INTELLIGENT CONTROL OF MAGNETIC BEARING SYSTEM

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Date : 9th May 2008

To my loving family

I have learnt much, most of all from my supervisor and from my friends.

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ABSTRACT

A magnetic bearing is a system which supports moving machinery without physical contact. Magnetic bearing advantages include lower and predictable friction, besides able to operate without lubrication. Magnetic bearings are increasingly being used as an alternative to rolling element in rotating industrial machinery such as compressors, turbines, pumps, motors and generators. It can be divided into two categories which are passive and active magnetic bearing. An active magnetic bearing consists of an electromagnet assembly; a set of power amplifiers which supply current to the electromagnets, a controller and gap sensors with associated electronics to provide the feedback required controlling the position of the rotor within the gap. The problem exist is that it can only exert an attractive force that cause the system inherently unstable and requiring the use of controller. Under extreme condition, the response of the rotor in magnetic bearing system becomes highly non-linear. This project is to design an intelligent controller for magnetic bearing system focused on MBC500 as a magnetic bearing research experiment. Fuzzy logic controller based on Sugeno approach as an intelligent controller is applied to control MBC500. The performance of the controller was analyzed using Matlab. At the end of this project, fuzzy logic controller using Sugeno approach which is able in stabilizing the position of the rotor of the magnetic bearing system will be designed.

ABSTRAK

Bebola magnetik adalah suatu sistem yang membolehkan suatu mesin yang berputar tidak mengalami sentuhan secara fizikal. Antara kelebihan bebola magnetik adalah ianya hanya mengalami kerosakan yang sedikit dan boleh dijangkakan, disamping mampu beroperasi tanpa pelincir. Penggunaan bebola magnetik semakin meningkat sebagai alternatif kepada elemen berputar di dalam mesin perindustrian seperti pemampatan, turbin, pengepaman, motor dan generator. Ia boleh dibahagikan kepada 2 kategori iaitu bebola magnetik pasif dan bebola magnetik aktif. Bebola magnetik aktif mengandungi himpunan elektromagnet iaitu set kuasa amplifier yang membekalkan arus kepada elektromagnet, pengawal dan pengesan untuk menghasilkan tindak balas yang membolehkan posisi palang antara gap dapat dikawal. Masalahnya, ia hanya dapat menyerap kuasa menarik yang akan menyebabkan sistem menjadi tidak stabil dan memerlukan pengawal. Di bawah keadaan yang ekstrem, tindak balas palang dalam sistem bebola magnetik menjadi semakin tidak sekata. Projek ini bertujuan untuk merekabentuk suatu pengawal pintar untuk mengawal sistem bebola magnetik khususnya MBC500 yang merupakan model untuk penyelidikan. Pengawal fuzzy logic menggunakan kaedah Sugeno akan diaplikasikan untuk mengawal MBC500. Prestasi pengawal akan dianalisis menggunakan Matlab. Pada akhir projek ini, pengawal fuzzy logic menggunakan kaedah Sugeno dapat direkabentuk untuk menstabilkan posisi palang bagi bebola magnetik.

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AI	-	Artificial Intelligent
AMB	-	Active Magnetic Bearing
DSP	-	Digital Signal Processing
FAM	-	Fuzzy Associative Memory
PID	-	Proportional-Integrated-Derivative
PSM I	-	Projek Sarjana Muda I
PSM II	-	Projek Sarjana Muda II

CHAPTER I

INTRODUCTION

Intelligent control of magnetic bearing system is a project that will exposed to MBC500 magnetic bearing system. This research project focused on fuzzy logic controller using Sugeno approach to stabilize the MBC500 system.

1.1 Overview

The application of active magnetic bearings in rotating machinery has increased in recent years. They are being used as an alternative to rolling-element and fluid-film bearings. As the applications of active magnetic bearings can be found broadly, the importance for designing the appropriate and efficient controller to monitor the magnetic bearings becomes vital.

