UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Manufacturing Engineering

DISTURBANCE REJECTION USING DISTURBANCE FORCE OBSERVER FOR XYZ POSITIONING TABLE

Jailani B Jamaludin

Master of Science in Manufacturing Engineering

2015

DISTURBANCE REJECTION USING DISTURBANCE FORCE OBSERVER FOR XYZ POSITIONING TABLE

JAILANI B JAMALUDIN

A thesis submitted
in fulfilment of the requirements for the degree of Master of Science in Manufacturing Engineering

Faculty of Manufacturing Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2015

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Manufacturing Engineering.

Signature : ....

Name : ASSOC. PROF. DR. ZAMBERI JAMALUDIN

Date : ....

DEDICATION

Gratitude to God Almighty ALLAH S.W.T and His Messenger MUHAMMAD S.A.W

that has given me the perfection for

solving this thesis.

Special thanks to my father and mother,

Jamaludin Bin Abu Hassan and Saerah Binti Kob,

also not forgetting all the lecturers, staffs and friends of the

Universiti Teknikal Malaysia Melaka

involved directly or indirectly,

a lot of help in preparing this thesis.

Only ALLAH S.W.T is able to respond to the

dignity of life helped me

deal with this.

ABSTRACT

In milling process, disturbance forces such as friction force and cutting force act directly on work surfaces thus producing external impact on the drives system of the positioning table. This effect must be compensated in order to preserve accuracy and quality of the final product. The characteristic of these cutting forces varied with cutting variables such as spindle speed, depth of cut, and feed rate. This thesis focuses on cutting force compensation using disturbance force observer (DFO) as an add-on control module to a classical and conventional PID control structure. DFO is a type of estimator that estimates precisely disturbance forces with prior knowledge of the cutting force harmonics frequencies content. The DFO was designed based on cutting forces measured from actual milling cutting process performed at constant depth of cut of 0.5mm, feed rate of 2000mm/min, and spindle speed of 1000rpm. These measured cutting data was applied as actual disturbance into the XYZ positioning milling table for numerical analysis and experimental validation of the estimator design. All numerical analysis was performed using MATLAB and Simulink software. In machine controller design, conventional controllers such as PID and cascade controller are widely used for positioning control. Therefore, based on this observation, four different control configurations were considered; PID controller, cascade P/PI controller, PID controller with inverse model based disturbance observer (IMBDO), and PID with DFO module. This thesis compares the performance of the PID controller that was combined with an observer, either IMBDO or DFO. Numerical and experimental analyses were performed using maximum tracking errors, root mean square (RMS) of the tracking errors, and magnitudes of the Fast Fourier Transform (FFT) of the tracking errors. Results obtained showed that PID with add-on DFO module produced superior performance against other control configurations. PID combined with DFO produced the most percentage reduction in maximum tracking error averaging at 93.76% for input disturbance frequencies of 5Hz, 15Hz and 35Hz. In comparison, cascade P/PI controller managed to record a 66.22% error reduction while PID with IMBDO produced a reduction of 52.75%. In term of RMS error, the experimental results showed that PID in combination with DFO produced the most percentage reduction that was 63.89% compared to the PID controller and PID with IMBDO and cascade P/PI where each produced a reduction of only 33.33%. Lastly, for FFT error analysis, the experimental results showed that PID combined with DFO produced the most improved performance with an average reduction of 74.87% at harmonic frequencies of 2.833Hz, 17.33Hz and 35.17Hz. This was in comparison to cascade P/PI controller and PID with IMBDO that produced a reduction of 44.39% and 21.97% respectively. Further studies on improvement of control performance especially in areas such as robustness and adaptivity of the control scheme to changing cutting conditions are desired.

