MAGNETIC LEVITATION SYSTEM: MODELING AND CONTROL

MOHD SHASRUL SYAFIQ BIN MOHAMAD SHARIP

This report is submitted in partial fulfillment of the requirement for the Degree of Bachelor in Mechanical Engineering (Design and Innovation)

Faculty of Mechanical Engineering
University Technical Malaysia Melaka

APRIL 2009

I/we admit that have read

This report and to my/our opinion this report

Fulfill in terms of scope and quality for the Bachelor of Mechanical Engineering

(Design and Innovation)

SIGNATURE :

NAME OF SUPERVISOR :

DATE :

SIGNATURE :

NAME OF SUPERVISOR :

DATE :

"I hereby declare that this project report is written by me and my own effort and that no part has been plagiarized without citation"

Signature :
Name of Writer : Mohd Shasrul Syafiq Bin Mohamad Sharip
Date : 9 April 2008

ACKNOWLEDGEMENT

Syukur alhamdullilah and thanks to Allah s.w.t for giving me the opportunity to complete this PSM I & II research project. I would like to appreciate my gratitude to my supervisor, Mr Zairulazha bin Zainal who helped and guided me through the completion of PSM I & II. He has given me a lot of help while doing the research and corrected me when I make a mistake.

Not to forget, my appreciation to my friends and family for the help and support and also to others who directly or indirectly involved in this PSM I &II research project.

ABSTRACT

Magnetic levitation system is used to levitate object by using attraction force or repulsive force between magnetic force and ferromagnetic material. The levitation of an object is possible using a control system to help stabilize the magnetic force. This report discussed on modeling and control of the magnetic levitation system. The discussion is made to gain better understanding of the behavior of the magnetic levitation system. The selection of PID controller and fuzzy logic is to identify the best solution for the magnetic levitation system or either there is a difference from using one or another. The research explained step by step on finding the result. The modeling is done to find the transfer function of the system. Then the suitable controllers are design. The final block diagram is then analyzes and stimulate to see the result.

ABSTRAK

Sistem apungan magnetik digunakan untuk mengapungkan sesuatu benda dengan menggunakan daya tarikan atau daya tolakan antara medan magnet dan bahan feromagnet. Untuk mengapungkan sebuah objek memerlukan satu sistem kawalan bagi membantu memantapkan daya magnet. Kajian ini dilakukan untuk melihat model dan kawalan sistem apungan magnetik. Kajian ini dibuat untuk mendapatkan pemahaman lebih baik berhubung dengan tingkah laku sistem apungan magnetik. Pemilihan pengawal PID (*PID Controller*) adalah untuk mengenalpasti penyelesaian terbaik untuk sistem apungan magnetik atau sama ada penggunaan kawalan tersebut mempunyai perbezaan atau persamaan. Kajian ini menjelaskan setiap langkah yang diammbil sehingga tamat kajian. Model matemaik di cari bagi membolehkan system tersebut berfungsi. Kemudian alat-alat kawalan yang sesuai dihasilkan. Akhirnya analisis dan simulasi dijalankan untuk melihat hasilnya.

TABLE OF CONTENT

CHAPTER		CONTENT	PAGE
		DECLARATION	**I**
		ACKNOWLEDGEMENT	**ii**
		ABSTRACT	**iii**
		ABSTRAK	**iv**
		TABLE OF CONTENT	**v**
		LIST OF TABLES	**ix**
		LIST OF FIGURES	**X**
		LIST OF SYMBOLS	**xiii**
		LIST OF APPENDICES	**xiv**
CHAPTER 1		**INTRODUTION**	**1**
	1.1	Background	1
	1.2	Objective	2
	1.3	Scope	2
	1.4	Problem statement	2
	1.5	Report Outline	3
CHAPTER 2		**LITERATURE REVIEW**	**4**
	2.1	Introduction	4
	2.2	Definition	4
	2.3	How Its Work	5
	2.4	Method to Make a Magnetic Levitation System	5
	2.4.1	Servo-stabilized Electromagnetic Suspension (EMS)	5

	2.4.2	Electrodynamic Suspension (EDS)	6
	2.4.3	Inductrack.	7
	2.5	Usage of Magnetic Levitation	8
	2.6	Control System	9
	2.7	Type of Controller Used	10
	2.7.1	PID Controller	10
	2.7.2	Fuzzy Logic	12
CHAPTER 3		**METHODOLOGY**	**13**
	3.1	Introduction	13
	3.2	Research Methodology Flowchart	14
	3.3	Research of Parameters of Levitation System	16
	3.4	Mathematical Model	17
	3.5	Design Process Model	17
	3.6	Design Magnetic levitation System Without Controller in Simulink Matlab	19
	3.6.1	Signal Generator Block	19
	3.6.2	Constant Block	19
	3.6.3	PS Add Block	20
	3.6.4	Inport Block	20
	3.6.5	Outport Block	21
	3.6.6	Scope Block	22
	3.6.7	Saturation Block	22
	3.6.8	Transfer Fcn Block	23
	3.6.9	Subsystem Block	24
	3.6.10	Sum Block	25
	3.6.11	Gain Block	26
	3.6.12	Demux Block	26

