Symbols and Acronyms

Process control uses many symbols in equations and drawings. The equation symbols are presented here, and the drawing symbols are presented along with common process sketches in Appendix A. The symbols selected for this Table are used multiple times in the book and explained only where they are first used. If a symbol is used only once and explained where used, it is not included in this table. Each entry gives a short description and where appropriate, a reference is given to enable the reader to quickly find further explanation of the symbol and related technology.

Symbol	Description and reference
A	Cross-sectional area of a vessel
A_i	Fraction of component i
AR	Amplitude ratio, equations (4.70) and (4.72)
A/D	Analog to digital signal conversion, Figure 11.1
C	Concentration (mol/m^3); subscript indicates component
CDF	Control design form, Table 24.1
C_p	Heat capacity at constant pressure Process capability, equation (26.7)
C_{pk}	Process capability, equation (26.8)
C_v	Heat capacity at constant volume Valve characteristic relating pressure, orifice opening, and flow through an orifice, equation (16.13)

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Symbol	Description and reference
CSTR	Continuous-flow stirred-tank chemical reactor
CV	Controlled variable
CV_i	Inferential controlled variable
CV^f	Future values of the controlled variable due to past changes in manipulated variable
CV_m	Measured value of the controlled variable
D	Disturbance to the controlled process
$D(s)$	Denominator of transfer function, characteristic polynomial, equation (4.42)
DCS	Digital control system in which control calculations are performed via digital computation
DMC	Dynamic matrix control, Chapter 23
DOF	Degrees of freedom, Table 3.2
D/A	Digital-to-analog signal conversion, Figure 11.1
E	Error in the feedback control system, set point minus controlled variable, Figures 8.1 and 8.2 Activation energy of chemical reaction rate constant, $k = k_0 e^{-E/RT}$
E^f	Future errors due to past manipulated variable changes
F	Flow; units are in volume per time unless otherwise specified
fc	Fail close valve
F_c	Flow of coolant
F_D	Flow rate of distillate
F_h	Flow of heating medium
fo	Fail open valve
F_R	Flow rate of reflux in distillation tower
f_{tune}	Detuning factor for multiloop PID control, equation (21.8)
F_V	Flow rate of vapor from a reboiler
ΔF_{max}	Largest expected change in flow rate, used to tune level controllers, equations (18.12) and (18.13)
$G(s)$	Transfer function, defined in equation (4.45) for continuous systems and equation (L.14) for digital systems The following are the most commonly used transfer functions: The argument (s) denotes continuous systems. If digital, replace with (z). $G_c(s)$ = feedback controller transfer function (see Figure 8.2) $G_d(s)$ = disturbance transfer function $G_p(s)$ = feedback process transfer function $G_s(s)$ = sensor transfer function $G_v(s)$ = valve (or final element) transfer function

Symbol	Description and reference
	$G_{cp}(s)$ = controller transfer function in IMC (predictive control) structure, Figure 19.2
	$G_f(s)$ = filter transfer function which influences dynamics but has a gain of 1.0
	$G_{ff}(s)$ = feedforward controller, equation (15.2)
	$G_{ij}(s)$ = transfer function between input j and output i in a multivariable system; see Figure 20.4
	$G_m(s)$ = model transfer function in IMC (predictive control) structure, Figure 19.2
	$G_m^+(s)$ = noninvertible part of the process model used for predictive control, equation (19.14)
	$G_m^-(s)$ = invertible part of the process model used for predictive control, equation (19.14)
	$G_{OL}(s)$ = "open-loop" transfer function, i.e., all elements in the feedback loop, equation (10.24)
h	Film heat transfer coefficient
H	Enthalpy, equation (3.5)
HSS	High signal select, Figure 22.9
ΔH_c	Heat of combustion
ΔH_{rxn}	Heat of chemical reaction
I	Constant to be determined by initial condition of the problem
IAE	Integral of the absolute value of the error, equation (7.1)
IE	Integral of the error, equation (7.4)
IF	Integrating factor, Appendix B
IMC	Internal model control; see Section 19.3
ITAE	Integral of the product of time and the absolute value of the error, equation (7.3)
ISE	Integral of the error squared, equation (7.2)
k	Rate constant of chemical reaction
$k_0e^{-E/RT}$	Rate constant of chemical reaction with temperature dependence
K	Matrix of gains, typically the feedback process gains
K_c	Feedback controller gain (adjustable parameter), Section 8.4
K_i	Vapor-liquid equilibrium constant for component i
K_{ij}	Steady-state gain between input j and output i in a multivariable system, equation (20.11)
K_p	Steady-state process gain, (Δoutput/Δinput)
K_{sense}	An additional term to specify the sign of feedback control when the controller gain is limited to positive numbers, equation (12.12)
K_u	Value of the controller gain (K_c) for which the feedback system is at the stability limit, equation (10.40)

