UNIVERSITI TEKNIKAL MALAYSIA MELAKA

CUTTING FORCE COMPENSATION ANALYSIS USING SLIDING MODE CONTROL

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

by

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UNIVERSITI TEKNIKAL MALAYSIA MELAKA

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I hereby, declared this report entitled "Cutting Force Compensation Analysis using Sliding Mode Control" is the results of my own research except as cited in references.

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Author's Name	: **CHIEW TSUNG HENG**
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APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of UTeM as a partial fulfilment of the requirements for the degree of Bachelor of Manufacturing Engineering (Robotics & Automation) with Honours. The member of the supervisory committee is as follow:

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ABSTRAK

Projek ini adalah tertumpu pada analisa kawalan daya pemotongan dengan menggunakan teknik kawalan sliding mode (SMC). Dalam proses pengisaran, terdapat daya gangguan yang akan mempengaruhi prestasi pemotongan. Salah satu jenis daya gangguan ialah daya pemotongan. Kawalan sliding mode merupakan salah satu jenis alat kawalan teguh yang dapat diaplikasikan dalam pengawalan daya pemotongan. Eksperimen telah dijalankan untuk mengenalpasti ciri-ciri daya pemotongan apabila parameter pemotongan dimanipulasikan kerana parameter pemotongan dapat mempengaruhi hasil daya pemotongan. Dalam eksperimen, dinamometer Kistler telah digunakan untuk mengumpul data daya pemotongan yang terhasil dalam proses pengisaran aluminium pada paksi x. Data ini kemudian dianalisa melalui teknik Fast Fourier Transformation (FFT) untuk mendapatkan analisis spektrum. Terdapat dua jenis komponen yang penting dalam mereka-bentuk kawalan sliding mode dan perlu ditelitikan iaitu hukum kawalan dan fungsi peralihan. Merujuk kepada kajian sebelumnya, komponen-komponen itu telah dihasilkan dan seterusnya menghasilkan diagram Simulink. Terdapat dua jenis pendekatan pada kawalan sliding mode iaitu "ideal sliding motion" dan "pseudo sliding motion". Parameter-parameter iaitu lamda,, gain, K dan delta,δ bagi kedua-dua pendekatan didapatkan melalui teknik cuba-jaya. Didapati bahawa "ideal sliding motion" menghasilkan fenomena "chattering" manakala "pseudo sliding motion" menghasilkan isyarat yang lebih lancar. Keputusan ini menunjukkan "pseudo sligin motion" dapat mengurangkan fenomena "chattering". Merujuk kepada keputusan, kawalan sliding mode dapat hampir menghapuskan ralat posisi yang diakibatkan oleh isyarat gangguan. Akhirnya, prestasi kawalan sliding mode dibandingkan dengan prestasi alat kawalan klasik iaitu alat kawalan PID dan didapati Kawalan sliding mode menunjukkan prestasi yang lebih baik berbanding dengan alat kawalan PID.

ABSTRACT

This project is focused on the cutting force compensation analysis using sliding mode control. In milling process, there are disturbance forces that affect the cutting performance. One of the disturbance forces is cutting force. In order to compensate the cutting force, the sliding mode control which is a robust controller is designed and applied. As the cutting force is influenced by the cutting parameters, the characteristic of the cutting force with different cutting condition is identified and determined through experiment. The Kistler dynamometer is used to collect the data of cutting force along x-axis during end milling process on aluminium work piece. The data collected through experiment is analyzed using Fast Fourier Transformation (FFT) to produce spectral analysis. Two main components of sliding mode control namely; switching function and control laws are considered and designed. By developing the switching function and control laws based on the system of previous work in literature, the Simulink diagram is designed and formed. Two approach of signum function which is ideal sliding motion and pseudo sliding motion are designed. The parameters namely; lamda,, gain, K, and delta,δ for both controllers are obtained through trial and error method. It is noticed that the ideal sliding motion produced output signal with chattering phenomenon while the pseudo sliding motion produced smooth output signals. This verified that pseudo sliding motion is a method that able to solve chattering problem ideal sliding motion as suggested in literature. The compensation results are captured and analyzed. It is found that the designed controller can almost reduce the tracking error of system with the presence of cutting forces. Lastly, the performance of the sliding mode control is compared to the classical PID controller. It is found that the performance of sliding mode control is better than the classical PID controller. The analysis results are then concluded and other methods of solving chattering problem mentioned in literature are suggested to be proven in future study.

DEDICATION

For my Father, Chiew Boon Hoy and my Mother, Lai Wai Leng

Their loving and unconditional support throughout my life

To my brothers,

Without whose love and assistance this may not be completed

And also for those I love very much.

