



شبكة المعلومات الجامعية
التوثيق الإلكتروني والميكرو فيلم

بسم الله الرحمن الرحيم



HANAA ALY



شبكة المعلومات الجامعية
التوثيق الإلكتروني والميكروفيلم



شبكة المعلومات الجامعية التوثيق الإلكتروني والميكروفيلم



HANAA ALY



شبكة المعلومات الجامعية
التوثيق الإلكتروني والميكروفيلم

جامعة عين شمس التوثيق الإلكتروني والميكروفيلم

قسم

نقسم بالله العظيم أن المادة التي تم توثيقها وتسجيلها
علي هذه الأقراص المدمجة قد أعدت دون أية تغييرات



يجب أن

تحفظ هذه الأقراص المدمجة بعيدا عن الغبار



HANAA ALY



Cairo University

ADVANCED TECHNIQUES IN MECHATRONIC SYSTEMS

By

Akram Mohamed Fahmy Abdelghany Singer

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
in
Mechanical Design and Production Engineering

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2020

ADVANCED TECHNIQUES IN MECHATRONIC SYSTEMS

By
Akram Mohamed Fahmy Abdelghany Singer

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
in
Mechanical Design and Production Engineering

Under the Supervision of

Prof. Dr. Galal Ali Hassaan

Dr. Mohamed Ahmed Elgamil

Emeritus Professor of System Dynamics
Mechanical Design and Production
Engineering
Faculty of Engineering, Cairo University

Assistant Professor of System Dynamics
Mechanical Design and Production
Engineering
Faculty of Engineering, Cairo University

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT

2020

ADVANCED TECHNIQUES IN MECHATRONIC SYSTEMS

By
Akram Mohamed Fahmy Abdelghany Singer

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
in
Mechanical Design and Production Engineering

Approved by the
Examining Committee

Prof. Dr. Galal Ali Hassaan,

Thesis Main Advisor

Prof. Dr. Mohammed Elsayed Elaraby,

Internal Examiner

Prof. Dr. Mahmoud Galaleddin Mohammed Rabie,

External Examiner

- Military Technical College

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2020

Engineer's Name: Akram Mohamed Fahmy Abdelghany Singer
Date of Birth: 24 /09 /1980
Nationality: Egyptian
Phone : 01000495500
Address: Heliopolis
Registration Date: 01 /10 / 2013
Awarding Date: 2020
Degree: Master of Science
Department: Mechanical design and Production Engineering
Supervisors: Prof. Dr. Galal Ali Hassaan
Dr. Mohamed Ahmed Elgamil
Examiners: Prof. Dr. Galal Ali Hassaan (Thesis main advisor)
Prof. Dr. Mohammed Elsayed Elaraby (Internal examiner)
Prof. Dr Mahmoud Galaleddin M.Rabie (External examiner)
Military Technical College



Title of Thesis: ADVANCED TECHNIQUES IN MECHATRONIC SYSTEMS

Key Words: PI-PD controller, PD-PI controller, controller tuning, process disturbance rejection ,controller robustness

Summary: Sever oscillations in modern industrial processes are completely undesirable. Also, controller tuning needs to tackle this issue. PI-PD and PD-PI are controllers within the second generation of the PID controller-family which is proposed to solve this issue with improved performance regarding the spike qualities associated with the conventional PID controller. This work has demonstrated that utilizing the PI-PD and PD-PI controllers are fit for tackling the issues of the profoundly oscillated third order process. The controllers are tuned by minimizing error based performance indices such as: ISE, IAE, ITAE, ITSE, and ISTSE of the closed loop control system using the MATLAB optimization toolbox. The maximum percentage overshoot, and settling time are utilized to control the performance of the closed loop control system. The tuning of the used PI-PD and PD-PI controllers using the current tuning procedure is compared with a tuning technique based on using the minimum ITAE standard form.

Disclaimer

I hereby declare that this thesis is my own original work and that no part of it has been submitted for a degree qualification at any other university or institute.

I further declare that I have appropriately acknowledged all sources used and have cited them in the references section.