The main advantage of the active magnetic bearings over the conventional bearings is their higher mechanical efficiency due to reduced friction losses since no contact occurs between the rotor and the bearing stator during operation of the machine. The fact, the operation of the magnetic bearings is contactless allows them to achieve a higher operating speed compared to conventional bearings. The achievable speed is essentially limited by the strength of the rotor material. These bearings do not require lubrication and therefore their installation are cleaner compared to the rolling-element and fluid-film bearing types.

Magnetic bearing system can be described as a device that uses electromagnetic forces to support a rotor without mechanical contact. It can be divided into two categories which are passive and active magnetic bearing. For active magnetic bearing, the force on the rotor can be controlled by changing the current flow through the magnet coils. The problem exist is that it can only exert an attractive force that cause the system inherently unstable and requiring the use of controller.

An intelligent controller as an alternative control strategy is proposed. Here, fuzzy logic controller using Sugeno approach will be identified and designed in controlling and stabilizing the position of the rotor of the magnetic bearing system. This project will be implemented using Matlab.

1.2 Objective

The objectives of this project are:-

1. To design a fuzzy logic controller using Sugeno approach which is able to stabilize the position of the rotor of the magnetic bearing system.
2. To analyze the performance of controlled system using Matlab software package.

1.3 Scope of Project

The scope of this project is to design a controller which is able to stabilize the position of the rotor of magnetic bearing system. Here, fuzzy logic controller based on Sugeno approach which is computationally efficient is proposed. The performance of controlled system will be analyzed using Matlab. This project will be focused on MBC500 magnetic bearing system.

1.4 Problem Statement

A magnetic bearing is a system which supports in moving rotating machinery without physical contact. Magnetic bearing advantages include higher mechanical efficiency due to reduced friction losses since no contact occurs between the rotor and the bearing stator during operation of the machine. It is lower and predictable friction, besides able to operate without lubrication. Magnetic bearings are increasingly used in industrial machines such as compressors, turbines, pumps, motors and generators.

Magnetic bearing is an electromagnetic device, which maintains the relative position of a rotor with respect to a stationary part. As a result, magnetic bearing requires continuous power input and an active control system to hold the load to be stabled.

Here, a new control system using fuzzy logic controller based on Sugeno approach will be designed to stabilize the position of the rotor of the magnetic bearing system. Fuzzy logic is widely used in machine control which is effective in controlled. The fuzzy logic approach makes it easier to conceptualize and implement control systems.

1.5 Structure of the Report

This report opens with a short introduction of the project. The chapter includes overview, objectives, scope and also problem statements of the project.

The next chapter is devoted to the literature review of the magnetic bearing system, focused on MBC500 which is magnetic bearing research experiment. The chapter also includes a preview of the main theme of this project: intelligent control of fuzzy logic using Sugeno approach.

Next chapter follow discuss about the project methodology on the process to design intelligent control of magnetic bearing system.

Continue after, next chapter then discussed all the result outcomes and discussion. Project hypothesis will be done decided either the project had achieved the objective.

Lastly, this report contents the conclusion of the project and suggestion on the overall project also discuss some possible directions for further research.

CHAPTER II

LITERATURE REVIEW

This chapter will cover about project literature review. Before a controller can be designed, designer must have sufficient knowledge of the system that need to be controlled. So, this project begins by collecting information about the system from all available sources; books, journal, thesis, internet etc. This project is mainly focused on MBC500 magnetic bearing system and fuzzy logic controller based on Sugeno approach.

2.1 Active Magnetic Bearing

Active magnetic bearings (AMB) are being increasingly utilized in rotating machinery as an alternative to the more conventional rolling element and fluid-film bearing types. They have certain advantages over the conventional bearings especially in rotating machinery applications that require oil-free operation. The non-contact operation between the rotor and the magnetic bearings reduces the frictional losses. This in turn increases their mechanical efficiency to a magnitude that is not achievable by rotors mounted on conventional bearings [10].

The ability to vary the dynamic characteristics of a rotor magnetic bearings system within a considerable range by merely changing the parameters of its controller and without having to modify the dimensions of the rotor is also an added advantage. Further, allow active control of the position and balancing of the rotor which is not easily implemented for rotor supported by conventional bearing types.

