ECE 5390 Practicum Assignment 5

Dynamic Electromechanical Suspension System Compensation Design

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I. Introduction

Practicum 5 expands on the material of Practicum 4, exploring a linear, translational electromechanical system rather than a solely mechanical system.

The rest of this report is organized as follows. Section 2 analyzes the extremes of such a system, while Section 3 derives the transfer function to derive the best dampening for given inputs. Section 4 concludes on the safety and comfort of each design.

II. Analysis of the Dynamic, Electromechanical Suspension System

The system in question can be seen in **Figure 1**, a mass in an enclosure with a wire fixed to it, passing through a magnetic field fixed to the mass. System parameters include

$$M = 4\,kg$$

$$K_F = 2\,nt/m$$

$$K_B = 1\,v/(\frac{m}{s})$$

The first consideration is an analysis of only the mechanical components of the system in **Figure 1** by treating terminals A and B as an open circuit. The behavior of this system follows the original examples of the system from Practicum 4, with dampening $f_v = 0$. The position of the mass x_2 can be seen in **Figure 2**. This system's short coming is it will not reach steady state and will continue to *just* touch the enclosure.

The second extreme is a short circuit between terminals A and B leading to infinite current, infinite force, and therefore an overdamped system. This response can be seen in **Figure 3**. This system's short coming is the mass will experience the full impact.

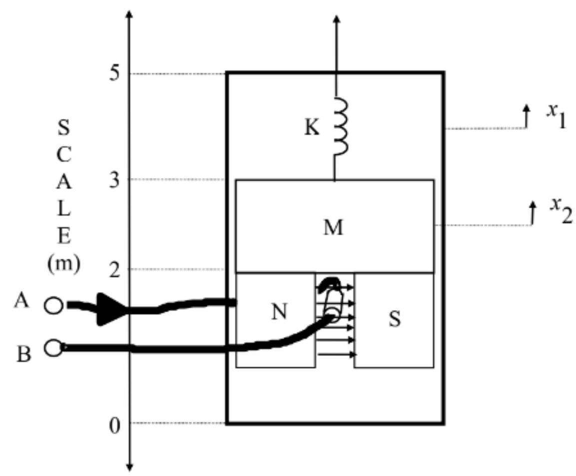

Fig. 1: Electromechanical suspension system

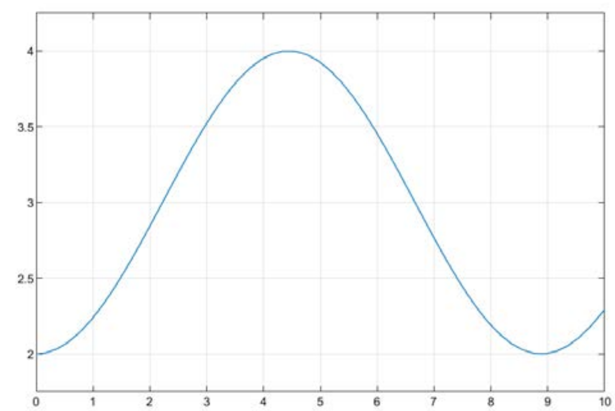

Fig. 2: Response of x2 to u(t) while open circuited

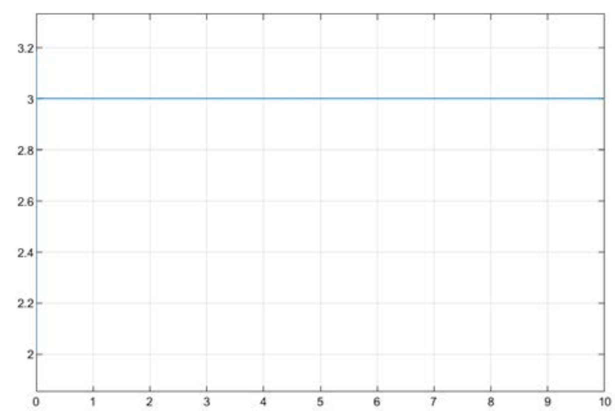

Fig. 3: Response of x_2 to u(t) while short circuited

III. System Design

Deriving the Damping Coefficient

To study the dampening, f_v, as a function of a resistor R connected across terminals A and B, the transfer function is derived as:

$$\frac{X_2(s)}{X_1(s)} = \frac{\frac{K_F K_B}{R}s + K}{Ms^2 + \frac{K_F K_B}{R}s + K}$$

To match the normalized form of a second order unit response $H(s) = \frac{N(s)}{\frac{s^2}{\omega^2}+\frac{s}{\omega Q}+1}$:

$$\frac{X_2(s)}{X_1(s)} = \frac{\frac{K_F K_B}{KR}s + 1}{\frac{Ms^2}{K} + \frac{K_F K_B}{KR}s + 1}$$

