UNIVERSITI TEKNIKAL MALAYSIA MELAKA

PID AND CASCADE CONTROLLER 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

MUHAMMAD NASIRUDIN BIN TAJUDIN
B051110232
920609-07-5099

FACULTY OF MANUFACTURING ENGINEERING

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TAJUK: **PID AND CASCADE CONTROLLER FOR TRACKING PERFORMANCE OF XY TABLE BALLSCREW DRIVE SYSTEM**

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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 & Automation) (Hons). The member of the supervisory is as follow:

………………………………

(Ir. Dr. Lokman Bin Abdullah)

ABSTRACT

As the technology advancing into a new era, the constant need of high accuracy in term of tracking, robustness, low cost, high flexibility, better surface finish and speed in machine tool have trigger the development of advance technologies to compensate the weakness in the traditional machine. The machining problem in terms of high disturbance force and tracking performance quality of work piece materials need to be solved. Therefore this research is focusing on one of the demand of machine tool that is better tracking accuracy. The objective of this research is to propose and design parameters of the control strategy for tracking performance of the system. Then the proposed controller are validated through simulation and experimental work or mathematical model and lastly to the controller are analysed and compared the effectiveness in term of tracking performance. The controller are test at X-axis of XY table for setting of frequency 0.7 Hz with amplitude 1 mm and 15 mm. The maximum tracking error for PID at 1 mm and 15 mm was 0.007104 and 0.1066 respectively. While maximum tracking error for Cascade P/PI at 1 mm and 15 mm was 0.00937 and 0.1406 respectively. Then the percentage error calculated for PID at 1 mm and 15 mm was 0.7104 % and 0.7106 % respectively. Cascade P/PI at 1 mm and 15 percentage errors was 0.937 % and 0.9373 % respectively. The outcome of the RMS error is the largest at 15 mm amplitude by PID controller system and the lowest RMS error at 15 mm amplitude by Cascade P/PI controller system. Even though RMS error gives an accurate picture of tracking performance rather than using maximum tracking error, but still both maximum and tracking error result agree that Cascade P/PI controller performed better from PID controller at high amplitude for machine tool application. This is because of the percentage error reduction between PID and Cascade P/PI controller is 86.07 %.

ABSTRAK

Pada masa kini, apabila teknologi semakin canggih keperluan untuk memiliki ketepatan yang tinggi, keteguhan, kos yang rendah,fleksibiliti, kekemasan permukaan dan kelajuan di dalam peralatan mesin telah mencetuskan permulaan kepada pengkajian dalam teknologi. Oleh itu kajian ini memfokuskan kepada salah satu kehendak dalam peralatan mesin iaitu ketepatan pengesanan yang lebih baik. Objektif kajian ini adalah untuk mencadangkan dan merekacipta parameter untuk ketepatan pengesan yang berfungsi. Setelah itu, pengawal-pengawal yang dicadangkan telah disahkan melalui cara memandingkan keputusan simulasi dan eksperimentasi ataupun model metematik dan kebersanan dalam terma ketepatan pengesanan. Di tetapkan frekuensi 0.7 Hz dengan amplitud 1 mm dan 15 mm dan mengunakan paksi X, “XY table”. Kesilapan pengesanan maksimum bagi PID di 1 mm dan 15 mm adalah 0,007104 dan 0,1066. Manakala kesilapan pengesanan maksimum untuk Cascade P / PI pada 1 mm dan 15 mm adalah 0,00937 dan 0,1406 . Kemudian ralat peratusan dikira untuk PID di 1 mm dan 15 mm adalah masing-masing 0,7104 % dan 0,7106 %. Cascade P / PI pada 1 mm dan 15 peratus adalah kesilapan masing-masing 0,937 % dan 0,9373 %. Hasil ralat RMS adalah yang terbesar di 15 mm amplitud oleh sistem pengawal PID s dan ralat RMS yang paling rendah pada 15 mm amplitud oleh sistem pengawal Cascade P / PI. Walaupun kesilapan RMS memberikan gambaran yang lebih tepat untuk prestasi pengesanan, namun pengesanan maksimum dan juga kesilapan RMS memberikan keputusan yang sama iaitu memilih pengawal Cascade P/PI sebagai yang terbaik daripada pengawal PID untuk amlpitud yg tinggi untuk pengunaan peralatan mesin. Ini adalah kerana peratusan pengurangan ralat diantara PID dengan cascade P/PI adalah sebanyak 86.07 %.

