Index

a
accelerator setting, 87
accumulation variables, 3
advanced control algorithms, 111, 257
– closed-loop disturbance response, 258
– open-loop disturbance response, 258
advanced level control, 69, 82
air/fuel ratio control, 92
air-to-open, 10
– globe control valve, 31
algebraic equations, 25
– Riccati equation, 278
ammonia synthesis loop, pressure control, 136
amplitude ratio, 305
analogue systems, 5
angle criterion, 296, 298
angles of departure/approach, 132
antisurge, 90
approximate implicit integration, 55
ARIMAX model, 108
– fit of linear discrete SISO model, 250
auto-correlation function, 97, 234, 254
autoregression, 108

b
bang-bang control, 65
batch least-squares, 110
batchwise liquid–liquid extraction optimal solution, 310
Bellman's principle of optimality, 309
block flow diagram, 100, 106
boiler furnace control scheme, 92
Boolean expression, 22
bounded double-plume
– search starting fixed golden section line search limits, 319
– search starting with relative golden section line search limits, 319
Bristol array, 91

c
capacitor, 36
cause-effect matrix, 87
CEM, initial, 227
chlorination, 43
closed Loop, 63, 294
– characteristic equation, 130, 193
– constrained, 201
– control, 112, 290
– damping ratio, 131
– poles, 112, 114, 276
– setpoint step response, 209
– stability, 135
– system, 295
– transfer function, 52, 71, 192, 215, 268
column bottom temperature
– control scheme, 79
– by reboiler steam valve, 80
column pressure
– control, 77
– drops, 14
– sudden drop, 226
comparator, 113
compensator, 52
compressor, 38, 90
concentration isopleth field, 142
concentric pipe heat exchanger, 33
condenser cooling water adjustments, 121
conditional stability, 305
conditioning reservoir, 43
conical hopper, 36
conjugate gradient method, 144
constraints, 118, 125
– dynamic matrix, 125
continuous linear state system, 113
continuous SISO system, 112
controllability, 88,
'controllable system' pole placement approach, 114
control strategy design
– for processing plants, 73, 217

Applied Process Control: Essential Methods, First Edition. Michael Mulholland.
© 2016 Wiley-VCH Verlag GmbH & Co. KGaA. Published 2016 by Wiley-VCH Verlag GmbH & Co. KGaA.

control valve, 156, 159
conventional distillation columns, 73
cross-correlation functions, 97, 110, 233
cross-limiting air/fuel control, 92
cross-limiting control scheme, 95
crystalliser, 34
Cv factor, 10
cyclohexane, 29
cyclohexanol, 9

d
damping, 295
– factors, 34, 132, 294, 299, 301
– – of poles, 133
dead-beat control, 258
decay ratio, 137
defuzzification, 58, 196
– algorithms, 196
de Larminat's approach, 112, 266
delayed step (dead beat) responses, 111
depropaniser column, 77
differential equations, 25, 27, 34, 35, 36, 37
differential pressure, 9
diophantine equation, 116
– Bézout equation, 264, 268
discrete algorithm, 48, 50
discrete computer system, 51
discrete equations, 106
discrete form
– *versus* continuous, 4
– of equation, 191
discrete linear input–output system, 116, 125
discrete model, 50, 63
discrete state model, 57
– linear state, 114
discrete system
– behaviour, 51
– model, 99
dispersion parameters, 143
distillation columns, 13, 14, 28, 66, 82
– preheat train of, 120
– pressure control, 30
distributed systems, 32
dividing-wall column, 83
DMC
– controller, 124
– IMC block Block of, 283
– industrial versions of, 118
– 'internal model' block of, 118
– matrices in control scheme, 120
double-effect evaporator, 69
Downhill Simplex Search method, 143
DP cell, 7, 8, 9, 154
– diagram and short explanation, 9
draught fan, 7
dynamic matrix, 3, 56, 119, 121
– control, 122
– controller, 118
dynamic programming technique, 3, 139
– to find optimal number of buckets, 140

e
electrical thermostatic heating element, 127
electric kettle, 42
electric power, 42
electronic DP cell, 8
electronic signals, 9
ellipsoid
– search starting with fixed golden section line search limits, 318
ellipsoidal cloud
– with centroid, 144
'equal percentage'
– characteristic, 10, 11
– control valve, 11
equation error, 108
ethyl acetate (EtAc), 81
ethylene, 35
– polymerisation reactor, 35
– reaction rate of, 35
Euler equation, 201
Euler integration, 25, 33, 59, 104, 105
evaluated matrix exponential points, 200
evaporation sequence
– optimal, 139
evaporator, 118
– optimal solution, 309
exothermic reaction, 22, 25, 43, 75, 84
extended Kalman filter, 3

f
'fail-closed' (FC), 85
'fail-open' (FO), 85
fast Fourier transform, 98
fault tree, 23, 163
feedback, 137
– contribution, 265, 269
– control, 90
– – strategy, 134
filter, 99, 100, 104
finite impulse response, 110
first-order irreversible reaction, 39
– endothermic reaction, 35, 37, 89, 134
first-order linear ODEs, 310
first-order loss mechanism, 27
first-order process, 47
first-order response, 113, 234
first-order system, 38, 111
fixed bed catalytic reactor, 32, 81
flame-out detector, 20

