UNIVERSITI TEKNIKAL MALAYSIA MELAKA (UTeM)

DESIGN OF MODEL REFERENCE ADAPTIVE CONTROL (MRAC) FOR MACHINE TOOL APPLICATIONS

This report is submitted in accordance with requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Manufacturing Engineering (Robotic and Automation) (Hons)

by

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UNIVERSITI TEKNIKAL MALAYSIA MELAKA

BORANG PENGESAHAN STATUS LAPORAN PROJEK SARJANA MUDA

TAJUK: **Design of Model Reference Adaptive Control (MRAC) for Machine Tool Applications**

SESI PENGAJIAN: 2015/16 Semester 2

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I hereby, declared this report entitled “Design of Model Reference Adaptive Control (MRAC) for Machine Tool Applications” is the results of my own project except as cited in references.

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APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of UTeM as a partial fulfillment of the requirements for the degree of Manufacturing Engineering (Robotic and Automation) (Hons.). The member of the supervisory committee is as follow:

....

IR. DR. LOKMAN BIN ABDULLAH

ABSTRACT

High accuracy and speed are the attributes demanded in controller design for machine tool in manufacturing industries. The presence of some factors such as physical vibration produced from mechanical structure of machine tools and friction force can reduce the machine tool performance. The main objective of this project is to design a Model Reference Adaptive Controller (MRAC) for machine tool applications. The next objectives are to improve tracking accuracy and transient response of the system and to validate the controller through simulation and experimental work. MRAC controller consist of a model reference and a feedback loop control system by using an algorithm namely Lyapunov approach. Software used for tracking performance of the machine tools is MATLAB/Simulink and dSPACE software. The tracking performances of the proposed controller were evaluated based on maximum tracking error, root mean square of error (RMSE). The transient responses were evaluated based on steady state error, peak time, rise time, settling time and percent overshoot. Results showed that percentage error reduction between MRAC and PI controller during simulation was 96.21% while during experimental was 99.79%. Finally, results also showed that MRAC has percent overshoot of 2.65% compared to PI controller which produced percent overshoot of 3.85% during experimental. However, further recommendations are desired. These include the implementation of MIT rule and calculation of Augmented error method in MRAC.

ABSTRAK

Ketepatan dan kelajuan adalah sifat-sifat yang diperlukan dalam proses rekabentuk sistem kawalan bagi proses pemesinan dalam sektor pembuatan. Kehadiran beberapa faktor seperti gegaran yang dihasilkan daripada rekabentuk sesuatu mekanikal sebuah mesin dan daya geseran boleh menyebabkan berlakunya ketidaktepatan prestasi mesin. Objektif utama projek ini adalah untuk merekabentuk satu model rujukan kawalan suai atau dipanggil sebagai sistem kawalan MRAC untuk diaplikasikan pada alat mesin. Selain itu, objektif projek ini juga adalah untuk meningkatkan pengesanan ketepatan dan tindakan fana alat mesin, dan membuat validasi terhadap sistem kawalan melalui simulasi dan eksperimen. Sistem kawalan MRAC meliputi satu model rujukan dan satu gelung maklum balas sistem kawalan di mana satu algoritma dipanggil pendekatan Lyapunov digunakan. Perisian yang digunakan untuk prestasi ketepatan pada alat mesin ialah MATLAB/Simulink dan dSPACE. Prestasi ketepatan pada sistem kawalan yang dicadangkan dinilai berdasarkan “Maximum Tracking Error”and “Root Mean Square of Error (RMSE)”. Tindakan fana dinilai berdasarkan “Steady-State Error”, masa kemuncak, masa menaik, masa penetapan, dan peratus terlajak. Keputusan menunjukkan bahawa peratusan pengurangan ralat antara sistem kawalan MRAC dan PI melalui simulasi ialah 96.21% manakala melalui eksperimen ialah 99.79%. Di samping itu, keputusan menunjukkan sistem kawalan MRAC menghasilkan peratus terlajak sebanyak 2.65% berbanding sistem kawalan PI di mana menghasilkan peratus terlajak sebanyak 3.85% semasa menjalani eksperimen. Walaubagaimanapun, kajian lanjut dan pembaharuan terhadap projek ini adalah diperlukan. Antara penambahbaikan yang boleh dilakukan ialah menggunakan peraturan MIT dan kaedah Ralat Augmented dalam MRAC.