	3.7	Analysis The Open Loop Transfer Function, G(s)	27
	3.8	Designing Controller	27
	3.8.1	PID Controller	28
	3.9	Analysis and Simulation Complete System using Matlab	30
	3.10	Comparing Result	30
	3.9	Conclusion	31
CHAPTER 4		**MODELING AND CONTROL**	**32**
	4.1	Mathematical Modeling	32
	4.2	Magnetic Levitation Process Model	37
	4.2.1	Magnetic Levitation Process Model without controller	37
	4.2.2	Magnetic Levitation Process Model with PID Controller	41
CHAPTER 5		**ANALYSIS AND DISCUSSION**	**45**
	5.1	Magnetic Levitation Without Controller	45
	5.2	Magnetic Levitation with PID Controller	47
	5.2.1	With $K_p = 1$, $K_i = 10$, $K_d = 0.03$	47
	5.2.2	With $K_p = 1$, $K_i = 10$, $K_d = 0.1$	49
	5.2.3	With $K_p = 1$, $K_i = 10$, $K_d = 0.7$	50
	5.3	Comparison Between Magnetic Levitation System without Controller and Magnetic Levitation System With Controller Using Matlab Command.	51
	5.3.1	Step Response	51

	5.3.2	Root Locus	53
	5.3.3	Bode Diagram	55
CHAPTER 6		**CONCLUSION**	**56**
	6.1	Conclusion	56
	6.2	Recommendation	57
		REFERENCES	58
		BIBLIOGRAPHY	59
		APPENDICES	61

LIST OF TABLE

BIL	CONTENT	PAGE
3.3	Parameters of the magnetic levitation system	16
3.18	Effects of each of controllers Kp, Kd, and Ki on a closed-loop system	29

LIST OF FIGURES

BIL	CONTENT	PAGE
2.1	Example of electromagnetic suspension (EMS)	6
2.2	Transrapid Shanghai Maglev, transit train that used magnetic levitation technology	8
2.3	Maglev wind turbine	9
3.1	Flow chart of the project methodology	14
3.2	Flow chart of the Complete research methodology	15
3.4	Block diagram transformation (a) multiply rule and (b) addition rule (c) feedback rule	17
3.5	Signal Generator Block	19
3.6	Constant Block	19
3.7	PS Add Block	20
3.8	Inport Block	20
3.9	Outport Block	21
3.10	Scope Block	22
3.11	Saturation Block	22
3.12	Transfer Fcn Block	23
3.13	Subsystem Block	24
3.14	Sum Block	25
3.15	Gain Block	26
3.16	Demux Block	26

3.17	Basic block diagram for PID controller	28
4.1	Magnetic Levitation Diagram	31
4.2	Mathematical diagram	32
4.3	Step 1 of simplify magnetic levitation system diagram	38
4.4	Step 2 of simplify magnetic levitation system diagram	38
4.5	Step 3 of simplify magnetic levitation system diagram	39
4.6	Last step of simplify magnetic levitation system diagram	39
4.7	Magnetic levitation linear model	40
4.8	Complete magnetic levitation system model without controller	41
4.9	Simple magnetic levitation block diagram with PID controller	41
4.10	Parallel model of PID controller diagram	42
4.11	Complete magnetic levitation system model with PID controller	43
4.12	Magnetic levitation linear model with PID control	43
5.1	Graph taken before saturation for system without controller	45
5.2	Position of ball in the system	46
5.3	Graph taken before saturation for system with controller	47
5.4	Final result for ball position using PID controller	48
5.5	Graph taken before saturation for system with controller	49
5.6	Final result for ball position using PID	49

	controller	
5.7	Graph taken before saturation for system with controller	50
5.8	Final result for ball position using PID controller	50
5.9	Step response be between Magnetic levitation system without controller (blue) and magnetic levitation system with controller (green)	51
5.10	Root locus of magnetic levitation without controller	53
5.11	Root locus for magnetic levitation with PID controller	54
5.12	Bode diagram	55