Name: Akram Mohamed Fahmy Abdelghany Singer

Date: 27 / 8 / 2020

Signature:

Dedication

To the memory of my father *Mohamed Fahmy Abdelghany Singer*. To his beloved soul.
May Allah Almighty bless him.

Acknowledgement

Praise is to Allah for helping me to complete this work and relieving me during hard times. I would like to express my greatest gratitude and appreciation to Prof. Dr. Galal Ali Hassaan, for his great assistance and supervision to put this work in its final form.

I am deeply indebted to Dr. Mohamed Ahmed Elgamil, for his attention and supervising this research. His regards and guidance led to the completion of the work in the present form.

Also I want present my deepest gratitude and many thanks for to Dr. Amr Sarhan, Dr. Sherif Saleh, and Dr. Ahmed Said from the Military Technical College for their pushing in the work. Always they help me to be in the best environment of work.

Also, a great part of this research wouldn't have been possible without the aid of Engineer Abdullah Ali Ismail, and Engineer Samy Zamzam for his kindness, great help, and technical support.

Last but not the least; my special thanks go to my wife for being there for me whenever I need her support.

Akram Fahmy

Table of Contents

LIST OF TABLES	vii
LIST OF FIGURES	viii
NOMENCLATURE.....	x
ABSTRACT.....	xiv
Chapter 1: INTRODUCTION	1
1.1 PREFACE.....	1
1.2 FIRST GENERATION OF PID CONTROLLERS	1
1.3 SECOND GENERATION OF PID CONTROLLERS	2
1.4 LITERATURE SURVEY ON PI-PD CONTROLLERS	4
1.5 LITERATURE SURVEY ON PD-PI CONTROLLERS	5
1.6 SCOPE OF WORK	6
1.7 THESIS OUTLINE	6
Chapter 2: THIRD ORDER PROCESS SIMULATOR	7
2.1 INTRODUCTION.....	7
2.2 PROCESS TRANSFER FUNCTION AND PARAMETERS	7
2.3 THIRD ORDER PROCESS STEP TIME RESPONSE.....	7
2.4 EFFECT OF PROCESS PARAMETERS ON TIME RESPONSE	8
2.4.1 Effect of K_{i3}	8
2.4.2 Effect of T_1	9
2.4.3 Effect of T_2	9
Chapter 3: CONTROLLING THE THIRD ORDER PROCESS USING A PI-PD CONTROLLER.....	10
3.1 INTRODUCTION.....	10
3.2 PI-PD CONTROLLER STRUCTURE AND CONTROL SYSTEM TRANSFER FUNCTION	10

3.3	CONTROLLER TUNING	13
3.3.1	Tuning using MATLAB.....	13
3.3.2	Tuning using ITAE standard forms.....	14
3.4	Checking the PI-PD controller Robustness	15
3.4.1	Process uncertainty.....	15
3.5	Disturbance Rejection using the PI-PD controller	19
3.5.1	Controller tuning for disturbance rejection	20
3.5.2	Comparison with PID controller	21
3.6	CONCLUSION	22
Chapter 4:	CONTROLLING THE THIRD ORDER PROCESS USING A PD-PI CONTROLLER.....	23
4.1	INTRODUCTION.....	23
4.2	PD-PI CONTROLLER STRUCTURE AND CONTROL SYSTEM TRANSFER FUNCTION	23
4.3	CONTROLLER TUNING	25
4.3.1	Tuning using MATLAB.....	25
4.3.2	Tuning using ITAE standard forms.....	27
4.3.3	Comparison with other controllers.....	27
4.4	CHECKING THE PD-PI CONTROLLER ROBUSTNESS.....	28
4.4.1	Process uncertainty.....	29
4.5	DISTURBANCE REJECTION USING THE PD-PI CONTROLLER	31
4.5.1	Controller tuning for disturbance rejection	32
4.5.2	Comparison with other controllers.....	33
4.6	CONCLUSION	34
Chapter 5:	EXPERIMENTAL WORK.....	35
5.1	Arduino Mega 2560.....	35