flooded condenser technique, 30, 77
flotation, 27
flow control, 67
– loop, 8
flow controller, 8
flow reactor, mixed, 75
flow variation, 32
fluidised riser reactor, 21
forgetting factor, 110
fourth-order Runge–Kutta scheme, 54
– of integration, 52
frequency components, 98
frequency variations, 64
friction
– constant, 159
full metering control
– with Oxygen trim control, 232
furfural
– flow controller, 69
– hydrogen stream drawn, 88
furnace, 120, 123
– draught systems, 7
– ducting, hazardous situation, 232
fuzzy model, 58
– conditional statements, 196

g
gain margin, 135
GAMS®, 141
– environment, 147
gas cushion, 129
gas distribution network, 140
gas leak, 20
gauge pressure, 17, 38
Gaussian plume formula, 143
Gaussian sample, 196
global optimisation, 3
golden section line search, 144
– converges, 318

h
hazard, 20
heat exchanger, 62, 120
heat transfer salt (HTS), 74
hydrodealkylation, 23
hydrogenation reactor, 68, 88
hypochlorite dosing rate, 43
hysteresis, 10

i
identity matrix, 243
IDP method, 126
implicit numerical form, 36
impulses, 46
– modulated form, 186
– modulated signal, 45, 186
– in setpoint, 214
inherent valve, 157
in-line chlorinator
– for camp site, 93
input–output systems, 3
installed valve situation, 157
instrumentation, 7
– and control scheme, 77
integral action controllers, 213
integral time, 63, 307
– scales, 97
integration formulas, 54
integration transfer function, 189
interlocking system, on Ladder Diagram, 18
inverse response, 124
I/P converter, 31
iterative dynamic programming (IDP), 125
iteratively chosen pole locations, 301

j
jacketed stirred vessel, 30

k
Kalman filter (KF), 3, 107, 110, 248, 250, 280
– algorithm, 103, 115
– covariance matrix, 242
– gain matrix, 274
KA oil, 79
kickback valve, 38
KO drum, 79

l
Laplace domain, 47
– transfer function, 39
Laplace model, 168
largest modulus, 112
lead compensator, 51
least-squares fitting, 239, 246
limit cycle, 208
linear continuous system, 133
linear control valve, 15
linear differential equation, 31, 37, 38, 53
linear discrete model
– closed loop, 272
– least squares fit of, 246
linear dynamic matrix control (LDMC), 124
linear gain matrix, 241
linearisation, 3, 88, 184
linearised discrete model, 126
linearised ODEs, 165
linearization, 171
linear model, 53, 101, 173
linear program, 144
– programming problem, 141

linear quadratic regulator (LQR), 115, 280
– controlling, 139
linear system, 50
linear vector–matrix equation, 62
LPG plant, 38
LP_Solve, 141
LQR closed-loop equation *versus* Kalman filter state update equation, 115
LQR gain matrix, 115
Luenberger observer, 100, 274

m
maleic anhydride, 21
Markov process, 61
– variation, 242
mass balances, 28, 239
mass-flow, 9
MATLAB®, 97, 129, 141
– algorithm, 101
– program, 33, 44, 185, 192,
– – closed-loop transfer function, 264
– – open-loop transfer function for the modulus calculations, 262
– program using LP_Solve
– – closed-loop transfer function, 270
MATLAB®
– FFT function, 98
matrix exponential, 55, 59,
– function, 44
matrix transfer functions, 5
mean-time-to-failure, 22
measurement, 107
– variance of error, 107
mercury manometer, 33
MIMO closed-loop stability, 138
MIMO controllers, 227
MIMO discrete input–output system closed-loop stability, 133
MIMO robust control, 137
MIMO system
– open-loop and closed-loop stability of, 132
mineral flotation cell, 27
minimal prototype controllers, 111
mission time, 23, 161
mixed integer non-linear programming (MINLP) problem, 147
mixed-logical-dynamical methods, 127
'modal control' system, 113, 114
'Monte Carlo' method, 21
Morari Resiliency index, 32, 89, 229
multidimensional extremum search, 142
multiplicative uncertainty, 138
multistage batch-wise liquid–liquid extraction, 139

n
n-butane
– catalytic oxidation of, 21
Nichols chart, 136, 137
noise components, 98
non-dominated sorting genetic algorithm (NSGA), 146, 325
– with two objectives – production and yield, 324
non-interacting tanks, 61
non-linear environment, 143, 144
nonlinear model, 173
Nyquist plots, 112, 135, 138, 305

o
objective function
– for DMC controller, 124
– used in dynamic matrix control, 118, 121
observability matrix, 229
1-octene separation column, 83
open loop, 62, 293
– behaviour, 70, 89
– characteristic equation, 130, 293
– cooled reactor system, 45, 51
– matrix, 194
– poles, 114, 272, 276
– response, 56, 122, 194, 286
– step response test, 123
– system, 51, 135
– – stability of, 45
optimal control action, 115
optimal evaporation sequence, 139
optimal flight plan, 311
optimisation, 139, 309
orifice plate, 8
overshoot oscillation, 199
o-xylene, 66, 81, 210
ozone control system, 23