The disadvantage of the AMB is their lower bearing pressure capacity compared to fluid-film bearings of the same physical dimension. Another disadvantage is magnetic bearings also highly non-linear characteristics.

2.2 MBC500 Magnetic Bearing System

The MBC500 is an active magnetic bearing consisting of two active radial magnetic bearings and a supported rotor or shaft mounted on top of an anodized aluminum case. The shaft is actively positioned in the radial directions at the shaft ends, it is passively centered in the axial direction, and it freely rotates about its axis. Included in the system are four linear current amplifier pairs, one pair for each radial bearing axis, and four internal lead-lag compensators, which independently control the radial bearing axes.

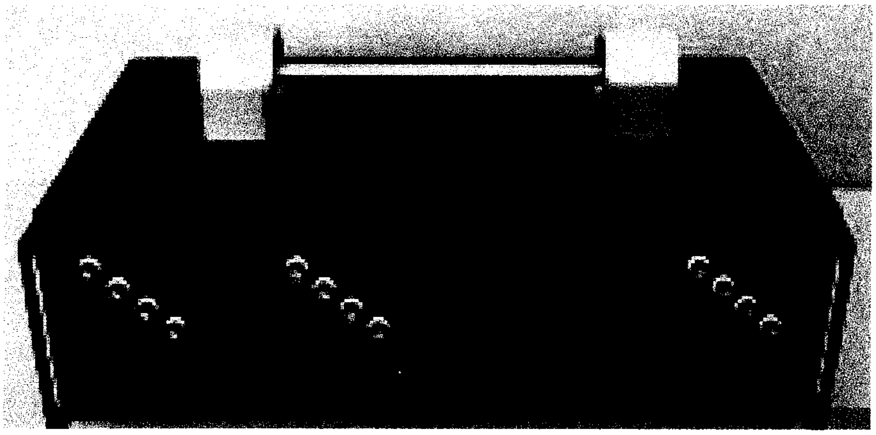

Figure 2.1: MBC500 Magnetic Bearing System

The front panel is a graphical representation of the system dynamics with 12 BNC connections for easy access to system inputs and outputs. Four front panel switches allow the user to open the loop for the internal axis controllers independently. With all internal loops open a sophisticated 4 by 4 external controller can be implemented. The control bandwidth is roughly 1 kHz so external controllers are typically DSP-based or analog.

