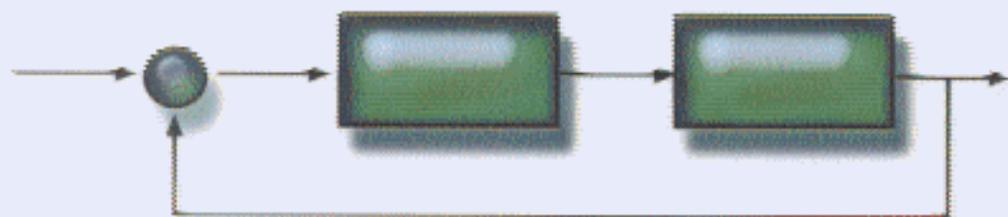


Handbook of
PI and PID
Controller Tuning Rules



Aidan O'Dwyer

Imperial College Press

Contents

Preface.....	vii
1. Introduction.....	1
1.1 Preliminary remarks.....	1
1.2 Structure of the book.....	3
References.....	4
2. Controller Architecture.....	5
2.1 Introduction.....	5
2.2 PI controller structures.....	5
2.3 PID controller structures.....	6
2.3.1 Ideal PID controller structure and its variations.....	6
2.3.2 Classical PID controller structure and its variations.....	8
2.3.3 Non-interacting PID controller structure and its variations.....	9
2.3.4 Other PID controller structures.....	11
2.3.5 Comments on the PID controller structures.....	12
2.4 Process modelling.....	12
2.5 Organisation of the tuning rules.....	16
References.....	16
3. Tuning Rules for PI Controllers.....	19
3.1 FOLPD model.....	19
3.1.1 Ideal controller — Table 5.....	19
3.1.2 Ideal controller in series with a first order filter — Table 6.....	46
3.1.3 Ideal controller in series with a second order filter — Table 7.....	47
3.1.4 Controller with set-point weighting — Table 8.....	48
3.1.5 Controller with proportional term acting on the output — Table 9.....	50
3.2 Non-model specific.....	51
3.2.1 Ideal controller — Table 10.....	51
3.2.2 Controller with set-point weighting — Table 11.....	54

3.3 IPD model	55
3.3.1 Ideal controller — Table 12	55
3.3.2 Ideal controller in series with a first order filter — Table 13	61
3.3.3 Controller with set-point weighting — Table 14	62
3.3.4 Controller with proportional term acting on the output — Table 15	64
3.4 FOLIPD model	65
3.4.1 Ideal controller — Table 16	65
3.4.2 Controller with set-point weighting — Table 17	67
3.5 SOSPD model	69
3.5.1 Ideal controller — Table 18	69
3.5.2 Controller with set-point weighting — Table 19	83
3.6 SOSIPD model — repeated pole	86
3.6.1 Controller with set-point weighting — Table 20	86
3.7 SOSPD model with a positive zero	88
3.7.1 Ideal controller — Table 21	88
3.8 Third order system plus time delay model	89
3.8.1 Ideal controller — Table 22	89
3.8.2 Controller with set-point weighting — Table 23	90
3.8.3 Third order lag plus time delay (TOLPD) model — ideal controller — Table 24	91
3.8.4 TOLPD model — repeated pole — controller with set-point weighting — Table 25	92
3.9 Unstable FOLPD model	93
3.9.1 Ideal controller — Table 26	93
3.10 Unstable SOSPD model (one unstable pole)	96
3.10.1 Ideal controller — Table 27	96
3.11 Delay model	98
3.11.1 Ideal controller — Table 28	98
3.12 General model with integrator	100
3.12.1 Ideal controller — Table 29	100
References	102
4. Tuning Rules for PID Controllers	107
4.1 FOLPD model	107
4.1.1 Ideal controller — Table 30	107
4.1.2 Ideal controller in series with a first order lag — Table 31	130
4.1.3 Ideal controller in series with a second order filter — Table 32	132
4.1.4 Ideal controller with weighted proportional term — Table 33	133

4.1.5	Ideal controller with first order filter and set-point weighting 1 — Table 34.....	134
4.1.6	Controller with filtered derivative — Table 35.....	135
4.1.7	Classical controller 1 — Table 36.....	138
4.1.8	Series controller (classical controller 3) — Table 37.....	149
4.1.9	Classical controller 4 — Table 38.....	151
4.1.10	Non-interacting controller 1 — Table 39.....	152
4.1.11	Non-interacting controller 2a — Table 40.....	153
4.1.12	Non-interacting controller 2b — Table 41.....	156
4.1.13	Non-interacting controller based on the two degree of freedom structure — Table 42.....	159
4.1.14	Non-interacting controller 4 — Table 43.....	162
4.1.15	Non-interacting controller 6 (I-PD controller) — Table 44.....	164
4.1.16	Industrial controller — Table 45.....	165
4.2	Non-model specific.....	168
4.2.1	Ideal controller — Table 46.....	168
4.2.2	Ideal controller with weighted proportional term — Table 47.....	172
4.2.3	Controller with filtered derivative — Table 48.....	173
4.2.4	Ideal controller with set-point weighting — Table 49.....	181
4.2.5	Classical controller 1 — Table 50.....	182
4.2.6	Series controller (classical controller 3) — Table 51.....	183
4.2.7	Classical controller 4 — Table 52.....	185
4.2.8	Non-interacting controller 4 — Table 53.....	186
4.3	IPD model.....	187
4.3.1	Ideal controller — Table 54.....	187
4.3.2	Ideal controller with first order filter and set-point weighting 2 — Table 55.....	190
4.3.3	Controller with filtered derivative — Table 56.....	191
4.3.4	Classical controller 1 — Table 57.....	193
4.3.5	Classical controller 4 — Table 58.....	195
4.3.6	Non-interacting controller based on the two degree of freedom structure — Table 59.....	196
4.3.7	Non-interacting controller 4 — Table 60.....	198
4.3.8	Non-interacting controller 6 (I-PD controller) — Table 61.....	199
4.4	FOLIPD model.....	200
4.4.1	Ideal controller — Table 62.....	200
4.4.2	Ideal controller in series with a first order lag — Table 63.....	203

