# ESTABLISHMENT OF CONTROL ALGORITHM USING INTELLIGENT PID FOR MACHINE TOOLS APPLICATION

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

by


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I hereby, declared this report entitled "Establishment of Control Algorithm Using Intelligent PID For Machine Tools Application" is the result of my own research except as cited in references.

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# APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of Universiti Teknikal Malaysia Melaka as a partial fulfilment of the requirement for Degree of Manufacturing Engineering (Hons). The member of the supervisory committee is as follow:

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# ABSTRAK

Permintaan untuk ketepatan, kestabilan, dan kelajuan tinggi mendorong peningkatan teknologi alat dan kaedahnya tinggi. Peralihan keperluan baru-baru ini telah membawa kepada era baru dan mencabar dalam bidang alat dan kawalan mesin. Kecekapan alat mesin dipengaruhi oleh gangguan seperti daya geseran dan daya pemotong. Objektif projek merancang, menganalisis strategi kawalan baru untuk mengimbangi kesan daya pemotongan dan ketepatan kedudukan sistem pemacu skru bola meja XY. Kesan daya pemotong pada proses pemesinan telah diterokai dengan pelbagai teknik yang diperkenalkan dan dianalisis. Projek ini mencadangkan pengawal PID Fuzzy untuk mendapatkan prestasi pengesanan aplikasi alat mesin yang lebih baik sebagai pengawal PID pintar. Pengawal PID bercampur dengan pengawal kabur mengembangkan PID Fuzzy bergantung pada model matematik sistem alat mesin CNC. Pengawal yang dicadangkan ini dianalisis secara simulasi. Untuk mengawal sistem skru bola, pengawal dilaksanakan dan memperoleh hasil yang lebih baik. Pengenalpastian sistem dan pemodelan untuk mendapatkan tindak balas fungsi frekuensi (FRF) dan fungsi pemindahan sistem dilakukan pada masa yang sama dengan pengenalpastian daya pemotongan. Prestasi penjejakan sistem akan dibandingkan dengan tiga jenis pengawal iaitu pengawal PID, pengawal PID Fuzzy Adaptive dan pengawal NPID. Prestasi pengawal akan dibandingkan mengikut prestasi ralat penjejakan dan ralat kuasa dua punca (RMSE). Laporan ini menunjukkan bahawa gabungan pengawal PID dan inferensi Fuzzy dapat meningkatkan prestasi rak alat mesin. Hasil projek ini menunjukkan peningkatan 85.69% tanpa penapis tambahan dan 90.47% dengan penapis tambahan dari segi nilai RMSE jika dibandingkan dengan pengawal NPID. Walau bagaimanapun, peningkatan prestasi alat mesin perlu dikaji berdasarkan pampasan lain seperti pampasan geseran dan juga kajian lebih lanjut mengenai pengawal yang dicadangkan ini untuk mendapatkan lebih banyak ketepatan dan prestasi pengesanan yang baik.

# ABSTRACT

The demand for high precision, stability, and speed encourages the improvement of the machine tools technologies and methods are high. In the field of machining tools and control, this recent revolution in standards has led to a new and demanding era. The efficiency of the machine tool is affected by disturbance such as friction force and cutting force. The design goals of the project are to explore a new control technique to help compensate for the consequences of the cutting force and positioning precision of the XY table ball-screw drive system. A different technique which implemented and studied the cutting force effects on the machining process has been explored. This project proposes a Fuzzy PID controller to get a better tracking performance of the machine tools application as an intelligent PID controller. The PID controller mixed with the fuzzy controller develops Fuzzy PID relying on CNC machine tool system mathematical model. This proposed controller is analyses by simulation. To control the ball-screw system, the controller is implemented and has gained a better result. The system identification and modelling for obtaining the frequency function response (FRF) and the system transfer function performed at the same time with cutting force identification. The tracking performance of the system will be compared with three types of the controller which is PID controller, Fuzzy Adaptive PID controller and NPID controller. The performance of the controller will be compared according to the performance of tracking error and root means square error (RMSE). This report demonstrates that the combination of the PID controller and Fuzzy inference can increase the racking performance of the machine tools. The result of this project showed the improvement of 85.69% without additional filter and 90.47% with the additional filter in term of RMSE value when compared to the NPID controller. However, the improvement of the machine tools performance needs to study in the view of other compensation such as friction compensation and also the further study regarding these proposed controllers to get more accuracy and good tracking performance.

# DEDICATION

Alhamdulillah, all praise to Allah for giving me the change to complete my final year project while through the covid-19 pandemic situation.

