CONTROLLER DESIGN BASED ON Q-PARAMETERIZATION METHOD

HUSSEIN SULEIMAN MOHAMED

A project report submitted in partial fulfillment
of the requirements for the award of the degree
of Master Engineering
(Electrical-Mechatronic and Automatic Control)

Faculty of Electrical Engineering
Universiti Teknologi Malaysia

MAY 2007

DEDICATIONS

“*To all my beloved family: Father, Mother, Brothers and Sisters”*

ACKNOWLEDGEMENTS

First of all, gratefulness of thanks to our creator,” ALLAH” S.W.T for this continuous blessing, which make this work neither the first nor the last.

This dissertation is the culmination of my entire formal education, starting with primary school when I was six years old, and I extend my appreciation to all the teachers and other individuals who helped me along the way.

My upmost gratitude and especial “thank you” to, Associate *Professor Dr. Mohamed Noh Bin Ahmad* for giving this opportunity to work under his supervision and for sharing his great knowledge and experience with me. Also for his guidance, help and oversight throughout my project.

I thank and send my deep appreciations to my family “parents and brothers and sisters for their love and support all their blessings had made it possible for me to face all the challenges. I would like to express a special “thank you “goes to my friend Salah Ramadan for his support and stand beside me when I was need help in all time.

I would like to express my appreciation and convey my deepest gratitude to Mr. Abdul Rashid Husain for his guidance to complete this research. Appreciation is also extend to all people who gave the author heartfelt corporation and shared their knowledge and for giving some their valuable time.

ABSTRACT

This project presents the application of a robust controller design based on " Q-parameterization" theory (some time referred to as "Youla parameterization") for on a Magnetic suspension balance beam system. This controller is used in order to achieve both robust stability and good dynamic performance against the variation of system parameters. In the Q-parameterization method, the set of all stabilizing controllers of magnetic suspension balance beam system (MSBB) is characterized by a free parameter Q. This free parameter is chosen to using optimization technique to satisfy robust stability and other design requirements. The work was carried out in three stages. First, it starts with the derivation of the mathematical model of a magnetic suspension balance beam system (MSBB) in state space form. Second, the proposed Q-parameterization controller design methodology is presented. It should be noted that the degree of the resulting controller usually equals the degree of the plant plus the degree of the Q-parameter can be chosen to obtain a lower or higher order controller. Finally, the performance of the Q- parameterization controller in controlling the balance beam control system will be illustrated. For comparison purposes, the simulation of the pole placement and integral controllers were also carried out. Simulation results show the effectiveness of the proposed controller.

ABSTRAK

Projek ini melibatkan applikasi pengawal *robust* berasaskan teori parameter-Q (dikenali juga sebagai parameter Youle) keatas sebuah loji *Magnetic Suspension Balance Beam* (MSBB). Pengawal ini direkabentuk untuk mencapai kestabilan *robust* disamping prestasi yang baik terhadap perubahan parameter sistem. Rekabentuk pengawal untuk sistem MSBB menggunakan kaedah parameter-Q ditentukon oleh parameter bebas Q. Parameter bebas Q ini dipilih untuk memenuhi keperluan kestabilan *robust* dan keperluan rekaan yang lain. Kerja penyelidikan ini melibatkan tiga tahap keria. Didalam tahap pertama, model matematik dalam format kaedaan-ruang untuk sebuah system MSBB akan dijalankan dahulu. Pada tahap kedua, metodologi rekabentuk pengawal parameter-Q yang dicadangkan akan dibentangkan. Perlu diingat bahawa tertib pengawal (kebiasaannya menyamai tertib loji bersta terib parameter-Q) boleh dipilih samada untuk mendapatkan tertib pengawal yang lebih rendah atau lebih tinggi. Pada tahap akhir, presetasi pengawal parameter-Q yang dicadangkan didalam mengawal sistem MSBB akan dibentangkan. Untuk tujuan perbandingan, penyelakuan menggunakan pengawal perletakan kutub beserta kawalan kamiran juga akan dibentangkan. Keputusan simulasi membuktikan keberkesanan pengawal yang dicadangkan.

