

Introduction to Process Control



For MATLAB® exercises use the following URL
http://www.crcpress.com/e_products/downloads/download.asp?cat_no=DK496X

Jose A. Romagnoli
Ahmet Palazoglu



Taylor & Francis
Taylor & Francis Group

Contents

Section I

Introduction	1
--------------------	---

Chapter 1

Why Process Control?	3
1.1 Historical Background	4
1.2 Role of Control in Process Industries	5
1.2.1 Traditional Role of Process Control	5
1.2.2 Expanded Role of Process Control	7
1.3 Objectives of Control	9
1.3.1 What About Performance?	10
1.3.2 Economic Benefits of Control	10
1.4 Summary	12
Continuing Problem	12

Chapter 2

Definitions and Terminology	15
2.1 Concepts and Definitions	15
2.2 Control Design Problem	18
2.3 Control System Design	21
2.4 Control Design Project	22
2.4.1 Preliminary Engineering	23
2.4.2 Detailed Engineering	24
2.4.3 Implementation	24
2.4.4 Installation	24
2.4.5 Commissioning	25
2.4.6 First Production Startup and Turnover	25
2.4.7 Training	25
2.5 Summary	25
Continuing Problem	25

Section I Additional Reading	27
Section I Exercises	29

Section II

Modeling for Control	35
----------------------------	----

Chapter 3

Basic Concepts in Modeling	37
3.1 Types of Models	38
3.2 Classification of Models	38
3.3 State-Space Models.....	42
3.4 Input-Output Models.....	43
3.5 Degrees of Freedom.....	46
3.6 Models and Control	47
3.7 Summary	48

Chapter 4

Development of Models from Fundamental Laws.....	51
4.1 Principles of Modeling	51
4.2 Models Based on Fundamental Laws	52
4.3 Role of Process Simulators in Modeling.....	58
4.3.1 New Trends in Process Simulations	59
4.4 Summary	61
Continuing Problem	62

Chapter 5

Input-Output Models: The Transfer Function	65
5.1 Linear (Linearized) Model	65
5.1.1 Deviation Variables	66
5.1.2 Higher Dimensional Equations.....	68
5.1.3 Linear State-Space Model.....	69
5.2 Concept of Transfer Function	70
5.3 Transfer Functions of SISO Processes	71
5.3.1 Asymptotic Theorems.....	73
5.4 Properties of Transfer Functions	74
5.5 Nonrational Transfer Functions	76
5.6 Summary	78
Continuing Problem	79

Chapter 6

Models from Process Data	83
6.1 Development of Empirical Models	83
6.1.1 Performing the Experiments	84
6.1.2 Developing the Model	85
6.1.3 Evaluating the Model	85
6.2 Process Reaction Curve.....	86
6.3 Linear Regression in Modeling	90
6.4 Summary	94

Section II Additional Reading	95
Section II Exercises	97

Section III

Process Analysis	105
------------------------	-----

Chapter 7

Stability	107
7.1 Stability of Linear Systems	107
7.2 Input–Output Stability	111
7.3 Routh’s Criterion	113
7.4 Root-Locus Method	116
7.5 Summary	117

Chapter 8

Dynamic Performance	119
8.1 First-Order Processes	119
8.2 Second-Order Processes	123
8.3 Multi-Capacity Processes	127
8.4 Effect of Zeros	133
8.5 Effect of Time Delays	136
8.6 Summary	137

Chapter 9

Frequency Response	139
9.1 What is Frequency Response?	139
9.2 Complex Numbers in Polar Coordinates	140
9.3 Construction of the Frequency Response	141
9.4 Evaluation of the Frequency Response	143
9.5 Bode Diagrams	145
9.6 Nyquist Diagrams	147
9.7 Summary	150

Section III Additional Reading	151
Section III Exercises	153

Section IV

Feedback Control	157
------------------------	-----

Chapter 10

Basic Elements of Feedback Control	159
10.1 Feedback Control Problem	159

10.2	Control Law	162
10.2.1	Proportional Mode	162
10.2.2	Integral Mode	164
10.2.3	Derivative Mode	164
10.2.4	Three-Mode Controller (PID)	164
10.3	Closed-Loop Transfer Functions	165
10.4	Closed-Loop Performance	167
10.4.1	Proportional Mode	167
10.4.2	Integral Mode	169
10.4.3	Derivative Mode	171
10.4.4	Integral Windup	172
10.5	Summary	173
	Continuing Problem	173