Special thanks to my family especially my mother, Hafida binti Endut who always support in my study and also to my father, Husni bin Che Hussin who always guide me through the difficulty in my studies. May Allah bless both of you.

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# TABLE OF CONTENT

# LIST OF TABLES

# LIST OF FIGURES

# LIST OF ABBREVIATIONS

| | | |
|---|---|---|
| AI | – | Artificial Intelligen |
| CAD/CAM | – | Computer Aid Design/Computer Aid Machining |
| CC | – | Cohen Coon |
| CHR | – | Chien Hrones Reswick |
| CNC | – | Computer Nurmerical Control |
| DAQ | – | Digital Acquisition Board |
| ENPID | – | Enhanced Nonlinear Proportional Integral Derivative |
| FDIDENT | – | Frequency Domain Identification |
| FFT | – | Fast Fourier Transform |
| FL | – | Fuzzy Logic |
| FLC | – | Fuzzy Logic Controller |
| FRF | – | Frequency Response Function |
| HSS | – | High Speed Steel |
| MN-PID | – | Multi-Rate Nonlinear Proportional Integral Derivative Controller |
| NC | – | Numerial Control |
| NN | – | Neural Network |
| NPID | – | Nonliinear Proportional Integral Derivative |
| PID | – | Proportional Integral Derivative |
| RMSE | – | Root Mean Square Error |
| SMC | – | Sliding Mode Control |
| SN-PID | – | Self-Regulation Nonlinear Proportional Integral Derivative |
| ZN | – | Ziegler Nichols |

# LIST OF SYMBOLS

| | | |
|---|---|---|
| *V* | - | Voltage |
| *mm* | - | Millimetre |
| *Z(s)* | - | Position of the XY Table Ball-screw Drive System |
| *R(s)* | - | Input voltage |
| *e-sT* | - | Transfer function of time delay |
| *G(s)* | - | Transfer function of system model |
| *Kp* | - | Proportional gain |
| *Ki* | - | Integral gain |
| *Kd* | - | Derivative gain |
| *L* | - | Time delay |
| T | - | Time constant |
| *e(t)* | - | Tracking error |
| N | - | Nonlinear gain |
| *emax* | - | Maximum allowable tracking error |
| *t* | - | Time |
| *f* | - | Frequency |
| *e(k)* | - | Error |
| *ec(k)* | - | Error changes |

# CHAPTER 1

## INTRODUCTION

This chapter concerns the implementation of the project entitled "Establishment of Control Algorithm Using Intelligent PID for Machine Tool Applications." This chapter will cover the background of the project, which consists of the introduction of a machine tool, a PID controller and an intelligent PID controller. Besides, this chapter deals with the statement of problems, the objective and the scope of the project.

### 1.1 Background

Machine tools are machines that make the material parts into products of the desired shape by making the cutting process. The milling machine is running when the cutting tool is rotated to remove the undesired part of the workpiece. The cutting process results in the disturbance of the cutting force, which leads to the machine's low performance and affects the surface quality of the component. In order to achieve reasonable product surface consistency, Ogun and Jackson (2017) argued that the efficiency of the XY Table is still under investigation. It is usually associated with mechanical accuracy systems in the manufacturing sector.

The disturbance of the cutting force is considered a factor affecting the performance of the machine tool. The controller should be configured to mitigate the effect of disturbance of the cutting force. In this mission, a better controller will be launched to refine the XY feed table drive system's tracking output with cutting force. The mechanical ball-screw is illustrated in Figure 1.1. It provides a platform for helical ball bearings for translating rotational motion into linear motion. The ball-screw drive system with servo motor provides an ideal decrease of forces compared to the use of a linear motor. It is used in the industry by reducing the cutting force in the manufacturing process.

Figure 1.1: Ball-screw

PID controller is well known and established controller in the world of the control system. This is due to its simples design and straightforward approach (Toscano, 2005). The three-component gains $K_P$ (proportional), $K_I$ (integral) and $K_D$ (derivative) are significant in tracking both transient and steady-state response. Each of the components has its functionality where $K_p$ provides the overall control actuation, $K_I$ helps in reducing steady-state error while $K_D$ improves the transient response of the system (Kiam Heong Ang et al., 2005). The tuning process involves the combination of these three terms to obtain optimum performance of the system (Abdullah et al., 2012). As compared to the well known and simple structure fixed gain PID controller, intelligent PID controller is easier to handle the unknown parameter variation.