DEDICATION

First of all I will dedicated to Allah S.W.T, The Almighty God who gave his strength and knowledge for completing my Final Year Project (FYP)

To my beloved parents, Mr. Tajudin Bin Hamzah and Mrs. Nazirah Binti Md Noordin for their understanding and support morally and financially.

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LIST OF ABBREVIATIONS, SYMBOLS AND NOMENCLATURE

AC	-	Alternate Current
CNC	-	Computer Numerical Control
DC	-	Direct Current
DSP	-	Digital Signal Processing
FFT	-	Fast Fourier Transform
FYP	-	Final Year Project
FRF	-	Frequency Response Function
G_m	-	System Model Transfer Function
I/O	-	Input/Output
K_f	-	Motor Constant
PID	-	Proportional, Integral, Derivative
PI	-	Proportional, Integral
PD	-	Proportional, Derivative
P/PI	-	Proportional/Proportional, Integral
MIMO	-	Multiple Input Multiple Output
ZPTEC	-	Zero Phase Tracking Error Controller
RMSE	-	Root Mean Square Error
RMS	-	Root Mean Square
PSM	-	Projek Sarjana Muda
SISO	-	Single Output Single Input
LTI	-	Linear Time Invariant
DAC	-	Digital to Analog
NLLS	-	Nonlinear Least Square
T_d	-	Time Delay

V	-	Voltage
sec	-	Seconds
mm	-	millimetre

CHAPTER 1

INTRODUCTION

1.1 Background

The advancement of technologies boosts the need for accuracy, robustness, speed and quality of the product in machine tool industries. However, the existing of disturbance in machine tool system will lead to the in accuracy and poor surface finish of the product produce. In general, there are two type of disturbance, one is cutting force and the other is friction force. Therefore this project is focusing on accuracy in tracking performance.

The cutting force is produce from the contact in between the cutting tool and the work piece, thus it exist in nature of the milling process and it simply be refrain from it (Abdullah et al., 2012). As stated by Kalpakjian et al. (2013), the cutting force is determined by the milling parameters such as the depth of cut and spindle speed.

XY Table is a basic structure of CNC machine. It has been widely use in machine tool industries. Good examples of CNC machine are work feeder of CNC lathe, CNC milling and drill press. In general, XY table consist is X-axis and Y-axis motion, where each motion axis is driven by individual actuator such as DC servomotor through high precision ball screw (Patrick et al., 2012).

According to Chiew et al. (2012), the PID controller are applied in many industrial uses such as temperature control of refrigerator and air conditioning system. Its flexibility allowed the benefits from the improvement of technology. The PID controller is the combination of PI and PD controller that improve both steady state error and transient response.

1.2 Problem Statement

As the technology advance into a new era, the constant need of high accuracy, robustness and speed in machine tool have trigger the development of advance technologies to compensate the weakness in the traditional machine. The machining problem in terms of high disturbance force and tracking performance in term of lower maximum tracking error and root mean square error (RMSE) have reduce the quality of the product produce. There are two types of disturbance force namely cutting force disturbance and friction force disturbance. Today, computer numerical control machine or also known as CNC machine is a machine that can easily produce metal product into the designed shape. This machine play major role as it is been widely used in manufacturing industries. XY table is basic structure of CNC machine that used propagate the material for machining. Since there is a need for improving the tracking performance of a machine tool, therefore in order to obtain high accuracy, robustness and speed in machine tool to reduce the disturbance force, it is a must to design a suitable controller to compensate those disturbance forces.

1.3 Objective

The objectives of this research project are:

i. To propose and design parameters of the control strategy for tracking performance of the system.

ii. To validate the control strategy that been proposed through simulation and experimental work or mathematical model.

iii. To analyse and compare the effectiveness of the PID controller and Cascade P/PI in term of tracking performance.

1.4 Scope

The research project scopes are:

(a) Using only PID controller and Cascade P/PI controller.

(b) Using only X-axis of XY table ball screw drive system.

(c) Amplitude used are 1 mm and 15 mm and frequency used of 0.7 Hz.

(d) The tracking performance of XY table ball screw drive system are compared based on tracking error and root means square error (RMSE)

1.5 Organization of Report

The research report is organized as stated:

(a) Chapter 2 included the literature review of mechanical drive system, disturbance forces and controller design approach of the drive system for the machine tools.

(b) Chapter 3 consist of methodology in this research project. The methodologies are flow chart and Gantt chart, experimental setup, system identification and system modelling and also motor constant identification.

