A	Analog:
	computation, 257
Alation 52	signals, 212–215, 358–359
Accumulation, 53	Anti-reset windup, 399-402, 604-605
Accuracy:	715
numerical integration, 83–84	Array (see Relative gain array)
sensor, 383, 772–773	Averaging filter, 394
Adaptive tuning:	Averaging level control, 563-564,
expert system, 528	569–570
gain scheduling, 518, 529, 709, 715	
input conversion, 519	
reasons for, 512-517	
relay auto-tuning, 527	В
selection of method, 529	В
valve characteristic, 520–525	
Alarms, 795, 890	Bandwidth, 419
Aliasing:	Benefits, control, 28–35, 423–425
antialiasing filter, 393	Blending:
•	controllability, 627, 637
due to sampling, 362, 989	
Amplitude:	gasoline, 866
amplitude ratio, 121–123, 316, 412,	interaction, 632
988-989	loop pairing, 663
response to sine, 121	model, 621
(See also Frequency response)	operating window, 625

Characteristic, valve:
examples, 520-525
inherent, 520
specifying for linearizing loopgain, 524
Characteristic equation:
definition, 309, 630
relation to stability, 309-310, 316, 643
987
Characteristic polynomial:
definition of, 108, 932
relation to stability, 109
roots of, 109, 932
Checklist, for design, 820–822
Chemical reactor, packed bed:
cascade, 471–473
feedforward, 495–497
inferential, 549–552
variable structure, 713–714
Chemical reactor, stirred tank, 62, 72,
84–86
isothermal, 62, 72
nonisothermal:
cascade design, 475–476
control design, 835
control performance, 438–440
linearized, 900
•
model for, 85, 897–901
multiple input-output, 163–165
operating window, 781–783
recycle, with, 785
selecting variables, 216–218
signal select, 710–712
transfer function, 902
series:
block diagram, 944
inverse response, 944–945
model, 64–67, 943–944
transfer function, 944
stability, without control, 902–906
steady-states:
calculating, 902–904
multiple, 905
stabilizing via control, 905
Combustion:
benefits for, 32–34
excess oxygen control, 27
fuel control, 500-501
(See also Fired heater)
Complex numbers:
magnitude, 122, 316-317, 936-937
phase angle, 122, 316-317, 936-937
polar form, 122, 316–317, 936–937

Composition control:	Control—Cont.
blending and mixing, 270, 282,	feedforward, 488
512–519, 646–648	objectives, seven categories, 20–25,
chemical reactor, 37, 216, 438, 475, 835	768, 838
flash, 23, 537–544, 768, 802–803	(See also Model predictive control)
(See also Distillation)	Control design form, 768, 838
Computation:	Control objectives, 20, 216, 269, 768
analog, 257–258	Control performance:
digital, 358–362	best possible, 426-427, 490
Computer:	control system factors, 433-440
analog, 257–258	economic analysis, (see Benefits,
digital, 358–362	control)
control implementation, 365-367,	faction dead time, 279, 426-429
974, 983–989	factors affecting, 444
simulation, 82-84, 422-425	by frequency response, 412–415
(See also Digital control)	measures, 219-223, 240-241
Computer-aided calculations, 82–84,	multivariable systems:
421–422	disturbance type, 667, 677–679
Conservation	interaction, 616
component, 53	(See also Relative disturbance gain)
energy, 53, 898	process factors, 425–432
material, 53	robust, 268–269, 411
Constitutive relationships, 54	by simulation, 422
Constraints, 26	Control system:
control, 715–720	hierarchy, 829
hard or soft, 767–770	layout, 9–10, 212–213, 359–361
valve position control, 718–719	Control valve:
(See also Operating window)	characteristic, 520
Continual improvement, 859	dynamics, 776
Continuous cycling, 342–343	failure position, 777
Continuous-flow stirred tank (CST):	range, 776
chemical reactor:	selection, 217
	Controlled variable:
heat-integrated, 785	
with recycle, 155–157	selection of, 7–8, 225, 536, 771–773, 775, 787, 840
(See also, Chemical reactor, stirred	• •
tank)	Controller:
heater, 76–80, 253–257, 458–461,	dimensionless gain, 397
483–486	error, 242–243
mixer, 186–187, 223–225, 270, 512	execution frequency, 370, 373
Continuous-time variables, 98, 212	flowchart, 403
Control:	frequency response of, 325–326
algorithms:	location, 9–10
DMC, 735–748	manipulated variable, 217
IMC, 590–600	measured variable, 216
lead/lag, 485–486	nonlinear, 517, 567
PID, 252	performance (see Control performance)
Smith predictor, 600–603	sense switch, 396–397
approaches, 228	tuning:
automated vs. manual, 228-231	Ciacone, 278–286
benefits, 28-35, 425	comparison, 347
definition, 6	dynamic matrix, 750
design, 216-218, 823, 834	fine, 289–293
feedback, 6-7, 212, 243	goals, 268–269

