ANALYSIS AND CONTROL OF VIBRATION IN MACHINE TOOLS

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

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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 (Robotics and Automation) (Hons). The members of the supervisory committee are as follow:

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ABSTRAK

Antara tujuan bagi projek ini adalah untuk menganalisis ciri-ciri getaran alat mesin, mereka bentuk pengawal dan model pemerhati dan mengesahkan fungsi sistem kawalan. Ketepatan memainkan peranan penting dalam meningkatkan kualiti sistem kawalan. Walau bagaimanapun, getaran dikenali sebagai daya gangguan berpunca daripada pusingan alat mesin akan mengurangkan ketepatan sistem kawalan. Oleh itu, kesan getaran yang negatif perlulah disingkirkan dengan mereka bentuk satu pengawal bagi mengurangkan kesan buruk tersebut. Dalam kajian ini, pengawal "cascade P/PI" dan model pemerhati telah dipilih sebagai pengawal untuk mengawal getaran. Sistem penilaian telah dilakukan untuk mencari fungsi pemindahan. Kemudian, pengawal "cascade P/PI" dan model pemerhati telah direka bentuk dengan menggunakan perisian MATLAB Simulink dan kaedah "loop shaping" sambil mengambil kira faktors "gain margin", "phase margin", rajah "Nyquist" serta lebaran. Analisis berangka telah dijalankan dengan menggunakan perisian MATLAB Simulink. Dua parameter seperti kualiti penjejakan dari segi penjejakan ralat maksimum dan keupayaan mengurangkan gangguan dari segi penganalisis ralat min punca kuasa dua telah dikaji. Sistem kawalan tersebut telah dianalisis dengan mempunyai gangguan isyarat dan tanpa gangguan isyarat, maka perbandingan antaranya telah dibuat. Projek ini menggunakan "sinusoidal" isyarat sepenuhnya untuk kajian. XYZ mesin pengilangan digunakan sebagai sistem kedudukan manakala daya pemotongan dan "band limited white noise" digunakan sebagai gangguan isyarat. Seterusnya, pengesahan terhadap fungsi pengawal telah dibuat dengan menjalankan eksperimen XYZ mesin pengilangan. Keputusan yang diperolehi menunjukkan bahawa pengawal "cascade P/PI" berintegrasi dengan model pemerhati telah mengurangkan gangguan yang tinggi pada kadar 21 peratus. Untuk menambahbaikkan sistem pengawal tersebut, "speed feedforward" dicadangkan untuk meningkatkan keteguhan sistem kawalan.

ABSTRACT

The aim of this report is to analyze the characteristic of vibration on machine tools, to design a controller and an observer, and to validate the performance of control system. Precision and accuracy play important role in enhancing the performance and quality of the control system. However, vibration, is known as disturbance force that occur on machine tool can reduce the accuracy of the system. Hence, a compensator is required to design for mitigating the vibration effect to the system. In this project, a cascade P/PI controller and an inverse model based disturbance observer were chosen as compensator to control the vibration effect. Firstly, the behavior of the system was evaluated by finding its transfer function. Then, a cascade P/PI controller and disturbance observer were designed in MATLAB Simulink environment by applying the principle of traditional loop shaping method with taken into consideration on phase margin, gain margin, Nyquist diagram and bandwidth. Numerical analysis was carried out using MATLAB Simulink software. Two parameters were analyzed; disturbance rejection in root mean square tracking error and maximum amplitude of tracking error. The tracking performance of the control system was analyzed with and without input disturbances signals, then a comparison was made between them. A sinusoidal input reference was applied for this project. XYZ stage was used as positioning system whereas band limited white noise and cutting forces were utilized as emitting disturbance signal. To validate the performance of controller, an experimental analysis was conducted on the test setup. Based on the result obtained, a cascade P/PI controller with an add-on module, disturbance observer had reduced the disturbance efficiently by 21%. Further improvement was recommended by adding the speed feedforward to enhance the robustness of control system.

DEDICATION

Only

my beloved father, Lim Foo Lian

my appreciated mother, Chong Yuen Yee

my adored sister, Lim Mei Kee

for giving me moral support, money, cooperation, encouragement and also understandings

Thank You So Much & Love You All Forever

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LIST OF ABBREVIATIONS

ASTM	-	American society for testing and materials
DAC	-	Data acquisition unit
FRF	-	Frequency Response Function
FFT	-	Fast Fourier Transform
IMBDO	-	Inverse Model Based Disturbance Observer
PID	-	Proportional-Integral-Derivative
PI	-	Proportional-Integral
P	-	Proportional
RMS	-	Root Mean Square

LIST OF SYMBOLS

mm	-	Millimetre
vpm	-	Vibration per minute
N	-	Newton
Hz	-	Hertz
$^{\circ}$	-	Degree
dB	-	Decibel
m	-	Order of numerator
n	-	Order of denominator
w_c	-	Cut off frequency
rpm	-	Revolution per minute

CHAPTER 1

INTRODUCTION

This research is about the study and analysis of the vibration control of a milling machine where the machine tool is under rotational motion. Milling process normally leads to many types of vibration troubles. The research will demonstrate the understanding of the vibration troubles and how to minimize it.

1.1 Background of Study

Machine tool vibration basically is considered as undesirable phenomena. This undesirable vibration causes a huge problem in the manufacturing industry. Vibration occurs due to the excitation that appear on the material deformation and distortion. Sometimes, the long and slim drill bit is generally required to pre-drill hole as a marking on a work sample, thus totally contribute extra sensitive to the vibration. These vibrations will bring to some adverse effect such as low dimensional accuracy, poor surface finish of the work samples, undesirable noise, and most critically shorten the machine tool life.