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Abbreviations

AC	-	Alternative current
C	-	Controller
CCDS	-	Cylindrical capacitive displacement sensor
DAQ	-	Data acquisition
FFT	-	Fast Fourier Transform
FMD	-	Force measurement dynamometer
FYP	-	Final Year Project
GMS	-	Generalized Maxwell-slip
HSS	-	High speed steel
IMP	-	Internal Model Principle
NG	-	No-go
P	-	Proportional
PD	-	Proportional-plus-derivative
PI	-	Proportional-plus-integral
PID	-	Proportional-plus-integral-plus-derivative
Q	-	Quality factor
Q-filter	-	Low pass filter
RC	-	Repetitive Controller
rpm	-	Revolution per minute
SMC	-	Sliding Mode Control

Symbols

V	-	Cutting speed	[mm/min]
D	-	Cutter diameter	[mm]
N	-	Spindle speed	[rev/min]

t_c	-	Un-deformed chip thickness	[mm]
f	-	Feed	[mm/tooth]
v	-	Feed rate	[mm/min]
d	-	Depth of cut	[mm]
n	-	Number of edges of cutter	[tooth]
F	-	Force	[N]
t	-	Time	[s]
f	-	Frequency	[Hz]
C (s)	-	Output function	
G (s)	-	Considered system function	
G_c (s)	-	Controller function	
N (s)	-	Notch filter	
Q (s)	-	Quality factor function	
R (s)	-	Input function	
sgn (s)	-	Signum function	
sign (s)	-	Signum function	
d	-	Disturbance signal	
u	-	Reference input signal	
z	-	Output signal	
K	-	Gain	
$\dot{x}$	-	derivative of x	

CHAPTER 1
INTRODUCTION

A project cannot be started if there is no objective to be achieved or problems to be solved. As a result, an introduction chapter is a crucial element for a project. In the chapter of introduction, it will introduce the background of the project, reasons of the project and objectives to be achieved in the project. To start the project entitle "Cutting Force Compensation Analysis using Sliding Mode Control", in this chapter, the background will be discussed in section 1.1, followed by problem statement in section 1.2, objectives in section 1.3, scope in section 1.4 and lastly organization in section 1.5.

1.1 Background

High accuracy and precision is crucial especially in manufacturing field as the demand is sky-rocketing lately. As a result, high accuracy and precision in machine tools is critical in achieving high standards put forward by the customers. However, the cutting performance of the machine tools application is usually not capable in achieving desired accuracy and precision. There are many factors in affecting the cutting performance such as the mechanical structure of machine tools and disturbance forces which included frictional force and cutting force. One of the manufacturing processes to be focused is milling process as it is a common method for metal removal process in many industries such as automobile, aerospace and textile machinery. The cutting performance of milling process is important as this process is applied in many fields. In milling process, the most significant factor that affecting the cutting performance is disturbances forces such as frictional forces and cutting forces. The disturbance forces are forces that cannot be avoided as it is the nature of the process.

One of the disturbance forces is cutting force. Cutting force will occur whenever there is cutting process for any machine tools application. Basically, cutting force is determined through the cutting parameters set. In milling operation case, the cutting parameters such as feed rate, depth of cut and spindle speed may influence the cutting force. Changes in cutting parameters will influence the cutting force produced, thus resulting in different performance outcome of finished work piece. Cutting force will cause vibration during cutting process and this may lead to inaccuracy and failure in meeting requirement of customers. As the cutting force cannot be avoided, a method should be applied in order to compensate this cutting force to improve the cutting performance of machine tools.

1.2 Problem Statement

In order to improve the accuracy and precision of milling process, cutting forces that are presented during milling operation should be compensated. Controller design plays an extremely important role in compensating the cutting forces. Since the cutting parameters will influence the characteristic of cutting force produced, the behavior of cutting forces at different cutting parameters should be determined before designing the controller. Sliding mode control which is a robust controller will be applied in this project to compensate the cutting force. The design criteria and performance of robust controller should be identified and determined.

1.3 Objective

The objectives of this project are:

(a) Determine the behavior of cutting forces at different cutting parameters in milling process.

(b) Compensate the cutting forces based on the analysis data collected from experimental milling process using sliding mode control approach.

1.4 Scope

The scopes of this project are:

(a) Compensation of cutting forces observed in x-axis of end milling process.

(b) Cutting parameters that will be manipulated and analyzed are spindle speed and depth of cut only.

(c) Controller design approach used in the project is sliding mode control.

1.5 Organization

The project is organized as listed below:

(a) Chapter 2 gives an introduction and literature review on current practices in manufacturing processes especially relating to the performance of milling processes.

(b) Chapter 3 discusses on the methodology including the overall flow chart and planning of the project.

(c) Chapter 4 presents the results relating to the experiment, analysis of collected data and controller design of this project.

(d) Chapter 5 is the discussion that discuss on the results of analyzed data that obtained from simulation of the designed controller and evaluation of performance of the designed controller.

(e) Chapter 6 is the conclusion that concludes the project by presenting the final outcome and achievement of this project and states future work that could further improve the outcome of this project.