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	DECLARATION	ii
	DEDICATION	iii
	ACKNOWLEDGEMENT	iv
	ABSTRACT	v
	ABSTRAK	vi
	CONTENTS	vii
	LIST OF TABLES	xi
	LIST OF FIGURES	xii
	LIST OF SYMBOLS	xvii
	LIST OF ABBREVIATIONS	xix
I	**INTRODUCTION**	1
	1.1 Introduction	1
	1.2 Objective	3
	1.3 Scope of Project	3
	1.4 Research Methodology	4
	1.5 Layout of Thesis	5
II	**LITERATURE REVIEW**	7
	2.1 The magnetically suspended balance beam System	7
	2.2 the Q-parameterization Controller	9

III	**MAGNETICALLY SUSPENDED BALANCE BEAM SYSTEM**	13
	3.1 Introduction	13
	3.2 Mathematical Model of Magnetically Suspended Balance Beam system	14
	3.3 State-space Model	19
	3.4 Linearized Model	21
	3.5 Simulation diagram for the model MSBB system	21
	3.6 Summary	23
IV	**POLE PLACEMENT CONTROLLER DESIGN**	24
	4.1 Introduction	24
	4.2 Pole Placement Technique without Integral Control	24
	4.2.1 Pole Placement Technique without integral to control the MSBB System	25
	4.3 Pole Placement Technique with Integral Control	29
	4.3.1 Pole Placement Technique with integral to Control the MSBB System	31
	4.4 Computer Simulation Using MATLAB/SIMULINK	34
	4.4.1 Pole Placement Technique without integral to control the linear MSBB System	34
	4.4.2 Pole Placement Technique without integral to control the nonlinear MSBB System	36
	4.4.3 Pole Placement Technique with integral to Control the MSBB System	38
	4.5 Summary	40

V	**The Q-PARAMETERIZATION CONTROLLER DESIGN**	41
	5.1 Introduction	41
	5.2 The Q-parameterization Theory	42
	5.3 Controller objective	43
	5.4 Controller synthesis	43
	5.5 Design of the proposed controller using Q-parameterization theory	47
	5.6 Computer Simulation Using *MATLAB/SIMULINK*	58
	5.6.1 Computer Simulation Using *MATLAB/ SIMULINK* for Linear of the MSBB System	58
	5.6.2 Computer Simulation Using *MATLAB/ SIMULINK* for nonlinear of The MSBB System	60
	5.7 Summary	62
VI	**SIMULATION RESULTS AND DISCUSSION**	63
	6.1 Introduction	63
	6.2 Results for linear model of MSBB System	64
	6.3 Results for nonlinear model of MSBB System	68
	6.4 Comparison between Various Results	71
	6.4.1 Simulation of linear and nonlinear models of the MSBB System	71
	6.4.1.1 The Q-parameterization controller	71
	6.4.1.2 Pole placement state feedback controller	73
	6.4.2 Comparison between Pole Placement technique and Q-parameterization controller	74
	6.4.2.1 Simulation using linear model of the MSBB System	74

	6.4.2.2 Simulation using nonlinear model of the MSBB System	76
	6.4.3 Comparison between pole placement technique and Q-parameterization Controller for linear and nonlinear of the MSBB System	78
	6.5 Results for the MSBB System by suing the pole Placement with integral Control	80
	6.6 Comparison between pole placement with integral and Q-parameterization Controller for the MSBB System	82
	6.6.1 Linear model of the MSBB System	82
	6.6.2 Nonlinear model of the MSBB System	84
	6.7 Summary	88
VII	**CONCLUSIONS AND SUGGESTIONS**	89
	7.1 Conclusions	89
	7.2 Suggestions for Future work	91
REFERENCES		92

LIST OF TABLES

TABLE NO	TITLE	PAGE
3.1	Balance beam parameter	14
6.1	Description for design specification and poles	63
6.2	Comparison of various cases between pole placement technique and Q-parameterization controller	76
6.3	Comparison between pole placement technique and Q-parameterization Controller	78
6.4	Comparison of various cases	80
6.5	Comparison between Q-parameterization controller and pole placement with and without integral control	86