(c) Chapter 4 describe and further discuss on the controller design, analysis, validation and result of PID controller and Cascade P/PI based on maximum tracking error and also root mean square error (RMSE).

(d) Chapter 5 concludes the findings and the results generate with respect to tracking performance of XY table ball screw system of X-axis with the recommendation for future study.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

Nowadays, in machine tool society, the high accuracy and robustness characteristic are the aim of the positioning system in the machine tool for accommodating against various disturbance force (Abdullah et al., 2013). To realise this needs, the specific controller are design especially for the machine tool. One of the item that can add to the high accuracy and robustness is the tracking performance of it drive system. The presence of the disturbance force can further cause inaccuracy in tracking and positioning (Abdullah et al., 2012). Disturbance forces are classified as cutting force and friction force. In order to improve the tracking performance the controller need to compensate one of the disturbance forces that is cutting force.

In this chapter, the information regarding the study are provided. Firstly, the state of art on motion control of machine tool are discussed in section 2.2 that covers the mechanical drive system in section 2.2.1 and disturbance in drive system in section 2.2.2. Then in section 2.3 the method of getting a good tracking performance by using controller design approach is discussed thoroughly. Lastly in section 2.4 the summary of the literature review is stated.

2.2 State of the Art on Control in Machine Tool

Entering this modern era, the mechanical drive system have advanced into latest technology with a higher demand. This advancement of drive systems are needed to counter the demand of high speed, precise positioning and tracking performance. As this situation happen, the task become more challenging to strive for a better tracking system. In general, the state of the art of control in machine tool section will discuss about the chronological change in mechanical drive system and also about the disturbance force and the ways to compensated it.

2.2.1 Mechanical Drive System

The evolution of the mechanical drive system have replace the use of old type of drive system that is rack and pinion with more advance mechanism of direct drive such as piezoelectric drive system and also linear drive system. This event have offers the manufacturing industries the speed and precision of machine that they needed to produce a higher quality product with shorter time.

First is the rack and pinion drive system. It have a pair of circular gear that been calledpinion and also a linear gear that is called as a rack and it function to transform rotational motion into linear motion, as shown in Figure 2.1 (Abdullah, 2014). According to Altintas et al. (2011), the rack and pinion drives are suitable for longer distance of feed travel and to realize it the several racks must be combine together.

The ability to go for longer distance of feed is because of the power transfer and the system produce a high torque with low revolution. Futhermore, the drive system design should be having high torsional stifness and also clearance freedom and it can be done by seperation of pinion or drive the pinion with two motor in opposite direction (Altintas et al., 2011).

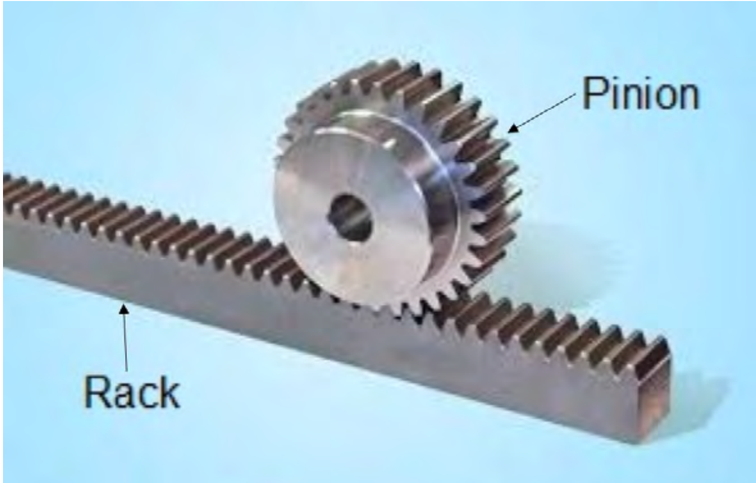

Figure 2.1: Example of Basic Rack and Pinion Drive System

Next is the ball screw drive system that is been shown in Figure 2.2. Ball screw drive system is the main drive system that been used by the XY table in this research. This conventional type of this drive structure is a type of transmission mechanism that used to converts motion of motor from rotary motion to linear motion and it consist of gearing elements and the lead-screw (Jamaludin, 2008).

The advantages of the ball screw drive system is the ability to adjust with it environment to a range of machine sizes, feed rates and process forces (Pritschow, 1998).However, there are still some problem exist in this drive system. According to Abdullah (2014), the performance of the drive system in the term of tracking accuracy is also been influence by the component of lead screw pitch tolerance that lead to transmission error. Furthermore, by Abdullah (2014), state that the friction force that exist in nature of electromechanical ball screw and bearing structure will degrade the tracking accuracy of the drive system.