S NO STATE OF THE STATE OF THE

Controller—Cont.	Derivative—Cont.
tuning—Cont.	Laplace transform of, 101
IMC, 598	mode:
Lopez, 287	behavior, 249-252
multiloop, 638–646	frequency response, 326
robustness, 268-269, 338-341	noise transmission, 252, 292-293
Ziegler-Nichols, 329–330, 347	time, 250
Corner frequency, 323	z-transform, 978
Critical frequency, 315	Design, control:
Crossover frequency, 315 CST (see Continuous-flow stirred tank)	control design form (CDF), 768–769, 838–839
	controllability, 780-781
	degrees of freedom, 778
D	dynamics:
D	disturbance, 444
	feedback, 444
Domning	loop pairing, 695
Damping:	operating window, 624-626, 681, 781
coefficient, 138–139	788–789
critically, 139 overdamped, 139	procedure, integrated, 834
underdamped, 139	process decomposition, 831
Dead time:	sequence of steps, 823
Bode plot, 324	temporal hierarchy, 825
compensation, 600	Detuning factor, 678
computer programming, 922	Deviation variables, 71, 111
definition, 103	Diagnostic:
discrete, 977	model, 183
effect on performance, 426-427	tuning, 290
effect on stability, 334–337	Difference equations:
frequency response, 318	controllers, 367, 493, 595, 994-995
Padé approximation, 913	discrete models:
Decay ratio, 220	approximate, 923
Decentralized control, 616-617	empirical, 188
Decoupling:	exact, 923, 986
application criteria, 690	Differential equations:
designs:	discrete form, 188, 923, 986
calculated controlled variables,	linearization of, 70–72
685–686	numerical solution:
calculated manipulated variables,	error control, 84
684–685	Euler, 83, 423
explicit controller calculations,	Runge-Kutta, 84
686–689	solution by:
performance, 689-690	integrating factor, 895
sensitivity to errors, 689–690	Laplace transforms, 102
(See also Interaction)	Digital control:
Degrees of freedom:	computing network, 359
in control design, 217, 460–461, 708,	dynamic matrix control, 735
711,778	internal model control, 595
effect of control, 254, 778	lead/lag, 493
in modelling, 54–55	performance of PID, 367–369
Derivative:	ringing, 370–371, 982, 992
approximation, 366	sampling:
definition of, 56 filter, 402	hold, types of, 364–366
mc1, 402	period selection, 369

