UNIVERSITI TEKNIKAL MALAYSIA MELAKA

SYSTEM IDENTIFICATION OF XY TABLE BALLSCREW DRIVE SYSTEM

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

by

WAN FATIN ATHIRAH BINTI ROMLEE
B051110205
920104075034

FACULTY OF MANUFACTURING ENGINEERING
2015

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

BORANG PENGESAHAN STATUS LAPORAN PROJEK SARJANA MUDA

TAJUK: **System Identififcation of XY Table Ballscrew Drive System**

SESI PENGAJIAN: 2014/15 Semester 2

Saya **WAN FATIN ATHIRAH BINTI ROMLEE**

mengaku membenarkan Laporan PSM ini disimpan di Perpustakaan Universiti Teknikal Malaysia Melaka (UTeM) dengan syarat-syarat kegunaan seperti berikut:

1. Laporan PSM adalah hak milik Universiti Teknikal Malaysia Melaka dan penulis.
2. Perpustakaan Universiti Teknikal Malaysia Melaka dibenarkan membuat salinan untuk tujuan pengajian sahaja dengan izin penulis.
3. Perpustakaan dibenarkan membuat salinan laporan PSM ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. **Sila tandakan (✓)

☐ SULIT (Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia sebagaimana yang termaktub dalam AKTA RAHSIA RASMI 1972)

☐ TERHAD (Mengandungi maklumat TERHAD yang telah ditentukan oleh organisasi/badan di mana penyelidikan dijalankan)

☑ TIDAK TERHAD

Disahkan oleh:

_______________________ _______________________

Alamat Tetap:

No 55, Jalan Desaria 16,
Taman Desaria, Nilai,
71800 Negeri Sembilan.

Tarikh: _______________________

Cop Rasmi:

Tarikh: _______________________

** Jika Laporan PSM ini SULIT atau TERHAD, sila lampirkan surat daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali sebab dan tempoh laporan PSM ini perlu dikelaskan sebagai SULIT atau TERHAD.

DECLARATION

I hereby, declared this report entitled “System Identification of XY Table Ballscrew Drive System” is the results of my own research except as cited in references.

Signature	:	………………………………………….
Author’s Name	:	Wan Fatin Athirah Binti Romlee
Date	:	25 June 2015

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)

ABSTRAK

Pengenalan sistem adalah langkah pertama dalam proses reka bentuk pengawal bagi sistem mekatronik. Proses ini dilakukan dengan tujuan untuk mendapatkan model matematik yang tepat bagi mewakili input dan output sistem supaya strategi reka bentuk kawalan dapat direka untuk meningkatkan prestasi sistem. Dalam projek ini, proses pengenalan sistem tersebut dilaksanakan pada struktur mesin CNC asas iaitu sistem XY yang dipacu oleh sistem bebola skrew menggunakan salah satu teknik yang terkenal dalam sistem pengenalan iaitu pendekatan domain frekuensi. Terdapat dua jenis pendekatan domain frekuensi yang kerap digunakan iaitu pendekatan domain bukan parametrik dan berparameter dan kedua-duanya digunakan dalam projek ini. Selain itu, perbandingan model matematik yang diperolehi daripada pendekatan parametrik digunakan juga dilakukan untuk mendapatkan fungsi rangkap pindah yang paling tepat bagi mewakili sistem. Hasilnya dihakimi berdasarkan keperluan semasa prosedur pengesahan model seperti nilai selang keyakinan parameter dan pemerhatian grafik model penyuaian terbaik.

ABSTRACT

System identification is the first step in any controller design process for a mechatronic system. This process is carried out with the aim of obtaining a transfer function that can accurately represent the system input and output so that control design strategies can later be applied to improve performance of a system. In this project, the system identification process is carried on a basic CNC machine structure which is XY table ballscrew drive system using one of the well-known technique for system identification which is frequency domain approach. There are two type of frequency domain approaches which are non-parametric and parametric frequency domain approaches and both are applied in this project. Moreover, comparison of mathematical models obtained from the parametric approaches used was also being done in order to obtain the most accurate transfer function to represent the system. The result was judge based on the requirement during model validation procedure like the value of parameter confidence intervals and graphical observations of the best fit models.

DEDICATION

Alhamdulillah.

To my beloved

parents,

Romlee Bin Abdul Wahab & Sharifah Zarohi Zunita Binti Syed Md Zaki

siblings,

Wan Nurul Ashikin, Wan Aina Eleena, Wan Amir Asyraf

Wan Nuha Afiqah

and

those involved directly and indirectly in completion of this project.