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LIST OF SYMBOLS

%OS	-	Percentage Overshoot
K_1	-	Adaptation Gain 1
K_2	-	Adaptation Gain 2
T_s	-	Settling Time
T_p	-	Peak Time
sec.	-	second
G_m	-	Transfer Function of Reference Model
e	-	error
u	-	control signal
ϴ	-	constant
t	-	Time
K_P or k_p	-	Proportional gain
K_i or k_i	-	Integral gain
γ	-	Adaptation gain
r	-	Position reference input
y	-	Plants output/ Position output
y_m	-	Model output
U_c	-	Input signal

LIST OF ABBREVIATIONS

PID	-	Proportional, Integral, Derivative
PI	-	Proportional, Integral
MRAC	-	Model Reference Adaptive Control
MIT	-	Massachusetts Institute of Technology
RMSE	-	Root Mean Square Error
S.S.E	-	Steady State Error
Max.	-	Maximum

CHAPTER 1

INTRODUCTION

This chapter covers the introduction of the project entitled “Design of Model Reference Adaptive Control (MRAC) for Machine Tool Applications”. In this chapter, it will cover project background which consists of introduction of adaptive control design and MRAC model. In addition, this chapter touches on the problem statement, objective and scope of project.

1.1 Project Background

A closed-loop control system, known as a feedback control system is a control system that has one or more feedback loops. In closed-loop control system, an output of the system is feedback to the loops to compare the actual output with the desired output. This comparison can reduce the error by automatically adjusting the systems input, and produce more accurate result for the system. In addition, the closed-loop control system able to increase the systems sensitivity, enhance robustness against external disturbances and produce a reliable performance. Thus, it is a must to design a controller for the said purpose. A good example of a controller is PID controller.

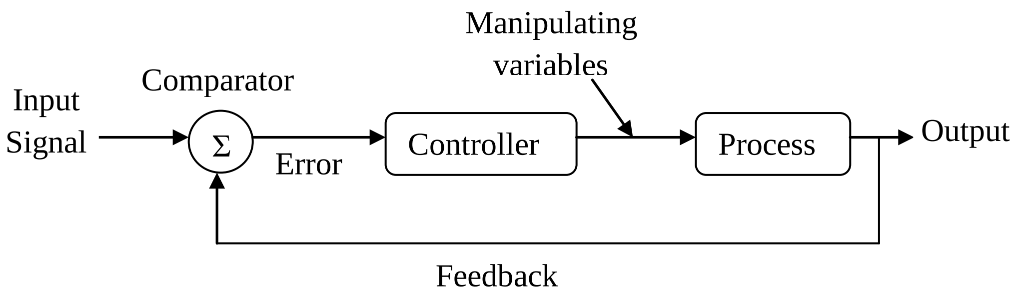

Figure 1.1: Feedback control system

PID controller, which consists of proportional, integral and derivative gain elements that are commonly used in industrial processes due to its flexibility attributes. A proportional band, the controller output is proportional to the error or a change in measurement based on the controller. In addition, the proportional to the error at instant time, t is called “present error”. Furthermore, the controller output in integral action is proportional to the amount of time the error that can eliminate offset. The proportional to the integral of the error up to the instant, t is interpreted as the “past” error. Finally, the controller output in derivative action is proportional to the rate of change of the measurement or error. The proportional to the derivative of the error at the instant, t is interpreted as the prediction of the “future” error. The performance of a PID controller is controlled by the choice of its parameter with some tuning. Bt tuning the PID controller, the desired control performance can be obtained by choosing suitable values for its adjustable parameter. As compared to the well-known and simple structured fixed gain PID controllers, adaptive controllers are very effective to handle the unknown parameter variations and environmental changes.

