

Contents

<i>Preface</i>	xv
<i>Acknowledgements</i>	xix
1. INTRODUCTION TO THE CONTROL PROBLEM	1
1.1 Control Systems: Terminology and Basic Structure	1
1.2 The Genesis and Essence of the Feedback Control Theory	8
1.3 Feedforward-Feedback Control Structure	14
1.4 Multivariable Control Systems	16
1.5 Scope and Organization of the Book	23
2. DYNAMICAL SYSTEMS MODELLING AND RESPONSE: THE TRANSFER FUNCTION	25
2.1 Introduction	25
2.2 State Variable Models	28
2.3 Impulse Response Models	33
2.4 The Laplace Transform	36
2.5 Laplace Transforms of Signals useful for Control System Analysis	38
2.6 Laplace Transforms for Simple Systems	43
2.7 Transfer Function Models	46
2.8 Characteristic Parameters of First- and Second-Order Models	55
2.9 Sinusoidal Transfer Functions	61
2.10 Models of Mechanical Systems	63
2.11 Models of Thermal Systems	70
2.12 Models of Hydraulic Systems	77
2.13 Models of Operational-Amplifier Circuits for Implementing Proportional-Integral-Derivative Modes of Control	82
<i>Review Examples</i>	92
<i>Review Questions</i>	95
<i>Problems</i>	95

3. MODELS OF INDUSTRIAL CONTROL DEVICES AND SYSTEMS	104
3.1 Introduction	104
3.2 Generalized Block Diagram of a Feedback System	105
3.3 Block Diagram Manipulations	106
3.4 Signal Flow Graphs and the Mason's Gain Rule	111
3.5 DC Motor Speed Control	117
3.6 DC Motor Position Control	127
3.7 AC (Carrier) Control Systems	131
3.8 Hydraulic Devices for Motion Control	141
3.9 Pneumatic Devices for Process Control	147
<i>Review Examples</i>	155
<i>Review Questions</i>	159
<i>Problems</i>	160
4. BASIC PRINCIPLES OF FEEDBACK AND CHARACTERISTICS OF PROPORTIONAL-INTEGRAL-DERIVATIVE MODES OF CONTROL	169
4.1 Introduction	169
4.2 The Control Objectives	172
4.3 Feedback Control System Characteristics	178
4.4 Proportional Mode of Feedback Control	190
4.5 Integral Mode of Feedback Control	193
4.6 Derivative Mode of Feedback Control	197
<i>Review Examples</i>	200
<i>Review Questions</i>	206
<i>Problems</i>	206
5. CONCEPTS OF STABILITY AND THE ROUTH STABILITY CRITERION	215
5.1 Introduction	215
5.2 Bounded-Input Bounded-Output Stability	217
5.3 Zero-Input Stability	221
5.4 The Routh Stability Criterion	222
5.5 Stability Range for a Parameter	232
<i>Review Examples</i>	234
<i>Review Questions</i>	237
<i>Problems</i>	237
6. PERFORMANCE SPECIFICATIONS ON SYSTEM TIME RESPONSE	241
6.1 Introduction	241
6.2 The Performance Specifications	242
6.3 Transient Response Specifications in terms of Pole Locations	247
6.4 Effects of an Additional Zero and an Additional Pole	257
6.5 Desired Closed-Loop Pole Locations and the Dominance Condition	262

- 6.6 Steady-State Error Constants and System-Type Number 264
- 6.7 Introduction to Design and Compensation 268
- 6.8 Tunable PID Controllers 277
 - Review Examples* 279
 - Review Questions* 286
 - Problems* 287

7. THE ROOT LOCUS TECHNIQUE AND COMPENSATOR DESIGN USING ROOT LOCUS PLOTS **297**

- 7.1 Introduction 297
- 7.2 The Root Locus Concept 298
- 7.3 Guidelines for Sketching Root Loci 307
- 7.4 Selected Illustrative Root Loci 318
- 7.5 Reshaping the Root Locus 326
- 7.6 Cascade Lead Compensation 336
- 7.7 Cascade Lag Compensation 342
- 7.8 Cascade Lag-Lead Compensation 345
- 7.9 Cascade PID Compensation 348
- 7.10 Minor-Loop Feedback Compensation 350
- 7.11 The Root Locus of Systems with Dead-Time 353
 - Review Examples* 355
 - Review Questions* 362
 - Problems* 362

