Fast Steering Mirror (FSM) Design Exercise

David Miller

May 6, 2024

Introduction The purpose of this document is capture the learning process of trying to apply my graduate coursework from UT Austin in modeling, simulation, and control of physical systems to design a FSM. This is a system I am already familiar with through my work as a quality engineer at L3Harris Technologies, SSG, which is why I selected it as a vehicle to reinforce and document some of the concepts from those courses I found useful.

System Overview The FSM system is composed of several key components:

1. Mirror (including any items affixed to the mirror necessary for actuation and position sensing)
2. 2-Axis Hinge
3. Mirror Actuators
4. Mirror Position Sensors
5. Electronic Control Unit

From a mechanical design perspective, there are several key design choices:

1. Hinge type, conventional (gimbal) or flexurized?
2. Actuator type, solenoid or piezoelectric?
3. Position sensors, eddy current, strain gage, ultrasonic?

For the purpose of this exercise, I will be using the design I am familiar with as a starting point, which utilizes a flexurized hinge, solenoid type actuators, and eddy current position sensors. The modeling of this system can be broken into 3 parts:

1. Mirror and Flexure dynamics (Plant)

2. Solenoid-Magnet dynamics (Actuator/Controller)

3. Eddy Current Sensor dynamics (Estimator/Observer)

The mirror and flexure dynamics are relatively straightforward to computed based on the physical dimensions and material properties of the mirror, flexure, and other moving components. The plant can be modeled as a 2nd Order rotational system with mass moment of inertia J, rotational stiffness K, and damping constant B. J and K can be computed as described above, and by assuming a damping ratio $\zeta = .01$, common for metallic structures, B can be computed from J and K. The derivation is shown below for a rotational 2nd Order System:

$$\begin{aligned}
\ddot{\theta} + 2\omega_n\zeta\dot{\theta} + {\omega_n}^2\theta &= 0 \\
J\ddot{\theta} + B\dot{\theta} + K\theta &= 0 \\
\ddot{\theta} + \frac{B}{J}\dot{\theta} + \frac{K}{J}\theta &= 0 \\
\omega_n = \sqrt{\frac{K}{J}} 2\omega_n\zeta &= \frac{B}{J} \\
B &= 2\zeta\sqrt{KJ}
\end{aligned}$$