Digital control— <i>Cont.</i> sampling— <i>Cont.</i> simulation, 423	Dynamic matrix control (DMC)—Cont. multivariable formulation, 744–748 predictive structure, 728
tuning modifications for, 370	single-variable formulation, 738
Dimensional analysis, tuning, 278–286	tuning, 750
Direct-acting feedback, 396	Dynamics:
Distillation:	dead time, 103, 140, 324, 328
cascade control, 690	first-order systems, 57, 137, 323, 328
composition control of:	integrating process, 140-141, 564-566,
inferential, 545–549	325, 328
interaction in, 637	recycle systems, 155, 840
operating window, 625-626	second-order systems, 138-140, 324,
relative disturbance gain (RDG),	328
679–680	series systems, 143, 328
tuning for, 648	staged systems, 157
decoupling control, 689	(See also Modelling procedure)
dynamic matrix control of, 746–747, 754–756	
feedforward control of, 500-501	_
industrial case study, 949-960	E
modelling of:	
empirical, 62, 622-623	F
fundamental, 157-163	Economic value of control, 28–35 Electrical circuit, 137, 138
regulatory control of:	Emergency control systems, 20, 230–231,
energy balance, 664	794–799
material balance, 665	Empirical modelling:
Distributed control system:	dead time, 144, 179–181, 190
advantages of, 361	diagnostics, 61, 183, 194
structure of, 359	experimental design for, 181, 188
Disturbance:	multivariable systems:
causes, 7	open-loop, 197, 622
interaction effects (see Relative	partial closed-loop, 629, 670
disturbance gain) models, 220, 224, 415, 444, 496, 666	process reaction curve, 179
response, closed-loop:	signal-to-noise, 182
frequency response, 412–418	six-step procedure, 176
simulation, 422–425	statistical method, 188
Dominant variable, 779, 827	use in control analysis, 280, 338–343
Draining tank, 75–77, 106–107	Energy balance: in modelling, 53–54, 898
Drawings, 12–13	strategy in distillation, 664
instrument symbols, 889–892	Energy reduction, control systems for, 23,
process equipment, 892-894	716–717, 791, 861–866
valve symbols, 892	Environmental protection, 21, 768, 797
Dynamic compensation, 551	Equal-percentage characteristic, 521
Dynamic matrix control (DMC):	Equilibrium, ideal stage, 159
approximate inverse for, 729	Equilibrium, phase, 159, 538
controller formulation, 737-738	Error:
discrete step process model, 730-734	measures of control performance, 219
feedback signal, 740–742	in sensor measurement, 383, 773
future prediction, 735	variable used by controller:
horizon, 737	model predictive, 585, 741
model, step-weight, 730	proportional-integral-derivative,
move suppression, 743	242–243

Euler:	Feedforward control—Cont.
identity, 934	perfect, 484
numerical integration, 83	performance guidelines:
Evaporator, 676	dynamic behavior, 491
Evolutionary operation, 871	model error, 490
Experimental modelling (see Empirical	stability, effect on, 488, 502
modelling)	tuning, 493
Exponential filter:	Fieldbus, 375
analog, 390, 393	Filtering:
digital, 392, 988	algorithms:
predictive control, 593	continuous, 390
principle, 389	discrete, 392, 988
External feedback, 399	aliasing in, 393
External variable, 54,	low-pass, 390
	perfect, 390
	performance, effect on, 391
E	reasons for, 389
F	z-transform, 979
	Final control element, 5, 10, 212–213,
Enter postal frestions 107,021	226, 438, 776–777
Factor, partial fractions, 107, 931	Final value theorem, 104, 979
Factorization, model, 590	Fine tuning, 289–293
Feasible region (see Operating window) Feedback control:	Finite difference, 366–367, 493, 923
	Fired heater:
block diagram for, 243, 463, 586, 630 components of loop, 212–213	cascade control, 494
compared with feedforward, 488	feedforward, 522–524
definition, 6	industrial case study, 961–972
negative, 6	loop pairing, 694–695
performance (see Control performance)	outlet temperature control, 29
pluses and minuses, 229	-
positive, 142	First-order system:
selecting variables in, 216–218, 438,	continuous, 137
536, 775, 779, 828	discrete approximation, 922
(See also PID; IMC; DMC)	dynamic behavior, 59, 137–138
Feedforward control:	Bode diagram, 323
algorithms for:	example systems, 137
digital, 492–493	frequency response, 328
general derivation, 485	time-domain responses, 136
lead/lag, 485-486	series of:
transfer function, 488	interacting, 145–148
block diagram for, 489	noninteracting, 143–145
design criteria for, 487	transfer function for, 144
goal, 484	Flash process:
digital implementation, 492	alarms for, 795-796
examples:	control design for, 802
chemical reactor, 495	control objectives for, 20-25, 768-769
distillation, 501	controllability of, 787-788
fired heater, 499-500	degrees of freedom, 787-788
heat exchanger, 497–498	dynamic response of, 803
feedback:	inferential control of, 537-541
combined with, 486, 497	operating window, 788–789
comparison with, 488	safety control, 794–799

