

Index

a

acceptable control, inputs for 161
 adaptive data analysis 254, 272–273
 aliasing 233
 amplitude-phase-frequency diagram 27
 anti-reset windup 236
 anti-windup 236
 in cascaded control systems 238–239
 general formulation 239–240
 for “normally closed” controllers 244–245
 in observer-based controllers 241–243
 arrival cost 195–196, 198
 auctioneering control 55–56
 augmented Kalman filter (AKF) 188
 autocorrelation function 251–252, 254, 267, 275, 278, 279, 286
 autotuning 95, 102, 253

b

backlash compensation 264–265
 backlash detection 263–265
 simultaneous stiction and backlash detection 265–266
 bandwidth frequency 72, 145, 147
 bicoherence function 268
 binary distillation column model 315–317
 BLT tuning 100, 101
 Bode diagrams 27–29, 33, 34, 47, 48, 112
 Bode stability criterion 26, 30, 32–36, 79, 82, 158
 bumpless transfer 5, 86, 91, 245–247

c

cascaded control systems 54–55, 80, 238–239
 CLIFFTENT performance function 299
 closed loop bandwidth 37, 67, 76, 78, 227, 234, 235
 closed-loop disturbance gain (CLDG) 104, 106, 107
 closed-loop stability 26, 27, 31–37, 99, 148, 184, 212–213, 219, 222, 229
 closed-loop transfer functions 15, 17–19, 42, 46, 48, 78, 89, 102, 104, 146, 147, 151–156
 complementary sensitivity function 17, 100, 101, 108, 146, 153, 156, 157
 composite systems, transfer functions of 15–19
 continuous-time models 3, 4, 6, 30, 193
 control configuration 51–112, 136
 controllability 37–40, 46, 47, 62, 64, 65, 75, 135, 169, 212, 285, 314
 controlled variables
 desirable characteristics 128
 measurement combinations as 130–131
 controlled variable selection 122–132
 local analysis 125–127
 controller tuning 81–95
 convergent cross mapping 274–275

- coprime factorizations 43–44, 46
 - cross-correlation function 257–258, 266, 274
- d**
- deadtime, estimated 281–283
 - decay ratio 143, 252
 - decentralized controllers, tuning of 76–107
 - decouplers 61–62, 69, 167, 243–244
 - decoupling 61–62, 66, 243–244
 - degree of nonlinearity (DNL) 268, 273
 - degrees of freedom (DOF) 116, 118, 121–122, 125, 127, 130, 132, 140, 179–181, 219–221, 272, 277
 - detectability 40–41, 188, 201, 212
 - detection
 - cross-correlation function 257–258
 - histograms for 258–260
 - OP-PV plot 260–262
 - discrete-time implementation 91, 233–235, 245
 - discrete-time models 2–4, 6–8, 46, 175
 - dynamical systems
 - in continuous time 1–2
 - in discrete time 2–3
- e**
- economic control benefit assessment
 - economic performance functions 298–299
 - estimating achievable variance reduction 300
 - expected economic benefit 299–300
 - operational constraints 297–298
 - optimal operation 297–298
 - worst-case backoff calculation 300
 - execution order 235
 - explicit MPC 174, 217
 - extended Kalman filter (EKF) 187–190, 193, 198
- f**
- feedback connection 16
 - feedforward control xxix, 51–54, 60, 121, 160, 162–164, 166–167, 283–285, 287–288
 - first-order-plus-deadtime (FOPDT) model 86, 88–91
 - fluid catalytic cracker (FCC) 206–207, 315, 318–320
 - Fourier–Motzkin elimination 184, 222, 303–305, 307
 - fractional timestep time delays 8–9
 - frequency analysis 24–27, 30, 35, 79, 81–85
 - frequency domain 8, 25, 57, 74, 143, 145–148, 252, 254, 277
 - frequency response 8, 11, 24, 26, 27, 31–37, 82
- g**
- gain and phase margin 147–148
 - gain margin 35, 147, 282
 - gain scheduling 97–98
 - Gramian-based input–output pairing 74–75
 - input and output selection 63–65, 75
 - Granger causality 276–277
- h**
- half rule of SIMC model reduction 91
 - Hammerstein model 266
 - Hankel interaction index array 75–76
 - Hankel norm 46–47, 75
 - Hankel singular values 46–47, 65
 - Hanus’ self-conditioned form 240–244
 - Harris index 278–279
 - calculating 280–281
 - modifications 282–283
 - use of 285–286
 - hen-and-egg type 115
 - Hessian matrix 174–175, 211, 223–224
 - hidden modes 41
 - high-density plots 269–271

