Table of Contents

Preface 9

PART I - CONTROL

Chapter 1 System Dynamics and Differential Equations

1.1 Introduction. 13
1.2 Some System Equations 13
1.3 System Control. 19
1.4 Mathematical Models and Differential Equations 21
1.5 The Classical and Modern Control Theory 23

Chapter 2 Transfer Functions and Block Diagrams

2.1 Introduction. 27
2.2 Review of Laplace Transforms 27
2.3 Applications to Differential Equations. 38
2.4 Transfer Functions 39
2.5 Block Diagrams. 41

Chapter 3 State-Space Formulation

3.1 Introduction. 49
3.2 State-Space Forms 49
3.3 Using the Transfer Function to Define State Variables 57
3.4 Direct Solution of the State Equation 62
3.5 Solution of the State Equation by Laplace Transforms 70
3.6 The Transformation from the Companion to the Diagonal State Form. 73
3.7 The Transfer Function from the State Equation 78

Chapter 4 Transient and Steady State Response Analysis

4.1 Introduction. 83
4.2 Response of First Order Systems 84

4.3 Response of Second Order Systems. 86
4.4 Response of Higher Order Systems 92
4.5 Steady State Error. 95
4.6 Feedback Control 99

Chapter 5 Stability

5.1 Introduction. 107
5.2 The concept of Stability 107
5.3 Routh Stability Criterion 110
5.4 Introduction to Liapunov's Method 116
5.5 Quadratic Forms 126
5.6 Determination of Liapunov's Functions. 128
5.7 The Nyquist Stability Criterion 131
5.8 The Frequency Response 131
5.9 An Introduction to Conformal Mappings 138
5.10 Applications of Conformal Mappings to the Frequency Response . 142

Chapter 6 Controllability and Observability

6.1 Introduction. 149
6.2 Controllability 149
6.3 Observability 155
6.4 Decomposition of the System State 157
6.5 A Transformation into the Companion Form 165

Chapter 7 Multivariable Feedback and Pole Location

7.1 Introduction. 171
7.2 State Feedback of a SISO System. 171
7.3 Multivariable Systems. 175
7.4 Observers. 188

PART II - OPTIMAL CONTROL

Chapter 8 Introduction to Optimal Control

8.1 Control and Optimal Control. 197
8.2 Examples. 197
8.2.1 Economic Growth 197
8.2.2 Resource Depletion 200
8.2.3 Exploited Populations 200
8.2.4 Advertising Policies 201
8.2.5 Rocket Trajectories 203
8.2.6 Servo Problem 204
8.3 Functionals 204
8.4 The Basic Optimal Control Problem 206

Chapter 9 Variational Calculus

9.1 The Brachistochrone Problem 209
9.2 Euler Equation 210
9.3 Free End Conditions 219
9.4 Constraints. 222

Chapter 10 Optimal Control with Unbounded Continuous Controls

10.1 Introduction. 231
10.2 The Hamiltonian 233
10.3 Extension to Higher Order Systems. 235
10.4 General Problem 238

Chapter 11 Bang-Bang Control

11.1 Introduction. 245
11.2 Pontryagin's Principle. 249
11.3 Switching Curves. 254
11.4 Transversality Conditions 258
11.5 Extension to the Boltza Problem 261

Chapter 12 Applications of Optimal Control

12.1 Introduction. 267
12.2 Economic Growth 267
12.3 Resource Depletion 270
12.4 Exploited Populations 274
12.5 Advertising Policies 276
12.6 Rocket Trajectories 279
12.7 Servo Problem 281

Chapter 13 Dynamic Programming

13.1 Introduction. 289
13.2 Routing Problem. 289
13.3 D.P. Notation 291
13.4 Examples. 295
13.4.1 Resources Allocation 295
13.4.2 Production Planning. 297
13.5 Bellman's Equation 300
13.6 The Maximum Principle 307

Appendix 1 Partial Fractions 315

Appendix 2 Notes on Determinants and Matrices

A2.1 Determinants 319
A2.2 Partitioned Matrices. 322

A2.3 Eigenvectors and Eigenvalues 323
A2.4 The Companion Matrix 325
A2.5 The Cayley–Hamilton Theorem 326
A2.6 Linear Dependence and the Rank of a Matrix 328

Solutions to Problems 331

Bibliography 393

Index 397