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
1.1	Symmetric balance beam on two magnetic bearings.	2
3.2	The simulation block diagram for (MSBB) equations	22
4.1	Pole Placement Technique without Integral Control	25
4.2	Pole Placement Technique with Integral Control	29
4.3	SIMULINK implementation of equation (3.21)	34
4.4	SIMULINK implementation of equation (3.21)	34
4.5	SIMULINK implementation of equation (4.15) for pole placement Technique without integral	35
4.6	Complete simulation diagram of linear model for MSBB system	35
4.7	Complete simulation diagram of pole placement technique without integral control for MSBB linear system	36
4.8	Complete simulation diagram of nonlinear model for the MSBB system	37

4.9	SIMULINK implementation of equation (4.15) for pole placement Technique without integral	37
4.10	Complete simulation diagram of pole placement technique without integral control for MSBB nonlinear system	38
4.11	SIMULINK implementation of equation (4.35) for pole placement with integral	39
4.12	Complete simulation diagram of pole placement technique with integral control for MSBB linear system	39
5.1	Block diagram of one parameter –control feedback system	43
5.2	Generalized region of stability	44
5.3	Basic feedback structures.	45
5.4	Block diagram of Q-parameterization	46
5.5	Q-parameterization as modification to nominal controller	46
5.6	one parameter controller feedback system	56
5.7	Complete simulation diagram of linear model for MSBB system	58
5.8	Complete simulation diagram of linear model for the MSBB System with Q-parameterization Controller	59

5.9	Complete simulation diagram of linear model for MSBB system with Q-parameterization Controller	59
5.10	Complete simulation diagram of nonlinear model for the MSBB System	60
5.11	Complete simulation diagram of linear model for MSBB system with Q-parameterization Controller	61
5.12	Complete simulation diagram of linear model for MSBB system with Q-parameterization Controller	61
6.1	Step disturbance force (1-N-m) at time =0.15 seconds	65
6.2	Displacement angle for linear MSBB System with 1 N-m disturbance using pole placement controller.	65
6.3	Input voltage for linear MSBB System with 1 N-m disturbance using pole placement controller.	66
6.4	Displacement angle for linear MSBB System with 1 N-m disturbance using Q-parameterization controller.	67
6.5	Input voltage for linear MSBB System with 1 N-m disturbance using Q-parameterization controller.	67
6.6	Displacement angle for nonlinear MSBB System with 1 N-m disturbance using pole placement controller.	68
6.7	Input voltage for nonlinear MSBB System with 1 N-m disturbance using pole placement controller.	69

6.8	Displacement angle for nonlinear MSBB System with 1 N-m disturbance using Q-parameterization controller.	69
6.9	Input voltage for nonlinear MSBB System with 1 N-m disturbance using Q-parameterization controller.	70
6.10	Comparison of displacement angle between both systems of the MSBB with Q-parameterization controller	72
6.11	Comparison of input voltage between both systems of the MSBB with Q-parameterization controller	72
6.12	Comparison of displacement angle between both systems of the MSBB with the pole placement technique	73
6.13	Comparison of input voltage between both systems of the MSBB with the pole placement technique	73
6.14	Comparison of displacement angle for linear model of the MSBB System	75
6.15	Comparison of input voltage between for linear of the MSBB System	75
6.16	Comparison of displacement angle for nonlinear model of the MSBB System	77
6.17	Comparison of input voltage between for nonlinear of the MSBB System	77

6.18	Comparison of displacement angle for linear and nonlinear model of the MSBB System	79
6.19	Comparison of input voltage between for nonlinear of the MSBB System	79
6.20	Displacement angle for the MSBB System with 1 N-m disturbance by using pole placement with integral control	81
6.21	Input Voltage for the MSBB System with 1 N-m by using the pole placement with integral control	81
6.22	Comparison of displacement angle for the MSBB System	83
6.23	Comparison of input voltage for the MSBB System	83
6.24	Comparison of displacement angle for nonlinear of the MSBB System	84
6.25	Comparison of input voltage for nonlinear of the MSBB System	85
6.26	Comparison of displacement angle for nonlinear of the MSBB System	85
6.27	Comparison of input voltage for nonlinear of the MSBB System	86

