Closed Loop Magnetic Levitation Control of a Rotary Inductrack System

Functional Requirements List and Performance Specifications

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Introduction:

Fig. 5 shows the Halbach array and the inductrack system developed by senior ECE students in previous years. The system currently functions in open-loop mode, but the initial step is to make the system operate using closed-loop control.The next goal of this project is to choose a microcontroller that will allow the system to control levitation height with a standalone system. An FPGA board will be the controller used for closed loop system. The motor is currently driven by a direct voltage input, but the primary goal of this project is to drive the motor using a PWM signal to control the motor's velocity, thereby controlling the levitation height directly from the microcontroller. If all these tasks are completed the safety enclosure will be improved, and the FPGA will be mounted on a PCB.

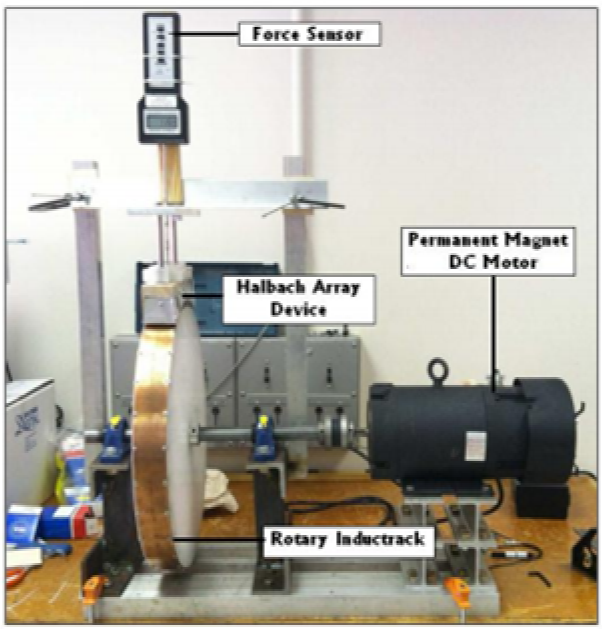

Fig. 5. Laboratory Model of Halbach Array Magnetic Levitation

After deciding on a platform for implementing the controller, the next goal is to select and add a speed sensor which will send inductrack velocity to the controller.

System Block Diagrams:

This project will take the previously created Halbach array magnetic levitation system and add a controller to make the system a closed-loop control system. The primary focus of the project will be to choose a platform and design a controller that can process a user's input, and convert it into a PWM signal to drive the motor of the Maglev system. The overall system will look like the block diagram in Fig. 6.

