MODERN CONTROL OF MAGNETIC BEARING SYSTEM

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This report is submitted in partial fulfillment of the requirements for the award of Bachelor of Electronic Engineering (Telecommunication Electronics) With Honours

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MAY 2008

"I hereby declare that this report is the result of my own work except for quotes as cited in the references"

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Date : 9 MAY 2008

To my dearest father, mother, and family for their encouragement and blessing

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ABSTRACT

Today, magnetic bearings have been introduced into the industrial world as a valuable machine element with quite a number of new features, and increasingly used for a large variety of applications. Their unique features make them attractive for solving rotor-bearing problems in a new way and allow new design approaches for rotating machinery. Magnetic bearings systems are increasingly used in industrial machines such as compressors, turbines, pumps, motors and generators. The advantages by using this system include high reliability, clean environments, high speed applications, and position and vibration control. However, the magnetic bearing system used has limitations where the system is unstable and higher cost needed. In order to avoid this difficulty, this project comes where a state feedback controller will be designed. The project comes with three essential objectives; the firstly is formulate the mathematical model of magnetic bearing system. For the next objective it is design a modern control system that is able to stabilize the position of the rotor of magnetic bearing system. The last one is analyze the performance of the controlled system using MATLAB/ Simulink. For the methodology, it is start by find out the formulation model mathematically and checks the performance of controllability and stability for this system. Next, the magnetic bearing system modeling is built in MATLAB/ Simulink software. At that moment, the controller is design and analyzes the state feedback controller that. Performance and stability of the controlled system are evaluated and design iterations of the controller are performed until a controller is found which meets the design requirements.

ABSTRAK

Pada masa sekarang, *'magnetic bearings'* diperkenalkan di dalam bidang industri sebagai satu elemen mesin yang sangat penting dengan memiliki pelbagai ciri dan mula meningkat penggunaannya dalam berbagai-bagai aplikasi. Memandangkan *'magnetic bearings'* ini mempunyai ciri-ciri yang tiada bandingannya, jadi ia amat sesuai untuk mengatasi atau pun menyelesaikan masalah berkaitan dengan *'rotor-bearing'* dengan menggunakan kaedah baru. Di dalam bidang perindustrian mesin pula, penggunaan sistem *'magnetic bearings'* juga mula meningkat dan mula digunakan di dalam peralatan mesin tertentu. Antara kelebihan menggunakan sistem ini termasuklah ketahanan yang tinggi, persekitaran yang bersih dan aplikasi kepantasan yang tinggi. Walaupun begitu, terdapat kekurangan dalam sistem *'magnetic bearing'* di mana sistem ini tidak stabil dan memerlukan kos penggunaan yang tinggi. Bagi mengatasi masalah tersebut, projek ini direka dengan kawalan tindakbalas dan mempertimbangkan tiga objektif utama. Objektif yang pertama ialah mendapatkan persamaan model matematik bagi sistem *'magnetic bearing'*. Objektif seterusnya ialah mereka bentuk sebuah sistem kawalan moden yang mampu menstabilkan kedudukan rotor bagi sistem *'magnetic bearings'*. Objektif yang terakhir ialah menganalisis perlaksanaan sistem kawalan tersebut menggunakan perisiaan MATLAB/ Simulink. Bagi metodologi kajian, terdapat lima langkah penting dan ia bermula dengan memperoleh persamaan model matematik dan menyemak kestabilan dan kemampuan kawalan bagi sistem tersebut. Kemudian, sistem 'magnetic bearings' direka di dalam perisian MATLAB. Selepas itu, pengawal direka dan pengawal dengan keadaan tindakbalas dianalisis. Perlaksanaan dan kestabilan sistem kawalan dinilai dan pengulangan semula rekaan dilakukan sehingga sistem kawalan tersebut memenuhi kehendak rekaan.