Flow:	Heat exchanger—Cont.
control, 13	cascade, 458
measurement, 387	dynamic model, 76-80
ratio, 499, 684	feedback control transient, 256
value, 80	feedforward, 486
Forcing function, 895	linearizing characteristic, 523-524
Frequency distribution, 31–35	refrigeration, 475, 884-885
Frequency response, 121	steam condensing, 777
amplitude ratio, 121–122	stirred tank, 76–80
of basic systems, 323–326, 328	Heaviside, 932
Bode plot, 123	Hierarchy, 476, 826, 829
closed-loop control performance, 412–420	High signal select, 713
computer program for, 317, 421	Histogram, 29-31
direct evaluation, 122	Hold:
phase angle, 121, 123	first order, 364
of series systems, 144, 316–317	zero-order, 364
shortcut from transfer function, 122	Holdup time, 562
in stability analysis:	Horizon:
Bode stability, 314–316	input, 749
transient, complete, 119-120	output, 749
Furnace (see Fired heater)	Hydrocracker control, 753

G

Gain: controller: feedback, 245, 587 feedforward, 485 nonlinear, 567 frequency dependent, 315 margin, 338 process, 87 disturbance, 224 feedback, 224, 254 multivariable process, 627 steady-state, 58 Gain scheduling, 518, 529

Н

```
Heat exchanger:
with bypass:
feedback control, 784
model, 76–80, 939–942
numerator zero, 941
recycle systems, 785
transient response, 942
```

I

```
Identification (see Empirical modelling)
IMC (see Internal model control)
Impulse function, 101
Inferential control:
  block diagram, 537
  design criteria, 542
  design procedure, 543
  examples:
     chemical reactor, 549-552
     combustion, 552-554
     distillation, 545-549
     flash process, 537-541
  goal, 536
  multiple correlated measurements, 554
Initialization:
  controller, 245, 402
  filtering, 392
Input:
  terminology for control, 6
  terminology for modelling, 53
  typical time functions, 220-222
Input-output (see Cause-effect
     relationship)
Input processing:
  conversion, 212-213, 387
  filtering, 389
```


Input processing—Cont.	Internal model control (IMC)—Cont.
units, 388	structure, 592
validity, 387	tuning:
Integral:	for IMC controller, 598
Laplace transform of, 102	for PID controller, 609
numerical approximation, 366	Inventories:
z-transform, 978	control of (see Level)
Integral stabilizability, 692	models for, 564-565
Integral error measures:	reasons for and against, 562–563
IAE, integral of absolute value, 219	sizing, 562, 572–574
IE, integral of error, 219, 677	Inverse:
ISE, integral of squared, 219	
ITAE, integral of product of time and	approximate, 590
absolute, 219	exact model, 588, 729–730
Integral mode:	feedback as, 588
advantage/disadvantage, 249	Inverse Laplace transform, 99
equation for explicit mode, 248	Inverse response:
•	control performance, 430-431, 444,
implicit (see Model predictive control)	996–1000
tuning constant, 248	multivariable systems, 669-671
(See also Anti-reset windup)	open-loop, 152-155, 943-946
Integral windup (see Anti–reset windup)	ISE (see Integral error measures)
Integrating factor, 58, 895	ITAE (see Integral error measures)
Integrating process:	`
dynamic behavior, 136	
general form, 140–141	
levels, 564	J
stability, 307–308	J
(See also Level control)	
Integrity, 637, 672, 692	Jacketed reactor, 476
Interacting series, 145–148	Jacketed reactor, 470
Interaction:	
block diagram, 624	
controllability, effect on, 627, 651	L
(See also Decoupling)	L
definition, 620	
integrity, effect on, 672-674, 692, 850	Las (sas First ander systems)
measure of (see Relative gain array)	Lag (see First-order system)
modelling:	Laplace transform:
empirical, 622	applications:
fundamental, 621	solving ODE, 102
operating window, effect on, 624-626,	transfer function, 111
789	of common functions, 100
performance, feedback control:	definition of, 98
loop pairing, 671–681	of derivatives, 101
tuning, 682–683	of integrals, 102
stability, effect on, 638	partial fractions, 107, 931–935
transfer function, 629–630	properties, 98–99
tuning, 641–646	Lead:
-	lead/lag algorithm, 485–486, 595, 687
(See also DMC)	923
Internal model control (IMC):	time constant, 152
digital form, 595, 994	
filter for, 593	Least squares:
model inverse, approximate, 590, 994	as approximate inverse, 737
performance, 597	assumptions in, 191