LIST OF SYMBOLS

A	-	N x N system matrix for the Magnetically Suspended Balanced Beam
B	-	N x 1 input matrix for the Magnetically Suspended Balanced Beam
C	-	1 x N output matrix for the Magnetically Suspended Balanced Beam
E	-	N x 1 disturbance matrix for the Magnetically Suspended Balanced Beam
R	-	Set point (radian)
X	-	State vectors
f_d	-	Disturbance of the system (N)
θ	-	Gap displacement (radian)
$\dot{\theta}$	-	Velocity of gap displacement (radian/second)
$\ddot{\theta}$	-	Acceleration of gap displacement (radian/seconds2)
i'	-	Overall instantaneous current (A)
i_o	-	Steady current (A)
$e`$	-	Control voltage (V)
K_x	-	Magnetic bearing open loop stiffness (N/m)
K_i	-	Actuator current gain (N/A)
La	-	Half bearing span (m)
J	-	Mass moment of Inertia about the pivot point (kg/m2)
g_o	-	Steady gap (m)
Q	-	Parameter arbitrary stable proper transfer function
K	-	Controller

$S(s)$	-	Sensitivity function
$N(s)$	-	Coprime factorization stable transfer function
$D(s)$	-	Coprime factorization stable transfer function
$\widetilde{N}(s)$	-	Coprime factorization stable transfer function
$\widetilde{D}(s)$	-	Coprime factorization stable transfer function
$X(s)$	-	Coprime factorization stable transfer function
$Y(s)$	-	Coprime factorization stable transfer function
$\widetilde{X}(s)$	-	Coprime factorization stable transfer function
$\widetilde{Y}(s)$	-	Coprime factorization stable transfer function

LIST OF ABBREVIATIONS

MSBB	-	Magnetically Suspended Balance Beam

CHAPTER I

INTRODUCTION

1.1 Introduction

The selection of the controllers' plays an important role in the design of any plant controller .This is simply because it is the heart of the system. By making a wise choice, the controller can achieve the exact predetermined results and achieve the best robust stability and performance.

In recent years, a new control method has surfaced in the literature. The method which is called the Q-parameterization method (sometime referred to as the Youla parameterization method) is a modern control design method suitable for both stable and unstable plants. It is used mainly to design a stabilizing controller for any system where simple conventional control can not guarantees acceptable results.

There are several robust control methods available in literature. Nonlinear methods such as sliding mode control or linear methods such as pole placement control as well as H_2, LQG, and Q-parameterization control are among the controllers that has been applied to various control fields. In this thesis, the Q-parameterization controller is applied to control a Magnetically Suspended Balance Beam (MSBB) system.

The Magnetically Suspended Balance Beam (MSBB) is a balancing system that used two magnetic coils to balance the beam as shown in Figure 1.1. These two magnetic coils are placed at each end of the beam, one at the right hand side and one in the left hand side. It can be easily described as a small see-saw.

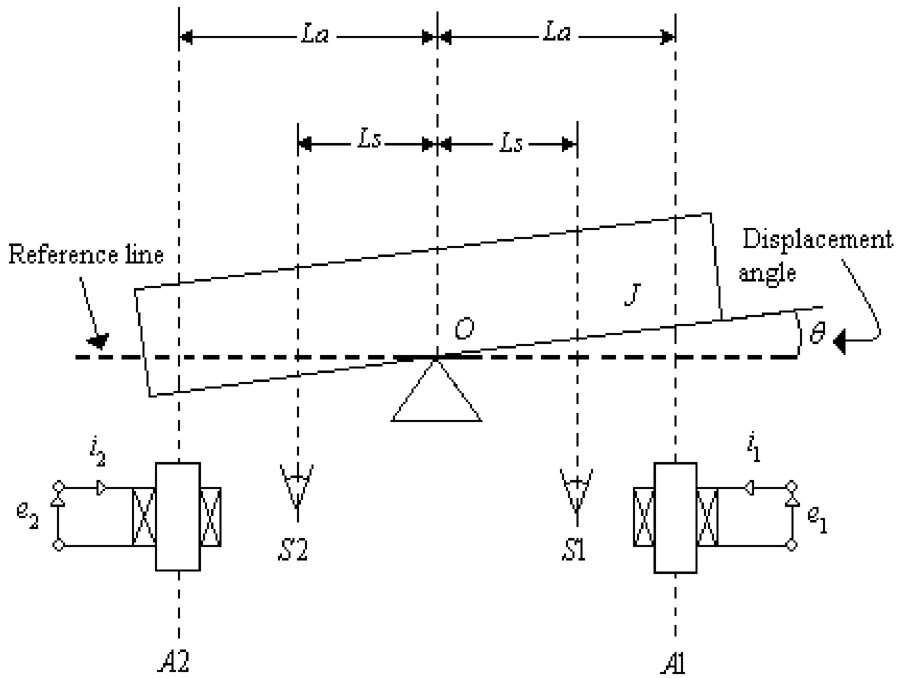

Figure 1.1: Symmetric balance beam on two magnetic bearings.

