Title: **Automatic Control II: Modeling and Linearization of a Mag. Lev. System**
Course: **Laboratory Experiments 4 (CSE411)**
Lab No.: **12** ***Category:*** **Automatic Control**
Date: **28/2/2023** ***Due:*** **13/3/2023** ***Time:*** **4 Hours**

Objectives:

1. To study how to build a mathematical model of a non-linear system analytically.
2. To study how to build a mathematical model of a non-linear system in Simulink.
3. To study the concept of an operating point.
4. To understand how linearize a non-linear system around an operating point.

Hardware Requirements:

- ✓ Feedback 33-006 Magnetic Levitation System.
- ✓ PC.

Software Requirement:

- ✓ MATLAB R2018 or higher.
- ✓ Simulink.

Pre-lab:

1. What are the magnetic levitation system applications?
2. What is an operating point? How can you get an operating point for a system?

Part 1: Model Description:

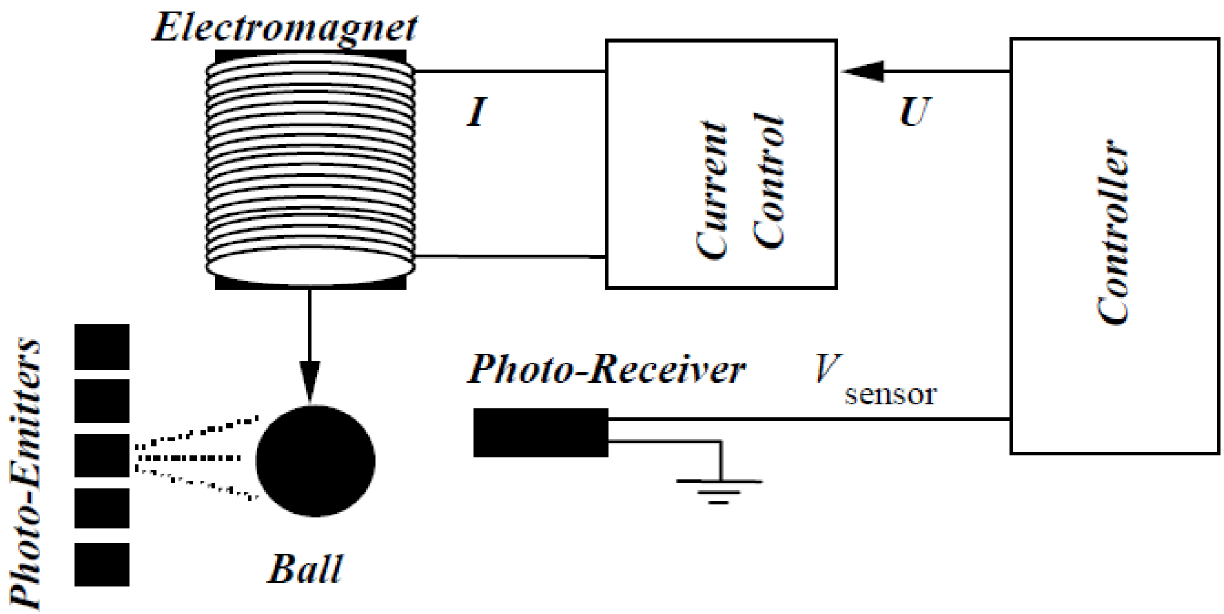

Figure 1 Maglev System Block Diagram

System Parameters:

Core	Iron
Core Diameter	25 mm
Coil Diameter	80 mm
Number of Turns	2850
Resistance	22 Ω
Inductance	227 mH at 1 kHz 442 mH at 120 kHz
Operating Range of Distances	18 mm : 27 mm
Mass of Steel Ball	0.021 Kg

Part 2: Analytical Modeling:

1. The ball is affected by two opposite forces: weight and magnetic forces.

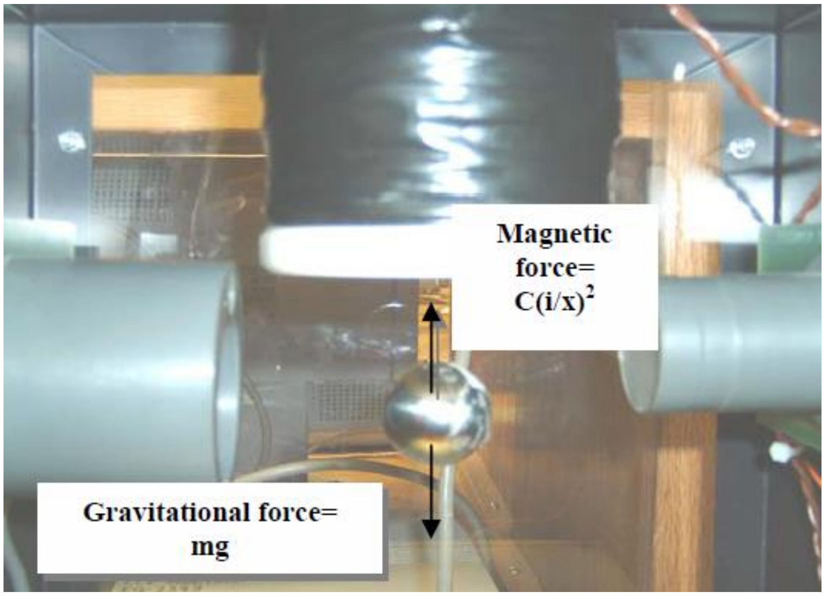

Figure 2 Forces affecting the steel ball

2. The system can be described by the following differential equation:

$$m.\ddot{x} = m.g - k.\left(\frac{i}{x}\right)^2$$

$where,$
$x: ball\ dispalcement$
$m: ball\ mass$
$g: gravity\ acceleration$
$i: current\ through\ coil$

3. k is the coil constant and can be computed by:

$$k = m.g.\frac{x_0^2}{i_0^2}$$

4. The voltage interface circuit can be described by the following equation:

$$i = 0.15U + i_0$$

5. The output voltage of the photo led sensor for position is modeled by:

$$V = -450.3(x - x_0)$$

Part 3: Simulink Model of Mag. Lev. System:

Build a Simulink model for the mag. lev. system using analytical derived model.

Part 4: Analytical Linearization:

1. The system is described by the following differential equation:

$$\ddot{x} = g - \frac{k}{m}.\left(\frac{i}{x}\right)^2$$

2. Compute an equilibrium point:

$$g = f(x,i) = \frac{k}{m}\left(\frac{i}{x}\right)^2 \Rightarrow i_0 = 0.8, x_0 = 0.0225$$

3. Using Taylor series approximation:

$$\ddot{x} = -\left(\frac{\partial f(x,i)}{\partial i}\bigg|_{x_0,i_0}.\Delta i + \frac{\partial f(x,i)}{\partial x}\bigg|_{x_0,i_0}.\Delta x\right)$$

4. Using Laplace Transform to get the transfer function:

$$s^2.\Delta x = -(K_i.\Delta i + K_x \Delta x)$$

$$\frac{\Delta x}{\Delta i} = -\frac{K_i}{s^2 + K_x}$$

$where,$

$$K_i = \frac{2g}{i_0}$$

$$K_x = \frac{-2g}{x_0}$$

Part 5: Linearization Using Simulink Linearization Tool (MATLAB 2020 or higher):

1. Run: Simulink → Apps → Model Linearizer → Linear Analysis.
2. Compute an operating point using: Operating Point → Trim Model with the following configurations:

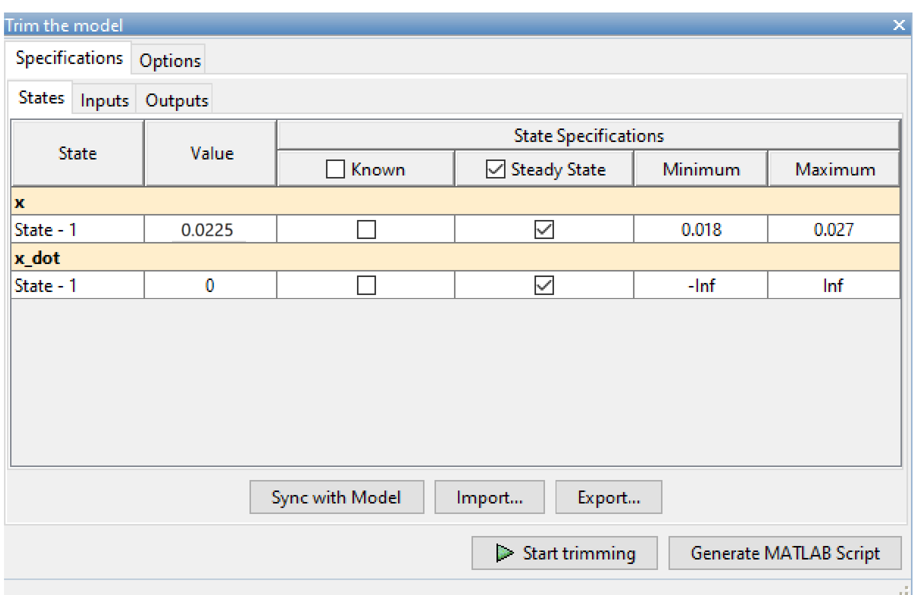

Figure 3 States Configurations

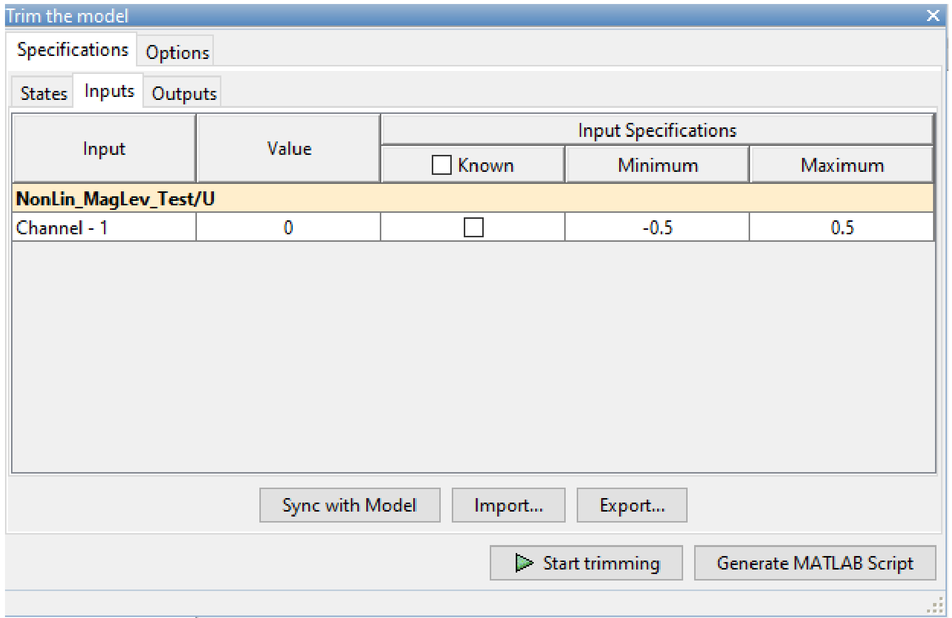

Figure 4 Inputs Configurations

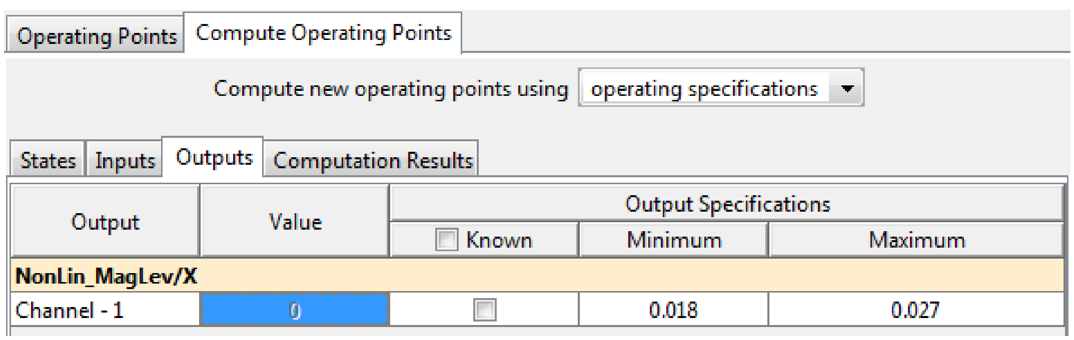

Figure 5 Outputs Configurations

3. Use the computed operating point to start a linearization task (Check I/O first)

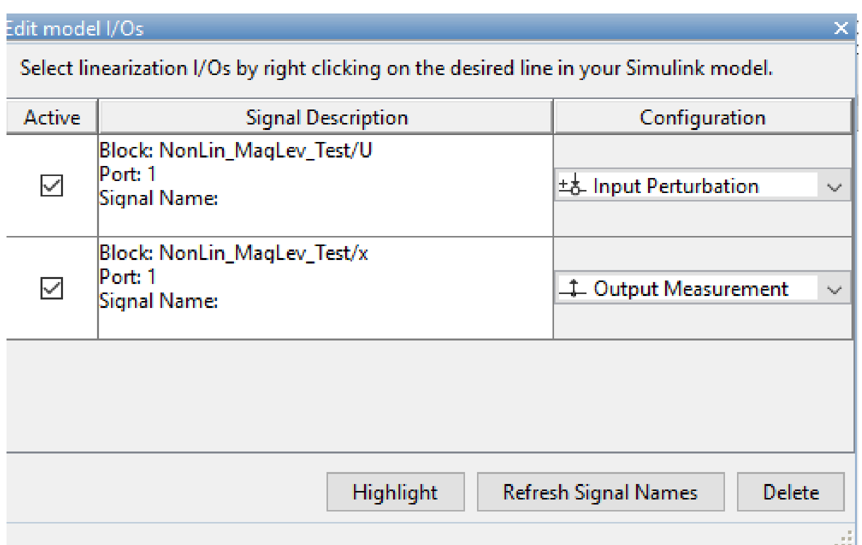

Figure 6 I/O Configurations for Linearization