i

IMC-PID tuning 88–89
 impulse response model 279–280, 284
 independent design techniques 77,
 100–102
 inherent robustness of feedback 53, 223,
 285
 inner function 44
 input multiplicative uncertainty 166
 input resetting control 57–59
 interactor matrix 287
 internal controller scaling 96–97
 internal model control (IMC) 45, 88–89,
 102
 internal stability 41–42, 44, 148
 inventory control, consistency of 138–140
 ISE optimal control 156
 bounds from 156–157
 Iterated Extended Kalman Filter (IEKF)
 189–190, 193

k

Kalman filter 187–193, 197–198, 200,
 202, 226

l

Laplace transform 9–11, 196
 left half-plane (LHP) 18, 23, 28–29, 42,
 78, 90, 152, 155, 311
 linear controllers 4, 240–241
 linearization 3
 deviation variables 4
 equilibrium point 4
 trajectory 6
 linear models xxvii, 3–6, 7, 10, 75, 165,
 213
 linear quadratic optimal control
 144, 174
 loop shaping 77–79, 103–107, 156, 168
 lumped models 2

m

manipulated variables 51, 132
 and RGA 71
 selection of 132–135

manual oscillation diagnosis 256–257
 mass balance control 136–140
 maximal output admissible set 183–184,
 220, 307
 maximum modulus principle 152–153,
 162
 midranging control 57
 minimal representation 11–14, 18, 23
 minimum singular value rule 127–128
 model-based predictive control (MPC)
 xvii, 173–228
 calculations
 enlarging terminal region 220–222
 input blocking 219
 warm-starting optimization
 218–219
 controllers
 accurate models 227
 input usage or constraint violations
 227
 maintenance 228
 misconceptions 226–227
 performance monitoring for
 288–289
 plant model 228
 robustness of 222–225
 and integrator resetting 208–210
 linear programming (LP) formulation
 173–174, 211, 216–217, 227,
 307
 quadratic programming (QP)
 formulation 173–185, 194, 197,
 211, 214, 216–220
 monovariabe Nyquist Theorem
 32–34
 monovariabe systems 15, 19, 32, 36,
 145, 146, 147–150, 153, 166
 moving horizon estimation (MHE) 193
 multiloop controller tuning 99–103
 multiple timestep time delays 8
 multivariable loop-shaping 103–107
 multivariable Nyquist theorem 32, 36
 multivariable systems 149
 poles of 19
 zeros of 20–22

n

Niederlinski index 73
 nonlinear model 3, 6, 56, 189, 190, 225,
 226
 non-minimal 12
 normalized coprime factorization 44
 nullspace method 130, 140
 for implementation error 130–131
 Nyquist D-contour 31–33, 36, 73

o

observability 38–40, 46, 47, 64, 65,
 74, 75
 offset blocking 219
 offset-free control
 disturbance estimation and 200–203
 disturbance handling and 199–210
 requirements for 199–200
 one degree of freedom controller 5, 6
 open-loop frequency response 26, 31–37
 open loop gain 67, 69, 77, 78, 83–85,
 108
 optimal operation 57, 115–117, 122–125,
 140, 297–298
 optimization variables 179–181, 218
 oscillating control loops 250–256, 260
 Oscillation Contribution Index (OCI)
 273–274
 Oscillation detection
 Forsman and Stattin method 255
 Hägglund method 253–254
 Miao and Seborg method 252–253,
 255
 outer function 44
 output multiplicative uncertainty
 166
 overshoot 81, 91–95, 143, 158, 159,
 209

p

parallel systems 16
 partial relative gains 72–73
 participation matrix 75, 76
 perfect control, inputs for 161