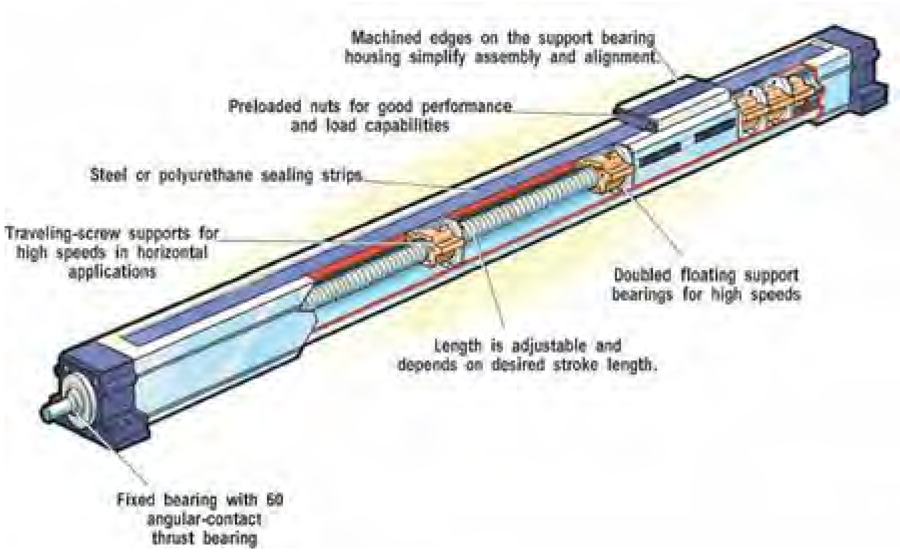

Figure 2.2: Example of Basic Ball Screw Drive System

Third drive system is linear drive system. According to Jamaludin (2008), the linear motor with direct drive technique or simply known as linear drive system is the improvement of the ball-screw drives system as it has no mechanical transmission between motor and load thus eliminate friction and backlash that are normally present in the transmission mechanisms such as gear boxes, harmonic drives and rack-and-pinion systems. In addition, the total system friction also been lowered in guide ways. This also gives better tracking performance as the transmission errors are gone.

The magnetic force in between the linear motor; primary and secondary parts moved the XY table, therefore in the linear drive there is no flexible motion transmission and the guide system is similar to the ball screw drives system (Altintas et al., 2011). In addition, Altintas et al. (2011) stated that as linear motor can reach a higher accelerations while carrying light mass of material, the ball screw drive system can retain its acceleration capacity for an alternative form of material mass caused by the inertia reflected to the rotary motor reduced.

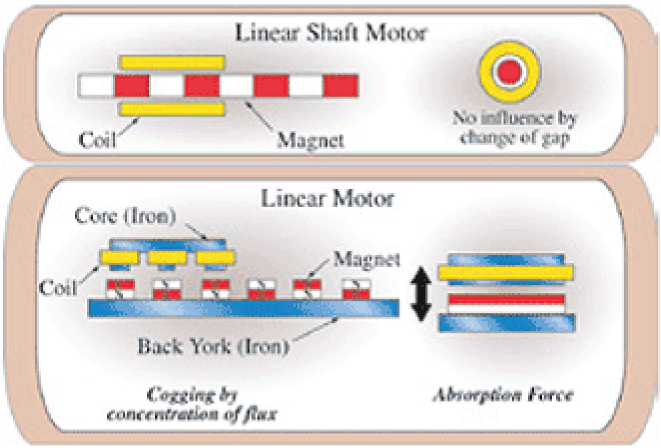

Figure 2.3: The Example of Iron Core for the Linear Drive System

The fourth mechanical drive system is piezoelectric drive system. In micro-machining sectors, piezoelectric actuators became an important component as it can supply a higher force and high stiffness of movement with nano-scale resolution but restricted by it minimum travelling distance (Elfizy et al., 2004). According to Abdullah (2014), there is a large number of exposed ceramic discs that is coated with flexible insulation material in the fundamental of the assembled type of piezoelectric actuator to give a better dynamic performance for actuating the movement of the XY Table. The general theory of piezoelectric actuator shown in Figure 2.4 is the ability to produce a large force by generating electric charge in response to be applied in mechanical loads to drive the locomotion of the system.

Figure 2.4: Example of Piezoelectric Drive Actuator