The damping coefficient can be found by relating ω values and ζ:

$$\omega^2 = \frac{K}{M}$$

$$Q = \frac{R\sqrt{KM}}{K_F K_B}$$

$$\zeta = f_v = \frac{1}{2Q} = \frac{K_F K_B}{2R\sqrt{KM}}$$

Choosing a spring constant $K = 4\ N/m$,

$$f_v = \frac{2 \cdot 1}{2R\sqrt{4 \cdot 4}} = \frac{1}{4R}$$

Dampening a $1.5u(t)$ Step

Should $x_1(t)$ undergo a step change given by $x_1(t) = 1.5u(t)$, a resistor of value R can be connected across terminals A-B to dampen the response of $x_2(t)$. The model for this system can be seen in **Figure 4** with its corresponding response plot in **Figure 5**. The system can remain open-circuited as this step change is not enough to cause collision between mass and enclosure. However, this would lead to infinite oscillations and so a resistor $R = 0.5\ \Omega$ is attached across terminals A-B to achieve a settling time of 60.3 seconds.

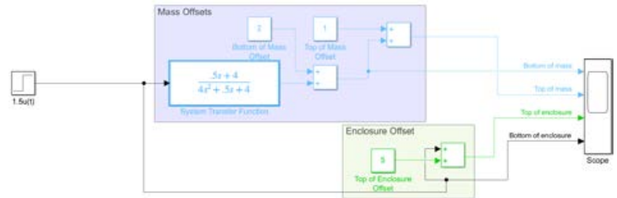

Fig. 4: Step change model

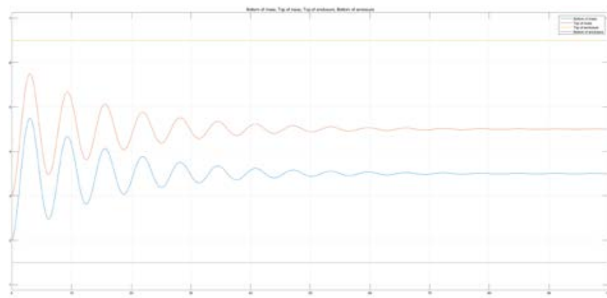

Fig. 5: Top and bottom of mass within top and bottom of the enclosure (1.5u(t) input)

Dampening a $2.5u(t)$ Step

Should $x_1(t)$ undergo a step change given by $x_1(t) = 2.5u(t)$, there would be a collision between the bottom of the enclosure and the bottom of the mass resting at $x_2 = 2\ m$. This cannot be simulated, but it can be seen in **Figure 6** that without dampening the mass would also collide with the top of the enclosure. A resistor $R = 0.417\ \Omega$ achieves minimum negative acceleration, and the top of the mass comes 4-millimeters short of the enclosure.

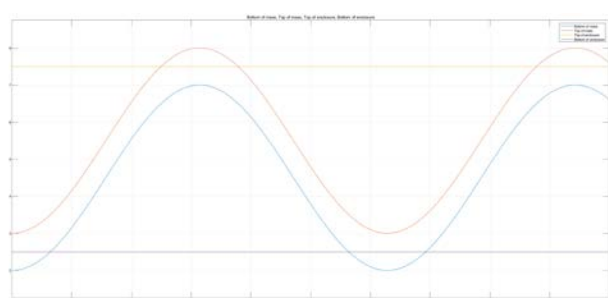

Fig. 6: A 2.5u(t) step change leading to collisions

The response with dampening can be seen in **Figure 7**. This dampening achieves a settling time of 50.8 seconds.

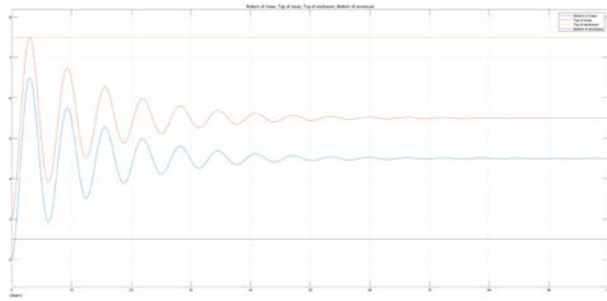

Fig. 7: Top and bottom of mass within top and bottom of the enclosure (2.5u(t) input)

IV. Discussion and Conclusion

Comparing the two designs calls into question their safety and comfort. The first system did not require dampening to avoid collision between the mass and the enclosure. However, it would oscillate infinitely. Minimal dampening was applied for a settling time of 60.3 seconds compared to the 50.8 seconds of the second system. The second system is subject to harsher negative acceleration to achieve a lower time and would be considered a less comfortable ride, should motion sickness not be a problem.

While the first system may be more comfortable purely in terms of acceleration, it is less safe than the second system. System 1 required no dampening for an input of $1.5u(t)$, however collisions would occur at lesser displacements in the position of the enclosure. The second system could withstand larger displacements than the first and is safer.

Considering both settling times are long for a suspension system, the safter system—System 2—would be the optimal choice. Further dampening could even be included.