ACKNOWLEDGEMENT

Alhamdulillah, all praise is due to Allah S.W.T, the Most Beneficent and the Most Merciful, who has taught me what I knew not.

Firstly, I would like to convey my deepest gratitude to my respected supervisor, Ir. Dr. Lokman Bin Abdullah for all the advices, guidance and motivation given throughout the completion of this project.

I would like to further extend my gratitude to all lecturers, researchers, friends in FKP, and technicians who have assisted me directly and indirectly throughout the progress in completion of my project. I will not forget all opinions and supports given.

Lastly, I want to whole heartedly give my appreciations to my beloved parents and siblings for giving me the unlimited supports and motivation when I faced the difficulties in carrying out this project.

Thank You.

TABLE OF CONTENT

APPENDICES

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS, SYMBOLS AND NOMENCLATURE

CNC	-	Computer Numerical Control
DSP	-	Digital Signal Processor
FDIDENT	-	Frequency Domain Identification Method
FRF	-	Frequency Response Function
GM	-	Gain Margin
GUI	-	Graphical User Interface
IDENT	-	Matlab Identification Toolbox
LLS	-	Linear Least Square Method
LTI	-	Linear Time Invariant
NLLS	-	Non-linear Least Square method
PID	-	Proportional-Integral-Derivative
PM	-	Phase Margin
PSM	-	*Projek Sarjana Muda*
SISO	-	Single-Input Single-Output

CHAPTER 1

INTRODUCTION

This chapter discusses about the background of ‘System Identification of XY Table Ball Screw Drive System’ project and covers the problem statement and objectives of the project. Besides that, the scopes of the project and structure of the report are also mentioned in this chapter.

1.1 Background

The invention of Numerically Controlled (NC) machine tool by John Parsons in Traverse City, MI with subcontract to the MIT Servomechanism Laboratory is the initiator of control of machine tool in the early 1950s (Koren, 1997). Nowadays, advanced of machine tool technology and the requirement for tracking accuracy and precise positioning had resulted in the development of machine control strategy (Abdullah, 2014).

The factors in machine tool that affect the tracking performance of the machine include mechanical structure of the machine, mass variation of workpiece and disturbance forces exist during machining like friction and cutting force (Jamaludin, 2008). If there are no measures taken to compensate these factors, it may results in decreasing surface finish quality of workpiece (Nijiri et al., 2012). Therefore, controller design process is introduced to compensate disturbances like cutting force and friction force in order to provide better quality of surface finish.

System identification is actually the first step in the control system design process for a mechatronic system. According to Zadeh (1962), system identification is the determination, on the basis of input and output, of a system within in a specified class of systems, to which the system under test is equivalent. In other words, system identification can be described as process of developing the mathematical model of a dynamic system based on observation on input and output data (Abdullah et.al. 2012). It relates real system application with the mathematical control model and theory. In obtaining the mathematical model or transfer function of the system using Matlab toolbox, model structure selection process is done repeatedly until the best model in the structure is computed and is then evaluated to see whether it satisfy the objectives. Based on Ljung (1999), there are six cycles in system identification process which are first to design an experiment and collect input-output data of the process to be identified, then examination of the data takes place followed by selection of model structure. Based on the input-output data and given criterion, best model in the model structure is then computed. Last but not least, the obtained model properties are examined. If the model obtained is not good enough, selection of model structure is repeated once again either with another model, other estimation method or by working further with the input-output data (Pal, 2006).

The machine tool involves in this project is XY table ball screw drive, a basic structure of computer numerical control (CNC) machine system which involves horizontal motion in X axis direction and vertical motion in Y axis. Like all ball screw drive system, this system converts rotary motion of motor into linear motion. This project focused on the system identification of XY table ball screw drive system using Matlab toolbox which is a vital initial process in order to design control strategy to compensate disturbances in the operation of the system.

1.2 Problem Statement

The development of machine tool technology and design methodologies is highly influenced by the demand in term of performance of machine tool which includes accuracy, robustness and speed of the machine. An integrated part of this machine tool and design is the machine tool controller (Jamaluddin, 2008). In control system design, system identification is the most important part and it is actually the very first step before developing a control strategy. Based on observation of the output and information from the input of a system, a mathematical model or transfer function that represents the real application of a system is developed by system identification process. This means that the aim of the system to achieve its objective in control system design process depends highly on the accuracy of the transfer function. Thus, for better performances of the XY table ball screw drive system, system identification has to be done to obtain transfer function that represents the operation of the system in order to proceed with the design of controller.

