UNIVERSITI TEKNIKAL MALAYSIA MELAKA

DESIGN OF CONTROLLERS FOR TRACKING PERFORMANCE OF XY TABLE BALL SCREW DRIVE SYSTEM

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

by

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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 Bachelor of Manufacturing Engineering (Robotics and Automation) (Hons.). The member of the supervisory is as follow:

………………………………

(Dr. Ir. Lokman bin Abdullah)

ABSTRAK

Laporan ini membincangkan hasil kerja perekaan pengawal untuk prestasi XY bola meja sistem pemaju skru. Terdapat tiga tuntutan penting dalam merekabentuk pengawal bagi pemesinan operasi dalam persekitaran pembuatan. Komponen tersebut termasuk ketepatan pengesanan yang tinggi, ketepatan pengesanan tinggi dan keteguhan. Evolusi peralatan mesin teknologi melalui kemajuan pengawal peralatan mesin menyebabkan permintaan yang berterusan dengan ketepatan pengesanan yang lebih baik dalam industri alat mesin. Objektif projek ini adalah untuk merekabentuk pengawal PID dan lata P / PI untuk prestasi XY bola meja sistem pemacu skru menjejaki dan bandingkan pengawal tersebut melalui simulasi dan eksperimen. Perbandingan keputusan antara simulasi menggunakan perisian Matlab manakala keputusan eksperimen menggunakan Googol Tech XY sistem bola meja memandu skru untuk membuktikan kejayaan pengawal yang direka. Pengawal ini direka berdasarkan analisis terhadap margin keuntungan, margin fasa, kadar lebar, kestabilan dan sensitiviti. Pengawal direka telah memenuhi peraturan kebiasaan untuk margin keuntungan dan margin fasa. Untuk margin keuntungan, peraturan kebiasaan adalah 4-10 dB manakala margin fasa adalah 30-90˚. Lata pengawal P/PI yang direka berjaya mengurangkan ralat penjejakan sistem berbanding dengan pengawal PID ketika eksperimen. Penambahbaikan dengan menambah satu lagi kaedah menganalisis pengawal yang direka oleh visualisasi menggunakan pemprosesan imej amat disyorkan. Ini membantu untuk mengesan kesilapan dengan mudah.

ABSTRACT

This report presents the work done on designing controllers for tracking performance of XY table ball screw drive system. There are three critical demands in designing controller for machining operation in many manufacturing environment. The components include high tracking accuracy, high tracking precision and robustness. The evolution of machine tools technology through advancement of the machine tools controller causes the persistent demand of better tracking accuracy in industry of machine tool. The objectives of this project are to design PID and cascade P/PI controllers for tracking performance of XY table ball screw drive system and to compare the controllers through simulation and experimental process. The comparison of the results between the simulation using Matlab software and experimental using absolute plant of Googol Tech XY table ball screw drive system shows the success of the designed controllers in terms of the tracking performance. The controllers are designed based on the analysis of gain margin, phase margin, bandwidth, stability and sensitivity. The designed controllers have fulfilled the rule of thumb for the gain margin and phase margin. For gain margin, the rule of thumb is 4-10dB while phase margin is 30-90º. Cascade P/PI controller designed successfully lowering the tracking error of the system compared to PID controller for experimental work. It is recommended to add another method of analysing the designed controller by visualization using image processing which helps to detect the tracking error of the system easily.

DEDICATION

To my beloved parents,
Anang bin Mohamad and Norriza binti Kasah

ACKNOWLEDGEMENT

First and foremost, all praise to The Almighty, who made this accomplishment possible. I seek his mercy, favor and forgiveness.

Thousands of thanks to my great supervisor, Dr. Ir. Lokman bin Abdullah for the help, encouragement and guidance from the beginning until end of this writing project.

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My thanks and appreciations also go to my colleagues in developing the project and people who have willingly helped me out with their abilities.

Thank you.