CHAPTER 2

LITERATURE REVIEW

A project or research cannot be completed before collecting required data and information. As a result, literature review is an important element that must be included in any research or project to gather required information. Through literature review, more details of information and knowledge regarding the objectives and requirement of the paper, project or research can be understood by conductor. With deep understanding in the work, a quality output only can be produced. In the literature review section of this paper, it consists of information that shall be considered and gathered in order to complete the research.

Basically, this project is focused on the compensation of cutting force in milling process. The literature review section of this report will explain on milling process (section 2.2), disturbances in milling process (section 2.3), parameters of cutting force (section 2.4), measurement of cutting force (section 2.5), compensation of cutting force (section 2.6) and the sliding mode control (section 2.7) .

2.1 Introduction

High accuracy and precision is crucial especially in manufacturing field as the demand is sky-rocketing lately. One of the manufacturing processes to be focused is milling process. In milling process, some problems such as quadrant glitches are occurred due to the positioning and tracking accuracy which causes by the disturbance forces. One of the disturbance forces is the cutting force which is a factor that contributed to the problems occurred. As a result, the compensation of cutting force is a must.

2.2 Milling Process

Milling process is one of the most versatile machining processes in manufacturing field. Kalpakjian and Schmid (2006) stated that milling operation is a process in which a rotating, multi-tooth cutter removes material while travelling along various axes with respect to the work piece. In other words, the work piece will be mounted on feed table and the cutting tool will rotate to remove materials. The milling cutters and milling operations consists of three basic types which are peripheral milling, face milling and end milling as shown in figure 2.1.

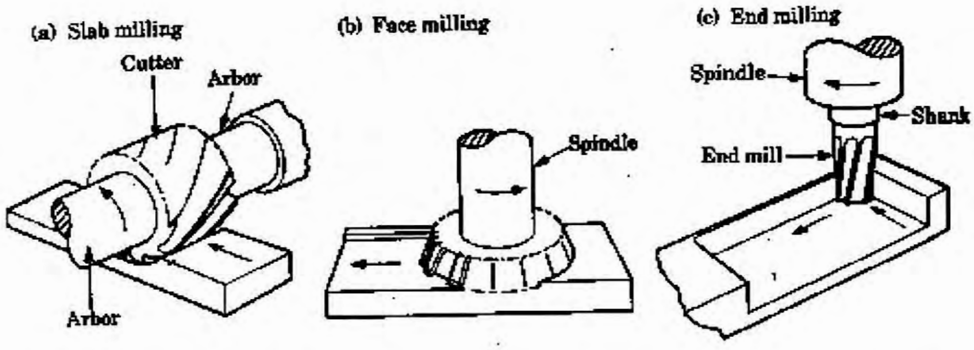

Figure 2.1: The three basic types of milling operation (Kalpakjian and Schmid, 2006).

In peripheral milling or known as slab milling, the work piece surface will be removed or milled by teeth located periphery of the cutter body. The axis of cutter rotation is parallel to the work piece surface. When compared to face milling, the cutter is mounted on the spindle that rotates at the axis perpendicular to the work piece surface. The surface of work piece will be milled by the cutting teeth which mounted on the cutter body (face of the cutter).

On the other hand, end milling is one of the basic types of milling operations. It is generally used in the vertical milling machine (Rao, 2009). It can be used to produce flat surfaces as well as various profiles such as milling slots, keyways and pockets. The cutting tool of end milling process consists of various types such as end mill and ball end mill. End mill generally has a straight shank or a tapered shank and is mounted on the spindle of milling machine.

However, the milled surface roughness of the work piece is not perfect as in fact, the milled surface consists of "spikes" which hard to be detected or observed by naked eyes. This is basically due to the disturbances that occurred during the milling process such as the friction forces and cutting forces. These forces greatly influenced the positioning and tracking accuracy of the milling process.

2.3 Disturbances in Milling Process

Disturbances that contribute to the ineffective positioning and tracking accuracy of milling process are basically the friction forces and cutting forces which cannot be avoided. Both forces will be generated whenever the milling process is conducted as it is the nature of the milling process.

Disturbances in milling operation will affect the dynamic stiffness of the system and causing tracking errors (Jamaludin , 2007). Dynamic stiffness is a level of capability measurement of a system in withstanding the disturbances. Tracking errors consists of two types which is axial tracking errors and contour tracking errors. The axial tracking error is the error occurred in single axis while the contour error is the error involving two axis such as x and y axis. Quadrant glitches (figure 2.3) will be formed due to contour tracking error which is another effect of the disturbances of the system. Basically, the dynamic stiffness, tracking errors and quadrant glitches can be linked together. When the dynamic stiffness of a system is improved, the tracking errors of the system as well as the quadrant glitches will be reduced. The disturbances in a system such as in milling operation should be compensated in order to improve the dynamic stiffness of the system and reducing the tracking errors.

As a result, compensating the disturbances in a system is crucial and basic knowledge in the disturbances is essential. The following section will explain these disturbance forces.