Chapter 11

	Stability Analysis of Closed-Loop Processes	177
11.1	Closed-Loop Stability	177
11.2	Routh's Criterion	179
11.3	Root-Locus Method	180
11.4	Frequency Response Methods	184
11.5	Summary	187
	Continuing Problem	188

Chapter 12

	Feedback Control Design	191
12.1	Design Objectives	191
12.1.1	Error-Based Criteria	192
12.2	Open-Loop Tuning (Cohen-Coon) Method	194
12.3	Closed-Loop Tuning (Ziegler-Nichols) Method	195
12.4	Autotuning (Relay) Controller	200
12.5	Practical Issues in PID Design	204
12.5.1	Direct and Reverse Action	205
12.5.2	Bumpless Transfer	206
12.5.3	PID Equation Forms	206
12.6	Summary	208
	Continuing Problem	209

	Section IV Additional Reading	211
	Section IV Exercises	213

Section V

	Multivariable Control	217
--	-----------------------------	-----

Chapter 13

Multivariable Systems: Special Cases	219
13.1 Cascade Control	219
13.2 Ratio Control	223
13.2.1 Ratio Computation	223
13.2.2 Set-Point Computation	223
13.3 Override Control	227
13.4 Summary	230
Continuing Problem	231

Chapter 14

Multivariable Systems: General Concepts	237
14.1 Characteristics of Multivariable Processes	237
14.2 Modeling of Multivariable Processes	238
14.3 Transfer Functions of Multivariable Processes	240
14.3.1 Poles and Zeros of MIMO Systems	242
14.4 Multivariable Feedback Control Structure	245
14.4.1 Closed-Loop Poles and Zeros	246
14.4.2 Stability of MIMO Closed-Loop Systems	247
14.5 Summary	249

Chapter 15

Design of Multivariable Controllers	251
15.1 MIMO Feedback Analysis	251
15.2 RGA Interaction Measure	256
15.2.1 Selection of Loops	258
15.3 Multiloop Controller Design	260
15.4 Design of Noninteracting Control Loops: Decouplers	261
15.5 Summary	265
Continuing Problem	265

Section V Additional Reading	273
Section V Exercises	275

Section VI

Model-Based Control	279
---------------------------	-----

Chapter 16

Model-Based Control	281
16.1 Feedforward Control	281
16.1.1 Feedforward-Feedback Control Strategy	283
16.2 Delay Compensation (Smith Predictor)	284

16.3	Internal Model Control (IMC) Structure.....	287
16.3.1	Concept of Perfect Control	289
16.3.2	IMC Design Procedure	290
16.3.3	PID Tuning using IMC Rules	294
16.4	Summary	295
	Continuing Problem	296

Chapter 17

	Model Uncertainty and Robustness.....	307
17.1	IMC Structure with Model Uncertainty	307
17.2	Description of Model Uncertainty	308
17.2.1	Additive Uncertainty	308
17.2.2	Multiplicative Uncertainty.....	309
17.2.3	Estimation of Uncertainty Bounds	309
17.3	IMC Design Under Model Uncertainty	311
17.3.1	Robust Stability	312
17.3.2	Robust Performance.....	313
17.4	Summary	317

Chapter 18

	Model Predictive Control (MPC).....	319
18.1	General Principles	319
18.1.1	Model Forms	321
18.2	Dynamic Matrix Control.....	323
18.2.1	SISO Unconstrained DMC Problem	325
18.2.2	Controller Tuning	326
18.3	Treatment of Process Constraints	327
18.4	State-Space Formulation of MPC	331
18.4.1	Infinite Horizon Problem.....	332
18.5	Summary	334
	Continuing Problem	335