I and a manage of the	NW (0 / 1 / 1 / 1 / 1 / 1 / 1 / 1 / 1 / 1 /
Least squares—Cont.	MIMO (see Interaction, Multiloop
in design of dynamic matrix control,	control; Multivariable control)
737–738	Mixing process, with dead time:
empirical modelling, 188-190	control of, 270–277, 413–415
solution of linear problem, 191	model of, 271
Level:	Mixing process, three-tank:
control of:	adaptive tuning for, 517–519
linear PI, 566	control of:
nonlinear PI, 567	derivative-only, 249–251
control objectives, averaging and tight,	integral-only, 248
563–564	internal model, 595
controller tuning, 568	proportional-integral-derivative,
draining tank, 75–77	282–285, 330–332
inventory size, 572	proportional-only, 245–248
process model for:	mismatch from true process:
non-self-regulating, 140, 565	due to nonlinearity, 283–285,
self-regulating, 75–77	512–517
sensors, 577	effect on control performance,
series processes, 574–576	431–432
Limit cycle, 906	effect on stability, 345–346
Linear operator, 70	model of:
Linear programming, 866–868	empirical, 186
Linearity, definition of, 70	fundamental, 223-224
Linearization, 71–72	input-output, 223
control loop, 517–529	Model predictive control (MPC):
effect on stability analysis, 275, 284,	for cascade control, 606
513–517	dead time, 606
Taylor's series, 71	error, feedback, 585
Load (see Disturbance)	with feedforward control, 607
Long-time behavior, 109, 119-121, 306,	filter for robustness, 592–593
936–937	internal model control (IMC), 590
Low-pass filter, 390	perfect control, 587–588
Low signal select, 710–713	process inverse:
Lumped-parameter model, 47, 53	approximate, 590
	exact, 587-588
	saturation of final element, 604
	Smith predictors, 600
M	structure, 586
	transfer function, 592
	two-degree-of-freedom, 594
Manipulated variable, 207, 212, 218, 226,	zero-offset requirements, 587, 593, 601
243, 276	(See also DMC)
Manual operation, 228	Modelling procedure, 50
Mass, conservation of, 53	approximate, 909
Master controller (see Cascade)	empirical, 175
Material, conservation of, 53	fundamental, 53
Maximum deviation, 221	linearized, 71
Maximum overshoot, 220	Moments:
Measured variable:	definition, 909
accuracy, 383 (See also Filtering)	for impulse response, 910
linearity, 387	use in correlations, 281, 286–287, 336,
range, 383-384	598
reproducibility, 383	use in modelling, 912
sensor dynamics, 212-216, 773	Monitoring, 23, 799

