TITLE: DESIGN OF SELF-TUNED PID CONTROLLER FOR LINEAR DIRECT DRIVE SYSTEM

Submitted in accordance with the requirement of the University Teknikal Malaysia Melaka (UTeM) for the Bachelor Degree of Manufacturing Engineering (Hons.)

by

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DECLARATION

I hereby, declared this report entitled "Design of self-tuned PID Controller for linear direct drive system" is the results of my own research except as cited in reference.

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APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of Universiti Teknikal Malaysia Melaka as a partial fulfillment of the requirements for the degree of Bachelor of Manufacturing Engineering (Hons.).

The members of the supervisory committee are as follow:

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(Principal Supervisor)

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(Co-Supervisor)

ABSTRACT

The purpose of this study is to design a self-tuned proportional integral derivative (PID) controller for linear direct drive system. Linear direct drive system is said to be the simplest drive system as it has no transmission between the driver, in this case motor and load (workpiece). There are many types of controller existing today used by industries for manufacturing process and PID controller is one of the most common controller used by industries for its simple structure and easy to implement. Tuning of PID is very important as the gain values in PID controller which are K_p, K_I,and K_D are set to have their own task in achieving the desired output. K_p is the proportional gain which provides the overall control actuation. K_I is the integral gain and it helps in decreasing the steady state errors and lastly K_D is the derivative gain which improves the transient response. Self-tuning method is a very significant method of tuning a PID controller as the gain values will be varied as the disturbances values vary. There are two types of disturbances that is highlighted in this project and they are friction force and cutting force. These two forces exist as in the real scenario, the performance of the PID controller will be affected by values injected into the system by these disturbances.

ABSTRAK

Tujuan kajian ini dijlankan adalah untuk mereka bentuk sebuah sistem kawalan *"PID"* talaan automatik untuk kegunaan sistem pemacu langsung. Sistem pemacu langsung telah dikenali sebagai sistem pemacu termudah oleh kerana tiada pengaliran di antara pemacu, di mana di dalam kajian ini motor, dan beban (bahan kerja). Terdapat banyak jenis sistem kawalan pada hari ini di industri-industri pemprosesan dan sistem kawan *"PID"* merupakan satu sistem kawalan yang terkenal dan banyak digunakan oleh pemaju pemaju industri kerana strukturnya yang mudah dan kesenangan untuk dipasang. Penalaan sistem *"PID"* adalah sangat penting kerana jumlah *"gain"* yang terdapat pada setiap blok di dalam sistem iaitu "K_p, K_I, dan K_D" dan setiap blok ini mempunyai tujuan atau tugasan yang tersendiri untuk membantu mendapatkan hasil yang diingini. K_p atau lebih dikenali sebagai *"proportional gain"* menyara keseluruhan kawalan aktuasi. K_I atau lebih dikenali sebagai *"integral gain"* membantu di dalam mengurangkan suatu *"error"* yang dipanggil *"steady state error"* dan akhir sekali, K_D atau dikenali sebagai *"derivative gain"* membaik pulih *"transient response"* di dalam sesebuah sistem. Kaedah penalaan sendiri atau lebih glamor dipanggil *"Self-tuning"* merupakan satu kaedah yang sangat penting di dalam menala pengawal*"PID"* kerana jumlah di dalam *"gain"* akan berubah serentak dengan perubahan jumlah gangguan yang juga akan berubah. Terdapat dua jenis gangguan yang ingin di tekankan iaitu geseran dan juga kuasa pemotongan. Dua gangguan ini adalah hukum alam di dalam sistem pemacu dan prestasi pengawal *"PID"* ini akan dianalisis Bersama dengan dua gangguan yang dimasukkan ke dalam sistem pemacu.

DEDICATION

Alhamdulillah. All praises to the most high.

To my beloved father, Mohamad Nor Bin Ahmad.
An engineer, my idol since I was a kid.
To my lovely mother, Suriyati Binti Samad.
She does everything even before I came into this huge Earth.
Their help and support mean the whole world to me.

To my lecturers, siblings and friends
They always know I can go far and give my very best, every single time.

I thank every single heart that beats around me.
Without them, I won't stand where I am standing nor sit where I am settling today.
May your kind deeds be paid and your kind hearts be loved.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Proportional Integral Derivative (PID) Controller is one of the most common controller used in many systems. A system is designed to give user the desired output by giving in the input which normally comes from the user too. The least percentage of error is the most desirable and the most efficient system a user wants to encounter with. This PID Controller is one of a few ways to achieve that least percentage of error. Therefore, controller is present in a system after a feedback. A closed loop system is a system which consists of input, plant or system, output and feedback. A feedback will run the plant again until the least percentage of error is given out as an output.