Chapter 19

	Practical Control of Nonlinear Processes.....	341
19.1	Operating Regime Modeling Approach	341
19.1.1	Global Model Structure	343
19.2	Gain-Scheduling Controller	346
19.2.1	Determination of Process Gains	349
19.2.2	Gain-Scheduling Implementation	349
19.3	Multimodel Controller Design	352
19.3.1	Multimodel MPC.....	354
19.4	Summary	357

Section VI Additional Reading.....	359
Section VI Exercises.....	361

Section VII

Control in Modern Manufacturing	365
---------------------------------------	-----

Chapter 20

Plantwide Process Control	367
20.1 Fundamentals of Plantwide Control	368
20.1.1 Material Recycle	369
20.1.2 Energy Integration	369
20.1.3 Chemical Component Inventories	370
20.2 Plantwide Control Design Procedure	373
20.3 Importance of Simulations for Plantwide Control	377
20.4 Targeting Economics and Environment	383
20.4.1 Economically Conscious Processes.....	383
20.4.2 Environmentally Conscious Processes	383
20.4.3 Process Integration for Economic and Environmental Improvement	384
20.4.4 Plantwide Control of Integrated Processes	385
20.5 Summary	389

Chapter 21

Industrial Control Technology.....	393
21.1 Evolution of Industrial Control technology	393
21.2 Generic Industrial Control Systems Architecture	394
21.2.1 Supervisory Environment	394
21.2.2 Control Environment	396
21.2.3 Communication Environment	396
21.2.4 Data Exchange.....	397
21.3 Summary	405
Continuing Problem	405

Chapter 22

Role of Process Control in Modern Manufacturing.....	411
22.1 Expanded Role of Control in Modern Manufacturing	411
22.2 Integrated Control Systems	419
22.3 Summary	425

Chapter 23

Data Processing and Reconciliation.....	429
23.1 Dealing with Missing Points	429
23.2 Outliers	432

23.3	Characterizing Process Data	434
23.4	Modeling Process Data	437
23.4.1	Model Fitting Based on Least-Squares Estimation	438
23.5	Data Reconciliation	439
23.6	Issues in Data Reconciliation	442
23.6.1	Process Model	442
23.6.2	Classification of Process Variables	444
23.6.3	Linear Data Reconciliation with Unmeasured Variables	445
23.6.4	Gross Errors	446
23.7	Summary	448

Chapter 24

Process Monitoring.....	449
24.1 Statistical Process Control.....	449
24.1.1 Control Charts	450
24.1.2 Control Chart Interpretation	451
24.1.3 Multivariate Charts	452
24.2 Principal Component Analysis (PCA)	453
24.2.1 Calculation of PCA	453
24.3 Multivariate Performance Monitoring.....	458
24.3.1 Elliptical Normal Operation region	460
24.3.2 T^2 and SPE Charts.....	462
24.3.3 Contribution Plots	463
24.4 Fault Diagnosis and Classification	463
24.5 Controller Performance Monitoring (CPM)	470
24.5.1 State Classification	472
24.5.2 Model Validation	472
24.5.3 Stochastic Performance Monitoring	473
24.5.4 Controller Oscillation Assessment	474
24.6 Summary	475

Section VII Additional Reading	477
Section VII Exercises	479

Appendix A

Linearization.....	483
A.1 Basic Steps in Linearization	483
A.2 Linearization Generalized	486

Appendix B

Laplace Transformation.....	491
B.1 Definition	491
B.2 Laplace Transform of Some Typical Functions	491

B.3	Some Useful Properties of the Laplace Transform	493
B.4	Partial Fraction Expansion.....	495

Appendix C

Matrix Operations.....	499
C.1 Vectors and Matrices	499
C.1.1 Special Matrices	500
C.2 Determinant and Inverse	500
C.3 Eigenvalue Decomposition	502
C.4 Singular-Value Decomposition	503
C.5 Vector and Matrix Norms	504

Appendix D

Basic Statistics.....	507
D.1 Sample Mean and Standard Deviation	507
D.2 Random Variables and Probability Distributions	508
D.3 Gaussian (Normal) Distribution	509
D.4 Correlations and Covariance	511
D.5 χ^2 and F Distributions	512

Index	515
--------------------	-----