An adaptive controller consists of two loops, an outer loop or normal feedback loop and an inner loop or parameter adjustment loop. Furthermore, the Model Reference Adaptive Control (MRAC) refers to an adaptive system in which adaptive controllers are designed by using a reference model to describe the desired characteristics of the machine tool application to be controlled that provides a stability performance. Besides that, the basic block diagram of MRAC system shown in Figure 2 shows that $y_m(t)$ is the output of the reference model and y(t) is the output of the actual machine tool application and difference between them called as an error or denoted by e(t).

An equation of this error is written by $e(t) = y(t) - y_m(t)$. So, MRAC can be applied in machine tool application in order to produce a better performance and accuracy.

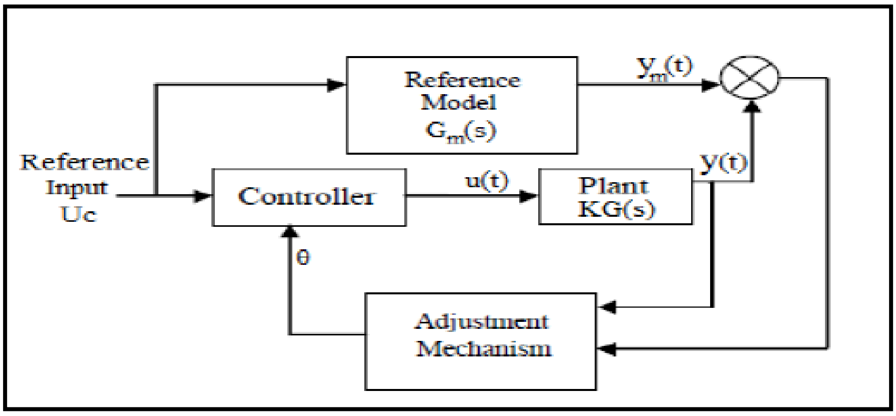

Figure 1.2: Example of Model Reference Adaptive Control (MRAC) Scheme

1.2 Problem Statements

The demand for better tracking performance in machine tools stimulates the improvement of machine tool technologies. A part included in the machine tool technology is the machine tool controller. A coordinated advancement of the different technology areas and good knowledge and understanding the factors that contribute to the machine accuracy and speed is important. One measure of accuracy is tracking performance that must be needed for machine tool application. The factors that can reduce the tracking performance are:

(i) Mechanical structure

(ii) Friction Force

The mechanical structure can reduce the tracking performance of machine tool. The mechanical of the system creates negatively to the dynamic and frequency response function (FRF) of the machine. The mechanical resonances are occurred during the movement of the machine tool and can reduce the stability of the system. The presence of machine tool resonance will create a physical vibration of the movement structure that can affect the tracking accuracy of a machine.

On the other hand, friction force is created between motor and support bearings of electromechanical drive system in nonlinear circumstances. The friction forces result a “quadrant glitches” in which accuracy of the system is disturbed. The glitches occur during the changing direction of the axis movement of the system.

These factors can be reduced by designing a better controller but it will result in a more complex control algorithm.

1.3 Objectives

The objectives of the project are:

i. To design a Model Reference Adaptive Control (MRAC) controller for machine tool applications to improve tracking performance and transient response.
ii. To validate the controller through simulation and experimental work.

1.4 Scope of Project

The scopes of the project are as follows:

i. The machine tool used is Ballscrew drive system XY table.
ii. The technique for design a controller is limited to PI controller and MRAC controller.
iii. The method used in designing MRAC controller is Lyapunov approach.
iv. The controllers are validated through simulation and experimental work using MATLAB and dSPACE software.

1.5 Organization of Report

This report focuses on designing a MRAC controller for obtaining precise position and tracking accuracy of XY Table Ball Screw Drive system. The report is organized as follows:

Chapter 2 discusses the literature review including introduction, why adaptive control, components of Model Reference Adaptive Control (MRAC) controller, MRAC modelling, stability analysis, system identification and summary.

Chapter 3 elaborates the project methodology including introduction, experimental setup, software requirement, system identification and summary.

Chapter 4 discusses the design and development including machine tools, model reference adaptive control (MRAC) design and MRAC simulation.

Chapter 5 discusses the result and discussion including MRAC diagram, experimental data collected, response of the machine tool system analysis and stability analysis.

Chapter 6 discussed the findings and the main results obtained with respect to MRAC controller design and recommendations for future work.