ABSTRAK

Dalam proses pengisaran, daya gangguan seperti daya geseran dan daya pemotongan yang bertindak secara langsung terhadap permukaan kerja menghasilkan impak luaran kepada sistem pemacu meja kedudukan. Kesan ini mesti dikurangkan untuk memelihara ketepatan dan kualiti hasil produk. Ciri-ciri daya pemotongan berbeza mengikut pembolehubah pemotongan seperti kelajuan pengumpar, kedalaman pemotongan dan kadar suapan pemotongan. Tesis ini memfokuskan pengurangan daya pemotongan dengan menggunakan 'disturbance force observer'(DFO) sebagai modul tambahan terhadap struktur kawalan klasik PID. DFO adalah sejenis penganggar yang menilai daya pemotongan secara tepat berdasarkan pengetahuan kandungan frekuensi-frekuensi harmonik daya pemotongan. DFO dicipta berdasarkan ukuran daya pemotongan daripada proces pengisaran sebenar dengan pemalar kedalaman pemotongan sebanyak 0.5mm, kadar suapan pemotongan sebanyak 2000mm/min dan kelajuan pengumpar sebanyak 1000rpm. Data ukuran pemotongan ini dilaksanakan sebagai gangguan sebenar terhadap meja kedudukan XYZ untuk analisis berangka dan pengesahan eksperimen terhadap rekaan penganggar. Semua analisis berangka dilaksanakan dengan menggunakan program MATLAB dan Simulink. Dalam industri pembuatan, pengawal klasik seperti pengawal PID atau pengawal lata digunakan secara umum untuk mengawal kedudukan dalam aplikasi pemesinan. Empat jenis konfigurasi pengawal yang diambil kira ialah pengawal PID, pengawal lata P/PI, pengawal PID bersama 'inverse model based disturbance observer' (IMBDO) dan pengawal PID bersama modul DFO. Memandangkan pengawal PID merupakan pengawal paling asas dan mudah berbanding pengawal lata, maka pengawal PID dipilih untuk penambahbaikan dengan tambahan modul penganggar (IMBDO dan DFO). Analisis ujikaji berangka dan eksperimen dilaksana dengan menggunakan ralat trajektori maksimum, ralat trajektori 'root mean square' (RMS) dan magnitud ralat trajektori 'Fast-Fourier-Transform' (FFT). Keputusan menunjukkan bahawa pengawal PID bersama modul DFO telah menghasilkan prestasi unggul berbanding dengan konfigurasi-konfigurasi kawalan lain. Di dalam analisis ralat maksima, pengawal PID bersama DFO menunjukkan keberkesanan tertinggi terhadap pengurangan ralat maksima dengan purata 93.76% (purata peratusan pengurangan untuk 5Hz, 15Hz dan 35Hz). Diikuti dengan pengawal lata P/PI sebanyak 66.22% dan terakhir PID bersama IMBDO iaitu 52.75%. Dalam analisis ralat RMS, keputusan eksperimen menunjukkan PID bersama DFO berupaya sebanyak 63.89% dalam peratusan pengurangan berbanding PID dan diikuti oleh pengawal lata P/PI dan PID bersama IMBDO dengan 33.33% untuk kedua pengawal tersebut. Dalam analisis terakhir iaitu ralat FFT untuk keputusan eksperimen, PID bersama DFO sekali lagi menunjukkan keupayaan ketara dalam peratusan penurunan dengan purata 74.87% (purata peratusan pengurangan untuk 2.833Hz, 17.33Hz dan 35.17Hz) diikuti dengan pengawal lata P/PI sebanyak 44.39% dan akhirnya PID bersama IMBDO iaitu 21.97%. Tetapi, kajian lanjut diperlukan untuk meningkatkan prestasi kawalan terutamanya dalam sektor keteguhan dan penyesuaian skema kawalan terhadap perubahan kondisi pemotongan.

ACKNOWLEDGEMENTS

First and foremost, I would like to convey my deepest gratitude to my respected supervisor, Assoc. Prof. Dr. Zamberi Bin Jamaludin. It is a great honour and pleasure to be able to work with him, who is spending his precious time for giving me ideas in and providing intellectual opinions throughout the learning process. Your kind advice, time, attention and dedication towards realizing this works are greatly appreciated and indebted.