phase margin 33, 35, 82, 84, 145,
 147–148, 157, 158
 PI/PID controller 66, 67, 108, 117, 286
 plantwide oscillations 269–278
 pole directions 19–20, 66, 149, 154, 168,
 313, 314
 pole polynomial 18, 19, 21
 poles and zeros
 of discrete-time transfer functions 23
 of transfer functions 18–22
 power spectral correlation index
 270–271
 power spectrum 252, 254, 257, 267, 269
 prediction horizon 6, 174, 176, 177, 179,
 182–185, 209, 211, 213, 220, 221,
 229, 282
 prefiltering data 255–256
 presampling filter 233
 principal component analysis 269
 Principle of the Argument 31, 32
 process knowledge 51, 277–278, 285, 289
 process model 6, 88, 173, 177, 185–199,
 215, 222, 224–226, 230, 278, 286,
 288, 291
 proportional integral derivative (PID)
 controller 27, 60, 66, 79–82, 86,
 88–90, 95, 108, 117, 158, 228, 238,
 245, 253, 286, 291
 push-through rule 17

r

ratio control 54
 real-time optimization (RTO) problems
 xxvii, xxix, xxxi, 117
 receding horizon estimation (RHE) 193
 filtering formulation 196
 smoothing formulation 196–198
 recursively feasible 182, 222, 229
 redundant constraints, removal of 307
 regulatory control 51–62, 65, 117–121
 relative gain array (RGA) xvii, 66, 68
 and diagonal input uncertainty 69–70
 and individual element uncertainty
 69
 as interaction measure 70

- and optimally scaled condition number 68–69
 - and pairing of controlled and manipulated variables 71
 - performance 103–104
 - and stability 70–71
 - and zeros in the right half plane 68
 - reset windup 60, 236
 - reverse acting controllers 26, 97
 - right half-plane (RHP) 18
 - poles
 - input factorization of 313
 - output factorization of 313
 - zeros
 - input factorization of 312
 - output factorization of 312
 - rigorous independent design 100–102
 - rigorous process models 225–226
 - Rijnsdorp interaction measure 73–74
 - rise time 143, 158, 159, 286
 - root cause location 273
- S**
- sampling interval 7–9, 30, 49, 91, 173, 233–235, 283, 317
 - second-order plus deadtime (SOPDT) models 90, 91
 - selective control 59–61
 - self-optimizing control
 - direct evaluation of loss 124–125
 - local method for 128–129
 - validity of local analysis for 131–132
 - sensitivity function 17, 74, 100, 103, 104, 108, 145, 146, 149–151, 153, 156, 157
 - sensitivity integrals and right half plane
 - poles 150
 - zeros 149
 - sequential design 65, 77, 102
 - series interconnection 8, 9, 15, 45
 - setpoint overshoot method 91–94
 - setpoint weighting 81, 82, 97, 99
 - settling time 143, 159, 286
 - SIMC 89–92, 108
 - simple feedback control loop 51, 52
 - simple IMC tuning 89–91
 - simple PI control anti-windup 237
 - simultaneous design 77, 103
 - single-loop controllers, tuning of 79–97
 - single-loop control structures 60–61
 - singular value decomposition (SVD) 22, 221, 269, 309
 - singular value composition 161
 - SISO loops 62, 65, 158
 - SISO systems 77, 287, 314
 - small gain theorem 36–37
 - spectral envelope method 271–273
 - split range control 56–57, 60
 - stability, linear system 23
 - stabilizability 40, 212
 - stabilization, input and output selection for 65–66
 - stable plants 45, 46, 73, 149, 225, 258
 - state-space model 8, 10, 11, 18, 23, 29, 39, 41, 46, 47, 175, 201
 - steady state error 123, 143, 144, 201
 - steady-state phase adjustment 26–27
 - step response method 86–88, 185–186
 - structured singular value 68, 101, 102, 165
 - superposition principle 180
 - surge attenuating controllers 98–99, 291
 - surrogate time series 267
 - system bandwidth 145
- t**
- terminal set 182, 220–222, 229
 - time delay
 - fractional timestep 8–9
 - in manipulated variables 7–8
 - in measurement 9
 - multiple timestep 8
 - time domain 24, 25, 143–146, 276
 - transfer entropy 275–277

U

- unachievable loop gain requirements
107
- undershoot 99, 143, 158, 159
- unscented Kalman filter 190–193
- unstable plants 45–46, 154, 182

V

- valve stiction 257
 - compensation 262–263

W

- weighted sensitivity minimization
157–158
- weighted system norms 146–147

Z

zeros

- poles and zeros of transfer functions
18
- transmission 16, 21, 22, 47, 48, 66,
107, 150, 236
- zero directions 22, 149, 314
- zero-order hold 7
- zero polynomial 21, 22
- Ziegler–Nichols closed-loop tuning
method 86
- Ziegler–Nichols open-loop tuning
88–89
- z transform 10–11

