



# Contents

<b>Preface</b>	<b>ix</b>
<b>Chapter 1 Introduction to Control Systems</b>	<b>1</b>
1-1 Introduction	1
1-2 Examples of Control Systems	4
1-3 Closed-Loop Control Versus Open-Loop Control	7
1-4 Design and Compensation of Control Systems	9
1-5 Outline of the Book	10
<b>Chapter 2 Mathematical Modeling of Control Systems</b>	<b>13</b>
2-1 Introduction	13
2-2 Transfer Function and Impulse-Response Function	15
2-3 Automatic Control Systems	17
2-4 Modeling in State Space	29
2-5 State-Space Representation of Scalar Differential Equation Systems	35
2-6 Transformation of Mathematical Models with MATLAB	39

2-7	Linearization of Nonlinear Mathematical Models	43	
	Example Problems and Solutions	46	
	Problems	60	
<b>Chapter 3 Mathematical Modeling of Mechanical Systems and Electrical Systems</b>			<b>63</b>
3-1	Introduction	63	
3-2	Mathematical Modeling of Mechanical Systems	63	
3-3	Mathematical Modeling of Electrical Systems	72	
	Example Problems and Solutions	86	
	Problems	97	
<b>Chapter 4 Mathematical Modeling of Fluid Systems and Thermal Systems</b>			<b>100</b>
4-1	Introduction	100	
4-2	Liquid-Level Systems	101	
4-3	Pneumatic Systems	106	
4-4	Hydraulic Systems	123	
4-5	Thermal Systems	136	
	Example Problems and Solutions	140	
	Problems	152	
<b>Chapter 5 Transient and Steady-State Response Analyses</b>			<b>159</b>
5-1	Introduction	159	
5-2	First-Order Systems	161	
5-3	Second-Order Systems	164	
5-4	Higher-Order Systems	179	
5-5	Transient-Response Analysis with MATLAB	183	
5-6	Routh's Stability Criterion	212	
5-7	Effects of Integral and Derivative Control Actions on System Performance	218	
5-8	Steady-State Errors in Unity-Feedback Control Systems	225	
	Example Problems and Solutions	231	
	Problems	263	

**Chapter 6 Control Systems Analysis and Design  
by the Root-Locus Method**

**269**

6-1	Introduction	269
6-2	Root-Locus Plots	270
6-3	Plotting Root Loci with MATLAB	290
6-4	Root-Locus Plots of Positive Feedback Systems	303
6-5	Root-Locus Approach to Control-Systems Design	308
6-6	Lead Compensation	311
6-7	Lag Compensation	321
6-8	Lag-Lead Compensation	330
6-9	Parallel Compensation	342
	Example Problems and Solutions	347
	Problems	394

**Chapter 7 Control Systems Analysis and Design by the  
Frequency-Response Method**

**398**

7-1	Introduction	398
7-2	Bode Diagrams	403
7-3	Polar Plots	427
7-4	Log-Magnitude-versus-Phase Plots	443
7-5	Nyquist Stability Criterion	445
7-6	Stability Analysis	454
7-7	Relative Stability Analysis	462
7-8	Closed-Loop Frequency Response of Unity-Feedback Systems	477
7-9	Experimental Determination of Transfer Functions	486
7-10	Control Systems Design by Frequency-Response Approach	491
7-11	Lead Compensation	493
7-12	Lag Compensation	502
7-13	Lag-Lead Compensation	511
	Example Problems and Solutions	521
	Problems	561

**Chapter 8 PID Controllers and Modified PID Controllers**

**567**

8-1	Introduction	567
8-2	Ziegler-Nichols Rules for Tuning PID Controllers	568

8-3	Design of PID Controllers with Frequency-Response Approach	577
8-4	Design of PID Controllers with Computational Optimization Approach	583
8-5	Modifications of PID Control Schemes	590
8-6	Two-Degrees-of-Freedom Control	592
8-7	Zero-Placement Approach to Improve Response Characteristics	595
	Example Problems and Solutions	614
	Problems	641

## **Chapter 9 Control Systems Analysis in State Space**

**648**

9-1	Introduction	648
9-2	State-Space Representations of Transfer-Function Systems	649
9-3	Transformation of System Models with MATLAB	656
9-4	Solving the Time-Invariant State Equation	660
9-5	Some Useful Results in Vector-Matrix Analysis	668
9-6	Controllability	675
9-7	Observability	682
	Example Problems and Solutions	688
	Problems	720

## **Chapter 10 Control Systems Design in State Space**

**722**

10-1	Introduction	722
10-2	Pole Placement	723
10-3	Solving Pole-Placement Problems with MATLAB	735
10-4	Design of Servo Systems	739
10-5	State Observers	751
10-6	Design of Regulator Systems with Observers	778
10-7	Design of Control Systems with Observers	786
10-8	Quadratic Optimal Regulator Systems	793
10-9	Robust Control Systems	806
	Example Problems and Solutions	817
	Problems	855

<b>Appendix A</b>	<b>Laplace Transform Tables</b>	<b>859</b>
<b>Appendix B</b>	<b>Partial-Fraction Expansion</b>	<b>867</b>
<b>Appendix C</b>	<b>Vector-Matrix Algebra</b>	<b>874</b>
<b>References</b>		<b>882</b>
<b>Index</b>		<b>886</b>