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LIST OF ABBREVIATIONS

ABBREVIATION	TITLE
EMT	-Electromagnetic
GUI	-Graphical User Interface
LTR	-Loop Transfer Recovery
LQG	-Line Quadratic Gaussian
MIMO	-Multiple Input Multiple Output
SFC	-State Feedback Controller

CHAPTER I

INTRODUCTION

1.1 Overview

The final project that develops is *'Modern Control of Magnetic Bearing System'*. This project is relating to a controller design and more focus on the magnetic bearing system. As an explanation, magnetic bearing system is a device that uses electromagnetic forces to support a rotor without mechanical or physical contact. In other word, a controller that is able to stabilize the position of the rotor by varying the electromagnet force will be designed. The system that proposed to control is the Magnetic Moments MBC 500. For this purpose, the formulation of the mathematical dynamic model of magnetic bearing system is derived initially and it was followed by establishing the state space model of the system. After that, system model is linearized at the equilibrium point and shaft is assumed as a rigid body. Next, a state feedback controller using a pole placement technique is designed using related software. This project will be implemented using MATLAB/ Simulink. Figure 1.1 shows the example of MBC 500 model.

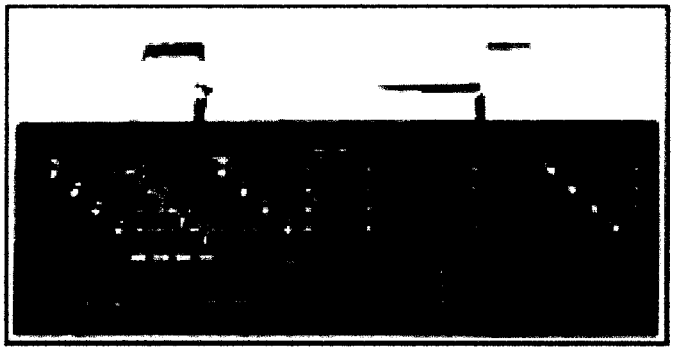

Figure 1.1: Example Model of MBC 500

1.2 Objective

1. To formulate mathematical model of magnetic bearing system.
2. To design a modern controller system this is able to stable the position of the rotor of magnetic bearing system.
3. To analyze the performance & stability of controlled system using MATLAB/Simulink.

1.3 Problem Statement

In general, magnetic bearings systems have been growingly used for industrial application. However, the magnetic bearing system that used has a limitation where the system is unstable and higher cost. In order to avoid this difficulty, this project comes where a state feedback controller will be designed. As a result, in stabilizing the position of the rotor of magnetic bearing system the desired rotor position is maintained.

1.4 Scope

- Formulate the mathematical modeling of magnetic bearing system.
- Build the magnetic bearing system modeling in MATLAB/Simulink platform.
- Design state feedback control using Pole placement technique.
- Analyze controlled system using MATLAB/Simulink.

