CONTENTS

Preface xi

Chapter 1 Introduction to Automatic Controls 1

1.1 Historical Development 1
1.2 Feedback Control Systems 2
1.3 System Representation 4
1.4 Modern Control Systems 6

Chapter 2 Representation of Control Components 8

2.1 Operational Notation 9
2.2 Mechanical Components 14
2.3 Electrical Components 18
2.4 Series and Parallel Laws 19
2.5 Analogies 26
2.6 Scale Factors 29
2.7 Thermal Systems 33
2.8 Fluid Systems 36

Chapter 3 Representation of Control Systems 48

3.1 Linearization of Nonlinear Functions 48
3.2 Linearization of Operating Curves 58
3.3 Hydraulic Systems 62
3.4 Pneumatic Systems 70
3.5 DC Motors 74
3.6 AC Motors 79
3.7 Block-Diagram Algebra 80
3.8 Speed Control Systems 83
3.9 Generalized Feedback Control System 90

Chapter 4 Steady-State Operation 105
4.1 Steady-State Analysis 105
4.2 Equilibrium 113
4.3 Proportional Control Systems 116
4.4 Integral Control Systems 121
4.5 Proportional Plus Integral Control Systems 123
4.6 Modes of Control 126

Chapter 5 Laplace Transforms 135
5.1 Classical Methods 136
5.2 Laplace Transform Method 144
5.3 Transform Properties 148
5.4 Initial Conditions 162
5.5 General Procedures 168
5.6 Piecewise Continuous Functions 174
5.7 Convolution Integral 177
5.8 Error Coefficients 180

Chapter 6 Transient Response 192
6.1 Inverse Transformations 194
6.2 Complex Conjugate Zeros 196
6.3 Damping Ratio and Natural Frequency 202
6.4 Computer Solution 208
6.5 Transient Response Specifications 217
6.6 General Form of Transient Response 221
6.7 Response to an External Disturbance 223
6.8 Routh's Stability Criterion 225
6.9 Summary 229

Chapter 7 The Root-Locus Method 240
7.1 Significance of Root Loci 240
7.2 Construction of Loci 246
7.3 General Procedure 256
7.4 Newton's Method and the Remainder Theorem 266
7.5 Loci Equations 269
7.6 Variation of Parameters 271
7.7 Computer Solution 277
7.8 Sensitivity 278

Chapter 8 Analog Computers 292
8.1 Computer Operations 293
8.2 Direct Programming 297
8.3 Time Scale 308
8.4 Simulation 313

Chapter 9 State-Space Methods 329

9.1 System Representation 329
9.2 Signal-Flow Graphs 342
9.3 Solution of State-Space Equations 349
9.4 Methods of Computing $\Phi(t)$ 353
9.5 Forced Response 362
9.6 Transfer Functions 369
9.7 Multivariable Systems 374

Chapter 10 Digital-Control Systems 390

10.1 Sampled-Data Systems 390
10.2 The z Transform 392
10.3 Inverse z Transforms 401
10.4 Block-Diagram Algebra 409
10.5 Transient Response 414
10.6 Filters 421
10.7 Discrete-Data Systems 427
10.8 Sampled-Data Control Systems 434
10.9 Computer-Controlled Systems 440

Chapter 11 Frequency-Response Methods 455

11.1 Frequency Response 455
11.2 Logarithmic Representation 461
11.3 Evaluating the Gain K 470
11.4 Equivalent Unity-Feedback Systems 473
11.5 Polar Plots 474
11.6 M and α Circles 477
11.7 Correlation between Transient and Frequency Response 480
11.8 Determining the Gain K to Yield a Desired M_p 490

Chapter 12 System Compensation 504

12.1 Nyquist Stability Criterion 504
12.2 Gain Margin and Phase Margin 513
12.3 Lead Compensation 519
12.4 Lag Compensation 526
12.5 Lag-Lead Compensation 530
12.6 Internal Feedback 533
12.7 Inverse Polar Plots 534
12.8 Stability Criteria in the Inverse Plane 540

Appendices 551

A Equilibrium Flow 551

B Fourier Series, Fourier Integral, and Laplace Transform 556

B.1 Fourier Series 556

B.2 Fourier Integral 558

B.3 Laplace Transform 559

Index 561