p
P controller, 307
PD controller, 71, 207
perturbation variables, 88
Petri net principles, 58
phase margin, 136
phthalic anhydride (PA), 74
– plant, 65, 81
– plant, risk, 21
– tubular catalytic reactor, 22
PI compensator, 131
PI controllers, 50, 111, 112, 129, 131, 132, 133, 137, 138, 207, 294
PID controller, 124, 131
pipe friction loss, 15
plant control schemes, 78
– basic elements, 203
Pneumatic capacitors, 36

pneumatic signal, 31
power law approximation, 133
power spectral density, 98, 235
prediction error, 107
preheat trains, 99
pressure, 70
– in boiler responds to heat input, 41
pressure-compensated temperature, 67, 83
– control for middle-cut composition, 84
pressure flow-smoothing capacitor, 129
pressure gauge, 10
pressure reduction valves, 17
principle components analysis, 98
principle of optimality, 115
probability, 162
– density function, 22, 162
– distribution in time, 162
– of occurrence, 19
proportional gain matrix, 273
proportional state feedback, 113
pseudo-Gaussian random variable, 59
pump–tank system, 52
pure integrating transfer function, 50

q
QDMC, 284
quadratic objective function, 116, 126
quality of control, 129

r
ramp function, 47
ramp input, 38
'Reaction Curve' method, 112
reactive distillation, 67
reactor, 35
– jacket, heat transfer oil circulates, 75
– recycle loop
– – with downstream product separation column, 87
– recycle scheme, 73
– temperature, 81
– – control, 75
real-time computer system, 45, 186
reboiler steam, 66, 226
recursion for optimal gain matrix, 115
recursive algorithm, 106
recursive least squares, 110, 249
recursive parameter estimation
– recursive model, 247, 249
recycle loop pressure, 78
– control, 78
refinery debutaniser column
– control scheme, 86
refinery distillation column, 16
reflux ratioed
– to column feed rate, 77
regulator, 115
relative gain array, 90
resistance device, 10
resistive friction force, 34
resonant peak, 136
robust control, 137
Riccati equation, 104, 115, 243
root locus, 130
Runge–Kutta integration, 53

s
sampling interval, 47, 99
s-domain transfer function, 39, 42
second-order process, 110
setpoint, 63
– contribution, 269
– impulse, 206
– ratio, 9
shrink/swell, 287
signal range, 8, 9
signal ranging, 9
simulated annealing, 145
simulation model, 108, 112
simulation program, 112
Simulink® model, 113, 266, 270
single-stage evaporator, 28
SISO controllers, 133, 227
SISO control loops, 87
SISO discrete model, 108, 113
SISO pairings, 231
SISO 'P' control, 229
SISO PI controllers, 133, 137
SISO process model, 110
SISO system, 228, 264, 268
slip-stick hysteresis, 159
Smith predictor, 99, 118, 283
square-root extractor, 9, 153
stability, 51
stability and quality of control, 293
standard deviation, 197
– of control actions, 127
state-based systems, 3
state-space vector–matrix form, 32
steady state, 25
steady-state
– closed-loop response, 206
steady-state gain, 11
– matrix, 89
steady-state offset, 70
steam drum level control
– piping and instrumentation diagram, 91
stem position, 160
step in setpoint, 214
stirred vessels, 31, 34
sulphuric acid plant, 85

supersaturation, 34
switching, 320
switch sequence for maximum net profit, 323
system of first-order ODEs, 59

t
tanks interconnected, 53
thermocouple, 10
thermosiphon boiler, 132
time constant, 34
time-correlated error, 108
time-domain integration, 113
time step loop, 25
toilet cistern, 71
top-hat distribution, 97, 162
transfer functions, 27, 30, 35, 40, 47, 48, 62, 70, 129, 130
trapezoidal integration, 47
tubular catalytic reactor, 84
Tustin approximation, 50, 52, 112
two degrees of freedom (RST) controller, 112
– discrete controller, 113
two-tank flow/level process, 134

u
unbounded quadratic optimum, 287
unbounded system, 124
unconstrained optimal control move(s), 118
Union-Carbide 'Unipol' gas-phase ethylene polymerisation reactor, 76
universal gas constant, 7
UOP Penex isomerisation plant, 78

v
vacuum column, 36
valve position, 31
– controller, 83
valve 'positioner', 173
valve signal
– variations, 154
valve slip-stick, 173
vapour flow rate, 69
vapour-phase hydrodealkylation plant, 23
venturi, 7
VPC setpoint, 210

w
water distribution system, 43
water pumping installation, 12
weighting matrix, 100, 241
white-noise components, 98
Wiggins water reservoir, 26
wind up, 213

z
z-domain polynomials, 116
z-domain transfer function, 46, 47, 49
zero-order-hold, 45
z-transforms, 48