8. NYQUIST/BODE FREQUENCY RESPONSE PLOTS AND SYSTEM STABILITY **372**

- 8.1 Introduction 372
- 8.2 Development of the Nyquist Stability Criterion 375
- 8.3 Selected Illustrative Nyquist Plots 381
- 8.4 Stability Margins 389
- 8.5 The Bode Plots 395
- 8.6 Stability Margins on the Bode Plots 411
- 8.7 Stability Analysis of Systems with Dead-Time 413
- 8.8 Frequency Response Measurements 417
 - Review Examples* 422
 - Review Questions* 426
 - Problems* 427

9. PERFORMANCE SPECIFICATIONS ON SYSTEM FREQUENCY RESPONSE **434**

- 9.1 Introduction 434
- 9.2 Performance Specifications in Frequency Domain 437
- 9.3 Frequency Response of a Standard Second-Order System 440
- 9.4 Constant- M Circles 448
- 9.5 The Nichols Chart 452

<i>Review Examples</i>	457
<i>Review Questions</i>	459
<i>Problems</i>	460

10. COMPENSATOR DESIGN USING BODE PLOTS

467

10.1	Introduction	467
10.2	Reshaping the Bode Plot	468
10.3	Cascade Lead Compensation	476
10.4	Cascade Lag Compensation	487
10.5	Cascade Lag-Lead Compensation	493
10.6	Cascade PID Compensation	497

<i>Review Examples</i>	501
<i>Review Questions</i>	509
<i>Problems</i>	510

11. DIGITAL CONTROL SYSTEMS

515

11.1	Industrial and Embedded Control	515
11.2	Use of Digital Computer as a Compensator Device	518
11.3	Configuration of the Basic Computer-Control Scheme	519
11.4	Principles of Signal Conversion	520
11.5	Shaft-Angle Encoders for Digital Measurement of Shaft Position/Speed	523
11.6	Digital Implementation of Analog Compensators	526
11.7	Formulation of Direct Digital Control Design Problem	532
11.8	The z -Transform	536
11.9	Closed-Loop Sampled-Data Systems: Transfer Function Models and Dynamic Response	541
11.10	s -Plane to z -Plane Mapping	547
11.11	Transform Design of Digital Controls	552

<i>Review Examples</i>	558
<i>Review Questions</i>	562
<i>Problems</i>	562

12. CONTROL SYSTEM ANALYSIS USING STATE VARIABLE METHODS

568

12.1	Introduction	568
12.2	Matrices	569
12.3	State Variable Representation	574
12.4	Conversion of State Variable Models to Transfer Functions	579
12.5	Conversion of Transfer Functions to Canonical State Variable Models	582
12.6	Solution of State Equations	594
12.7	Concepts of Controllability and Observability	602
12.8	Equivalence between Transfer Function and State Variable Representations	610

<i>Review Examples</i>	615
<i>Review Questions</i>	620
<i>Problems</i>	621

13. CONTROL SYSTEM DESIGN USING STATE VARIABLE METHODS	630
13.1 Introduction	630
13.2 State Variable Feedback Structure	631
13.3 Pole-Placement Design using State Feedback	633
13.4 State Feedback with Integral Control	638
13.5 Critique of Pole-Placement State Feedback Control	641
13.6 Observer-based State Feedback Control	643
13.7 Digital Control Design using State Feedback	648
13.8 Formulation of the Optimal Control Problem	653
<i>Review Examples</i>	656
<i>Review Questions</i>	659
<i>Problems</i>	660
14. NONLINEAR SYSTEMS ANALYSIS	665
14.1 Introduction	665
14.2 Some Common Nonlinear System Behaviours	667
14.3 Common Nonlinearities in Control Systems	668
14.4 Describing Function Fundamentals	671
14.5 Describing Functions of Common Nonlinearities	674
14.6 Stability Analysis by the Describing Function Method	680
14.7 Concepts of Phase Plane Analysis	686
14.8 Construction of Phase Portraits	689
14.9 System Analysis on the Phase Plane	695
14.10 Lyapunov Stability	702
<i>Review Examples</i>	706
<i>Review Questions</i>	711
<i>Problems</i>	711
REFERENCES	716
ANSWERS TO PROBLEMS	722
<i>Index</i>	741
APPENDIX A: MATLAB AND SIMULINK SUPPORT	
URL: http://www.mhhe.com/gopal/cs3e	
APPENDIX B: CONTROL THEORY QUIZ	
URL: http://www.mhhe.com/gopal/cs3e	