TANGKAMENTAKAN TANGKAMENTAK

Move suppression factor, 743, 749 Multiloop control:	Numerical solution methods— <i>Cont.</i> frequency response, 317, 421
block diagram for, 624, 630	for integrals, 366, 917
comparison with single-loop, 616	Nyquist, 314
control performance:	
input forcing, 663–669	
interaction, 628	
interactive dynamics, 669-671	0
operating condition, 663	
controllability, 626, 651, 780–781	
decoupling:	Objective function, 271, 736, 743, 864,
lead/lag, 687	866, 917
model sensitivity, 689	Objectives, control, 20, 268, 768, 838
loop pairing, 671	Offset, steady-state:
relative disturbance gain (RDG),	definition, 218, 240
677–681	with feedback control, 246, 249, 251
tuning, 646-649, 682	with feedforward control, 488
(See also Control design, Interaction)	integral mode, 249, 587
Multivariable control:	level control, 571
centralized:	On-off control:
model inverse for, 729, 738	heating, 5, 230
structure, 728	model, 67–69
(See also Dynamic matrix control;	One-way decoupling, 690
Multiloop control)	One-way interaction, 631, 636–637
	Open-loop operation, 228
	Open-loop transfer function:
	$G_{\mathrm{OL}}(s)$, 316
N	terminology, 328
	Operability, 778
	Operating window, 26–27, 226, 440,
Negative feedback, 6, 141-142, 207, 242	625–626, 720–721, 789
Niederlinski criterion, 692, 694–695	Optimization:
Noise:	constraints, 868
effect on tuning, 275–276, 292,	control methods for:
915–920	control design, 861
frequency content, 423–425	direct search, 870
signal-to-noise ratio, 182	model-based, 866
(See also Filtering)	in controller tuning:
Noninteracting series systems, 143	control objectives, 268, 917
Nonlinear:	correlations from, 281, 284, 598
control, 517, 520, 570	plant economics:
process, effect on operating window,	effect of variance, 31, 33
625–626, 782, 789	profit contours, 31, 43
process, effect on performance,	Order of system, 112
283–285, 512	Ordinary differential equations, 47, 56,
saturation, 399–402, 604, 707, 717	102
(See also Linearization)	Output:
Normal distribution, 30	meaning for control, 6
Numerical solution methods:	meaning for modelling, 53
for algebraic equations, 902–903	Overdamped, 138–139
for differential equations, 82–84	Overshoot, 219-220

P	Process dynamics:
	effect on control performance, 415,
Dealerd had	426, 438, 440, 663, 694
Packed bed:	effect on stability, 334
cascade control, 471–473	effect of zeros, 152, 939
empirical model, 202	empirical modelling of, 196
feedforward control, 495–497	fundamental modelling of, 53
Padé approximation, 913	linearized models, 74
Pairing, loop, 671	recycle process structures, 155
Partial control, 779, 827	series process structures, 152, 939
Partial fraction expansion, 107, 932–935,	staged process structures, 152, 939
980	Process examples, guide, 925–929
Performance, (see Control performance)	Process reaction curve, 179, 187
Period of oscillation, 121, 222, 315, 330,	Product quality, 23, 768
343	Profit function (see Objective function)
Periodic behavior, 5, 67, 343, 906	Proportional:
pH control, 527, 776	controller mode, 245
Phase angle, 121–123	tuning constant, 245
Phase equilibrium:	Proportional band, 398
in distillation, 159	
in flash process, 538	Proportional-integral-derivative (PID)
K values for, 538	in adaptive control, 517
relative volatility, 159	
Phase margin, 340	in cascade control, 458, 468–469 derivative mode, 250
Physical realizability, 496, 588	effect on offset, 251
PI, PID (see	
Proportional-integral-derivative	effect on stability, 326
controller)	digital form of controller, 367–369
Pneumatic:	frequency response, of controller, 366–367
control valve, 213	
controller, 257	initialization, 245, 402
signal transmission, 212–213, 891	integral mode:
Polar form:	effect on dynamic response, 249
complex numbers, 122, 316–318, 421	effect on offset, 249
frequency response for series systems,	effect on stability, 325, 336–337
317	windup, 399
Poles:	mode selection, 436
definition of, 113	output limits, 403
effect of control on, 247, 254–256, 259,	proportional mode:
313	effect of dynamic response, 245, 272
effect on dynamic response, 109, 113,	effect on offset, 245
310	effect on stability, 246
effect of process design on, 141–142,	tuning:
151, 155, 157, 425,	Ciancone, 281, 286
440, 564, 785, 902, 906	IMC, 609
effect on stability, 109, 310	Lopez, 287
Position (full) form of digital controller,	multiloop, 641–646
367	selection, 347
Predictive control (see Model-predictive	Ziegler-Nichols, 329, 347
control)	Proportional-only control, 245, 571
Primary controller (see Cascade control)	Pulse, input function, 64, 101

