Contents

UNIVERSIDAD NACIONAL DE ENTRE
FACULTAD DE INGENIER
CENTRO DE MEDIOS
BIBLIOTECA
99 12

Preface to the Fourth Edition xiii

Part 1 Understanding Feedback Control

Chapter 1. Dynamic Elements in the Control Loop 3

The Negative-Feedback Loop 4
Steady-State and Dynamic Gains 5
The Stability Limit 6
Loop Gain and Decay 8
Process Deadtime 9
The Static Mixer 9
Gain and Phase of Deadtime 10
Proportional Offset 11
The Integral-Control Mode 13
Gain and Phase of Integration 14
Integral Control of Deadtime 15
Integrated Error Criteria 16
Best Possible Load Response 18
PI Control of Deadtime 20
Process Capacity 22
Non-self-regulating Processes 23
Inventory Control 25
Self-regulation 28
Phase and Gain of a First-Order Lag 31
First-Order-plus-Deadtime Models 32
Best Practical Load Response 33
Natural Period and Dynamic Gain 35
PI Controller Performance and Tuning 36
Notation 38
References 40
Problems 40

Chapter 2. Analyzing Real Processes 41

Second-Order Processes 42
The Secondary Lag 42
Proportional Control 44
Proportional-plus-Derivative Control 45
Second-Order Processes with Deadtime 47
Multicapacity Processes 50
Noninteracting Lags 50
Interacting and Distributed Lags 52
Once-through Processes 54
PI Control of Distributed Processes 55
Steady-State Gain 56
Transmitter Gain 56
Dimensional Process Gain 57
Valve Gain 59
Valve Characteristics 59
Inherent Characteristics 60
Extending Rangeability 62
Installed Characteristics 64
Valve Characterizers 67
Notation 68
References 70
Problems 70

Chapter 3. The Five Common Control Loops 73

Flow Control 74
Dynamic Properties 74
Flowmeter Characteristics 77
Estimating System Accuracy 78
Pressure Regulation 82
Liquid Pressure 82
Gas Pressure 83
Vapor Pressure 84
Liquid-Level Control 85
Hydraulic Resonance 85
Proportional-Lag Control 86
Inverse Response 88
Quality Control 90
Dynamics of Mixing 90
Process Gain 94
Quality Measurements 95
Temperature Control 96
Multiple Interacting Lags 96
Heat Flow vs. Fluid Flow 98
Summary 99
Notation 100
References 101
Problems 102

Part 2 Selecting the Feedback Controller

Chapter 4. Linear Controllers 105

Performance Criteria 106
Error Magnitude 106
Integrated Error Functions 107
Statistical Error Functions 110
Robustness 113
PID Controllers 114
Mode Interaction 114
Tuning for Load Changes 116
Response to Cyclic Loads 122
Tuning for Set-Point Changes 125
Windup Protection 127
Model-Based Controllers 130
Internal Model Control 130
Model Predictive Control 133
The PIτ_d Controller 134
PIDτ_d Controllers 136
Interrupting the Control Loop 139
Sampling Analyzers 140
Digital Controllers 142
Notation 145
References 147
Problems 147

Chapter 5. Nonlinear Control Elements 149

Amplitude-Dependent Gain 149
Regenerative Oscillations 150
Limit Cycles 153
Nonlinear Filters 153
Nonlinear pH Control 156
Dynamic Nonlinear Functions 158
Deadband 158
Velocity Limit 161
Negative Resistance 163
Multiple-State Controllers 167
On-Off Control 167
Three-State Control 169
Optimal Switching 171
Fuzzy Logic 173
Notation 174
References 175
Problems 176

Part 3 Multiple-Loop Systems

Chapter 6. Improved Control through Multiple Loops 179

Cascade Control 179
Manipulating a Closed Loop 180
Secondary Variable as Primary Feedback 183
Tuning Cascade Controllers 185
Valve Positioners 187
Cascade Flow Control 188
Multiple-Output Control Systems 189
Total-Flow Control 189
Combining Modulating and On-Off Devices 191
Valve-Position Control 192
Balancing Parallel Passes 194
Selective-Control Loops 195
Multiple Inputs 195
Multiple Constraints 196
Variable Structuring 198
Adaptive Control Systems 200
Programmed Adaptation 200
Self-Tuning Controllers 202
Hill-Climbing Controllers 205
Notation 207
References 208
Problems 208