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LIST OF ABBREVIATIONS

P	-	Proportional
I	-	Integral
D	-	Derivative
VAV	-	Variable Air Volume
DSMC	-	Decoupled Discrete-Time-Sliding-Mode
SISO	-	Single - Input Single - Output
GUI	-	Graphical User Interface
FRF	-	Frequency Response Function
LTI	-	Linear Time Invariant
mm	-	millimetre
NLLS	-	Non-Linear Least Square
DSP	-	Digital Signal Processor
CNC	-	Computer Numerical Control
RMSE	-	Root Mean Square Error
GM	-	Gain Margin
PM	-	Phase Margin
dB	-	Decibels
RGB	-	Red - Green - Blue

CHAPTER 1

INTRODUCTION

This chapter gives an overview about the project entitled, “Design of Controllers for Tracking Performance of XY Table Ball Screw Drive System. Problem statement, objectives, scopes of work and outline of the project are presented in this chapter.

1.1 Background

Machining is a process to change size from bigger to smaller and surface finish of a material through removal of materials that could be achieved by straining the material to fracture or by thermal evaporation (“SMEDA - Engineering and Manufacturing,” n.d.). Machining system consists of machine tool, cutting tool and the part to be machined. A good machining is defined as a process that can constantly perform faster with high accuracy. It is crucial for the machine tools industry in parallel with the advanced of technology today. In general, it is important for the tracking performance to be accurate and precise. Tracking accuracy is concessional by the effect that comes from the dead zones and the huge friction forces that are generated in a high stiffness electromechanical ball screw and bearing structure (Jamaludin, 2008). The purpose of the feed drive is to locate the component to the machine tool and to the work piece to the desired position.

Accuracy in position and speed lead to the quality and productivity of the machine tools. The common pattern of machine tool axes includes the rotary motor and a ball screw transmission which is finite in speed, acceleration, stroke and accuracy (Wang, Brussel, & Swever, n.d.). The issues can be visibly rectified by using linear motors. However, the advantage of linear motors is it lead to the insistence of a controller design to solve the problems.

In general, machining processes in machine tools are affected by disturbance force. Disturbance force is divided into two types which are friction force and cutting force. There are three cutting parameters that will affect the behavior of the cutting force. The parameters are feed rate, depth of cut and spindle speed (Gokkaya, 2010).

1.2 Problem Statement

Nowadays, the demand for high speed and accuracy of machine tools are needed in machine tools industry. Thus, a good controller design is crucial in order to obtain good tracking performance of a machine tool.

Unnecessary vibration will lead to inaccuracy and poor surface quality. The compensation of cutting force disturbance is desired in order to obtain good tracking performance.

In order to design controllers for XY table ball screw drive system, it requires knowledge and understanding about the machining parameters and knowledge on controller design. A threaded shaft that provides a helical raceway which role as a precision screw is the essential prerequisite for the ball screw drive with conditions of enduring high trust load and low in-house friction. The dependence of the system on the ball screw drive to run from one position to another position is the result of the requirement. The main problem is to design controllers which are PID and cascade P/PI controller with comparison of simulation and experimental in order to obtain an accurate tracking performance of the system.

The controllers are made based on the design analysis where include the gain margin and phase margin analysis and stability analysis. Besides that, the tracking performances of the designed controllers are being compared using two different amplitudes which are 1 mm and 15 mm through experimental work. The controllers are compared with the simulation based on the tracking errors and Root Mean Square Error (RMSE). The realistic and comparatively simple controllers are applicable for the machine tool industry.

1.3 Objectives

The objectives of the project are:

i. To design PID and cascade P/PI controller for enhancement of tracking performance of XY table ball screw drive system.
ii. To compare the tracking performance of the designed controllers through simulation using Matlab software and experimental work using real plant of Googol Tech XY table ball screw drive system.
iii. To compare the tracking performance of the designed controllers using different amplitudes through experimental work.