In this project, the main task is to control the gap displacement angle of the beam. If the gap displacement angle is equal to the set point, it can be concluded that the designed controller is successful in controlling the angle and make the beam become stable.

The whole system is needed to be modeled first by using a state space equation. It has been found that this system is having a non linear model. From this nonlinear model, the linearization process has to be done first. After the linearized model has been acquired, the next task to do is to control the beam until it become stable.

Once the model has been acquired, the Q-parameterization controller is used to control the beam. For comparison purposes, the pole placement control (state feedback control) and an integral controller will also be considered. In both evaluations, the presence of step disturbance is also included in the system. The performance of both controllers in controlling the MSBB will be evaluated through extensive computer simulation using MATLAB/SIMULINK

1.2 Objective

The objectives of this project are as follows:

1. To formulate the mathematical model of a Magnetically Suspended Balance Beam (MSBB) System in state space form.
2. To design a controller based on the Q-parameterization method for stabilization of a Magnetic Suspension Balance Beam (MSBB) System.
3. To simulate the system using the designed controller.
4. To compare the results with pole placement controller (state feedback controller), and integral controller.

1.3 Scope of Project

The work undertaken in this project is limited to the following aspects:

1. The nonlinear mathematical model of MSBB system adopted in this work is as described in (*Baloh et al, 1999), (Lee. et al, 2001) and (Hu et al, 2002).*
2. The proposed Q-parameterization controller design methodology will be designed and applied to the system.
3. The performance of the balance beam control system will be illustrated by simulation using MATLAB/SIMULINK as the platform.
4. The results for Q-parameterization controller will be compared with pole placement controller (state feedback control) and integral controller.

1.4 Research Methodology

The research work undertaken in the following four development stages:

1. To study a Magnetic Suspension Balance Beam (MSBB) System and derive the state space equations.
2. The design of controller base on pole placement technique.
3. The design of controller based on Q-parameterization method will be explain and applied to the system.
4. The Performance and the results simulation for a Magnetic Suspension Balance Beam (MSBB) System using Q-parameterization controller will be established.
5. Analyzed the results by comparing it with pole placement controller and integral controller.

1.5 Layout of Thesis

This thesis contains eight chapters. Chapter II contains a brief literature review, first for model of the magnetically suspended balance beam (MSBB) System and second for design controller (Q-parameterization controller).

Chapter III contains a brief introduction of MSBB. In this chapter also, the mathematical model, which is a nonlinear model of the MSBB is presented. The linear mathematical model of the system is derived and then transforms into the state space representations.

Chapter IV presents the brief introduction of pole placement technique. Then the controller is designed using pole placement technique without integral and plus integral control. The use of integral control is to eliminate the steady-state error. The controller is designed base on design specification. For this design specification, the percentage overshoot % OS and settling time T_s that have been used are:

i. Percent of overshoot, %OS = 10%

ii. Settling time, T_s = 0.1 second.

Chapter V presents the brief introduction of controller design based on Q-parameterization method, the controller is designed using the Q-parameterization method to satisfy our requirement. Then, using the MATLAB programming, same as in Chapter IV, the Q-parameterization controller is also designed base on the same design specification.

For this s design specification, the percentage overshoot % OS and settling time T_s that have been used are:

i. Percent of overshoot, %OS = 10%

ii. Settling time, T_s = 0.1 second.

Chapter VI will be presents both the results and discussion of pole placement technique and the controller design based on Q-parameterization method. For the specification design there will be two graph presented. The first one is a gap displacement’s graph and another one is an input voltage’s graph. At the end of this chapter, the comparison between the pole placement technique and the Q-parameterization controller is done. Also the comparison between the pole placement technique with integral and the Q-parameterization controller is done.

Chapter VII conclude the work undertaken, suggestions for future work are also presented in this chapter.