An intelligent PID controller is designed to simplify the intelligent PID algorithm into a single-ship program. It has enhanced control effects and is flexible to the standard serial communication protocol, with the characteristic of cheap production and simple configuration. (Yu Chen et al, 2017). Intelligent PID controllers are PID controllers that take into account uncertain parameter components of the plant that may be extremely nonlinear or time-varying without any simulation process (Fliess et al., 2008). The basic function of PID controllers in tuning parameters may lose its significance. By using an intelligent PID controller, it can ensure better tracking performance without ever having to tune the PID parameter repeatedly, and can ensure suiTable adaptation when the plant changes over time. These controllers provide the most efficient response to these critical points for the application of machine tools, which is easier to implement (Fliess et al., 2008). The problem of machine tools could be solved by fuzzy logic control, which is classified as an intelligent control. Also, the fuzzy logic controller has become widely used in the industry. This new method, which uses fuzzy and PID controllers, is intended to be an improvement of the conventional technique as it preserves the linear structure of the PID controller.

## 1.2 Problem Statement

The demand for high precision, stability and speed encourages the improvement of the machine tool technologies and methods. The machine tool controller is an integrated part of technology and design. A coordinated and simultaneous improvement of different technologies, knowledge and a good understanding of the factors that committing to machine demand is important. Tracking performance system is one of the measurements that measure the accuracy of machine tools, which is determined by the following factors:

i. Mechanical structure
ii. Friction forces correlate
iii. Cutting forces

The mechanical structure can decrease the system tracking performance were mechanical. The dynamic and Frequency Response Function (FRF) has been committing negatively by mechanical resonances. The mechanical resonance happened during the act of the machine tool and it can diminish the stability of the overall system. The existence of the resonance that correlates with the physical vibration of the moving structure can influence the tracking performance of the system.

Under nonlinear incident, the friction force is generated from the motor and the support bearing of the electromechanical servo drive system. Friction compensation is spiked in the quadrant area amid circular movement and is known as' Quadrant Glitches'. The complicated nonlinear friction behaviour at motion inversion or similar zero velocity on each hub of a motion device is the object of Quadrant glitches in circular motion.

On the other hand, the cutting force can be assumed as disturbance forces that will influence the machine tool positioning precision system. During the cutting forces processes, the cutting forces will act as an input on the movement of the control system. Unneeded deviation and feedback that lead to low surface finish quality and precision can happen because of its high-frequency component. Hence, this component must be compensated.

## 1.3 Objective

The objective of the project is:

i. To design the positioning control algorithm using intelligent PID controller for a machine tool application.
ii. To analyse the effectiveness of the controller in term of maximum tracking error and root means square error (RMSE).
iii. To compare the effectiveness of PID, NPID and Fuzzy PID controllers with additional low pass filter.

## 1.4 Scope

The scope of the project are as follows:

i. The disturbance that will be considered is cutting force only.
ii. The spindle speed that uses for the cutting parameter is 1500 rpm, 2500 rpm and 3500 rpm.
iii. The sine waveform signal generator that uses is the frequency of 0.2 Hz and 0.4 Hz with an amplitude of 15mm.
iv. The compensation of cutting forces is applied in X-axes of XY feed table ball-screw driven system only.
v. The performance of the controller is compared based on the performance of the tracking error and root mean square error (RMSE).
vi. This project will only conduct in simulation.

# CHAPTER 2

## LITERATURE REVIEW

### 2.1 Introduction

The last few decades have shown great study on machine tool control methods, especially in the precise position. Machine tools include linear or rotary motor drives that feed on the engine. According to Altintas (2011), the two most popular drivers are ball-screw and linear drivers compared to rack and pinion drivers with high efficiency and accuracy in the machine tool industries. High accuracy is important in the machining process. However, the presence of disturbance force and mechanical structures in the machining process results in inaccurate positioning and tracking.

Most control devices are designed to provide greater stability, improved tracking performance, greater resistance to disruption and greater rejection of machine tools by friction. (Liu et., 2003). One of the technologies used in machine tools is milling machines. Machine Tables, motors, mechanical drives, and other mechanical components make up the basic structure of the milling machine. Several articles of machine tool mechanical drive systems were conducted in this project. Drive system disturbance is also identified. The disturbance generated in the drive during milling minimizes the tracking precision of machine tools. The most crucial disturbances to the detection performance are the cutting force and the friction force that has been mentioned by Dinh et al. (2016) and Mekid (2008).