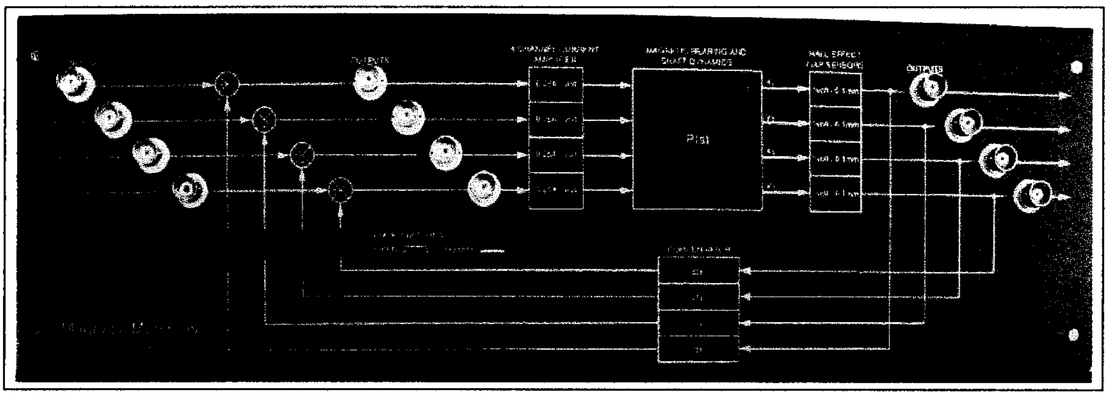

Figure 2.2: Front Panel Block Diagram

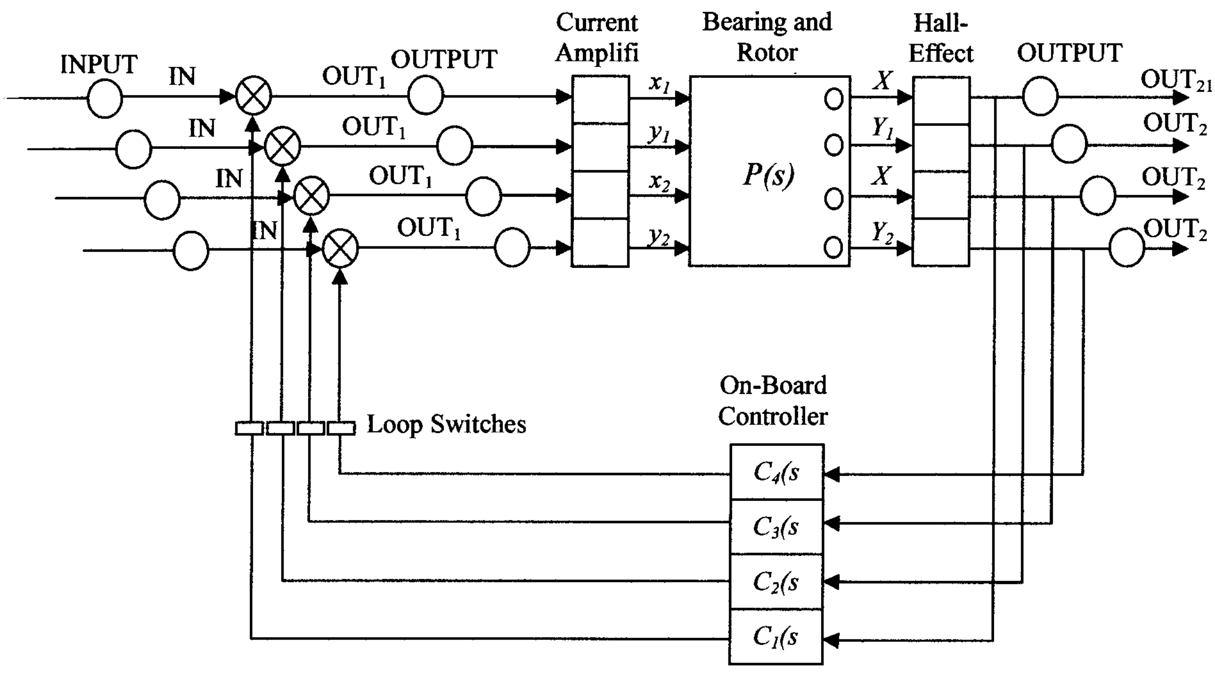

Figure 2.3: Illustrated of Front Panel Block Diagram

It is a known fact that MBC500 magnetic bearing system is an open-loop unstable system. It therefore requires a feedback control system to ensure stable operation. Most practical installation of the controller used for magnetic bearing supported rotating machinery is mainly of the analog PID type. But, this type of controller becomes ineffective when the rotating machinery is subjected to extreme operating conditions. Examples, due to high level of imbalance force.

2.2.1 MBC500 Analyses and System Configuration

For simplest analysis of the system, assume that the rotor acts as a rigid body. A rigid body is one which does not change shape. Therefore, the rotor also does not bend but rather experiences only translational or rotational motion. In addition, assume that the horizontal and vertical dynamics; i.e. the *x* and *y* directions, are uncoupled.

