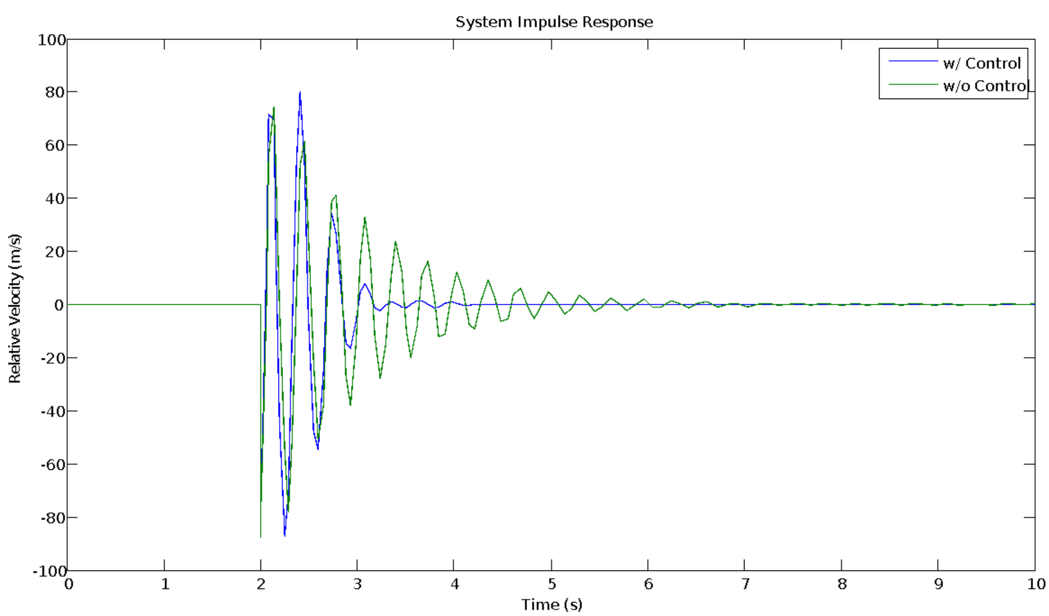

Figure 4: Passive and Active Damped System Simulation

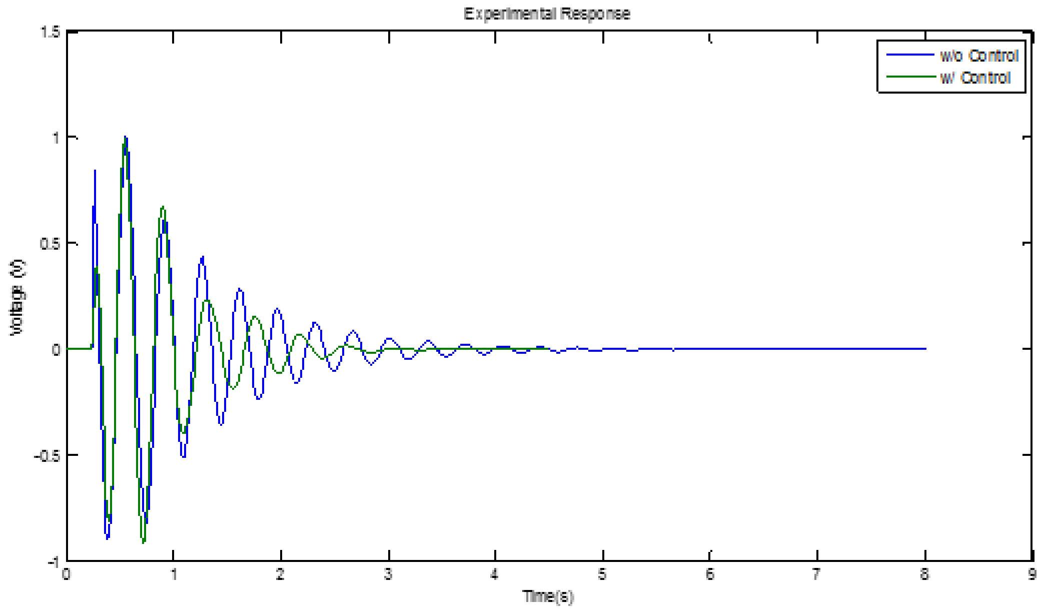

Figure 5: Experiment Comparing Passive vs. Active Damping

Conclusion

The completely undamped system had a settling time of more than 30s. The passive damped system had a settling time of 3.91s, and the active damped system had a settling time of 2.61s. Our system is faster and drastically reduces the number of upset stomachs. Based on market research, the controller will be priced at a lofty $2.5 million. Luckily, rich, non-seafaring real estate developers are prevalent in the current market and are willing to foot the bill.