Hence, the problem of cutting forces in milling processes was reviewed, and many controllers were suggested and evaluated. Most of the time, the PID-based controller was widely used (Chiew et al., 2012) and combined with other components for the disturbance compensation in much industrial application. This is because the PID controllers provide a simple design with proportional, integrated, and derivative gains. Based on these changes, modifications to the design can be recommended for this PID controller. For example, the use of fuzzy modal and neural networks is focused on adapting the PID controller based on the latest improvement (Nur Amira Anang et al., 2014). Savran and Kahraman (2014) stated that the conventional PID controller is difficult to use in nonlinear environments. The researchers, therefore, came forward with the concept of creating an adaptive turning method. The controller gains modification methods are performed online using Fuzzy predictor. Also, the use of a neural network is essential for PID controller improvement (Nur Amira Anang et al., 2014).

## 2.2 Control of Motion

### 2.2.1 Feet drive system

The machine tool drives control system is designed to perform the task of controlling the position and speed of the machine tool axis made by the CNC controller in the following commons. Feed drive systems generally composed of two main parts. Chien Yu lin and Ching Hung Lee (2017) mentioned that the first is an electronic control system and the second is a mechanical system such as ball-screws, bearings, servomotor and worktable. According to Sunan Huang et al. (2007), a special feet system related to the control of a milling machine consists of the following main components: tools, tool post, slides, bearing ball-screw, feed boxes, feed motors and lubrication systems, as illustrated in Figure 2.1. The researcher also notes that typically, the workpiece moves horizontally by the X-axis and Y-axis motors while the vertical tool is moved by the Z-axis motor. Yeung et al. (2006) proposed a model for virtual simulation, which modelled the influence of nonlinear phenomena, namely cutting force, friction and backlash. However, it considers the ball screws to be a rigid body and there is no consideration for the mass of the Table and the damping ration. This decrease the accuracy and responsiveness of mechanical drive systems (Chien Yu Lin and Ching Hung Lee, 2017). Ball screws and linear drives are most commonly used as machine tool feeders while long-range machine tools use rack and pinion drives. Generally, either a linear driver or a ball screw is selected as the feed driver (Rafan et al., 2012).

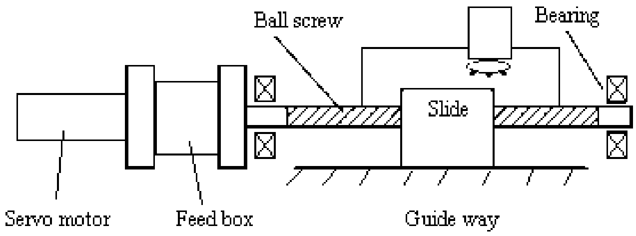


Figure 2.1: A feed drive system (Sunan Huang et al., 2007)

### 2.2.2 Ball-ccrew drive system

Position accuracy and tracking are often a problem in producing high productivity and quality of machine tools (Rafan et al., 2012). Ball-screw drivers are commonly used due to their high speed and acceleration capabilities, high efficiency and moderate pre-pressure (Pritschow, 1998). Furthermore, ball-screws have a high service life with no slip-slip effect (Neugebauer et al., 2009). Converting angular motion into linear motion by ball-screw drivers (Tsai et al., 2014). In general, servo-motor driven ball-screw drive systems are commonly used in many applications due to their low cost (Chen et al., 2004; Zhang et al., 2006, Kamalzaseh et al., 2010). The ball-screw driver consists of thrust bearings on both ends and the mesh with the ball re-circulating.



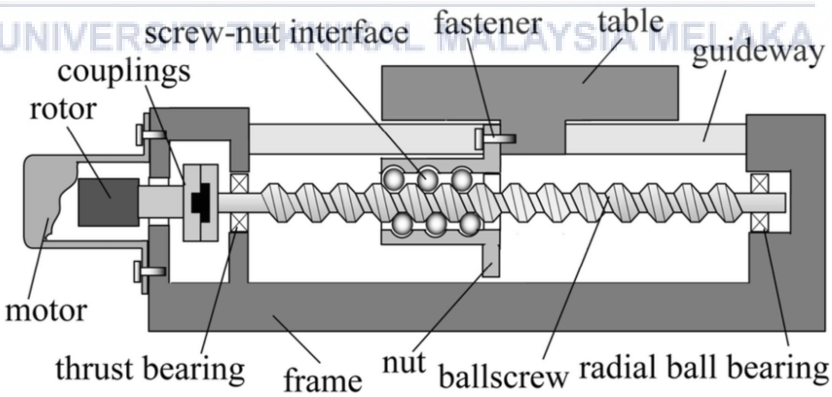


Figure 2.2: Schematic diagram of the ball-screw drive system (Haojin Yang et al., 2020)