LIST OF SYMBOLS

EMS	Electromagnetic suspension
EDS	Electrodynamics suspension
PID	Proportional-Integral-Derivative Controller
PI	Proportional-Integral Controller
PD	Proportional-Derivative Controller
P	Proportional Controller
I	Integral Controller
K_p	Proportional Gain
K_i	Integral Gain
K_d	Derivative Gain
X_0	the reference distance of the proper levitation system
m	The weight of the ball
R	the coil resistance
L	the inductance without the ball
β	sensor gain
I_0	the current of the electromagnetic coil when the ball is at X_0
$i(t)$	Current
$G(s)$	Open loop transfer function

LIST OF APPENDIXES

BIL	CONTENT	PAGE
A	Matlab Command Code	59
B	Gant Chart for the Projek Sarjana Muda PSM1	60
C	Gant Chart for the Projek Sarjana Muda PSM II	61

CHAPTER 1

INTRODUCTION

1.0 Background

Magnetic levitation system is a method to levitate object by using electromagnetic force only. The force from the magnetic field counteract with the gravitational force which make the object float. Magnetic levitation is not a new thing in engineering in fact Robert Goddard and Emile Bachelet in (1990's) is the earliest people that seen the theory of magnetic levitation. They envision coming up with frictionless transportation system using repulsive forces generated by alternating current. But the system is put on hold because it uses too much power for conventional conductors.

Nowadays the system is not a mere theory anymore but magnetic levitation system is highly used in high speed train like Shanghai Transrapid maglev, JR-Maglev by Japan Railways Group, Linimo (Tobu Kyuryo Line, Japan) and Southwest Jiaotong University, China.

Magnetic levitation system usually used a control system because the levitation with magnetic force alone is not stable. There are a lot of controllers that can be used with the magnetic levitation system. Thus, this is a suitable medium that can be used to understand the concept of feedback controller.

1.1 Objective

- To studies the control system of magnetic levitation system
- To investigate the suitable control system for magnetic levitation system
- To analyze and simulates the control system of magnetic levitation system using Matlab
- To see the differential between the result for system without controller and with controller

1.2 Scope

This report will explain the modeling and control of a magnetic levitation system. The report includes selecting the suitable controller for the magnetic levitation system and determination of the mathematical model for the controller. It also includes the analyzing and simulating a result achieve through Matlab.

1.3 Problem Statement

Magnetic levitation system has open up a new step towards the world transportation system. A lot of investor race to achieve better vehicle that not only fast but safe for human. Thus it is best to investigate personally the properties of the system. Other than that it will be great to learn about controller system trough studying the magnetic levitation system.

1.5 Report Outline

For this report of “projek sarjana muda”, it will consist of 6 chapters which the first chapter is all about the introduction on the report. The introduction contains background of the project, problem statement, the aim of the project, the objectives and scopes of the project and finally the outline of the report itself.

The second chapter of the report is the literature review of the project which is divided into several more chapters. The first literature review starts with some introduction of magnetic levitation. Then it continues with selection of controller and Matlab review.

The third chapter of this report is the methodology where it describes the methods that are used for this project. It describes all the processes involved from the first step until the final steps for the development of the research.

The fourth chapter is the mathematical modeling of the controller for the magnetic levitation system. This chapter explains the detail mathematical equation to obtain the best controller and the controller design.

The fifth chapter is the analysis and discussion where the result of analysis for controller design is shown. The controller is design using Matlab and analyze.

Finally the final chapter for this “projek sarjana muda” is the conclusion and recommendation for the research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter will cover topics such as definition, function, method to produce magnetic levitation. It also will explain about the control system, and controller used. The information in this chapter is mainly gathered from journals in the internet and research book.

2.2 Definition

According to Sci-Tech Encyclopedia, magnetic levitation system is a method of supporting and transporting objects or vehicles which is based on the physical property that the force between two magnetized bodies is inversely proportional to their distance. A stable and contactless suspension between a magnet (magnetic body) and a fixed guide way (magnetized body) is obtained using magnetic force that frequently compensates the gravitational force to stabilize and make it float. By using this principle, vehicle weight more than 40 tons can be levitate by generating a controlled magnetic force.

2.3 How Its Work

A magnetic force that can counteract a gravitational force is needed to levitate an object. But only metal or ferromagnetic material can be levitate so a metal usually attached to the object to levitate it. One important thing about magnetic force is that the force acting on an object in any combination of gravitational, electrostatic, and magnet static fields will make the object's position unstable. However there are methods to prevail the problem. It can be done by the usage of electronic stabilizer or diamagnetic materials.

2.4 Method to Make a Magnetic Levitation System

An object cannot levitate by itself There are several ways to levitate an object. Among them are servo-stabilized electromagnetic suspension (EMS), electrodynamic suspension (EDS), and Inductrack.

2.4.1 Servo-stabilized Electromagnetic Suspension (EMS)

The attraction between magnet will increase if the distance decrease and decrease if they faraway. These make the levitation force unstable. To make it stable, the opposed is required so variation from a stable position should push it back to the target position. Constant magnetic levitation can be accomplish by measuring the position and speed of the object being levitated, and using a feedback loop to continuously adjusting one or more electromagnets to correct its motion, thus forming a servomechanism.

