Design of Disturbance Rejection Controllers for a Magnetic Suspension System

Functional Description
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Introduction

One of the interesting aspects regarding control theory is the fact that there exist multiple methods of design to satisfy performance goals. Similar to most control techniques, the method being applied in this case relies heavily on detailed mathematical models of the plant. The method of choice for this project is the Internal Model Principle, which was developed by B.A. Francis and W.M. Wonham.

The theory behind Internal Model Principle is that the controller is required to augment poles onto a desired transfer function. When a disturbance becomes present in a system, the model, having already accounted for this disturbance before it ever arrived in the system, will completely reject the disturbance signal and leave the system output unchanged. With detailed knowledge of the plant and an understanding of advanced mathematics, feed-forward and feed-back loops can be created to pass reference signals and reject disturbances. More information will be presented on the principle after further research.

The goal of this project is to design multiple controllers to reject a variety of disturbance classes such as step, ramp and sinusoidal functions. The controllers will be compiled using Real-Time workshop in Simulink and ran on an xPC Target box. The
controllers on the xPC Target box will be mathematical models of the transfer functions. An additional feature of the project will be to have disturbance recognition hardware or software to select which controller is used in the disturbance rejection process.

Figure 1 - High-level Overall System Block Diagram

Figure 1 shows the high-level block diagram for the overall system. Each of the three subsystems shown has unique duties.

Host PC using Simulink and xPC software

The PC uses the Real-Time Workshop to compile C-code modeling the Simulink block diagrams and transfer functions. The controller models are then uploaded to the xPC Target Box using an Ethernet connection.

xPC Target Box with Controllers on board

The xPC Target box holds the mathematical controller models which will be used to stabilize and ultimately control the Magnetic Suspension System. The xPC Target Box is then controlled by the host via Ethernet, which dictates run/stop functionality and also forces data transfer back to the host. The xPC has built in analog to digital and digital to analog converters, which allow data to be sampled from the Magnetic Suspension System as well as allowing control signals to be applied to the system.
Magnetic Suspension System

The Magnetic Suspension System uses a magnetic field to suspend a hollow metal ball. There are two initial inputs to the system, which are a set point and a reference input. The set point serves the purpose of giving the system a known location at which the ball should be stabilized. The reference signal is used when the ball is going to be tracking the specific input signal. An input sinusoidal reference waveform, for example, will cause the ball to move in a sinusoidal motion matching the input waveform. The third input to the system is a disturbance, which will be rejected by the controller in the xPC Target Box.

There are two outputs of this system as well. The position signal and the ball position signal. The output of the Magnetic Suspension System is a physical position of the ball. There is a photo sensor that converts the ball position to a voltage signal, which becomes the second output of the system. The second output of the system is the position signal.

![Control Block Diagram](image_url)

**Figure 2 - Control Block Diagram**

Figure 2 represents the control block diagram for the system. The inputs and outputs of the system combine to form an error signal, which is now clearly composed of the reference, set point, and the position signal. This error signal then enters the xPC Target
Box, which is acting as the controller, and generates a correction plant control signal. The correction signal is then combined with the disturbance and fed to the Magnetic Suspension System, which is acting as the plant.

In figure 3, the Magnetic Suspension System Driver Model is shown more clearly. The \( u \) signal across the Coil Driver Circuit is actually \( u \) from the controller combine with the disturbance signal, assuming that there is one. The Coil Driver Circuit converts the voltage to a current, which in turn generates a magnetic field around the Electromagnet. This magnetic field is what attracts and ultimately suspends the ball at equilibrium. The current sensor is a one ohm resistor in series with the Electromagnet Coil. Having the current sensor at this location allows experimental data to be taken to verify accuracy.
Figure 4 - Ball Position Sensor

Figure 4 shows the method by which the ball position is determined. As the ball passes through the photo emitter’s path of radiation, it breaks the light that the photo detector should be seeing. This detector converts the broken beam into a voltage representative of the position of the ball.