Thank you to my lectures and friends especially Dr. Ir. Lokman Abdullah, Miss Nur Aidawati Rafan, Mr. Mohd. Nazmin Maslan, Chiew Tsung Heng, Tang Teng Fong, Madihah Maharof and all acquaintances whom know me for supporting me past three years during completing my research. This research cannot be succeeded without the help and opinions from them. Thanks for sharing the information of the research with me.

Last but not least, special thanks to my family at Perlis, father and mother who's never give up on me. Thank you for the warm care that provided by them every moment of my life.

TABLE OF CONTENTS

		PAGE
DECLARATION		
APPROVAL		
DEDICATION		
ABSTRACT		**i**
ABSTRAK		**ii**
ACKNOWLEDGEMENTS		**iii**
TABLE OF CONTENTS		**iv**
LIST OF TABLES		**vii**
LIST OF FIGURES		**ix**
LIST OF APPENDICES		**xiv**
LIST OF SYMBOLS		**xv**
LIST OF ABBREVIATIONS		**xvii**
LIST OF PUBLICATIONS		**xviii**
CHAPTER		
1.	**INTRODUCTION**	**1**
	1.1 Background	1
	1.2 Problem Statement	2
	1.3 Objectives	3
	1.4 Scopes	3
	1.5 Significance of Study	3
	1.6 Organization	4
2.	**LITERATURE REVIEW**	**5**
	2.1 Introduction of Milling	5
	2.2 Mechanical Drive System	8
	2.3 Disturbance Forces	12
	2.3.1 Friction Force	14
	2.3.2 Cutting Force	15
	2.4 Cutting Force Compensation	18
	2.5 Classical Controller	21
	2.5.1 PID Controller	22
	2.5.2 Cascade Controller	24
	2.6 Disturbance Observer	26
	2.7 Summary	31
3.	**METHODOLOGY**	**33**
	3.1 Overall Procedure of Experiment	33
	3.2 Experimental Setup	35
	3.3 System Identification & System Modeling	37
	3.4 Motor Constant Identification	43
	3.5 Cutting Force Measurement and Characterization	43
	3.7 Summary	48

4.	**CONTROLLER AND OBSERVER DESIGN**		**50**
	4.1	Design of Classical PID Controller	50
	4.2	Design of Cascade P/PI Position Controller	56
		4.2.1 Design and Analysis of Velocity Control Loop	57
		4.2.2 Design and Analysis of Position Control Loop	61
	4.3	Design of Inverse Model Base Disturbance Observer (IMBDO)	64
		4.3.1 Design and Analysis of the *Q*-filter	66
		4.3.2 Loop Characteristics of IMBDO	69
	4.4	Design of Disturbance Force Observer (DFO)	74
		4.4.1 Analysis of Disturbance Force Observer (DFO)	78
	4.5	Summary	82
5.	**RESULTS AND DISCUSSION**		**83**
	5.1	Results of PID Controller	83
		5.1.1 Tracking Error Using Sinusoidal Signal Input Disturbance	84
		5.1.2 Tracking Error Using Measured Cutting Force as Input Disturbance	86
		5.1.3 FFT Tracking Error of Sine Signal and Measured Cutting Force as Input Disturbance	87
	5.2	Results of Cascade P/PI Controller	89
		5.2.1 Tracking Error Using Sinusoidal Signal Input Disturbance	90
		5.2.2 Tracking Error Using Measured Cutting Force as Input Disturbance	92
		5.2.3 FFT Tracking Error of Sine Signal and Measured Cutting Force as Input Disturbance	93
	5.3	Results of Inverse Model Based Disturbance Observer (IMBDO)	96
		5.3.1 Tracking Error Using Sinusoidal Signal Input Disturbance	96
		5.3.2 Tracking Error Using Measured Cutting Force as Input Disturbance	100
		5.3.3 FFT Tracking Error of Sine Signal and Measured Cutting Force as Input Disturbance	102
	5.4	Results of Disturbance Force Observer (DFO)	105
		5.4.1 Tracking Error Using Sinusoidal Signal Input Disturbance	105
		5.4.2 Tracking Error Using Measured Cutting Force as Input Disturbance	109
		5.4.3 FFT Tracking Error of Sine Signal and Measured Cutting Force as Input Disturbance	111
	5.5	Discussion of Results	116
		5.5.1 Analysis of Maximum Tracking Error	116
		5.5.2 Analysis of RMS Tracking Error	119
		5.5.3 Analysis of FFT Tracking Error	122
		5.5.4 Analysis of Sensitivity Function	128
	5.6	Summary	130