1.4 Scope of Work

The scopes of this project are:

i. The axis involved of the Googol Tech XY table ball drive screw system is Y-axis only in order to improve the tracking performance in a vertical direction.
ii. The controllers are designed by simulation using Simulink of Matlab software.
iii. The performance of controller is determined based on tracking error and RMS error.

1.5 Structure of Report

This report consists of five chapters that will be explained briefly about this project. The first chapter is about an introduction which contains the project background, problem statement, objectives and scopes of the project. Second chapter supplies a literature review on the previous researchers on tracking performance of table ball screw drive system as well as the application and control system approaches. The approaches of the model and different type of controller for cutting force compensation are reviewed in chapter two. After that, Chapter 3 is the methodology of the project that provides the process and descriptions of the project. Next is Chapter 4 where the designed controller, simulation of the model results and tracking performance of the designed controllers using different amplitudes will be presented and discussed in details. Lastly, the outcome of the project will be concluded in Chapter 5. The recommendation for future improvement of the project also will be included in this chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Traditional machining processes consist of turning, boring, drilling, reaming, milling, threading, shaping, planing and broaching as well as abrasive processes such as grinding, ultrasonic machining, lapping and honing while advanced processes include electrical and chemical means of material removal as well as the use of abrasive jets, water jets, laser beams and electron beams (Gutowski, 2009). Milling can be defined as a process of removing materials which covers variety of operation in manufacturing industry.

It is a demand for the machining process to get higher tracking accuracy at faster speed. However, the presence of disturbance forces in the process obstruct in achieving the goal. There are two disturbance forces that might occur during machining. The disturbances are friction force and cutting force. In order to track these disturbances forces, a motion tracking controller can be made. Motion tracking controllers are designed with the objective of achieving maximum tracking accuracy and robustness against disturbance and plant uncertainties. The size of the tracking errors and actuator input signals are important indicators to validate a control system (Jamaludin, 2008).

The implementation of classical cascade controller for the purpose of controlling various types of engineering appliances has been vastly utilized by control engineer community.

PID or Proportional Integral and Derivative controller is a conventional controller where the controller is the most common used in the world of control system. The factors of PID controller which are the simplicity, transparent design and ability of solving many practical control problems have contributed to its wide acceptance (Wang, 2004). Cascade controller provides a simple structure of controller but yet functional and have the ability to satisfy the control design requirement. In general, the controller consists of two loops, namely velocity loop and position loop .One of the best motion tracking controllers is Cascade P/PI controller. Velocity loop consists of Proportional (P) and Integral (I) controller which is at the inner loop while position loop is at the outer loop that consist of a Proportional (P) controller.

This chapter describes information of tracking performance of XY table ball screw drive system. Motion Control in Machine Tool is discussed in Subchapter 2.2 which including the mechanical and disturbances in drive system. Subchapter 2.3 is the controller design. This is where the controller design, cascade design based on PID and controller design based on cascade PID controller is discussed and lastly is the summary of this chapter is discussed in Subchapter 2.4.

2.2 Motion Control in Machine Tool

Machine tool is one of mechanical system that is required to perform faster in high accuracy to increase the productivity of manufacturing. This shows that processes with faster speed of processing, low time consume and high accuracy become important factors of good machine tools.

2.2.1 Mechanical Drive System

Cutting tool and work piece are two components that are used by feed drives to locate their position to the required location. When the desired location is far, rack and pinion drive is used and the other two types of power of feed drives that are mostly used in industry are linear motor drives and ball screw drive as shown in Figure 2.1 (Altintas, Verl, Brecher, Uriarte, & Pritschow, 2011).