PID controller converts the error into a command to be sent into the plant or system. A zero error means that the desired output is obtained by the rate of change of time but it is very difficult to achieve because in engineering, to achieve perfection is impossible. The decision on choosing the best system is based on the actual result produced. The lesser error of output a system can produce or at least the nearer the actual output to the desired output, the better it is.

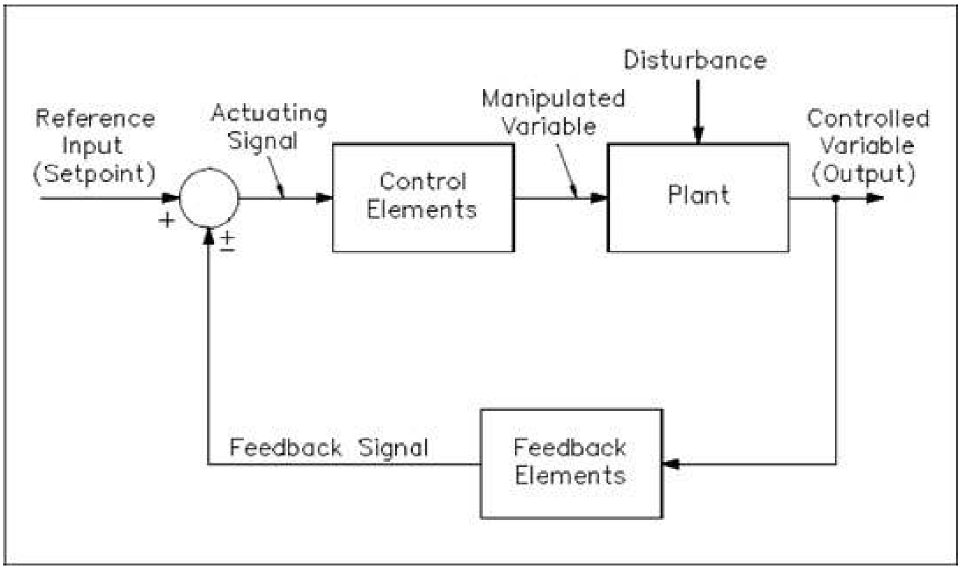

Figure 1.1: Block diagram of a closed-loop control system.

1.2 Problem Statement:

Two main demands in machine tools are high tracking accuracy and high precision (L. Abdullah et al., 2013). These two factors will contribute to a high flexibility system and a better surface quality product. The decrement of error percentage need to be execute to obtain the most desirable output in a system. All controllers including PID controller are tuned manually and as for manually-tuned is done by stopping the system and changing the value of proportional coefficient, integral coefficient and derivative coefficient. It is possible to tune a PID controller automatically and there are some approaches to achieve that. Amid all of those approaches, which self-tuned controller are best to be chosen as the most compatible self-tuned PID controller and this is done by comparing their tracking error and root mean square (RMS) error.

1.3 Objectives

The objectives of this research are:

a) To design a self-tuned PID controller for linear direct drive system.
b) To run the transfer function of linear direct drive system
c) To validate the performance of the controllers via simulation and experimental work.

1.4 Scope

The scopes of this research are:

i. This project focuses on the movement of the XY table for linear direct drive system.
ii. The methodology to conduct this project will be focusing on self-tuning method.
iii. The performance of the self-tuned PID controller will be judged by using two kind of errors which are tracking error and RMS error.
iv. The simulation of controller is validated using MATLAB/Simulink software only.
v. The frequency and amplitude used for the experiment to determine the precise positioning are 0.2Hz and 0.4Hz and 15mm only.
vi. The compensation of cutting force will be conducted at three different spindle speed which are 1500 rpm, 2500 rpm and 3500 rpm.

1.5 Importance of Study

This research is conducted to enhance the knowledge and understanding in term of designing the self-tuned PID controller and its contribution to the high accuracy and precision of machine tool especially for linear direct drive system. Among all of the techniques to design a self-tuned PID controller for linear direct system, the best technique is to be figured out by analyzing the tracking error and RMS error. Two beneficence of this research are listed as below

i. The best self-tuned PID controller to be used for linear direct drive system
ii. The comparison of the tracking performance amid the techniques to design a self-tuned PID controller for linear direct drive system.