Chapter 7. Feedforward Control 211

Steady-State Models 213
Linear Processes 214
Bilinear Processes 216
Ratio Control Systems 218
Ratio Flow Control 218
Digital Blending Systems 220
Dynamic Compensation 222
Uncompensated Responses 223
Deadtime and Lead-Lag Compensators 225
Tuning Dynamic Compensators 227
Combining Feedforward and Feedback 230
Impact on Integrated Error 230
Unknowns and Unmeasured Loads 233
Alternatives to Back Calculation 234
Single-Station Controllers 235
Adaptation 236
Notation 237
References 238
Problems 239

Chapter 8. Interaction and Decoupling 241

Relative-Gain Analysis 241
Different Open-Loop Gains 242
Properties of the RGA 244
Selection of Variables 246
Calculating Relative Gains 247
The Ratio Method 248
All Loops Open 250
All Loops Closed 251
The Slope Method 251
The Matrix Method 252
Decomposing Large Systems 254
Effects of Loop Interaction 254
Detuning Controllers 255
Relative Gains 0 to 1 257
Relative Gains Above 1 258
Negative Relative Gains 260
Dynamic Coupling 261
Decoupling 263
Rational Decouplers 264
Black-Box Decouplers 265
Stability of Decoupled Systems 268
Partial Decoupling 269
Linear Multivariable Systems 272
Notation 272
References 274
Problems 274

Part 4 Applications

Chapter 9. Energy Transfer and Conversion 277

Heat Transfer 277
Direct Contact 278
Sensible-Heat Exchange 279
Boiling and Condensing 285
Boiler Controls 288
Combustion Control 288
Drum-Level Control 291
Drum-Pressure Control 293
Steam-Temperature Control 294
Pumps and Compressors 295
Positive-Displacement Pumps 295
Centrifugal Pumps 296
Positive-Displacement Compressors 298
Compressor Antisurge Control 299
Notation 304
References 305
Problems 306

Chapter 10. Controlling Chemical Reactions 307

Chemical Kinetics 307
Chemical Equilibrium 308
Reaction Rate 310
Exothermic Reactor Stability 314
Controller Performance and Robustness 318
Continuous Reactors 321
Achieving Stoichiometry 322
Temperature Control 325
Maximizing Production 327
pH Control 328
Titration Curves 328
Design Recommendations 333
Notation 335
References 337
Problems 337

Chapter 11. Mass-Transfer Operations 339

Distillation 339
Modeling the Process 340
Relative-Gain Analysis 347
Disturbance Rejection 350
Maximizing Product Recovery 356
Minimizing Energy Consumption 359
Composition Feedback 360
Floating-Pressure Control 362
Sidestream Columns 366
Evaporation 369
Multiple-Effect Evaporation 369
Material-Balance Control 370
Vapor-Compression Evaporation 373
Drying 375
The Rate of Drying 375
Inferential Controls 378
Limitations and Extensions 379
Moisture Feedback 380
Notation 380
References 382
Problems 383

Chapter 12. Batch Process Control 385

Special Features of Batch Processes 385
The Zero-Load Process 386
Batch Endpoint Control 388
Semibatch Processes 390
Heating Material Batchwise 392

Controller Selection 393
Batch PID Control 393
Interacting PID and PIDτ_d Controllers 395
Set-Point Ramping 396
Batch Reactors 398
Temperature Control 398
Auxiliary Cooling 402
Optimizing Production 402
Batch Drying 404
Inferential Moisture Control 405
Heat Recovery 407
Drying Lumber 407
Notation 408
References 409
Problems 410

Appendix A. Symbols Used in Diagrams 411

Appendix B. Solutions to Problems 413

Index 431