6. CONCLUSION AND FUTURE STUDY **131**
6.1 Conclusion 131
6.2 Future Study 133

REFERENCES **135**
APPENDIX A **140**
APPENDIX B **141**

LIST OF TABLES

TABLE	TITLE	PAGE
3.1	System parameter of X-axis	42
3.2	The parameters for the cutting force characterization	45
4.1	Gain values of PID controller parameters	52
4.2	Gain margin and phase margin values	53
4.3	Gain value for velocity loop PI	58
4.4	Gain margin and phase margin of velocity open loop	59
4.5	Gain margin and phase margin of position open loop	63
4.6	Parameters for *Q*-filter	68
4.7	Gain margin and phase margin of system with IMBDO	72
4.8	Bandwidth of system with and without observer	74
5.1	Summarized tracking error of sinusoidal signal input disturbance for PID controller	85
5.2	RMS error of numerical and experimental results using PID controller	87
5.3	FFT tracking error of numerical and experimental results for PID controller	89
5.4	Summarized tracking error of sinusoidal signal input disturbance for cascade P/PI controller	91
5.5	RMS error of numerical and experimental results using cascade P/PI controller	93
5.6	FFT tracking error of numerical and experimental results for cascade P/PI controller	95

5.7	Summary of maximum tracking error data of system with sinusoidal input disturbance using PID controller and PID with IMBDO	98
5.8	Summary of numerical and experimental results of RMS tracking using PID controller and a PID controller with IMBDO	101
5.9	Summary of numerical and experimental results of FFT tracking errors using PID controller and PID controller with IMBDO	104
5.10	Summary of maximum tracking error data of system with sinusoidal input disturbance using PID controller and PID with DFO	107
5.11	Summary of numerical and experimental results of RMS tracking using PID controller and a PID controller with DFO	111
5.12	Summary of numerical and experimental results of FFT tracking errors using PID controller and PID controller with multiple harmonic DFO	115
5.13	Summary maximum tracking error for sinusoidal signal input disturbance	117
5.14	Summary percentage reduction of maximum tracking error for Sinusoidal signal input disturbance	117
5.15	Overall performance of PID with DFO in maximum tracking error	119
5.16	Summary of RMS tracking error for multi-sine, numerical and experimental results	119
5.17	Summary percentage reduction of RMS tracking error for multi-sine, numerical and experimental results	120
5.18	Overall performance of PID with DFO in RMS tracking error	122
5.19	Summary FFT tracking error for sinusoidal signal input disturbance	123
5.20	Summary percentage reduction of FFT tracking error for sine signal input disturbance	123
5.21	Overall performance of PID with DFO in FFT tracking error for sinusoidal signal input disturbance	125
5.22	Summary of numerical and experimental results for the magnitude of FFT tracking error with percentage reduction	126

LIST OF FIGURE

FIGURE	TITLE	PAGE
2.1	Peripheral milling (Kalpakjian & Schmid, 2013)	6
2.2	Face Milling (Kalpakjian & Schmid, 2013)	6
2.3	End milling (Kalpakjian & Schmid, 2013)	7
2.4	Picture of end milling	8
2.5	Figure of ball screw drive system	9
2.6	Figure of direct drive system	10
2.7	Rack and pinion drive system (Chiew, 2013)	11
2.8	Quadrant glitches in circular test (Jamaludin, 2008)	15
2.9	Forces acting in the cutting zone (Kalpakjian & Schmid, 2013)	16
2.10	Sample of Ferraris sensor (reproduce from Hiller, 2003)	19
2.11	Results of tracking error with and without estimator (Jamaludin, 2008)	20
2.12	General structure of PID controller	22
2.13	General structure of cascade p/pi controller	24
2.14	General structure of inverse model based disturbance observer (IMBDO)	27
2.15	General structure of disturbance force observer (DFO)	28
2.16	Schematic diagram of a cascade P/PI controller with a general state space observer (Jamaludin, 2008)	29
2.17	Measured tracking error for 1,2, and 3 harmonic synthesized cutting force (Jamaludin, 2008)	30

