

Contents

Preface	xi
About the author	xiii
1 Introduction	1
1.1 General introduction	1
1.2 A concise history of control	3
1.3 Open-loop control	5
1.4 Closed-loop control	6
1.5 Some examples of control systems	8
1.6 Definitions of standard terminology	10
1.7 Summary	12
Problems	12
Further reading	14
2 System representations	15
2.1 Introduction	15
2.2 Transfer functions	16
2.3 Block diagrams	25
2.4 Physical system realizations	32
2.5 Electromechanical devices	42
2.6 Summary	47
Problems	48
Further reading	54
3 System response using differential equations	56
3.1 Introduction	56
3.2 Steady-state response	57
3.3 Transient response	65
3.4 Errors	73
3.5 Servomechanisms	84

3.6	Summary	87
	Problems	88
	Further reading	92
4	System stability and performance	93
4.1	Introduction	93
4.2	The Routh–Hurwitz criterion	95
4.3	Root loci construction	102
4.4	Application of root loci	115
4.5	Compensation based on a root locus	125
4.6	Summary	131
	Problems	131
	Further reading	136
5	Frequency response analysis	137
5.1	Introduction	137
5.2	The Bode diagram	139
5.3	Compensation using the Bode plot	149
5.4	The Nyquist stability criterion	159
5.5	Compensation using the Nyquist plot	170
5.6	The Nichols chart	177
5.7	Compensation using the Nichols chart	184
5.8	Summary	191
	Problems	192
	Further reading	195
6	State equations	197
6.1	Introduction	197
6.2	State equations from transfer functions	198
6.3	Solution to the state equations	201
6.4	The characteristic equation	205
6.5	Canonical forms	209
6.6	Decomposition	213
6.7	Summary	216
	Problems	216
	Further reading	220
7	State variable feedback	222
7.1	Introduction	222
7.2	Controllability and observability	223
7.3	Controllability and observability in transfer functions	229
7.4	State variable feedback	232
7.5	State estimation	238

7.6	Summary	243
	Problems	243
	Further reading	248
8	Digital control	249
8.1	Introduction	249
8.2	Sampled data systems	249
8.3	Stability analysis	253
8.4	Digital compensation	256
8.5	State variable forms	261
8.6	Pole placement design	264
8.7	Summary	269
	Problems	269
	Further reading	273
9	Computing methods	274
9.1	Introduction	274
9.2	System simulation	275
9.3	Computer control	287
9.4	Computer-aided design	297
9.5	Summary	301
	Problems	302
	Further reading	304
10	Three-term controllers	306
10.1	Introduction	306
10.2	Proportional control	307
10.3	Proportional + integral control	312
10.4	PID control	319
10.5	Summary	329
	Problems	330
	Further reading	334
	Appendices	335
1	Matrix algebra	335
2	Tables of common transforms	343
3	Nonlinear systems	346
4	Unity feedback loops	355
	Index	358