
Contents

1	Introduction	1
1.1	Scope of Process Control.....	1
1.2	Proportional–Integral–Derivative Control Performance.....	2
1.3	Relay Feedback Identification	5
1.4	Conclusion.....	6
1.5	References	7
2	Features of Proportional–Integral–Derivative Control	9
2.1	Proportional–Integral–Derivative Controller	9
2.1.1	Proportional Control	9
2.1.2	Proportional–Integral Control.....	10
2.1.3	Proportional–Integral–Derivative Control	12
2.2	Proportional–Integral–Derivative Implementation.....	13
2.2.1	Reset Windup	13
2.2.2	Arrangement of Derivative Action.....	15
2.3	Proportional–Integral–Derivative Tuning Rules	17
2.3.1	Ziegler–Nichols Types of Tuning Rules.....	17
2.3.2	Model-based Tuning	19
2.4	Conclusion.....	20
2.5	References	20
3	Relay Feedback	23
3.1	Experimental Design.....	24
3.2	Approximate Transfer Functions: Frequency-domain Modeling	26
3.2.1	Simple Approach	27
3.2.2	Improved Algorithm	30
3.2.3	Parameter Estimation	32
3.2.4	Examples.....	32
3.3	Approximate Transfer Functions: Time-domain Modeling	36
3.3.1	Derivation for a Second-order Overdamped System.....	39
3.3.2	Results.....	41

3.3.3	Validation	44
3.4	Conclusion	44
3.5	References	46
4	Shape of Relay	47
4.1	Shapes of Relay Response	47
4.1.1	Shapes	48
4.1.2	Model Structures	50
4.1.2.1	First-order Plus Dead Time	50
4.1.2.2	Second-order Plus Small Dead Time	51
4.1.2.3	High Order	52
4.2	Identification	52
4.2.1	Identification of Category 1: First-order Plus Dead Time	52
4.2.1.1	Category 1a: True First-order Plus Dead Time	52
4.2.1.2	Category 1b: Approximated First-order Plus Dead Time	55
4.2.2	Identification of Category 2: Second-order Plus Small Dead Time ..	56
4.2.3	Identification of Category 3: High order	58
4.2.4	Validation	59
4.3	Implications for Control	62
4.3.1	Proportional–Integral–Derivative Control	62
4.3.1.1	Category 1: First-order Plus Dead Time	62
4.3.1.2	Category 2: Second-order Plus Small Dead Time	64
4.3.1.3	Category 3: High Order	64
4.3.2	Results	64
4.3.3	Extension	70
4.3.3.1	Dead-time-Dominant Process	70
4.3.3.2	Higher Order Process	71
4.4	Conclusion	72
4.5	References	73
5	Improved Relay Feedback	75
5.1	Analysis	76
5.1.1	Ideal (On–Off) Relay Feedback	76
5.1.2	Saturation Relay Feedback	78
5.1.3	Potential Problem	83
5.2	Improved Experimental Design	84
5.2.1	Selection of the Slope of Saturation Relay	84
5.2.2	Procedure	89
5.3	Applications	89
5.4	Conclusion	95
5.5	References	96
6	Multivariable Systems	97
6.1	Concept	97
6.1.1	Single-input–Single-output Autotuning	97
6.1.2	Multiple-input–Multiple-output Autotuning	99
6.2	Theory	101