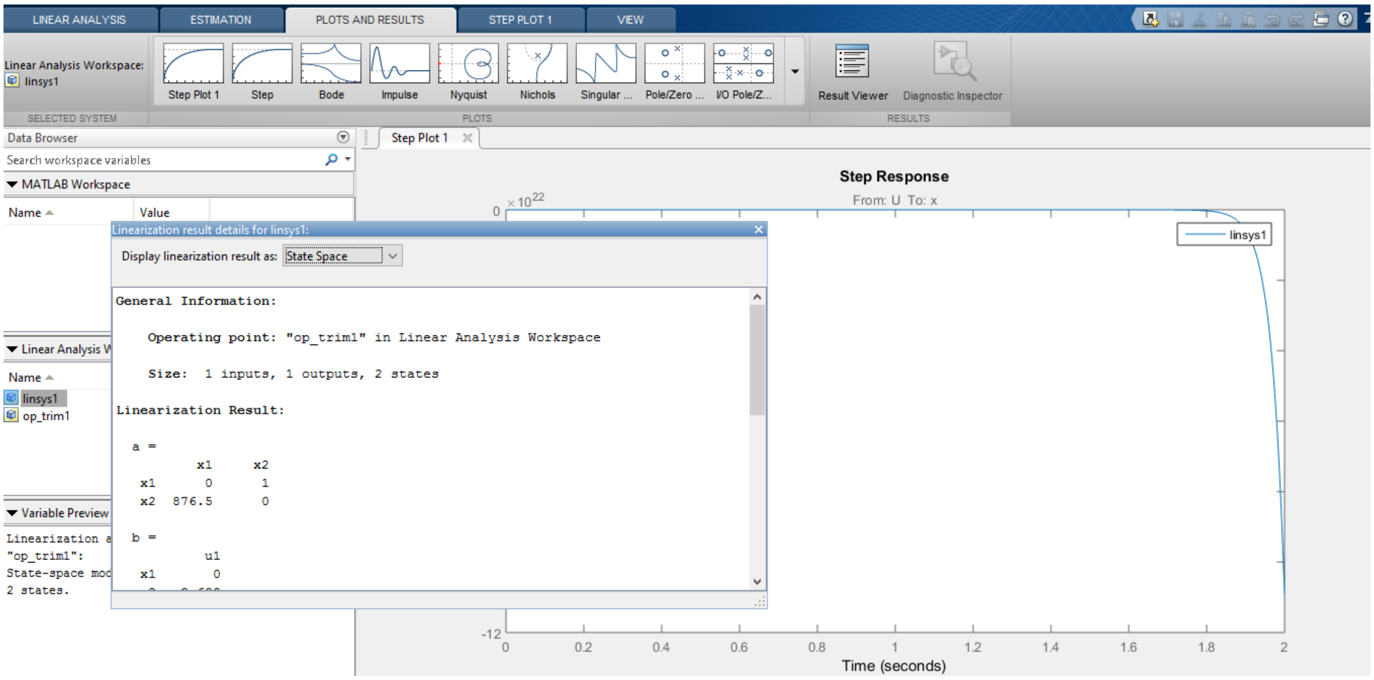

Figure 7 Linearization Results

On-Lab Assignment:

1. Implement nonlinear model and linearize the model using Simulink.

Technical References:

1. *Magnetic Levitation System; Getting Started: 33-006.* Feedback Instruments.
2. *Magnetic Levitation Control Experiments 33-942S.* Feedback Instruments.
3. *Modeling and Control of a Magnetic Levitation System*. Marwan K. Abbadi and Winfred Anakwa.