

Contents

Preface	vii
1. Introduction	1
1.1 Preliminary Remarks	1
1.2 Structure of the Book.....	2
2. Controller Architecture.....	4
2.1 Introduction	4
2.2 Comments on the PID Controller Structures	11
2.3 Process Modelling	12
2.3.1 Self-regulating process models	12
2.3.2 Non-self-regulating process models.....	14
2.4 Organisation of the Tuning Rules.....	16
3. Controller Tuning Rules for Self-Regulating Process Models	18
3.1 Delay Model	18
3.1.1 Ideal PI controller – Table 2	18
3.1.2 Ideal PID controller – Table 3	23
3.1.3 Ideal controller in series with a first order lag – Table 4	24
3.1.4 Classical controller – Table 5	25
3.1.5 Generalised classical controller – Table 6	26
3.1.6 Two degree of freedom controller 1 – Table 7	27
3.2 Delay Model with a Zero	28
3.2.1 Ideal PI controller – Table 8	28
3.3 FOLPD Model	30
3.3.1 Ideal PI controller – Table 9	30
3.3.2 Ideal PID controller – Table 10	78
3.3.3 Ideal controller in series with a first order lag – Table 11	118
3.3.4 Controller with filtered derivative – Table 12.....	122
3.3.5 Classical controller – Table 13	134
3.3.6 Generalised classical controller – Table 14	149
3.3.7 Two degree of freedom controller 1 – Table 15	152
3.3.8 Two degree of freedom controller 2 – Table 16	168
3.3.9 Two degree of freedom controller 3 – Table 17	170

3.4	FOLPD Model with a Zero	180
3.4.1	Ideal PI controller – Table 18	180
3.4.2	Ideal controller in series with a first order lag – Table 19	182
3.5	SOSPD Model	183
3.5.1	Ideal PI controller – Table 20	183
3.5.2	Ideal PID controller – Table 21	206
3.5.3	Ideal controller in series with a first order lag – Table 22	232
3.5.4	Controller with filtered derivative – Table 23.....	236
3.5.5	Classical controller – Table 24	238
3.5.6	Generalised classical controller – Table 25	251
3.5.7	Two degree of freedom controller 1 – Table 26	253
3.5.8	Two degree of freedom controller 3 – Table 27	264
3.6	SOSPD Model with a Zero	277
3.6.1	Ideal PI controller – Table 28	277
3.6.2	Ideal PID controller – Table 29	279
3.6.3	Ideal controller in series with a first order lag – Table 30	282
3.6.4	Controller with filtered derivative – Table 31.....	284
3.6.5	Classical controller – Table 32	286
3.6.6	Generalised classical controller – Table 33	288
3.6.7	Two degree of freedom controller 1 – Table 34	289
3.6.8	Two degree of freedom controller 3 – Table 35	292
3.7	TOSPD Model	293
3.7.1	Ideal PI controller – Table 36	293
3.7.2	Ideal PID controller – Table 37	296
3.7.3	Ideal controller in series with a first order lag – Table 38	297
3.7.4	Controller with filtered derivative – Table 39	298
3.7.5	Two degree of freedom controller 1 – Table 40	299
3.7.6	Two degree of freedom controller 3 – Table 41	302
3.8	Fifth Order System Plus Delay Model	303
3.8.1	Ideal PID controller – Table 42	303
3.8.2	Controller with filtered derivative – Table 43	305
3.8.3	Two degree of freedom controller 1 – Table 44	308
3.9	General Model	310
3.9.1	Ideal PI controller – Table 45	310
3.9.2	Ideal PID controller – Table 46	312
3.9.3	Ideal controller in series with a first order lag – Table 47	315
3.9.4	Controller with filtered derivative – Table 48	316
3.9.5	Two degree of freedom controller 1 – Table 49	317
3.10	Non-Model Specific	318
3.10.1	Ideal PI controller – Table 50	318
3.10.2	Ideal PID controller – Table 51	324
3.10.3	Ideal controller in series with a first order lag– Table 52	332
3.10.4	Controller with filtered derivative – Table 53	336
3.10.5	Classical controller – Table 54	341
3.10.6	Generalised classical controller – Table 55	343