6.2.1	Sequential Design	101
6.2.2	Process Characteristics	104
6.2.3	Sequential Identification	108
6.3	Controller Tuning	111
6.3.1	Potential Problem in Ziegler–Nichols Tuning	111
6.3.2	Modified Ziegler–Nichols Method	111
6.3.3	Performance Evaluation: Linear Model	115
6.4	Properties	117
6.4.1	Convergence	117
6.4.2	Tuning Sequence	119
6.4.3	Problem of Variable Pairing	120
6.4.4	Summary of Procedure	122
6.5	Applications	123
6.5.1	Moderate-purity Column	123
6.5.2	High-purity Column	124
6.5.3	T4 Column	128
6.6	Conclusion	130
6.7	References	130
	Appendix	132
7	Load Disturbance	135
7.1	Problems	135
7.1.1	Step Change versus Continuous Cycling	135
7.1.2	Effect of Load Change on Relay Feedback Test	138
7.2	Analyses	139
7.2.1	Causes of Errors	139
7.2.2	Output-biased Relay Feedback System	142
7.2.3	Derivation of Bias Value δ_o	144
	7.2.3.1 Effect of Load Disturbance	144
	7.2.3.2 Opposite Effect from Output-biased Relay	146
7.3	Summary of Procedure	148
7.4	Applications	149
	7.4.1 Linear System	150
	7.4.2 Binary Distillation Column	152
7.5	Conclusion	153
7.6	References	154
8	Multiple Models for Process Nonlinearity	155
8.1	Autotuning and Local Model	156
8.2	Model Scheduling	157
8.2.1	Takagi–Sugeno Fuzzy Model	157
	8.2.1.1 Single Input Systems	158
	8.2.1.2 Multiple Inputs Systems	160
8.2.2	Selection of Scheduled Variable	162
8.3	Nonlinear Control Applications	163
8.3.1	Transfer Function System	163
8.3.2	Tennessee Eastman Process	167

8.4	Conclusion.....	173
8.5	References.....	173
9	Control Performance Monitoring.....	175
9.1	Shape Factor for Monitoring.....	176
9.1.1	Shapes of the Relay Feedback.....	176
9.2	Performance Monitoring and Assessment.....	179
9.2.1	Optimal Performance.....	179
9.2.2	Proposed Monitoring and Assessment Procedure.....	180
9.2.2.1	Case 1: $\tau_I/\tau = 1$	180
9.2.2.2	Case 2: $\tau_I/\tau > 1$	180
9.2.2.3	Case 3: $\tau_I/\tau < 1$	181
9.2.3	Illustrative Examples.....	184
9.3	Applications.....	188
9.3.1	Second-order Plus Dead Time Processes.....	188
9.3.2	High-order Processes.....	193
9.4	Conclusion.....	196
9.5	References.....	196
10	Imperfect Actuators.....	197
10.1	Potential Problems.....	197
10.2	Identification Procedure.....	202
10.2.1	Two-step Procedure.....	202
10.2.2	Simultaneous Identification.....	205
10.3	Applications.....	206
10.3.1	Linear Systems.....	206
10.3.1.1	Noise-free System.....	206
10.3.1.2	Systems with Measurement Noise.....	207
10.3.1.3	Load Disturbance.....	210
10.3.2	Nonlinear Process.....	212
10.3.2.1	Two-step Procedure.....	212
10.3.2.2	Simultaneous Procedure.....	212
10.4	Conclusion.....	216
10.5	References.....	217
11	Autotuning for Plantwide Control Systems.....	219
11.1	Recycle Plant.....	219
11.2	Control Structure Design.....	222
11.2.1	Unbalanced Schemes.....	222
11.2.1.1	Column Overwork.....	222
11.2.1.2	Reactor Overwork.....	226
11.2.2	Balanced Scheme.....	227
11.2.3	Controllability.....	228
11.2.4	Operability.....	231
11.3	Controller Tuning for Entire Plant.....	232
11.3.1	Tuning Steps.....	233

11.3.1.1 Inventory Control	233
11.3.1.2 Ratio Control	233
11.3.1.3 Quality Loop	235
11.3.2 Closed-loop Performance	238
11.4 Conclusion	242
11.5 References	242
12 Guidelines for Autotune Procedure	245
12.1 Process Characteristics	245
12.1.1 The Shape	245
12.1.2 Load Disturbance	246
12.1.3 Nonlinearity	246
12.1.4 Noise	247
12.1.5 Imperfect Actuator	248
12.2 Available Relays	248
12.3 Specifications	249
12.3.1 Direct Tuning	249
12.3.2 Model-based Tuning	251
12.3.3 Multiloop System	252
12.4 Discussion	256
12.5 Conclusion	257
12.6 References	258
Index	259