3.1	Overall flow chart	34
3.2	Googol XYZ positioning table	35
3.3	Schematic diagram of experimental setup	36
3.4	Flow chart of system identification and system modeling	37
3.5	Simulink diagram of FRF measurement for XYZ positioning table	38
3.6	Input voltage (filtered random white noise)	39
3.7	Actual output position	39
3.8	Bode diagram of real system model & best fit model	40
3.9	A scheme of mass-spring-damper system	41
3.10	Block diagram of open loop system for motor constant estimation	43
3.11	Flow chart of cutting force characterization	44
3.12	The Kistler dynamometer	44
3.13	Diagram of prepared aluminum block	45
3.14	Schematic diagram of cutting force characterization	46
3.15	Picture of aluminum block during cutting force data collection	47
3.16	Original cutting force data from milling operation	47
3.17	Frequency analysis content for 1000rpm	48
4.1	Block diagram of a system with a PID controller	51
4.2	Bode diagram of open loop transfer function of the system	53
4.3	Nyquist diagram of open loop system	54
4.4	Closed loop transfer function of the system	54
4.5	Sensitivity functions of the system	55
4.6	Control scheme of a system with a cascade P/PI controller	56
4.7	Bode diagram of velocity open loop transfer function	58
4.8	Nyquist diagram of velocity open loop	59

4.9	Velocity closed loop transfer function	60
4.10	Sensitivity function of velocity loop	60
4.11	Bode diagram of position open loop transfer function	62
4.12	Nyquist diagram of position open loop system	62
4.13	Position closed loop transfer function	63
4.14	Sensitivity function of the position loop	64
4.15	Block diagram of the system with an IMBDO	65
4.16	Equivalent block diagram of the system with an IMBDO	65
4.17	Magnitude plot of the Q-filter and the $1/\Delta\ (s)$ function	68
4.18	Schematic diagram of the system with PID and IMBDO	69
4.19	Bode diagram of the system open loop transfer functions with and without observer	71
4.20	Nyquist diagram of system with and without observer	72
4.21	Bode diagram of closed loop transfer functions of system with observer and without observer	73
4.22	Sensitivity functions of systems with and without observer	73
4.23	Schematic diagram of PID controller with DFO	76
4.24	Schematic diagram for DFO (single harmonic)	76
4.25	Sensitivity function for one harmonic (17.33Hz)	80
4.26	Results of measured position error (a) in time domain and estimated position error (b) in frequency domain	81
5.1	Schematic diagram for numerical analysis of PID controller	84
5.2	Results of (a) sinusoidal signal input disturbance and (b) maximum tracking error for PID controller	85
5.3	Results of (a) multi-sine input disturbance and (b) RMS tracking error for PID controller	87
5.4	Results of RMS tracking error (a) numerical analysis and (b) experimental validation using PID controller	87

