DISTURBANCE FORCE SUPPRESSION IN LINEAR MOTOR DRIVE SYSTEM

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

by

TAN SIEW CHEN

B051510043

950224-06-5516

FACULTY OF MANUFACTURING ENGINEERING

(2019)

DECLARATION

I hereby, declared this report entitled "Disturbance Force Suppression in Linear Motor Drive System" is the results of my own research except as cited in reference.

Signature : ……………………………………

Author's Name : TAN SIEW CHEN

Date : 26th July 2019

APPROVAL

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

The supervisory committee is as follow:

……………………………………

(Supervisor) – Signature & Stamp

ABSTRAK

Dalam mana-mana sistem kedudukan, kehadiran pasukan gangguan mengurangkan pengesanan dan ketepatan kedudukan. Untuk memastikan ketepatan, kuasa-kuasa ini yang bertindak secara langsung pada sistem pemacu mesti dikompensasikan dengan cekap. Tujuan kajian ini adalah untuk menindas daya gangguan yang bertindak pada sistem pemacu linier sehingga memastikan ketepatan dan ketepatan yang tinggi. Motorik lurus adalah motor elektrik yang terdiri daripada pemegun dan pemutar yang membuat gerakan garis lurus tanpa berputar ke penukaran gerakan linear dengan itu meningkatkan kekakuan dan ketepatan sistem. Kekuatan gangguan seperti daya geseran dan daya pemotongan bertindak terus ke sistem pemacu motor linear dan mesti ditindas untuk memberikan ketepatan dan kualiti produk akhir. Pemerhatian kekerasan gangguan adalah sejenis penganggar yang digunakan dalam projek ini untuk menganggarkan secara eksplisit kekerasan gangguan. Pengamat daya gangguan telah direka dan disimulasikan menggunakan MATLAB / Simulink; perisian reka bentuk berangka dan kawalan. Pengawal P / PI lata adalah pengawal kedudukan lalai dan bersama-sama dengan pemerhati gangguan menindas pasukan gangguan menggunakan anggaran daya gangguan. Kesilapan penganggar dan ralat kedudukan dianalisis untuk mengesahkan ketepatan pemerhati. Parameter pengubah parameter pengamat, M telah direka untuk julat 0.031 hingga 0.139 sementara kelewatan masa direka untuk julat 0.125s hingga 0.224s. Keputusan menunjukkan bahawa kesilapan anggaran adalah dari 0.00001272 hingga 0.2776 volt untuk gangguan input 0.3 hingga 0.5 volt dan 2 hingga 4.5 Hz masing-masing manakala ralat kedudukan adalah dari 0.0103 hingga 2.2760 mikron.

ABSTRACT

In any positioning system, the presence of disturbance forces reduces tracking and positioning accuracy. In order to ensure precision, these forces acting directly on the drive system must be efficiently compensated. The aim of this study was to suppress disturbance forces acting on a linear drive system thus ensuring high precision and accuracy. Linear motor is an electric motor that consists of stator and rotor which create straight line motions without rotary to linear motion conversion thus improving system stiffness and accuracy. Disturbance forces such as friction forces and cutting forces act directly onto the linear motor drive system and must be suppressed in order to provide accuracy and quality of the final product. Disturbance force observer is a type of estimator used in this project to estimate explicitly the disturbance force. The Disturbance force observer was designed and simulated using MATLAB/Simulink; a numerical and control design software. A cascade P/PI controller was the default position controller and together with the disturbance observer suppressed the disturbance forces using the estimated disturbance forces. Estimator errors and position errors were analysed to validate the observer accuracy. The observer variable gain parameter, *M* was designed for the range 0.031 to 0.139 while the time delay was designed for the range 0.125s to 0.224s. Results showed that the estimation errors ranged from 0.00001272 to 0.2776 volt for input disturbance of 0.3 to 0.5 volt and 2 to 4.5 Hz respectively while the position errors ranged from 0.0103 to 2.2760 micron.