1.6 Organization of the report

This research focuses on the self-tuning PID Controller for linear direct drive system. To ease the understanding of this research, this report will be arranged and organized such below:

i. Chapter two (2) will describe on the basic type of controllers, PID controllers, type of drive systems and disturbances in machine tools correspond to
ii. Chapter three (3) will explain about the methods to be used to design a self-tuned PID controller for linear direct drive system.
iii. Chapter four (4) will present the results of tracking error and RMS error which indicate the performance of the self-tuned PID controllers.
iv. Chapter five (5) will focus on the discussion of all of the techniques used to design a self-tuned PID controller and recommendations for further research.

CHAPTER 2

LITERATURE REVIEW

Abstract

The ultimate aim of this study is to design a self-tuned proportional integral derivative (PID) controller for linear direct drive system. As we know, different drive systems have different transfer function obtained from system identification. A conventional PID controller has fix gain values for K_p, K_I,and K_D. A self-tuned PID controller is said to be able to vary the gain values when the disturbances values varies too.

2.1 Introduction

Proportional Integral Derivative (PID) controller is the basic controller used in many systems. Because of its simple structure, easy to implement, robust nature and number of tuning parameters are less, PID controllers are the most commonly used controllers in process industries (Chopra, Singla, & Dewan, 2014). Most of process industries have been using the PID controllers because of its simple structure, ease of implementation and robustness in operation (Kansha, Jia, & Chiu, 2008). The control performances of a PID controller is strongly affected by the PID gains itself. Most of the time, the output produced by the system consists excessive overshoots and long settling time, Ts and that is why a lot of approaches of tuning PID gains are proposed (Ashida, Wakitani, & Yamamoto, 2017). A lot of the tuning rules of PID controllers are correspond on a linear process model acquired either through carrying out step tests or by linearization a nonlinear process model around the nominal operating condition (Kansha et al., 2008).

2.2 Mechanical Drive System

Mechanical drive systems are often and frequently used in machine tools all over the world as one of its purposes is to convert rotational motion into translation motion. Another reason of using mechanical drive system is to match the speed and torque between the actuator and the load (Al-Sharif. Lutfi., 2017). Machines consist of a mechanical standpoint or in another word, a complex system of material bodies with different kinematic linkages. Moving mechanical systems may have one or more degrees of freedom and are categorized into plane and spatial. Individual members or bodies planar mechanical systems can undergo sliding moton, rotation and general plane motion (Gramblička, Kohár, & Stopka, 2017). Different drive systems have different tracking accuracy performances. The mechanical structure of the drive systems itself affects their tracking performances (Jamaludin, 2008). Two other factors that are very crucial in manufacturing process are high tracking accuracy and precision (Lokman Abdullah et al., 2013)

Mechanical drive systems can be described in terms of components consist of mass/inertia, frictional and stiffness properties. These components can be represented by sets of simultaneous differential equations (Whalley, Ebrahimi, & Abdul-Ameer, 2005). Direct drive systems have overshadowed some disadvantages of electromechanical drive systems. Direct drive systems have successfully contributed their speed and high tracking performance in industry compared to conventional electromechanical drive systems (Jamaludin, 2008). Some examples of mechanical drive system are conveyor belts, power-screws or lead-crews, sprocket and chain, gearbox, rack and pinion, pulley and belt and sheave and rope (Al-Sharif. Lutfi., 2017).

Into the bargain, drive dynamics are not the only limiting factor in machining performance. Considering the desired tracking accuracy and the surface quality, process stability is a very serious issue in machine tools hence, the structural dynamic stiffness of the machine tool will strongly affect the machining results or the output (Byrne, Dornfeld, & Denkena, 2003).

2.2.1 Rack and Pinion Drive System

Rack and pinion drive consist of two gears which always come in pair. It consists of a circular gear and a called pinion and a linear gear called rack. Rack and pinion drive system converts rotational motion into linear motion (L. Abdullah et al., 2015).

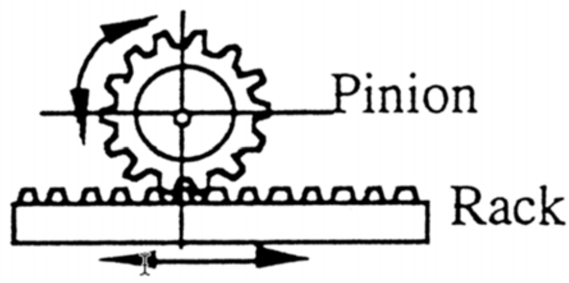

Figure 2.2.1: Rack and pinion drive system

It has higher stiffness than ball screw drives system. Rack and pinions are recognized to be used for large machine tools as their stiffness is independent of the travelling distance (Verl & Engelberth, 2018). Rack and pinion drive system are suggested for long travel distances. It is done by adding several tracks together, and a very long travel feed can be acknowledged (Altintas, Verl, Brecher, Uriarte, & Pritschow, 2011).