Symbol	Description and reference
L	Level
$\mathcal{L}$	Laplace transform operator, equation (4.1)
LSS	Low signal select, Figure 22.9
ΔL_{max}	Largest allowed deviation in the level from its set point due to a flow disturbance, used to tune level controllers, equations (18.12) and (18.13)
MIMO	Multiple input and multiple output
MPC	Model predictive control
MV	Manipulated variable, Figure 8.2
MW	Molecular weight
$N(s)$	Numerator of transfer function, equation (4.42)
NE	Number of equations
NV	Number of variables
OCT	Octane number of gasoline, equation (26.3*b*)
P	Pressure Period of oscillation
P_j	Performance at operation (interval) j, equation (2.3)
PB	Proportional band, Section 12.4
P_u	Ultimate period of oscillation of feedback system at its stability limit, equation (10.40)
ΔP	Pressure difference
PI	Proportional-integral control algorithm; see Section 8.7
PID	Proportional-integral-derivative control algorithm; see Section 8.7
Q	Heat transferred
QDMC	Quadratic Dynamic Matrix Control
r_i	Rate of formation of component i via chemical reaction
R	Gas constant
RDG	Relative disturbance gain, equation (21.11)
RGA	Relative gain array, equation (20.25)
RVP	Reid vapor pressure of gasoline, equation (26.3*a*)
s	Laplace variable, equation (4.1)
S	Maximum slope of system output during process reaction curve experiment, Figure 6.3
s^2	Variance (square of standard deviation) for a sample
SIS	Safety interlock system, Section 24.8
SP	set point for the feedback controller, Figure 8.2
SPC	Statistical process control, Section 26.3

Symbol	Description and reference
t	Time
T	Temperature
T_a	Ambient temperature
T_d	Derivative time in proportional-integral-derivative (PID) controller, Section 8.6
T_I	Integral time in proportional-integral-derivative (PID) controller, Section 8.5
T_{ld}	Lead time appearing in the numerator of the transfer function; when applied to feedforward controller, see equation (15.4)
T_{lg}	Lag time appearing in the denominator of the transfer function; when applied to feedforward controller, see equation (15.4)
$t_{28\%}$	Time for the output of a system to attain 28% of its steady-state value after a step input, Figure 6.4
$t_{63\%}$	Time for the output of a system to attain 63% of its steady-state value after a step input, Figure 6.4
Δt	Time step in numerical solution of differential equations (Section 3.5), time step in empirical data used for fitting dynamic model (Section 6.4), or the execution period of a digital controller (equation 11.6)
ΔT	Temperature difference
T_R	Reset time, Section 12.4
U	Internal energy, equations (3.4) and (3.5)
$U(t)$	Unit step, equation (4.6)
UA	Product of heat transfer coefficient and area
v	Valve stem position, equivalent to percent open
V	Volume of vessel
W	Work
x_i	Fraction of component i (specific component shown in subscript)
X_B	Mole fraction of light key component in distillation bottoms product
X_D	Mole fraction of light key component in the distillate product
X_F	Mole fraction of light key component in the distillation feed
z	Variable in z-transform, Appendix L
Z	Z-transform operator, Appendix L

Greek Symbols

α	Relative volatility Root of the characteristic polynomial, equation (4.42)
δ	Size of input step change in process reaction curve, Figure 6.3

Symbol	Description and reference
Δ	Change in variable Size of output change at steady state in process reaction curve, Figure 6.3
ϕ	Phase angle between input and output variables in frequency response, equation (4.73) and Figure 4.9
Γ	Dead time in discretee time steps, Section F.2, and equation (F.7)
η	Thermal efficiency, equation (26.1)
λ	Heat of vaporization
λ_{ij}	Relative gain, Section 20.5
θ	Dead time, Examples 4.3, 6.1 θ_d = disturbance dead time θ_{ij} = dead time between input j and output i θ_m = model dead time θ_p = feedback process dead time
ρ	Density
σ	Standard deviation of population
τ	Time constant τ_d = disturbance time constant τ_f = filter time constant τ_{ij} = time constant between input j and output I τ_m = model time constant τ_p = feedback process time constant
ω	Frequency in radians/time
ω_c	Critical frequency, in radians/time, Section 10.7
ω_d	Frequency of disturbance sine input
ξ	Damping coefficient for second-order dynamic system, equation (5.5)