3.10.7	Two degree of freedom controller 1 – Table 56	346
3.10.8	Two degree of freedom controller 3 – Table 57	349
4.	Controller Tuning Rules for Non-Self-Regulating Process Models	350
4.1	IPD Model	350
4.1.1	Ideal PI controller – Table 58	350
4.1.2	Ideal PID controller – Table 59	359
4.1.3	Ideal controller in series with a first order lag – Table 60	364
4.1.4	Controller with filtered derivative – Table 61	366
4.1.5	Classical controller – Table 62	368
4.1.6	Generalised classical controller – Table 63	371
4.1.7	Two degree of freedom controller 1 – Table 64	372
4.1.8	Two degree of freedom controller 2 – Table 65	378
4.1.9	Two degree of freedom controller 3 – Table 66	381
4.2	IPD Model with a Zero	383
4.2.1	Ideal PI controller – Table 67	383
4.3	FOLIPD Model	385
4.3.1	Ideal PI controller – Table 68	385
4.3.2	Ideal PID controller – Table 69	388
4.3.3	Ideal controller in series with a first order lag – Table 70	392
4.3.4	Controller with filtered derivative – Table 71	394
4.3.5	Classical controller – Table 72	395
4.3.6	Generalised classical controller – Table 73	397
4.3.7	Two degree of freedom controller 1 – Table 74	399
4.3.8	Two degree of freedom controller 2 – Table 75	416
4.3.9	Two degree of freedom controller 3 – Table 76	418
4.4	FOLIPD Model with a Zero	420
4.4.1	Ideal PID controller – Table 77	420
4.4.2	Ideal controller in series with a first order lag – Table 78	422
4.4.3	Classical controller – Table 79	423
4.5	I ² PD Model	424
4.5.1	Ideal PID controller – Table 80	424
4.5.2	Classical controller – Table 81	425
4.5.3	Two degree of freedom controller 1 – Table 82	426
4.5.4	Two degree of freedom controller 2 – Table 83	427
4.5.5	Two degree of freedom controller 3 – Table 84	429
4.6	SOSIPD Model	430
4.6.1	Ideal PI controller – Table 85	430
4.6.2	Two degree of freedom controller 1 – Table 86	431
4.7	SOSIPD Model with a Zero	436
4.7.1	Classical controller – Table 87	436
4.8	TOSIPD Model	437
4.8.1	Two degree of freedom controller 1 – Table 88	437

4.9	General Model with Integrator	438
4.9.1	Ideal PI controller – Table 89	438
4.9.2	Two degree of freedom controller 1 – Table 90	439
4.10	Unstable FOLPD Model	440
4.10.1	Ideal PI controller – Table 91	440
4.10.2	Ideal PID controller – Table 92	447
4.10.3	Ideal controller in series with a first order lag – Table 93	455
4.10.4	Classical controller – Table 94	458
4.10.5	Generalised classical controller – Table 95	462
4.10.6	Two degree of freedom controller 1 – Table 96	463
4.10.7	Two degree of freedom controller 2 – Table 97	473
4.10.8	Two degree of freedom controller 3 – Table 98	475
4.11	Unstable FOLPD Model with a Zero	480
4.11.1	Ideal PI controller – Table 99	480
4.11.2	Ideal controller in series with a first order lag – Table 100	481
4.11.3	Generalised classical controller – Table 101	483
4.11.4	Two degree of freedom controller 1 – Table 102	484
4.12	Unstable SOSPD Model (one unstable pole)	486
4.12.1	Ideal PI controller – Table 103	486
4.12.2	Ideal PID controller – Table 104	488
4.12.3	Ideal controller in series with a first order lag – Table 105	490
4.12.4	Classical controller – Table 106	491
4.12.5	Two degree of freedom controller 1 – Table 107	497
4.12.6	Two degree of freedom controller 3 – Table 108	503
4.13	Unstable SOSPD Model (two unstable poles)	506
4.13.1	Ideal PID controller – Table 109	506
4.13.2	Generalised classical controller – Table 110	508
4.13.3	Two degree of freedom controller 2 – Table 111	509
4.14	Unstable SOSPD Model with a Zero	511
4.14.1	Ideal PI controller – Table 112	511
4.14.2	Ideal controller in series with a first order lag – Table 113	513
4.14.3	Generalised classical controller – Table 114	516
4.14.4	Two degree of freedom controller 1 – Table 115	518
4.14.5	Two degree of freedom controller 3 – Table 116	520
5.	Performance and Robustness Issues in the Compensation of FOLPD Processes with PI and PID Controllers	521
5.1	Introduction	521
5.2	The Analytical Determination of Gain and Phase Margin	522
5.2.1	PI tuning formulae	522
5.2.2	PID tuning formulae	525
5.3	The Analytical Determination of Maximum Sensitivity	529
5.4	Simulation Results	529

5.5 Design of Tuning Rules to Achieve Constant Gain and Phase Margins, for All Values of Delay.....	534
5.5.1 PI controller design.....	534
5.5.1.1 Processes modelled in FOLPD form.....	534
5.5.1.2 Processes modelled in IPD form	536
5.5.2 PID controller design	539
5.5.2.1 Processes modelled in FOLPD form – classical controller	539
5.5.2.2 Processes modelled in SOSPD form – series controller.....	541
5.5.2.3 Processes modelled in SOSPD form with a negative zero – classical controller	542
5.5.3 PD controller design	542
5.6 Conclusions	543
Appendix 1 Glossary of Symbols and Abbreviations.....	544
Appendix 2 Some Further Details on Process Modelling.....	551
Bibliography	565
Index	599