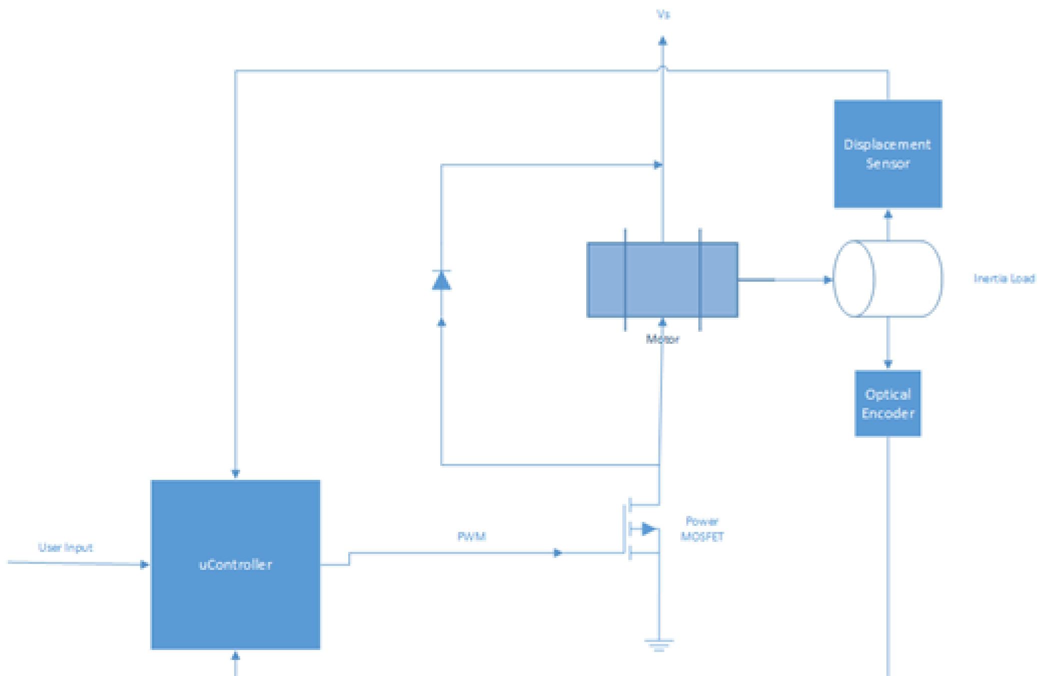

Fig. 6 HIGH LEVEL BLOCK DIAGRAM OF MLS

The controller design will use a lookup table and a classical digital control law to generate the PWM signal required to drive the motor. Classical digital control law design uses root locus and bode methods instead of state variable feedback control theory. The initial input will be entered in millimeters and then converted to the desired velocity. Separately, an optical encoder will produce a frequency which will be converted to velocity. The controller will then generate the PWM signal based on the velocity error found by subtracting the current velocity from the desired velocity. This process is shown in Fig. 7

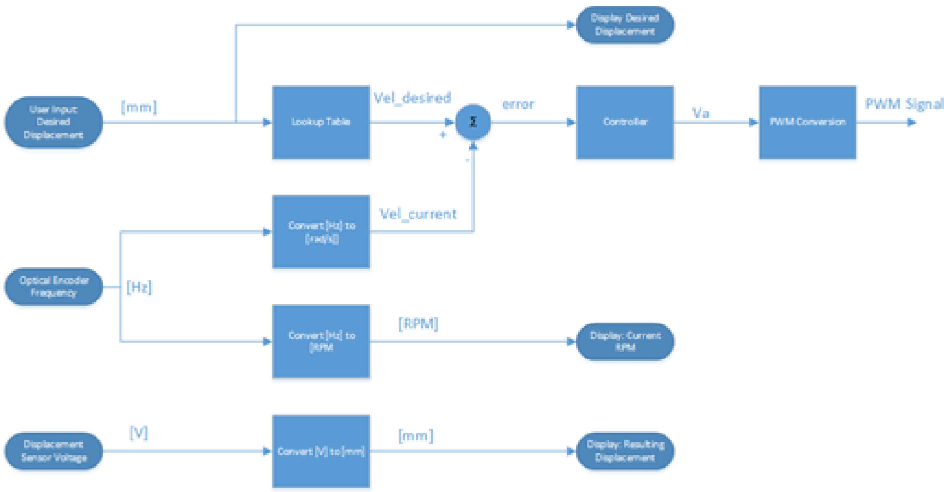

Fig. 7 BLOCK DIAGRAM OF CONTROLLER

Modeling and Controller Design:

The following transfer function converts input voltage to motor radial velocity was determined experimentally by the previous groups who worked on the magnetic levitation system.

$$C(s) = 75.71\frac{s+1.56}{s(s+76.92)} \qquad (1)$$

The previous group also designed a continuous time controller using Matlab.

$$G(s) = 109.09\frac{1}{s^2+92.62s+69.25} \qquad (2)$$

The open loop system and closed loop systems are simulated in Figure 8 below. Figure 9 shows the simulation results from the simulink model ran in Figure 8.