5.5	Results of (a) sinusoidal signal input disturbance and (b) FFT tracking error for PID controller	88
5.6	FFT tracking error (a) numerical and (b) experimental results for PID controller	89
5.7	Schematic diagram for numerical analysis of cascade P/PI controller	90
5.8	Results of (a) sinusoidal signal input disturbance and (b) maximum tracking error for cascade P/PI controller	91
5.9	Results of (a) multi-sine input disturbance and (b) RMS error for cascade P/PI controller	92
5.10	Results of RMS error (a) numerical analysis and (b) experimental validation using cascade P/PI controller	93
5.11	Results of (a) sinusoidal signal input disturbance and (b) FFT tracking error for cascade P/PI controller	94
5.12	FFT tracking error (a) numerical and (b) experimental results for cascade P/PI controller	95
5.13	Schematic diagram for numerical analysis of PID controller with an IMBDO	96
5.14	Maximum tracking errors for (a) PID controller and (b) PID controller with IMBDO using sinusoidal input disturbance at (i) 5Hz, (ii) 15Hz, and (iii) 35Hz	97
5.15	Results of (a) input disturbance and (b) measured tracking error with IMBDO activated	99
5.16	RMS tracking error using multi-sine input disturbance for (a) PID controller and (b) PID with IMBDO	99
5.17	Numerical results of RMS tracking error using input of measured cutting force data for (a) PID controller and (b) PID with IMBDO	100
5.18	Experimental results of RMS tracking error using input of measured cutting force data for (a) PID controller and (b) PID with IMBDO	101
5.19	Results of (a) Sinusoidal input disturbance signals and (b) FFT tracking error of PID controller with IMBDO	102
5.20	Numerical results of FFT tracking error for (a) PID controller and (b) PID controller with IMBDO	103

5.21	Experimental results of FFT tracking error for (a) PID controller and (b) PID controller with IMBDO	103
5.22	Schematic diagram for numerical analysis of PID controller with a DFO	105
5.23	Maximum tracking errors for (a) PID controller and (b) PID controller with DFO using sinusoidal input disturbance at (i) 5Hz, (ii) 15Hz, and (iii) 35Hz	106
5.24	Results of (a) sine signal input disturbance and (b) measured tracking error with DFO activated	108
5.25	RMS tracking error using multi-sine input disturbance for (a) PID controller and (b) PID with DFO	109
5.26	Numerical results of RMS tracking error using input of measured cutting force data for (a) PID controller and (b) PID with DFO	109
5.27	Experimental results of RMS tracking error using input of measured cutting force data for (a) PID controller and (b) PID with DFO	110
5.28	Results of (a) sinusoidal signal input disturbance and (b) FFT tracking error for PID controller with DFO	112
5.29	Tracking errors and FFT of Tracking errors for (a) PID without DFO and (b) PID with single harmonic DFO at 2.833Hz	113
5.30	Numerical results FFT of tracking errors for measured cutting force input disturbance using (a) PID controller and (b) PID controller with multiple harmonic DFO	114
5.31	Experimental results FFT of tracking errors for measured cutting force input disturbance using (a) PID controller and (b) PID controller with multiple harmonic DFO	114
5.32	Sensitivity plot for PID, PID with IMBDO and Cascade P/PI	128
5.33	Sensitivity plot for PID with DFO for 3 harmonic designs	129

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	Googol XYZ positioning table specification	140
B	Specification of Kistler dynamometer type 9257B	141

LIST OF SYMBOLS

π	-	Pi
$C(s)$	-	Output signal
d	-	External disturbance
$\hat{d}$	-	Estimated disturbance
D	-	Diameter of cutter
e_{pos}	-	Tracking error
F	-	Friction force
f	-	Feed per tooth
F_c	-	Cutting force
F_t	-	Thrust force
G_{PI}	-	PI controller
G_{PD}	-	PD controller
G_{PID} , G_{pid}	-	PID controller
$G(s)$, $G_s(s)$	-	Systemtransfer function
$G_{frf}(s)$	-	Real system dynamic
$G_n(s)$	-	Nominal plant
$G_n^{-1}(s)$	-	Inverse nominal plant
K_1 , K_p	-	Proportional gain
K_2 , K_i	-	Integral gain
K_3 , K_d	-	Derivative gain
K_f	-	Motor constant
M	-	Mass
N	-	Normal force
N	-	Rotational spindle speed
N	-	Newton

n	-	Number of teeth
$Q(s)$	-	Q-filter
R	-	Resultant force
$R(s)$	-	Input signal
S	-	Sensitivity
U	-	Input
V, v	-	Cutting speed (velocity)
V	-	Voltage
$V_{est}(s)$	-	Estimated velocity
Z	-	Output position
z_{ref}	-	Reference input
z_{act}	-	Actual output