2.2.2 Ball Screw Drive System

Ball screw drive system is used widely in manufacturing process especially in Computer Numerical Controlled (CNC). This drive system is more suitable to be used in CNC machine tools to position the workpiece relative to the tool. Ball screw drive system has a high stiffness, a reliable operation and able to reduce the inertia impact and the varieties of cutting force (F. Li, Jiang, Li, & Ehmann, 2018). This drive system also transform rotary motion into linear motion with high precision. Other than being used in CNC machine, ball screws also can be found in a lot of engineering systems that require very accurate position control (P. Li et al., 2018). Ball screw drive system is known as the most frequently used drive system in machine tools (Altintas et al., 2011).

The process forces are channeled through the ball screw into the machine structure during the cutting operations. Generally, ball screw drive system consists of a screw and a nut system. Both of the components equipped with raceways and rolling elements, which divide the raceways of spindle and nut system (Brecher, Eßer, Falker, Kneer, & Fey, 2018).

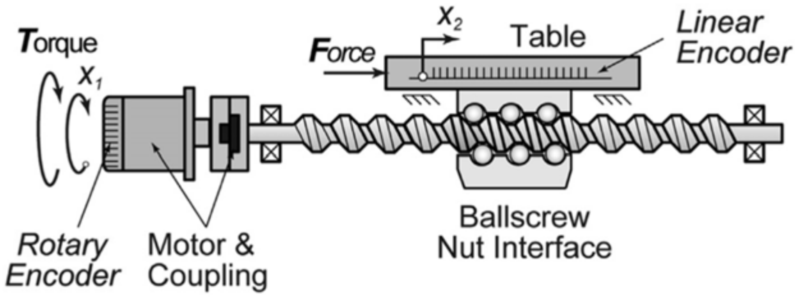

Figure 2.2.2: Schematic diagram of ball-screw drive system (Dumanli & Sencer, 2018).

Machining accuracy is strongly depending on the tracking performance of the ball screw drive system for a required trajectory. At a high speed and high acceleration machining process, the driving force of the motor rises up, which contributes to the incremental of the force between the components of the drive system. In this case, elastic deformation and vibration of some components become more significant as the force increases (F. Li et al., 2018).

2.2.3 Linear Direct Drive System

Another drive system that has an important role in machine tools is direct drive system. Linear direct drive system has lead over ball screw drive system as it has no mechanical transmission between motor and load (Jamaludin, 2008). Linear motors has no contact energy translation and has a high speed and acceleration, have been widely used to various areas requiring high accuracy and high speed motions (M.-F. Hsieh et al., 2007). Linear motor drive has become more famous and has been used for high-speed and high-precision machine tool applications because of its high rigidity, speed, acceleration, thrust as well as precision (Yang, Lu, Ma, Zhang, & Zhao, 2017).

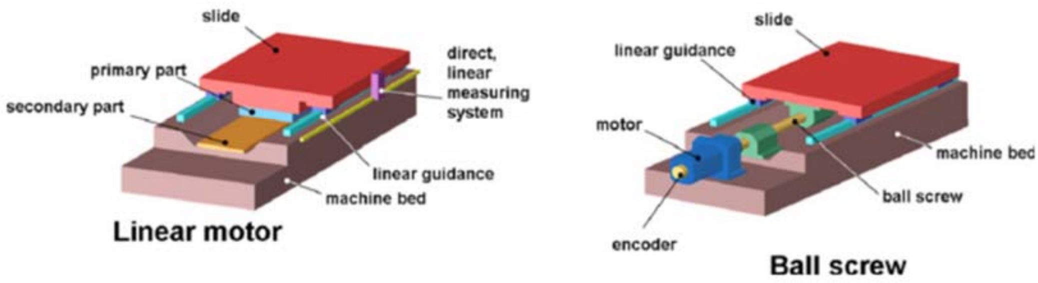

Figure 2.2.3: Linear and ball screw drive mechanisms (Altintas et al., 2011).

Ball screw and linear direct drive system mostly used as drive system in machine tools as their fundamental principles are known first followed by reviews of latest advances (Altintas et al., 2011).