1.5 Project Methodology

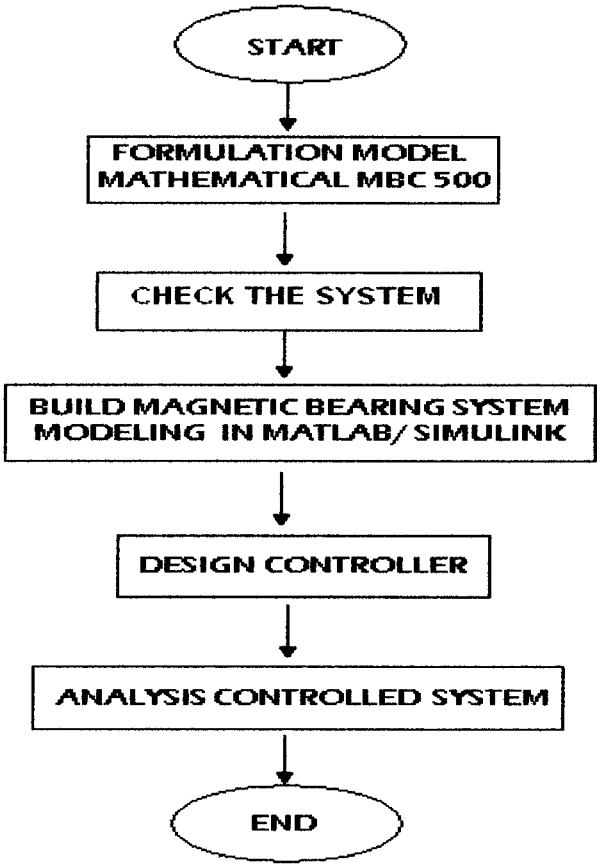

Figure 1.2: Project Methodology

1.6 Report Structure

Table 1.1 below shows the overview of the chapter that include in the final report. Then, we describe each chapter in details. This final project of "*Modern Control of Magnetic Bearing System*" contains six chapters.

Table 1.1: Overview of Report Structure

CHAPTER	TITLE
I	Introduction
II	Project Methodology
III	Literature Review
IV	Mathematical Modeling and State-Feedback Controller
V	Result and Discussion
VI	Conclusion and Recommendation

It begins with Chapters 1, and it contains an introduction of controller design and more focus to the magnetic bearing system. The MBC 500 is used as the model for magnetic bearing system. In addition, this chapter also discuss about some of main point as example objective, problem statement, scope of work and methodology overview.

Chapter 2 is relating to the research of methodology for design the controller of magnetic bearing system. Beside that, we try to find out and discuss about the problems that occur until this controller is design. The most important thing that will discuss is related with the method and approaches on how to solving that problem. Actually, this chapter describes each part in flow chart of Methodology.

Chapters 3 deals with the literature review for this magnetic bearing system project. In other word, this chapter will study and also research about the project

includes theory and concept of controller. This chapter also covers the perspective and method that will be used to complete this project. From this chapter, it become more understanding and knows about each method and theory. All the part in this chapter is describe more details.

Chapter 4 is mathematical modeling and how to design the State-Feedback Controller by using pole placement technique. In order to design a controller, the desired mathematical modeling is required. From here, the controller is able to design by using desired characteristics that we calculated and simulated.

Chapter 5 is an explanation and discussion about the final result when the controller totally complete. As a conclusion, the State Feedback Controller by using pole placement technique can be used. In other word, the final results that are obtained from the graph are stable and controllability.

Chapter 6 concludes and summarizes the works undertaken in this project. As a conclusion, all of the objectives are achieved. Finally '*Modern Control of Magnetic Bearing System*' is successfully design .For the future research, maybe the state feedback controller system can implement by using another technique which has more advantages compare with other.

CHAPTER II

PROJECT METHODOLOGY

2.1 Introduction

For this chapter, the project methodology has been discussed in details. As a beginning, the project methodology is explaining one by one level. The method consideration is also discussed in this chapter. Last but not least, the advantages of this system that is chosen from beginning until get the final result it also represented.

2.2 Explanation of Project Methodology

Control system design is a multistage process involving much more than the design of the controller itself. Before a controller can be designed, sufficient knowledge is needed and also understanding more about the system that should be to control. The designer begins by collecting information in relation to the system from all available sources.

Throughout of this project, consideration is only making to the five steps. In the first part, we focus on the derivation of physically based model for the MBC 500. It is

used to represent the system rotor as a rigid body and derive the corresponding equation. Then, the mathematically equation is derive and evaluated the equation is done. The final equation of the state-space and output equation can be getting. In order to design the State-Feedback Controller (SFC), it is necessary to find out these equations.

After the equation is obtained in state space order, the eigenvalues values and the controllability of the system are required to attain. The eigenvalues is finding with calculation by using certain formulation and from here the systems can be define either stable or not. Then, make sure the controllability of the system before the controller is design. The eigenvalues and controllability of the system that are reaching from calculation can be proving by using the MATLAB. It is important tasks before this project is carry on with other tasks.

