Closed Loop Control of Halbach Array Magnetic Levitation System Height (CLCML)

Functional List and Performance Requirements

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Introduction:

The initial goal of the project will be to fabricate a safe and stable environment for the system to be used. A Lexon enclosure will be designed as a protective barrier around the rotary inductrack. The primary goal of the project will be implementation of the closed loop control system that regulates the motor speed to control the magnetic levitation system height. The closed loop will be implemented by adding a microcontroller that uses the displacement sensor to read vertical displacement and adjust the motor's rotational velocity.

System Block Diagram:

The primary goal of the project will be implementation of this closed loop control system. The closed loop system will compare the desired levitation height with the measured levitation height and determine the necessary change to motor speed to achieve the desired levitation height. This change in motor rotational velocity will result in a change in the vertical component of magnetic force levitating the Halbach array. The overall system block diagram is shown in Figure 2.

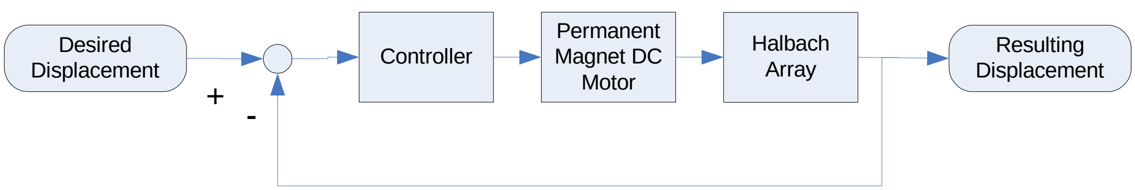

Fig. 2. High Level Overall System Block Diagram

An accurate model of the motor shall be experimentally determined for use in closed loop control design. The Dayton Permanent Magnet DC Motor model subsystem is shown in Figure 3.

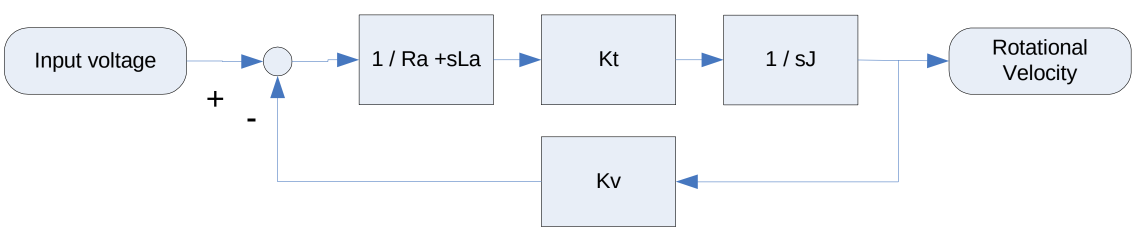

Fig. 3. Dayton Permanent Magnet DC Motor Model

A subsystem for the Halbach array model shall be modeled by the governing equations. Dr. Post and Dr. Ryutov [4] demonstrated that the magnetic force experienced by the device corresponding to lift force is given by equation (1):

$$\langle F_y \rangle = B_0^2 w/2kL*[\ 1/(1+(R/\omega L)^2)]*e^{-2k*y} \quad (1)$$

where $\omega = k*v$, v is the tangential velocity of the inductrack. Mr. DeDecker and Mr. VanIseghem [1] found their inductrack and Halbach array to have the following properties:

$$\mathbf{B_0 = 0.8060\ Tesla}$$
$$\mathbf{L = 7.532 \times 10^{-8}\ H}$$
$$\mathbf{R = 1.9 \times 10^{-5}\ \Omega}$$
$$\mathbf{k = 224.4}$$
$$\mathbf{w = 0.034\ m}$$

The model simplifies to the following relationship:

$$\mathbf{F(\omega) = 653.4*[\ \omega^2/(\omega^2+3.349x10^9)]*e^{-448.8*y}} \qquad (2)$$

where y is the current displacement. The output vertical force can be shown to cause displacement through the equation (3).

$$\mathbf{F = ma} \qquad (3)$$

This relationship shall be used to determine displacement. A control block diagram that model all of these relationship shall be determine. It shall accept the motor's rotational velocity as the input and output vertical displacement as shown in Figure 4.

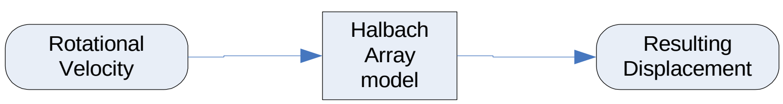

Fig. 4. Halbach Array Subsystem

The final susbsystem is the controller plant which shall be cascaded with the other two plants.

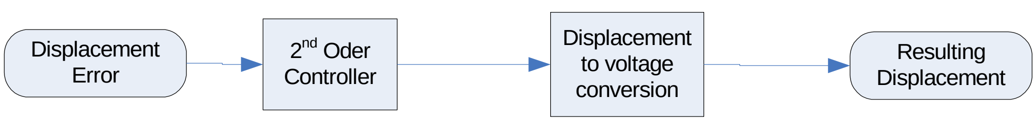

Fig. 5. Controller Subsystem

After the closed loop control has been successfully implemented and performs within the desired specifications, we shall begin research in an effort to fabricate a linear track and new Halbach array for linear motion.

Functional Requirements:

Safety Enclosure Requirements

- The enclosure shall enclose the front and back, sides and top of the rotary track in Lexon.
- The enclosure shall have a cutout for the rotor.
- The enclosure shall be stable enough to withstand the impact of a loose Halbach array device (465 grams) propelled at a velocity of 20 m/s

Motor Specifications:

The Dayton Permanent Magnet DC motor Model 42226A shall be used to rotate the inductrack.

- The motor shall have 1.5 horsepower.
- The motor shall be rated at 2500 RPM.

Displacement Sensor Specifications

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

- The sensor shall produce voltage that is linearly related to displacement accurate to within 0.1%.
- The sensor shall have infinite resolution.

Force Sensor Specifications

The Digital Force Gauge Model 475040 shall be used to measure the force produced by the Halbach array model.

- The gauge shall have a range up to 49 Newtons.
- The gauge shall have a resolution of 0.01 N.
- The gauge shall have an accuracy of +/- 0.4%.

Motor Model and Halbach Array Model

- The motor model shall predict rotational velocity accurate within +/- 5%.
- The Halbach array model shall predict vertical displacement accurate within +/- 5%.

Controller Design Specifications:

The second order controller shall be used to improve the system in following ways:

- The maximum overshoot of the system shall be <10%.
- The steady state error shall be less than 0.02 cm.
- The rise time shall be minimized.
- The settling time shall be less than 50 ms.

Microcontroller Design

- 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 calculated control signal within 1 ms.

Linear Track Design

- The linear track shall accommodate linear motion of the Halbach array until break velocity is reached.
- The linear track shall be designed to minimize break velocity.
- The linear track shall be designed to minimize leakage flux and eddy currents.

References:

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

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

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

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

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

[6] Post, Richard F., Sam Gurol, and Bob Baldi. "The General Atomics Low Speed Urban Maglev Technology Development Program." Lawrence Livermore National Laboratory and General Atomics.