2.3 Self-tuned Controller

There are a lot of approaches that have been proposed in self-tuning controllers. Tuning controller is one of the most important step in designing a controller that can produce the desired output. Compared to a conventional PID controller where a direct approach is used to obtain a certain preferred result as it has a fix value of gain for P,I and D. In machine tools, there are disturbances occur during the process such as frictional force, vibration and cutting force. The disturbances value are varies therefore, the gain values in PID controllers need to be varied proportionally correspond to the aforementioned value (L. Abdullah et al., 2013). The use of a linear model eases the tuning of PID controller but the performance of the conventional PID might degrade or become unstable as the underlying process dynamics are nonlinear and time-varying in nature. To overcome this issue which to improve or enhance the performance of the controller, various studies of designing nonlinear control techniques for PID controller have been proposed and developed since yesteryears (Kansha et al., 2008).

2.3.1 Self-tuning Controller (STC)

Self-tuning control is also known as adaptive control architecture and can be categorized into three classes which are Model Reference Adaptive Systems (MRAS), Heuristic Approach (HA) and Self-Tuning Controllers (STC) (Mendes, Osório, & Araújo, 2017). STC can be divided into two categories which are explicit STC (also called indirect STC) and implicit STC (also known as direct STC). Illustrated below are the block diagram for both explicit and implicit STC.

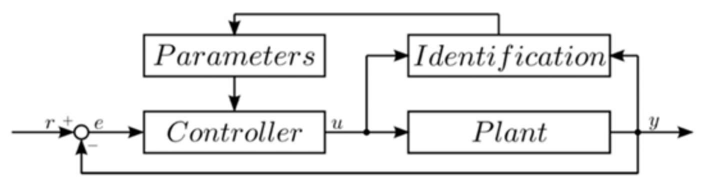

Figure 2.3: Explicit STC (Mendes et al., 2017).

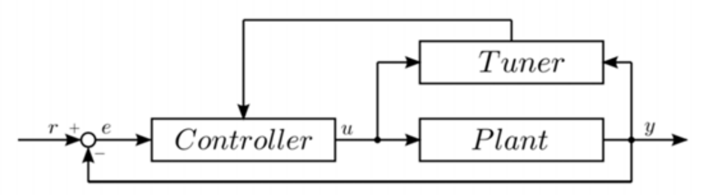

Figure 2.3.1 : Implicit STC (Mendes et al., 2017).

2.3.2 Lyapunov Approach

Lyapunov approach is a stable adaption mechanism in the continuous time domain. It is a derived approach where the PID controller senses or tracks a pre-specified feedback linearization control asymptotically (W.D. Chang et al., 2002). A technique named just-in-time learning (JITL) is considered not only because its prediction capability for non-linear processes can match that obtained by the neural network, but also its inherent adaptive nature (Cheng and Chiu, 2004). Three main steps in the JITL to determine the model output correlate with the query data:

i. Relevant data samples in the database searched to match the query data by some nearest neighborhood criterion
ii. A low-order local model is built based on the relevant data
iii. Model output is calculated based on the local model and the current query data

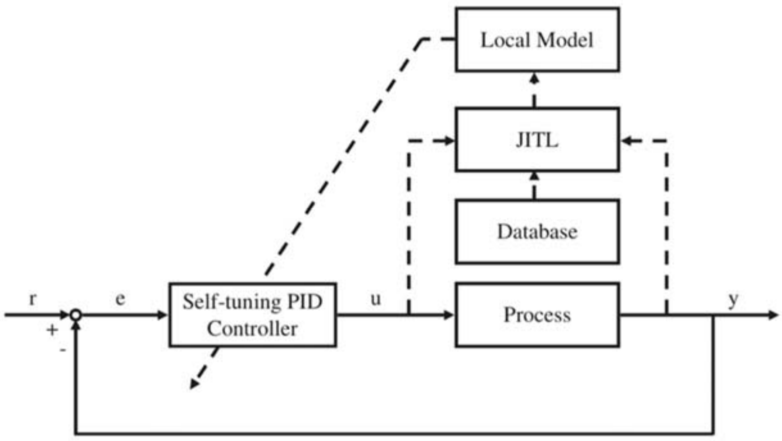

Figure 2.3.2: JITL based self-tuning PID control system.

2.4 Disturbances in Drive System

There are a lot disturbances occur in machine tool process that can affect some criteria such as surface roughness, required dimension and quality. Many kinds of disturbance could occur in machine tools such as force, vibrations, temperature, torque, strain and acoustic emission but the most crucial disturbances are friction forces and cutting forces. These disturbances could not just affect the workpiece, they could also affect the machine tool. The existence of disturbances during the machining processes in the form of friction forces and cutting forces have strongly affect the positioning and tracking accuracy of systems by slacking them (L. Abdullah et al., 2015).