1.3 Objectives

The objectives of the project are:

i. To develop mathematical model or transfer function of XY table ball screw drive system.
ii. To utilize several approaches in determining the transfer function which are parametric and non-parametric frequency domain approaches.
iii. To compare the difference between mathematical models obtained via non-linear least square method (NLLS), linear least square method (LLS), frequency domain identification method (FDIDENT), and Matlab identification toolbox (IDENT) in validating the mathematical model.

1.4 Scopes

The scopes of the project are:

i. This project focuses more on system identification process of the system. Basic proportional-integral-derivative (PID) controller is designed as well to complete the task.

ii. The system identification process in this project utilized the use of Matlab and Control desk software.
iii. Frequency domain identification method approach is used in this project.
iv. The plant is XY table ball screw drive system from Googol Tech Inc. Only Y-axis is covered in this project.

1.5 Structure of Report

This report is organized into five chapters. Firstly, Chapter 1 which is the introduction of the project that includes the background, problem statement, objectives, scopes and structure of the project. In Chapter 2, literature review which is the study regarding topic related to this project by prior researchers is discussed. Then, the methodology is discussed in Chapter 3. The process flowchart of carrying system identification process, procedure, related equipment and software is elaborated in this chapter together with the Gantt chart. Chapter 4 contains the result of system identification and discussion regarding the obtained function. Lastly, Chapter 5 is the conclusion of the finding and some recommendations for future improvement.

CHAPTER 2

LITERATURE REVIEW

This chapter discusses the motion control involves in machine tool which comprises of explanation on mechanical drive systems and disturbances involves in the system, extracted and explained based on previous studies that had been done by researchers. Fundamental ideas on system identification and classical controller are also included in this chapter.

2.1 Introduction

This chapter discusses about motion control in machines tool that involves explanation on mechanical drive system and disturbances that exist in drive systems. Basically, four type of mechanical drive system namely rack and pinion drive system, ball screw drive system, linear direct drive system, and piezoelectric drive system are explained in this chapter. Meanwhile the disturbances that are being highlighted in this chapter are the friction force and cutting force which plays a huge impact on the performance of a drive system. Next, system identification perspectives are being explained and these include identification algorithms, different type of model structure, model estimation and model validation. Lastly, classical controller approach in improving performance of machine tools comprises of proportional-integral-derivative (PID) controller is stated in this chapter.

2.2 Motion Control in Machine Tool

The continuous demand for higher speed and precision in machine tools electrifies the expansion of machine tool technology and design approaches. A sound knowledge and understanding of the factors that contribute to the machine accuracy are pivotal. One of the factors that influence negatively to the accuracy of a machine tool is the tracking performance of its drive system. As for the ball screw drive system of XY table ball, it is critically influenced by the factors like friction behavior and cutting force. This section focuses on the understanding, characterization and modelling of friction behavior and cutting forces besides explanation on different type of mechanical drive system available.

2.2.1 Mechanical Drive System

Mechanical drive system technology has evolved from the conventional electromechanical drive system to linear direct drive system (Jamaludin, 2008). This advancement has brought improvement in tracking performance and speed of the system applied in industry, besides abolishing the disadvantages of the old fashioned system. In machine tool, there are four common drive system being used which are rack and pinion system, ball screw drive system, linear direct drive system, and piezoelectric system (Abdullah, 2014).

A linear actuator which consist of a gear pair that produces linear motion by converting rotational motion of the gear is what meant by rack and pinion drive system. The “pinion” refers to the circular gear whereas the “rack” refers to the bar where the teeth of gear are attached to. Rack and pinion drive system are usually applied for long travel distance application since just by adding several rack together, a long feed travel can be achieved. Stiffness of the system is the combination of torsional stiffness of gear and pinion shaft together with the contact stiffness of rack-pinion-combination (Altintas, 2011). Altintas (2011) also suggested that the system should be designed as such the pinion should be separated in order to achieve free clearance motion. Figure 2.1 shows the mechanism of rack and pinion drive system.