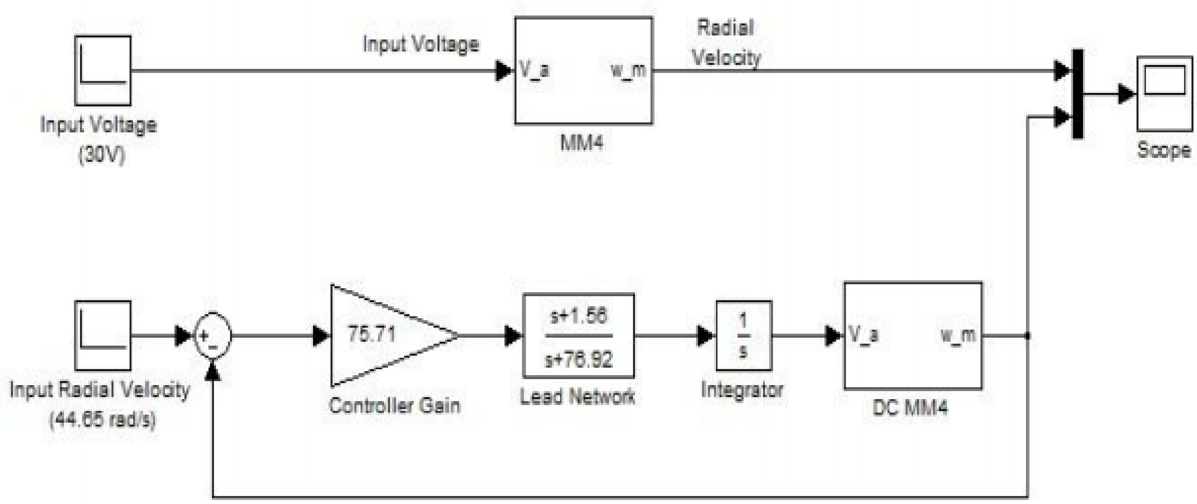

Fig. 8 OPEN AND CLOSED LOOP SYSTEM

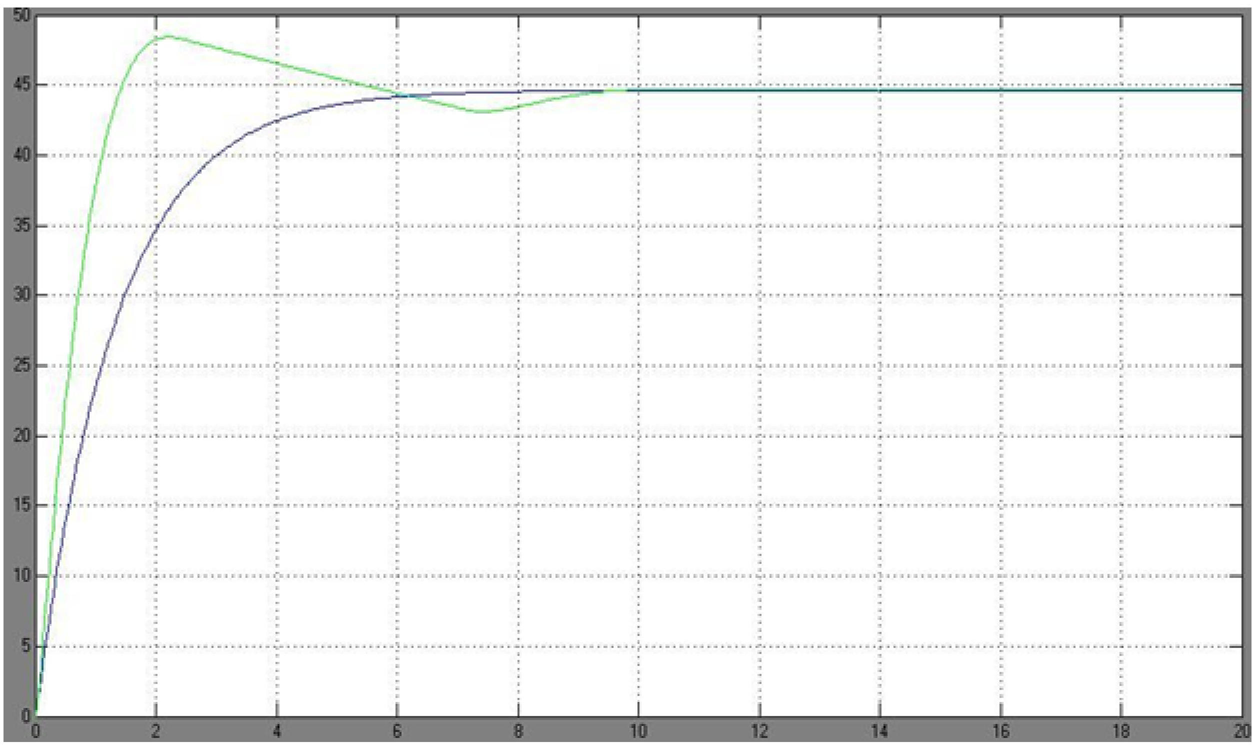

Fig. 9 SIMULATION RESULTS FOR FIGURE 8

The curve that overshoots 45 and then comes back down is the open loop response. The curve that goes right up to 45 is the closed loop response.

Digital Controller:

The continuous time controller was converted to a discrete time controller using the "C2D" function in MATLAB using sampling interval of 10ms. The discrete controller transfer function can be written as:

$$C(z) = \frac{0.5453 - 0.5369z^{-1}}{1 - 1.463z^{-1} + 0.4634z^{-2}}$$

(3)

This transfer function was re-written in the form of a difference equation to allow implementation on the microcontroller.

$$y(k) - 1.463\,y(k-1) - 0.4634\,y(k-2) = 0.5453\,x(k) - 0.5369\,x(k-1) \quad (4)$$

Functional Requirements and Performance Specifications:

Microcontroller Design:

- The microcontroller selected is a Spartan 3E FPGA board.
- The ADC chip has enough resolution to handle changes of .0002v in displacement sensor voltage.
- The microcontroller shall accept input for desired levitation height.
- The microcontroller shall digitally implement the controller model.
- The microcontroller shall sample displacement every 50 ms.
- The microcontroller shall calculate PWM control signal within 1 ms.

Controller Design Specifications:

- The maximum overshoot of the system shall be less than 10%.
- The steady state error shall be less than 0.02 mm.