4.4.3	Ideal controller with weighted proportional term — Table 64.....	205
4.4.4	Controller with filtered derivative — Table 65.....	206
4.4.5	Ideal controller with set-point weighting — Table 66.....	208
4.4.6	Classical controller 1 — Table 67.....	209
4.4.7	Classical controller 4 — Table 68.....	212
4.4.8	Non-interacting controller based on the two degree of freedom structure — Table 69.....	213
4.4.9	Non-interacting controller 4 — Table 70.....	215
4.4.10	Alternative controller 1 — Table 71.....	216
4.4.11	Alternative controller 2 — Table 72.....	217
4.5	SOSPD model.....	218
4.5.1	Ideal controller — Table 73.....	218
4.5.2	Ideal controller in series with a first order lag — Table 74.....	234
4.5.3	Ideal controller in series with a first order filter — Table 75.....	235
4.5.4	Controller with filtered derivative — Table 76.....	236
4.5.5	Ideal controller with set-point weighting — Table 77.....	238
4.5.6	Classical controller 1 — Table 78.....	239
4.5.7	Classical controller 2 — Table 79.....	243
4.5.8	Series controller (classical controller 3) — Table 80.....	244
4.5.9	Non-interacting controller 1 — Table 81.....	245
4.5.10	Non-interacting controller based on the two degree of freedom structure — Table 82.....	255
4.5.11	Non-interacting controller 4 — Table 83.....	260
4.5.12	Non-interacting controller 5 — Table 84.....	262
4.6	I ² PD model.....	263
4.6.1	Non-interacting controller based on the two degree of freedom structure — Table 85.....	263
4.7	SOSIPD model (repeated pole).....	264
4.7.1	Non-interacting controller based on the two degree of freedom structure — Table 86.....	264
4.8	SOSPD model with a positive zero.....	266
4.8.1	Ideal controller — Table 87.....	266
4.8.2	Controller with filtered derivative — Table 88.....	268
4.8.3	Classical controller 1 — Table 89.....	270
4.8.4	Classical controller 4 — Table 90.....	272
4.8.5	Non-interacting controller 1 — Table 91.....	273

4.8.6	Non-interacting controller based on the two degree of freedom structure — Table 92.....	274
4.9	SOSPD model with a negative zero	275
4.9.1	Ideal controller — Table 93	275
4.9.2	Controller with filtered derivative — Table 94	276
4.9.3	Classical controller 1 — Table 95	278
4.9.4	Classical controller 4 — Table 96	279
4.9.5	Non-interacting controller 1 — Table 97	280
4.9.6	Non-interacting controller based on the two degree of freedom structure — Table 98.....	281
4.10	TOLPD model	282
4.10.1	Ideal controller — Table 99	282
4.10.2	Non-interacting controller based on the two degree of freedom structure — Table 100.....	283
4.11	Unstable FOLPD model	285
4.11.1	Ideal controller — Table 101	285
4.11.2	Ideal controller with set-point weighting — Table 102.....	289
4.11.3	Classical controller 1 — Table 103	293
4.11.4	Non-interacting controller 3 — Table 104	294
4.11.5	Non-interacting controller 8 — Table 105	296
4.12	Unstable SOSPD model (one unstable pole).....	298
4.12.1	Ideal controller — Table 106	298
4.12.2	Ideal controller with set-point weighting — Table 107.....	300
4.12.3	Classical controller 1 — Table 108.....	301
4.12.4	Series controller (classical controller 3) — Table 109.....	302
4.12.5	Non-interacting controller 3 — Table 110	303
4.12.6	Non-interacting controller 7 — Table 111	311
4.13	Unstable SOSPD model (two unstable poles).....	314
4.13.1	Ideal controller — Table 112	314
4.13.2	Ideal controller with set-point weighting — Table 113.....	315
4.14	General model with a repeated pole	316
4.14.1	Ideal controller — Table 114	316
4.15	General stable non-oscillating model with a time delay.....	317
4.15.1	Ideal controller — Table 115	317
4.16	Fifth order model with delay	318
4.16.1	Ideal controller — Table 116	318
4.16.2	Controller with filtered derivative — Table 117.....	320
	References	323

5.	Performance and Robustness Issues in the Compensation of FOLPD Processes with PI and PID Controllers	331
5.1	Introduction	331
5.2	The analytical determination of gain margin and phase margin	331
5.2.1	PI tuning formulae.....	331
5.2.2	PID tuning formulae.....	334
5.3	The analytical determination of maximum sensitivity	337
5.4	Simulation results	338
5.5	Design of tuning rules to achieve constant gain and phase margins for all values of delay	342
5.5.1	PI controller design	342
5.5.1.1	Processes modelled in FOLPD form.....	342
5.5.1.2	Processes modelled in IPD form.....	344
5.5.2	PID controller design	346
5.5.2.1	Processes modelled in FOLPD form — classical controller 1	346
5.5.2.2	Processes modelled in SOSPD form — series PID controller	348
5.5.2.3	Processes modelled in SOSPD form with a negative zero — classical controller 1	348
5.5.3	PD controller design.....	349
5.6	Conclusions	349
	References	350
	Appendix 1: Glossary of symbols used in the book	351
	Appendix 2: Some further details on process modelling	357
	Index.....	369