Figure 2.1: Rack and pinion drive system

Another type of drive system is the ball screw drive system whereby it is the most common drive system applied in machine tool (Altintas, 2011). Figure 2.2 shows the ball-screw drive system with labelled components. The ball screw system consists of a nut with recirculating balls and there are thrust bearings supporting a screw at the two ends. This type of drive system is known by its main characteristics of converting rotary motion into linear motion. Pritschow (1998) has stated advantages of this type of system whereby it is applicable to various machine sizes, process forces and feed rates. Ball screw drives are also known to have high efficiency, low wear, and high service life without stick-slip effect. However based on study by Jamaludin (2008), the lead-screw elements have negative effect on performance of driver whereby it can produce transmission error that reduces the tracking accuracy of the system. Besides that, dead zones that result in backlash effect and large friction forces originating from high stiffness electromechanical ball-screw and bearing structure also contribute to reduce in tracking accuracy. To overcome this, high gain feedback controller is used but there are constraints due to resonance mode of the XY table structure. Moreover, the stiffness of lead screw also limits the position, velocity and acceleration of the system. Large additional inertia added to the system through the lead screw mechanism causes first natural frequency of system to be reduced which result in decrease in bandwidth of system. Hence, this will affect the tracking accuracy of the system. Therefore, system identification should be done to identify the dynamic behaviour of the ball screw driven system in order to further understand their characteristics and improve their performances.

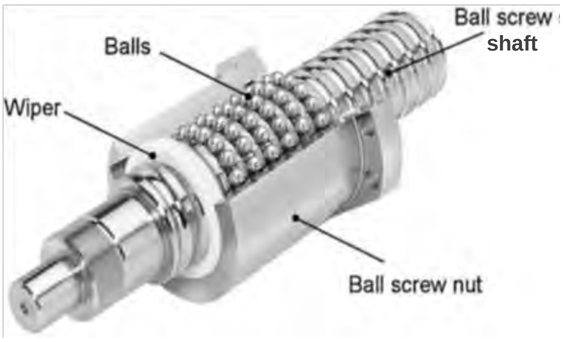

Figure 2.2: Structure of ball screw drive system (Altintas, 2011)

Next is the linear direct drive system which has similar guide system to ball screw drive system. Compare to ball screw drive system, linear direct drive system offers higher feed speed, acceleration and rapid positioning with higher servo band width. For this type of drive, magnetic force between the primary and secondary parts of the linear motor is the force that moved the table and this eliminate flexible motion transmission in this drives. Direct transmission of cutting load and mass to motor takes place in this system (Altintas, 2011). Hence, this can improve the tracking accuracy of the system since transmission errors can be eliminated when no physical transmission element involved. However, there exist some drawbacks in this system. When no transmission mechanism exists, positioning and tracking accuracy of the system is highly influenced by cogging forces, external disturbances and load variations. This condition provides more challenge in controller design activities. Furthermore, linear direct drive system is more expensive compared to conventional electromechanical drive since it requires cooling due to high level of heat generation. This type of drive system is used when positioning or tracking performance is required as in high-speed machining. Figure 2.3 shows the structure of linear direct drive system.

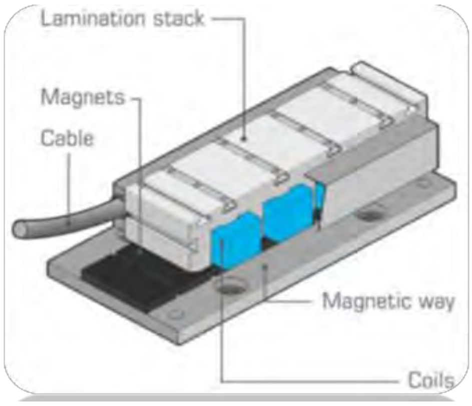

Figure 2.3: Structure of iron-core linear drive system (Abdullah, 2014)

Lastly the system that is normally used nowadays includes the piezoelectric drive system whereby it function using concept of inverse piezo effect that develops when it was found that piezoelectric materials undergo change in dimension when exposed to an electric potential (Maslan, 2012). In actuating the movement of XY table, stack type piezoelectric actuator mainly consists of several contacted ceramic discs shielded with flexible insulation material that increase the dynamic performance of the system as can be seen in Figure 2.4 (Abdullah, 2014). At high frequencies, piezoelectric actuator can generate sub-nanometres movement as the motion is derive from solid-state crystalline effects. It has the advantages of moving high loads up to tonnes. Besides that, it requires no maintenance and does not wear since there are no moving parts present (Maslan, 2012). Despite all the advantages, the application of this drive system is difficult to control due to their inherent nonlinearity and hysteresis. Hence, this limits the accuracy of the actuator. Among the steps taken to overcome this is by having an inverse operator as developed by Tao and Kokotovic (1995).