- The settling time shall be less than 6s.

Displacement Sensor Specifications

- The MTL002n3000b5c Linear Position Transducer shall be used to measure displacement produced by the Halbach array model.

- The range shall be 0-7 mm.
- The sensor shall produce a voltage that is linearly related to displacement and accurate to within 0.1%.
- The sensor shall have infinite resolution.

Optical Encoder:

- The EE-SG3 Omron optical encoder shall be used to measure the angular velocity of the system.
- The optical encoder shall read the system at a rate of 4 cycles per rotation.
- The PWM frequency shall be 1 kHz

Power Electronics:

- Gate Drive from microcontroller to mosfet.
- mosfet to motor.
- protective circuit.
- supply voltage of 90v to the motor.

References

[1] Kyle Gavelek, Victor Panek, Christopher Smith. Senior Project. “Closed Loop Control of Halbach Array Magnetic Levitation System Height”. Final Report, May 2013.

[2] Dirk DeDecker, Jesse VanIseghem. Senior Project. “Development of a Halback Array Magnetic Levitation System”. Final Report, May 2012.

[3] Glenn Zomchek. Senior Project. “Redesign of a Rotary Inductrack for Magnetic Levitation Train Demonstration”. Final Report, May 2007.

[4] Paul Friend. Senior Project. Magnetic Levitation Technology 1. Final Report, May 2004.

[5] Post, Richard F., Ryutov, Dmitri D., “The Inductrack Approach to Magnetic Levitation,” Lawrence Livermore National Laboratory.