5.2	THIRD ORDER PROCESS SIMULATOR.....	35
5.2.1	Process simulator electronic circuit.....	35
5.2.2	Setup for step response measurement of the third order process simulator ..	36
5.3	PI-PD CONTROLLER SIMULATOR	37
5.3.1	Setup for step response measurement of the PI-PD simulator	37
5.3.2	Experimental step response of the process controlled by PI-PD controller ..	38
5.4	PD-PI CONTROLLER SIMULATOR	39
5.4.1	PD-PI controller electronic simulator	39
5.4.2	Setup for step response measurement of the PD-PI simulator	39
Chapter 6: DISCUSSION AND CONCLUSIONS		42
6.1	INTRODUCTION.....	42
6.2	DISCUSSION.....	42
6.2.1	PI-PD controller	42
6.2.2	PD-PI controller	43
6.3	CONCLUSIONS	44
6.4	RECOMMENDATION FOR FUTURE WORK	45
REFERENCES		46
APPENDIX A:		53
APPENDIX B: PUBLISHED PAPERS.....		72
B1:Tuning of a PI-PD controller used with a third order process		73
B2:Robustness of PI-PD controller used with third order processes		74
B3:Disturbance rejection of a third order process controlled by a PI-PD controller		75
B4:Tuning of a PD-PI controller used with a third order process		76
B5:Robustness of PD-PI controller used with third order processes		77
B6:Disturbance rejection of a third order process controlled by a PD-PI controller		78

List of Tables

Table 1: Time-based specifications of the PI-PD controlled third order process.....	14
Table 2: Time-based specifications of the PI-PD controlled third order process Tuned using two techniques.....	15
Table 3: Time based specifications of the control system using PI-PD and PID controllers for disturbance rejection	22
Table 4: Time-based specifications of the PD-PI controlled third order process.....	26
Table 5: Time-based specifications of the control system using three controllers.....	28
Table 6: Time based specifications of the control system using PID, PD-PI and PI-PD controllers for disturbance rejection.	33
Table 7: Normalized time-based specifications of the control system using three controllers.	44

List of Figures

Figure 2.1: Block Diagram of Third Order Process	7
Figure 2.2: Unit step time response of the third order process.....	8
Figure 2.3: effect of K_{i3} on OS% and T_s	8
Figure 2.4: Effect of T_1 on OS_{max} and T_s	9
Figure 2.5: Effect of T_2 on OS_{max} and T_s	9
Figure 3.1: PI-PD controller - based control system [67].....	11
Figure 3.2: Unit step response of the PI-PD controller with a third order process tuned using different objective functions	13
Figure 3.3: Unit step response of the PI-PD controlled third order process using two tuning techniques.	15
Figure 3.4: Effect of process parameters variation on system settling time.....	16
Figure 3.5: Effect of process parameters variation on system maximum percentage overshoot.....	17
Figure 3.6: Effect of process parameters variation on system maximum percentage undershoot.....	17
Figure 3.7: Effect of process parameters variation on system Gain Margin (GM)	18
Figure 3.8: Effect of process parameters variation on system Phase Margin (PM)	18
Figure 3.9: Block diagram incorporating a PI-PD controller and a disturbed process.....	19
Figure 3.10: Control system block diagram with disturbance input	19
Figure 3.11: Time response of the control system with PI-PD controller and a third order process rejecting a unit step disturbance.....	20
Figure 3.12: Comparison between time responses using PID and PI-PD controllers	21
Figure 4.1: PD-PI controller-based control system	23
Figure 4.2: Unit step response of the PD-PI controller with a third order process tuned by different objective functions	26
Figure 4.3: Step response of the PD-PI controlled third order process tuned by ITAE standard form and present work tuning.	27
Figure 4.4: Step response of the third order process controlled by PD-PI, PI-PD and PID controllers.	28
Figure 4.5: Effect of process parameters variation on system settling time.....	29
Figure 4.6: Effect of process parameters variation on system maximum percentage overshoot.....	29
Figure 4.7: Effect of process parameters variation on system maximum percentage undershoot.....	30