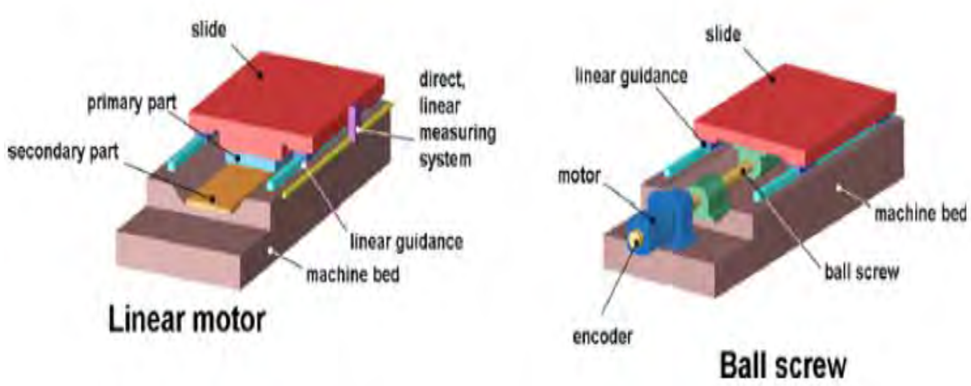

Figure 2.1: Linear and Ball Screw Mechanism

(Source: Altintas, Verl, Brecher, Uriarte, & Pritschow)

For rack and pinion drive, the straight rack can be considered as a segment of a gear having infinite pitch radius. The rotary motion of the pinion is converted into linear motion of the straight rack in this arrangement and may be manufactured with either straight spur or helical teeth (Collins, Busby, & Staab, 2010). The rack and pinion drive system is suitable for machine tools with long working path. This is because the rack and pinion drive system produced high torque with low revolution in power transfer (Altintas, 2011). Figure 2.1 shows the movement of rack and pinion in producing linear movement ("CR4 - Thread: Rack and Gear Design," n.d.).

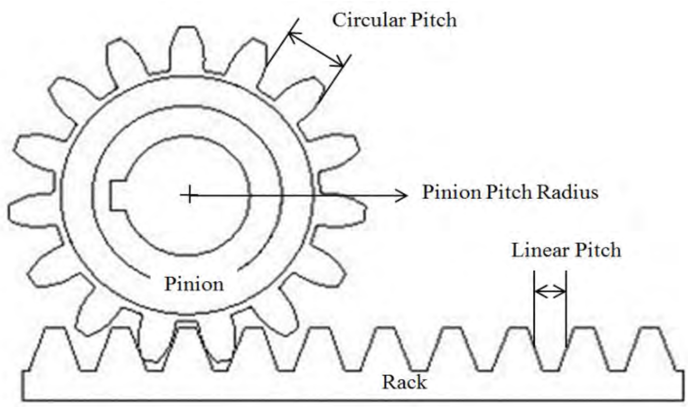

Figure 2.2: Rack and Pinion Drive System

(Source: Altintas, Verl, Brecher, Uriarte, & Pritschow, n.d)

The drive system that will be discussed is ball screw drive system. It is commonly used in many machine tools in providing linear motion for high speed machine tools. The ball-screw drive consists of a screw supported by thrust bearings at the two ends, and a nut with recirculating balls. The nut is connected to the table. One end of the ball-screw is either attached to a rotary motor directly or through gear or belt speed reduction mechanisms as shown in Figure 2.3. The nuts are preloaded to avoid backlash by adjusting the spacer, creating offset between the leads or using oversized balls. It is rather difficult to grind the pitch at uniform intervals, and the pitch errors are transmitted as position errors unless they are compensated (Altintas et al., 2011).