DEDICATION

Only

my beloved father, Tan Ka Lai

my appreciated mother, Eeh Lew

my adored sister and brother, Tan Siew Ho and Tan Seng Kiat

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

AJM	-	Abrasive Jet Machining
CAD	-	Computer-Aided Design
CMM	-	Coordinate Measuring Machines
CNC	-	Computer numerical control
DFO	-	Disturbance force observer
ECU	-	electronic control unit
EDM	-	Electro-discharge Machining
FYP	-	Final Year Project
IMBDO	-	Inverse model based disturbance observer
ISO	-	International Organization for Standardization
MRR	-	material-removal rate
P	-	Proportional
PD	-	proportional-derivative
PI	-	Proportional Integral
PID	-	proportional–integral–derivative
RMSE	-	Root Mean Square Error
USM	-	Ultrasonic Machining

LIST OF SYMBOLS

a	-	Acceleration
C(t)	-	Actual Plant
D	-	Disturbance
$\hat{D}$	-	Estimated disturbance force
dB	-	Magnitude
deg	-	degree
Hz	-	Hertz
K_i	-	Integral gain
K_p	-	Proportional gain
K_v	-	Deviation gain
k_f	-	Motor force constant
kg	-	Kilogram
M	-	Observer tuning parameter
mm	-	millimeter
N	-	Netwon
R(t)	-	Reference Position
F_f	-	Frictional force
s	-	Differentiator
s	-	seconds
u	-	Input voltage signal

µm	-	micrometer
v	-	voltage

CHAPTER 1

INTRODUCTION

1.1 Background

Linear motor is commonly used in industrial applications nowadays especially for tasks requiring high precision in positioning such as computer numerical control (CNC) machine. Linear motor, as shown in Figure 1.1 is an electric motor that consists stator and rotor which created a straight line motion. During machining, disturbance forces exist on linear motor drive system which caused by friction forces, cutting forces, mechanical structure and mass of workpiece that affect the quality of the final product.

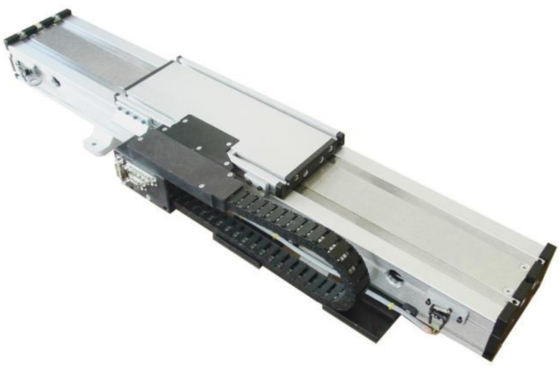

Figure 1.1: Linear actuator (Linear Actuator).

Machine tools are needed to perform advanced level in accuracy and precision. In purpose to meliorate productivity, high speed machining is acquisition more demand from manufacturers. Because of gear reduction mechanism, negative effects of rebound and structural flexibilities can be excluded by directly driven feed drivers. High acceleration and direct driving abilities of the linear motors are suitable utilized as good machine equipment feed drivers. No gearing mechanism of linear motor system make the feed drive and cutting process in the end milling are linked. Because of no gearing mechanism, it can provide high speed tracking, the cutting forces are directly act to the motors due to direct linking and have tight action on the tracking accuracy. The Coulomb friction are also shown for the linear motor drive system. The greater the hardness, the better the linear motor can support the external disturbances. Individual servomechanism for the feedback loop gain can determine the hardness. Since the motor output torque is affected by the gear reducer, the loop receives boosts with the gear ratio in a gear-drive system. However, linear motor drive system cannot gain this benefit of the reducer. The linear motor drive system requires a greater controller gain to compensate for the lack of the loop gain.