Q	Reset windup (see Anti-reset windup) Resonant frequency, 414 Reverse acting feedback, 306
Quadratic dynamic matrix control, 751 Quick-opening valve, 521	Reverse-acting feedback, 396 Ringing controller, 368, 992 Rise time, 219 Robustness: importance, 241, 512
R	performance, 268–269, 919 stability, 338, 345 tuning, 268, 919
Ramp:	Root locus, 312 Runge-Kutta numerical integration, 83
input function, 93	Kungo-Kutta namericai integration, es
output response, 93	
Random variable, normal distribution, 30	
Ratio control:	S
effect on stability, 519	S
as feedforward, 499	
flow ratio, 499	Safety, 20–21
reset by feedback, 519, 684	alarms, 795
Reactor (see Chemical reactor)	basic process control, 794
Realizable, 496, 588	failure position of final elements, 386
Real-time operating system, 360	good practices, 797
Real-time optimization (see Optimization)	safety interlock system (SIS), 796
Reconstruction of signal, 362	safety valves, 797
Recycle:	Sampling (see Digital control)
advantages of, 155–157, 785	Saturation of controller output, 398, 604,
alternative source/sink, 832	707, 717
control of systems with, 785, 832,	Second-order system, 138–139
845–846	Secondary controller (see Cascade)
effect of dynamic response, 156–157	Select, signal:
effect on stability, 156	degrees of freedom, 710
Refrigeration, 475, 885	design criteria, 715
Regression (see Least squares)	tuning, 714
Relative disturbance gain (RDG):	(See also Constraints, control)
integral error measure, 677	Selection of variables:
loop pairing, 678–679	controlled variables, 216, 773, 827–828
tuning factor, 678	manipulated variables, 216, 226, 438
Relative gain array (RGA):	measured disturbances, 487
calculation, 634	secondary cascade, 461
control integrity, 637, 672	Self-regulation, 141
definition:	Sense (see Controller sense switch)
dynamic, 637	Sensor:
steady-state, 633–634	accuracy, 383
interpretations, 636	cost, 772–773
loop pairing, 672–674, 695	dynamics, 215, 773
properties, 633–636	flow, 387
stability, 637	identification symbols, 889
Relative volatility, 159	level, 892
Reproducibility, sensor, 383, 773	noise, 276, 389, 424, 879
Reset (see Integral)	range or span, 383
Reset time, 398	reliability, 387
	- · · · · · · · · · · · · · · · · · · ·