Due to its critical effect to the machine tool, the vibration has been studied widely by some previous researchers to find out the preventive measures to mitigate vibration caused by the rotary machine tool. Tobias (1965) studied the unstable state of metal cutting process. The theory considered by Merchant (1944) was that the cutting force is directly proportional to the depth of cut. According to Nigm *et al.* (1977), dimensional analysis of orthogonal cutting under steady cutting state can be applied in modeling the cutting process. Furthermore, Minis *et al.* (1990) obtained the cutting transfer function by referring to the dynamic cutting force model in which the transfer function can be used to predict vibration in turning process.

1.2 Problem Statement

The typical rotational machine tools used in the milling machine can cause three types of vibration which are axial, lateral, and torsional. Axial vibration occurs along the length of machine tool. Lateral vibration occurs due to unbalance force and instability acting the drill bit. Torsional vibration occurs due to non-linear load applied on the drill bit. The performance of system is controlled by several external factors which include voltage variation and input cutting forces. Thus, a position compensator and an observer are required to design for rejecting the vibration disturbance due to the machining effect. A good design compensator and an observer were very important to ensure good tracking performance.

1.3 Objectives

The objectives of this project are as follow:

i. To analyze the vibration characteristics in machine tools.
ii. To design a controller and an observer to mitigate the vibration effect on machine tools.
iii. To validate the performance of the control system.

1.4 Scopes

The scopes of this project are as follow:

i. A XYZ feed table milling machine is used as positioning system.
ii. Vibration is occurred due to the interaction of machine tool and workpiece during cutting process.
iii. The control system consists of a cascade P/PI controller and an Inverse Model Based Disturbance Observer.
iv. MATLAB and Simulink software are used for control design and performance analysis.
v. Control performance analysis was based on transient response and frequency response characteristics.

1.5 Project Significance

This project plays a significant role in analyzing the vibration caused to machine tool. Firstly, vibration is identified as a critical problem to manufacturing industry. The root causes of vibration are studied and investigated. Once the causes are discovered, several alternatives and preventive measures are proposed to suppress the vibrations. Then, the most effective measure is selected to apply in this project. Next, the selected measure is then executed and implemented by designing a controller and an observer. Finally, the vibration absorber device is monitored regularly to reduce the vibration disturbance that came from the machining effect.

1.6 Contents of Report

This report is comprised of five chapters. Chapter one has been discussed as section above. Chapter two discussed the literature review of project based on previous researchers. It included the theories of vibration characteristics, causes and types of vibration, and the vibration control methods. The methods involved to collect the data and graphical presentation are covered in Chapter three. This is followed by the result and discussion in Chapter four which includes data presentation and tabulation, results interpretation, and discussion on vibration characteristics and how to control the vibration of machine tools. Finally, the conclusion and recommendations for future improvement are stated in Chapter five.

CHAPTER 2

LITERATURE REVIEW

This chapter relates information on vibration study and analysis in machine tools applications under rotational motion condition. The key topics covered in this chapter includes the overview of machining process, quality, and issues, fundamental of vibration, classifications, and terminologies of vibration, causes of vibration, vibration analysis, vibration of machine tools under rotational motion, vibration control, MATLAB Simulink, and summary.

2.1 Overview of Machining Process, Quality, and Issues

In recent decade, those technologies that applied in machining process have improved rapidly and widely. For example, numerical control is incorporated to enhance the computer monitoring system. Every year in the market, the ability of producing a new product has increased because the development of new ideas, concepts, tooling, materials, and manufacturing devices. Different machining processes have different demand. The increasing demand of market year by year, the accuracy, performance and flexibility are improved constantly to highest rate with creative and innovative solutions. Hence, all these enhancements greatly depend on the generation of precious knowledge and experiences.

Besides that, the milling fundamental must be understood first, then proceed to conduct machining process. But this is a very difficult task because the complicated of chip formation mechanism. According to recent trend, the computers and sensors are widely used and being focused on the managing, controlling, planning and monitoring of the machining process. The diagnosis aspects like surface finish, dimensional accuracy, productivity, and identification of vibrations can be conducted by the development of sensors and signal processing skills. The manufacturing border has expanded due to the enhancement of science, technology, manufacturing skills and the pressure from high competitive market (Quintana and Ciurana, 2011).

2.1.1 Overview of Milling Machine

Milling is defined as the machining process of applying rotary cutting tool to shape the solid materials by feeding in a direction at an angle with the cutting tool axis. Milling machine includes diverse of operations such as boring, turning, surface finishing and so on. It is very popular applied processes in manufacturing industry today for shaping parts into desired size.

Meanwhile, the movements of cutting tool are normally perpendicular to the axis. As the machine tool enters the workpiece, the edge of cutter cut into and exit from the workpiece, chips are produced with each pass. Therefore, it removes the material with many separate and small cuts by spinning the machine tool in high speed or controlling the workpiece carefully and slowly.

Furthermore, cutter is very important in machining process. There are many types of tools that used in milling machine. The cutting surface of cutting tool is made of rigid and high temperature resistant material. The high speed steel is a manufacturing material for low cost cutting tools whereas the cemented carbide is for high cost cutting tool. Thin film will coat on the cutter to decrease friction and increase the hardness as well (Usher and John, 1896).

Despite of how perfect the operations and functions of milling machine, however, vibration is appeared as a limitation to enhance the productivity, dimensional accuracy, and product quality. This issue has been a controversial and common topic that needs to research and investigate. This project focuses on compensating effects of vibration in machine tools.