External factors or disturbance signals that blast tracking capability affect cutting capability of machine tools. Automobile and aerospace are the examples of milling process which are the usual way for metal removal in many industries. Many investigator interest in improving cutting capability during milling process. Cutting forces and frictional forces are two major elements that affect cutting capability. In whatever machine tool application, cutting force occurs during cutting process. Variables that affect cutting force characteristics are cutting parameters for examples feed rate, depth of cut and spindle speeds. Reforming of different kind control strategies have been exploited and acknowledged to handle compensation of cutting force in milling process. Suitable controller and algorithms were used by for cutting force compensation. Alteration in milling parameters are utilized in order to form a neural network to compensate cutting force.

This project focuses on disturbance force suppression in linear motor drive system. In this project, disturbance force observer acts as disturbance force estimator to estimate the disturbance force acting on the product during machining. Cascade P/PI controller is then used to suppress disturbance forces estimated by the disturbance force observer in order to reach high accuracy and precision positioning in linear motor drive system.

1.2 Problem Statement

Disturbance forces are hardly estimated especially with regard to linear motor drive system. Disturbance forces directly affect the positioning and tracking accuracy of linear motor drive system. Hence, it will affect the quality of the final product.

Precision and accurate positioning during machining is important. It is hard to regulate the needs for micrometer or nanometer accuracy in linear motor drive system. Inaccurate tracking performance in milling process is caused among others by cutting forces that exist during the material removal process. This affect the tracking performance of linear motor drive system. Inaccuracy positioning is due to cutting forces generate undesired frequency harmonics. Moreover, the performance of disturbance suppression at high frequency causes inaccuracy tracking performance. Frequency domain of machining parameters may also affect cutting force parameter.

Another problem that occurs in the control system design is it has almost zero damping in linear motor drive system. Mechanical damping is formed only at the linear bearings holding the adjusting table linked to the linear motor. The rate of the inertial burden to the damping coefficient causes the mechanical time steady of the linear motor drive system is even greater than that of the gear decrease mechanism. Hence, the controller has to boost the damping of the feedback system (Choi, Hong, Kim, & Kim, 1999).

Ineffective cutting performance also due to frictional forces generate. Friction occurs in linear motor drive systems merging parts with related motion and it is usually a disturbance for control engineers caused by high nonlinearity and negative effect such as limit cycle and steady state errors. If want to obtain highly precision and sophisticated linear motor drive system, it is need to predict the friction accurately so that friction compensation can be more effectively. However, whatever how precision of mathematical models may be, it is generally hardly to gain friction exactly from nonlinear features due to almost every physical system is contribute to some degrees of model unsure. Three categories that contribute to model unsure are unidentified dynamic friction parameters and the inertia load known as regular or repeatable unknown quantities, unmeasurable friction state contribute to dynamic unsure and non-repeatable unidentified quantities such as inaccuracy modelling of some physical terms and external disturbance.

Disturbance forces can be suppress using mechanical design approach, process planning, and controller design. Controller design and observer based approach estimate external disturbances thus reducing effect to the accuracy of the system. There is a need to establish a method whereby this acting disturbance force can be compensated in order to achieve highly accurate and precision machining.

1.3 Objectives

The objectives of this project are:

i. to design a state-based observer that estimates input disturbance for a linear motion control system.
ii. to validate numerically the performances of the observer.
iii. to analyse tracking and disturbance rejection performances of the control system with the state observer.

1.4 Scope

The scope of this project are:

i. System considered is linear and single axis.
ii. Disturbance force observer is designed and simulated using MATLAB/Simulink
iii. Performance measures include estimation errors between estimated and actual values, and tracking error reduction.
iv. Analyse on disturbance rejection are based on root-mean-square error and maximum error
v. The amplitudes and frequencies of the disturbance force are limited to 0.3 to 0.5 volt and 2 to 4.5 Hz respectively.
vi. This study focuses on design and analysis of disturbance observer to eliminate disturbance forces compensation in milling machine