EMS happens when there are attractive forces between electromagnets and a ferromagnetic guideway. The electromagnet use magnetic attraction to pull the object upwards against gravity that gives some inherent lateral stability, but some use a combination of magnetic attraction and magnetic repulsion to push upwards.

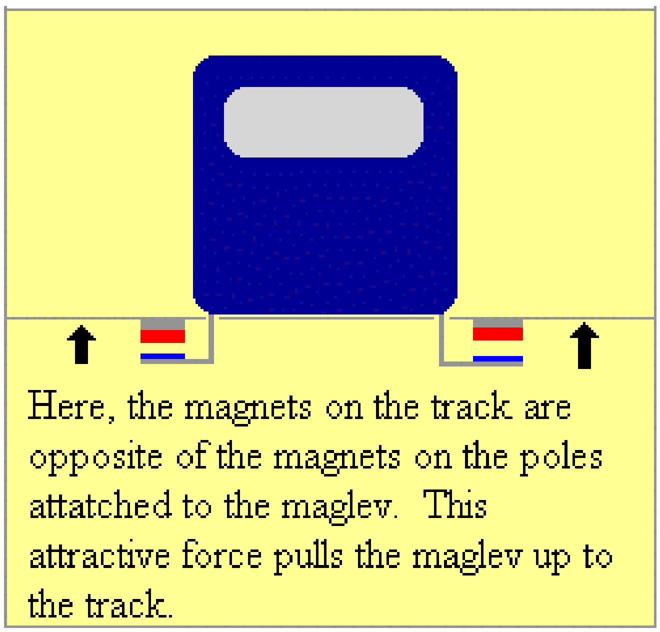

Figure 2.1: example of electromagnetic suspension (EMS)
(Source: http://www.mrfizzix.com/maglev/ems.htm)

2.4.2 Electrodynamics Suspension (EDS)

In the electrodynamics suspension system, the object is lift by the magnetic forces that act on the object and the base. The magnetic field is produced by either electromagnets or by an array of permanent magnets. The repulsive force in the system is created by an induced magnetic field in wires or other conducting strips in the track. EDS cannot occur at static it need some speed to gain the dynamic force. At slow speeds, the current induced in these coils and the resultant magnetic flux is not large enough to support heavy weight object. For this reason the object must have wheels or some other form of landing gear to support the object until it reaches a speed that can sustain levitation.

Propulsion coils on the base are used to exert a force on the magnets in the object and make the object move forward. The propulsion coils that exert a force on the object are effectively a linear motor: An alternating current flowing through the coils generates a continuously varying magnetic field that moves forward along the track. The frequency of the alternating current is synchronized to match the speed of the train. The offset between the field exerted by magnets on the train and the applied field create a force moving the train forward.

Since the electromagnetic field is developed as the vehicle moves, the flux produced by the onboard coils induces currents produce a magnetic sheets on the guideway. As a result, the induced currents produce a magnetic flux that opposes the magnetic flux of the onboard electromagnet, producing repulsive forces between the object and the guideway. Since the repulsive forces are produce as the object move above the passive coil on the guideway, the vehicles cannot be lifted unless a certain speed is achieve and therefore the electrodynamics suspension system requires

2.4.3 Inductrack.

Inductrack is a completely passive, fail-safe magnetic levitation system, using only unpowered loops of wire in the track and permanent magnets (arranged into Halbach arrays) on the vehicle to achieve magnetic levitation. The track can be in one of two configurations, a "ladder track" and a "laminated track". The ladder track is made of unpowered Litz wire cables, and the laminated track is made out of stacked copper or aluminum sheets.

2.5 Usage of Magnetic Levitation

Magnetic levitation system has been used a lot in transportation system normally in train. Nowadays a lot of high speed trains are made from the magnetic levitation system principle. Using this principle the friction between the train and the guideways are no longer there thus this will help the train move faster. This principle used in train only and not other vehicle because the magnetic levitation system need a guideway to operate and since road for cars are too vast it is quite impossible to bear the cost. Other than that, high speed train is safer than high speed cars. Train only functional on its track while car functional near people and building which can cause serious accident with wrong maneuver. Some examples of train using the magnetic levitation system are Shanghai Transrapid maglev, JR-Maglev by Japan Railways Group, Linimo (Tobu Kyuryo Line, Japan) and Southwest Jiaotong University, China.

Figure 2.2: Transrapid Shanghai Maglev, transit train that used magnetic levitation technology (Source: http://en.wikipedia.org/wiki/Magnetic_levitation_train)