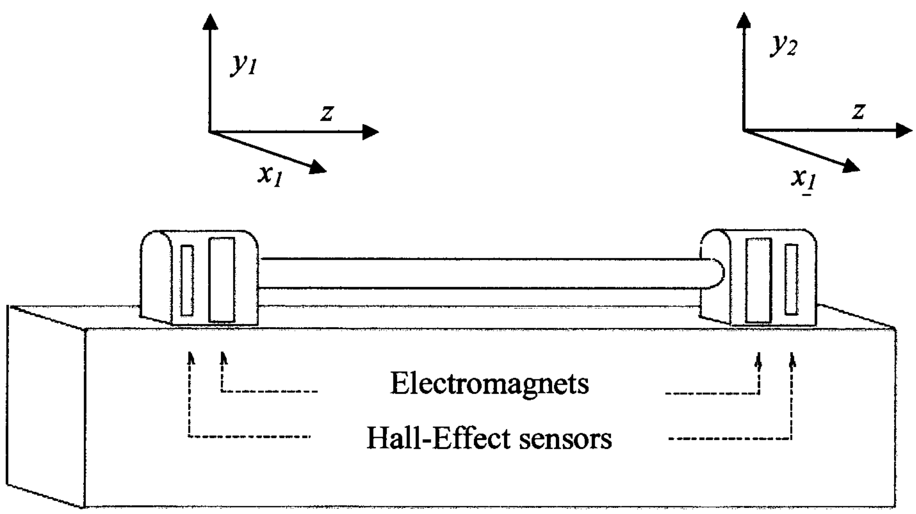

Figure 2.4: MBC500 System Configurations

The system, in theory, operates identically in the *x* and *y* directions except for the additional constant force due to gravity acting in the y direction. This constant force is not linear and cannot be modeled by a linear system model.

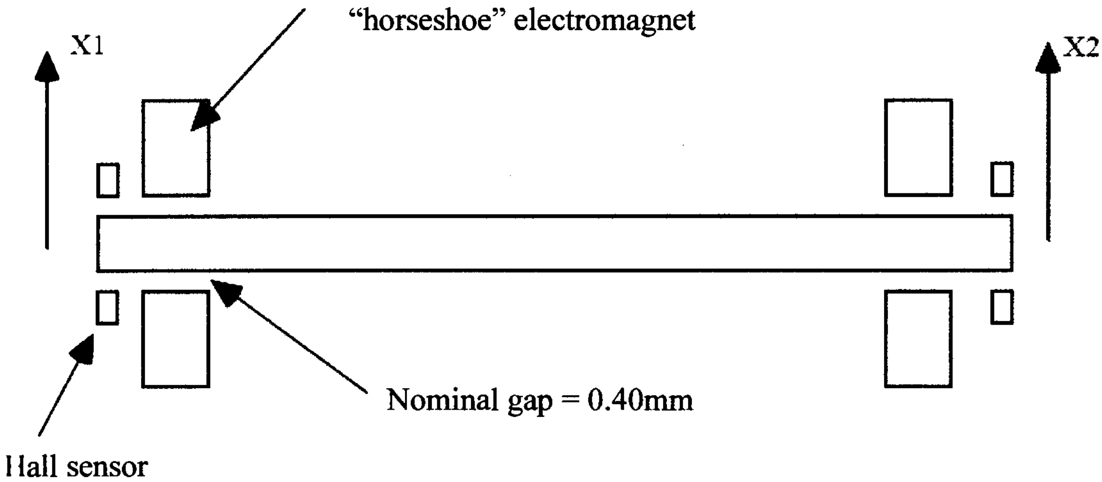

Figure 2.5: Shaft Schematic Showing Electromagnets and Hall-Effect Sensors

The nominal or desired rotor position corresponds to $x_1 = 0$ and $x_2 = 0$; equivalently $X_1 = 0$ and $X_2 = 0$ or $x_1 = 0$ and $\theta = 0$. In this position, the rotor is centered horizontally with respect to the front and back electromagnets on each end, and its long axis is parallel to the *z* axis.

An analysis of the geometry of the rotor will yield the following relationships.

$$x_1 = x_0 - \left(\frac{L}{2} - l\right) \sin\theta \tag{2.1}$$

$$x_2 = x_0 + \left(\frac{L}{2} - l_2\right) \sin\theta \tag{2.2}$$

$$X_1 = x_0 - \left(\frac{L}{2} - l_2\right) \sin\theta \tag{2.3}$$

$$X_2 = x_0 + \left(\frac{L}{2} - l_2\right) \sin\theta \tag{2.4}$$