Next, the magnetic bearing system modeling can be design when once suitable system model is obtained. The system model is linearized at the equilibrium point and it is design using pole placement technique. In system or plant model, it has two choices which are non-linear and linear. Then, the system is estimate in computer simulation by using MATLAB/Simulink. At that moment, the controller is built and its performance is evaluated on the actual system. The controller that we build it also used the MATLAB/ Simulink software.

After everything else is done, the designed of State Feedback Controller (SFC) must be analyzed. Performance and stability of the controlled system are evaluated and design iterations of the controller are performed until a controller is found which meets the design requirements.

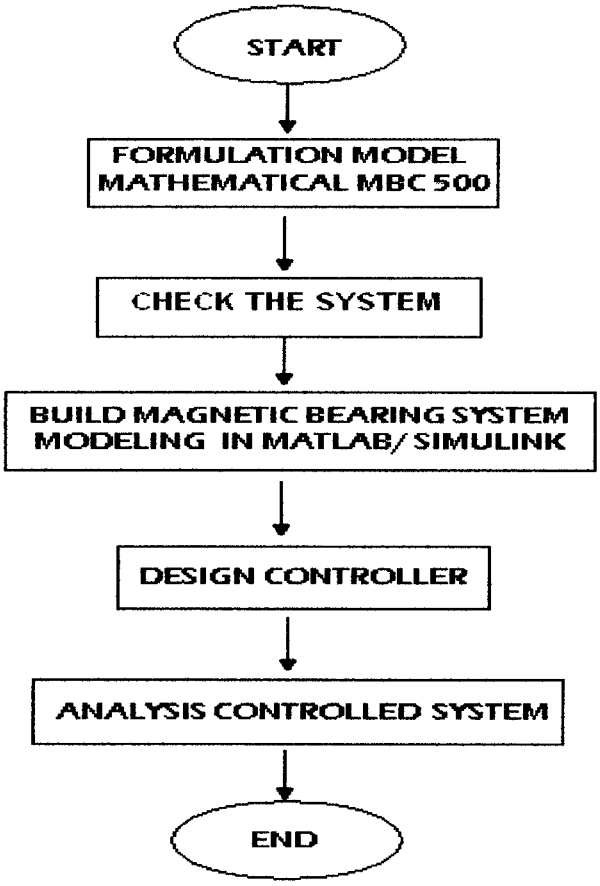

Figure 2.1: Project Methodology

2.3 Method Consideration

Today's powerful computer modeling and analysis tools such as MATLAB/ Simulink are now making it easier. This method is choosing based on quality designs and costly hardware prototypes. The computer peripherals industry, engineers are using analysis, modeling, and simulation tools to accomplish high-quality design and reduce the costly hardware in produce a product.

At the side of that, the matrix configuration also used in order to find out the all characteristics that are needed. In example, the determinant and inverse transformations

is used. It is two complete configurations in matrix form that are required to calculate. The best way to avoid this difficulty and solve it is by using MATLAB software and for this, the certain command is needed.

2.4 Advantages

According to the method consideration, this project rightly completes thoroughly using the MATLAB/Simulink software. MATLAB/ Simulink is one of software where it more familiar with the engineering student. As an introduction, we determine each advantages of this software in controller design.

During this project, the MATLAB software is used in order to run the system. MATLAB has a high-performance language for technical computing and it integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation. Because the knowledge about this software's already have, so, it make easy when we used this software.

Beside that, a matrices system also used to find out the result from the analysis. Matrices are often used to perform transformations on coordinates. They can do so in any number of dimensions. Matrices representing transformations can be multiplied together combining all of the translation into one. This means that matrices can save time when performing translations, in example for multiple rotations, translation, enlargements and so on. It can be combined into one matrix and can be executed in a single matrix operation. A matrix is a 2D array of numbers which can have any width and height.

In create the system/plant and State-Feedback Controller, it become easier when all the desired block that are needed is appear in Simulink Library Browser. Simulink is