LIST OF ABBREVIATIONS

AFLC	-	Adaptive fuzzy logic control
AMB	-	Active magnetic bearing
CNC	-	Computer numerical control
DFO	-	Disturbance force observer
DZC	-	Dead zone compensator
FFT	-	Fast-Fourier-Transform
FRF	-	Frequency response function
HSS	-	High speed steel
Hz	-	Hertz
IMBDO	-	Inverse model based disturbance observer
MLPANN	-	Multilayer Neural Network
MIFO	-	Model-Independent Force Observer
N-PID	-	Nonlinear proportional-integral-derivative
NCasFF	-	Nonlinear Cascade Feed Forward
N	-	Newton
P	-	Proportional
PD	-	Proportional-derivative
PI	-	Proportional-integral
PID	-	Proportional-integral-derivative
RPM	-	Revolution per minute
SISO	-	Single input single output
SMC	-	Sliding mode control
V	-	Voltage

LIST OF PUBLICATIONS

Journals:

Jamaludin, J., Jamaludin, Z., Abdullah, L., Chiew, T. H., 2015. Design and Analysis of Disturbance Force Observer for Machine Tools Application. Applied Mechanics and Materials, 761, pp. 148-152.

Abdullah, L., Jamaludin, Z., Salleh, M. R., Abu Bakar, B., Jamaludin, J., Chiew, T. H., and Rafan, N.A. 2014. Theoretical Analysis of Velocity and Position Loop Behaviour of Nonlinear Cascade Feedforward Controller for Positioning of XY Table Ballscrew Drive System. *Advanced Materials Research*, 845, pp. 831 – 836.

Abdullah, L., Jamaludin, Z., Ahsan, Q., Jamaludin, J., Rafan, N. A., Chiew, T. H., Jusoff, K., and Yusoff, M. 2013. Evaluation on Tracking Performance of PID, Gain Scheduling and Classical Cascade P/PI controller on XY Table Ballscrew Drive System. *World Applied Sciences Journal*, 21(1), 01-10.

Conferences:

Abdullah, L. Jamaludin, Z., Rafan, N. A., Jamaludin, J., Chiew, T. H., and Maidin, S., 2013. Assessment on Tracking error Performance of Cascade P/PI, NPID and N-Cascade Controller for Precise Positioning of XY Table Ballscrew Drive System. In: Raisuddin Khan, Md., *The 5th International Conference on Mechatronics (ICOM'13)*, Kuala Lumpur, 2 – 4 July 2013, IIUM Publication.

Jamaludin, Z., Abdullah, L., Chiew, T. H., Maarof, M., Jamaludin, J., and Bani Hashim, A.Y. 2012. Robustness in Cutting Force Compensation in Machine Tools Application. In: CIRP Associations, *CIRP 10th Global Conference on Sustainable Manufacturing 2012 (GCSM 2012)*, Istanbul Turkey, 31 October – 02 November 2012, CIRP Publication.

CHAPTER 1

INTRODUCTION

This chapter introduces a research entitled Disturbance Rejection Using Disturbance Force Observer for XYZ Positioning Table that includes a research background, problem statements, objectives, scopes, and overall content and organization of this thesis.

1.1 Background

Machine tool can be defined as a machine that enables various materials, metal in particular, to be produced into a required shape or form, from common everyday objects such as household products to the most intricate objects like aircrafts and satellites parts. Machine tool produces most of these objects and products with the intention for improving human's life quality. There are large diversity of machine tool types depending on the technologies, sizes and capacity of the designed product. A great example of a machine tool is CNC milling machine which is commonly applied in industrial sector for manufacturing purposes.

High accuracy and precision in machine tools is critical in achieving high standard as required by customers. However, the cutting performance of machine tools application is normally influenced by other external factors or disturbances that could reduce both accuracy and precision. This research proposes to focus on one manufacturing process that is milling process because it is a common method for metal removal processes in many industries such as automobile, aerospace, and else. The cutting performance of the milling process is important as this process is applied in many fields as mentioned before. During milling process, the most significant factors that could affect the cutting performance are