Sensor—Cont.	Stability—Cont.
reproducibility, 383, 773	analysis—Cont.
signal transmission, 890	Nyquist, 314
temperature, 388, 536	pole calculation, 308–313
Separable differential equation, 58, 895	root locus, 312-313
Set point, 218, 242–243, 458, 586	simulation, 248
Settling time, 220	chemical reactor, 902-906
Shannon's sampling theorem, 362	definition, bounded input-output,
Signal:	303–304
conversion, 212	effect of controller tuning, 312
analog to digital (A/D), 359	effect of process dynamics, 334
digital to analog (D/A), 359	effect of sampling period, 367–370
electronic to pneumatic, 212	feedforward, 488
digital transmission, 373	of linearized system, 305–308
dynamics, 213	margin, 338–340
electrical transmission, 212	multiloop, 630, 638
pneumatic transmission, 212	Staged systems (see Distillation)
ranges, 213	Standard deviation:
Signal-to-noise, 182	
Signal select, 710	of averages, 394
Simulation:	of data set, 30
closed-loop system, 423, 916	from set point, 221, 466
performance measures, 917	Statistical modelling, 189
process dynamics, 83-84	Statistical process control:
(See also Digital control)	capability index, 880–881
Sine input:	goal of preventing disturbances, 876
amplitude ratio, 121–123	Shewart chart, 876
first order, 123	specification limit, 881
flow attenuation, 572	Steady state:
typical input forcing, 136	error (offset), 240
(See also Frequency response)	feedforward control, 488
Single-input single-output (SISO) (see	operating window, 625-626
Single-loop control)	Steam heat exchanger:
Single-loop control, 5–6, 208, 218, 243	bypass, 784
SIS (see Safety)	condensing, 777
Slave controller, 460	Steam system:
Smith predictor:	boiler, 27, 862
system structure, 600	header, 862
tuning, 602	turbines, 885
zero offset, 601	Steam trap, 777
(See also Model predictive control)	Step:
Snowball effect, 847	input function, 58, 136-138, 162
Split range:	Laplace transform, 99
degrees of freedom, 706	test (see Process reaction curve)
design criteria, 709	Stiffness, 84
tuning, 708	Stirred tank (CST):
(See also Constraints, control)	chemical reactor, 62, 72, 85, 438, 835
Spring and dashpot, 137–138	897
Stability:	heat exchanger, 76-80, 458, 486, 523
analysis:	939–943
Bode, 314–317	mixer:
complex plane plots (see Root locus)	one-tank, 52, 270, 415
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	,,,

Stirred tank (CST)—Cont. mixer—Cont. three-tank, 186, 223, 282, 422-424, 512, 595-596 series reactors, 64, 430, 943 typical assumptions, 52, 899 Stochastic control performance, 293, 424, 879 Superposition, 70 Surge tank, 119, 562, 572 System definition, 52 Systems analysis, 135	Tuning, feedback controller: digital PID control, 370 dynamic matrix control, 750 effect of process on, 281, 334, 564–566, 645 internal model control, 598 multiloop PID, 645, 682 objectives (see Control, objectives) Smith predictor, 602 stability margin: gain margin, 338 phase margin, 340 (See also Proportional-integral-derivative, tuning) Tuning, feedforward controller, 496
Target, 585–586 Taylor series approximation, 71 Temperature control: distillation, 545 fired heater, 26, 31, 473, 500, 552, 961	Ultimate controller gain, 330, 993 Ultimate period, 330
flash drum, 21, 538, 802 stirred tank, 252–523 Three-mode controller (see Proportional-integral-derivative controller)	Underdamped process, 85, 138–139, 253–256, 899–903 Unstable systems: closed-loop system, 308–317 process without control, 307–308,
Time constant: empirical estimation, 179–180 relation to process, 74, 137, 271, 900, 942, 944 series of, 143–145 Time delay (see Dead time) Thermocouple, 388, 526 Thermowell, 940	899–907 Unsteady-state (see Dynamics) Utility systems: fuel gas system, 501, 810–811 hot oil, 885 steam system, 862 (See also Refrigeration)
Transfer function: closed-loop, 244, 462, 488, 586, 629–630 controller, 252–253	V
definition, 111, 118, 983 disturbance process, 224, 415, 666 feedback process, 224, 270–271, 622, 666 instrument, 213 matrix of, 624 poles of, 113, 255, 259, 312–313 zeros of, 113, 152 Transient (see Dynamics) Transmission interaction, 629 Transportation delay, 103–104 Tray, distillation, general balances, 159	Validation, model, 60–61 Valve: automated control: capacity, 217, 226, 385, 438–441, 625–626 characteristic, 520 dynamic response, 213 failure position, 386 pneumatic power, 212–213 range, 385 manual, 228, 892 positioner, 474

valve position control, 718

Velocity form, controller, 367

measure of performance, 221-222

Variance:

definition, 30

effect on dynamic response, 152, 943

closed-loop tuning, 329, 342-343

process reaction curve, 179-180

effect on stability, 113

open-loop tuning, 347

Ziegler-Nichols:

1017