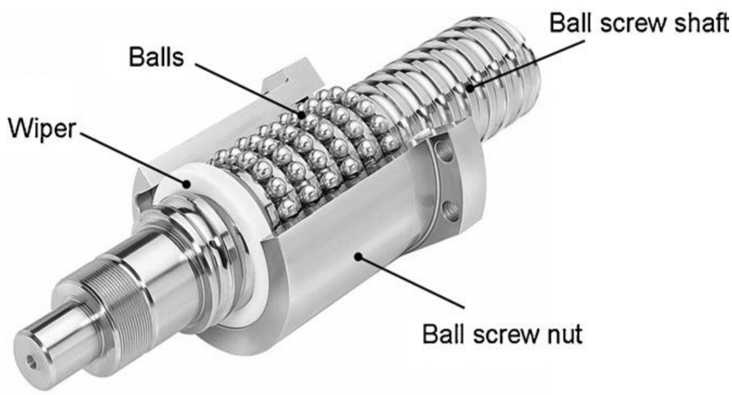

Figure 2.3: Structure of Ball Screw System
(Source: Altintas et al, 2011)

This drive system can be described as a mechanical system that converts rotary motion to linear motion where the rotary motion comes from the rotation of the ball screw before change into linear movement. Basic structure of ball screw mechanism is shown in Figure 2.4 ("Manufacturing Automation Laboratory (MAL) UBC," n.d.).

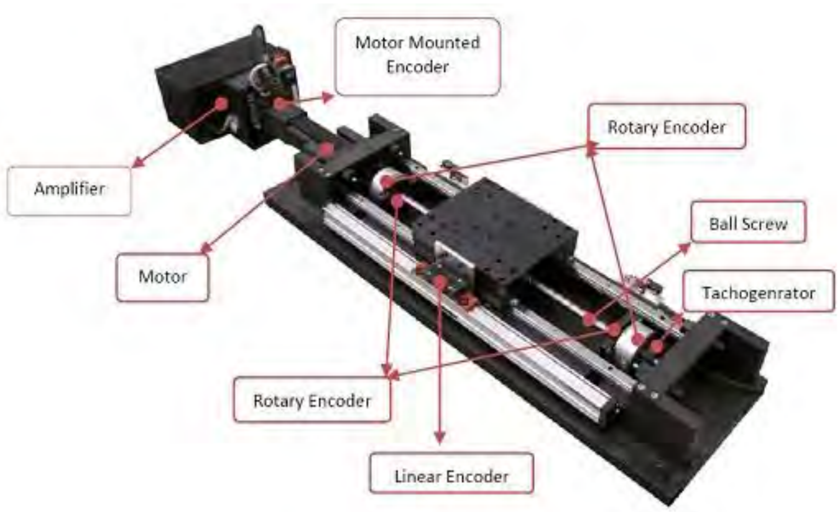

Figure 2.4: Ball Screw Drive System
(Source: http://mal.mech.ubc.ca/, n.d)

Last drive system that will discussed in this chapter is linear motor drive. This drive is different from the ball screw drive system as it is drives the machine tool feed axis in linear and does not need a mechanical transmission mechanism. The moving part of the liner motor is always attached directly to the load and the system can be appropriately described as having only one degree of freedom (Moscrop, 2008). Besides that, linear motors also described as special class of synchronous brushless servo motors as their function just like torque motors but are opened up and rolled out flat. Electrical energy is converted into linear mechanical energy with high level of efficiency through the interaction of the electromagnetic between the primary part which is the coil assembly and permanent magnet assembly as the secondary part. ("Direct drive linear motor principle - ETEL Innovative motion control," n.d.).

2.3 A Good Tracking Performance – A Controller Design Approach

2.3.1 Controller Design

Previous researchers have done many researches in tracking performance of machine tools either from Computer Numerical Control (CNC) machine or the basic structure of CNC machine which is XY Table. Based on literature review, there several controllers that can be used in motion control especially in tracking performance of XY Table. The controllers include traditional Cascade, Sliding Mode Control, Gain Scheduling, Proportional Integral Derivative (PID), Cascade Proportional Integral (P/PI), Non-PID and Non Cascade controllers. Characteristics of simple, transparent design and practical made PID controller as the conventional controller that proposed by past researchers. In the next two subchapters which is Subchapter 2.3.2 and Subchapter 2.3.3 will touch about controller design based on PID and controller design based on cascade PID controller respectively.