"Tuning Rule Bonanza"

Greg McMillan and Stan Weiner

Control Talk Column in Control Magazine's November 2006 Issue

The controller gain per the Ziegler Nichols reaction curve rule with the gain cut in half per industrial practice to increase smoothness and robustness is:

$K_c = 0.5 / (R * L)$

The figure used by Ziegler Nichols for the graphical estimation of R and L, showed the process initially lined out so that R is the ramp rate in %/minute divided by the change in manual controller output. For integrating and disturbance prone self-regulating processes, the initial ramp rate is not zero. If you use the change in ramp rate before and after the change in controller output, R becomes the integrating process gain used in the Lambda integrating process tuning rule and the short cut tuning method in *Good Tuning – A Pocket Guide.* Furthermore, if you realize that the process gain (K_p) divided by the process time constant (τ_p) is the integrating process gain (K_i) for a slow self-regulating process as outlined in my pocket guide, you can convert back and forth between the Ziegler Nichols equation and the more common equation seen in the literature:

$K_c = 0.5 / (K_i * \tau_d) = (0.5 * \tau_p) / (K_p * \tau_d)$

If you use the process dead time (τ_d) as the Lambda in the Lambda self-regulating and integrating process tuning rules, you end up with the above equations but with a slightly larger coefficient for the integrating process rule. Part of the conceptual hurdle is the visualization of the initial response before the inflection point of a slow self-regulating process as the ramp rate of an integrating process. For controllers tuned for fast disturbance rejection, the controller works off only the initial part of the response.

Another important point to realize is that the integrating process gain (K_i or R) is very small or equivalently the process time constant (τ_p) is very large relative to the dead time (τ_d) for temperature, composition, and gas pressure control of well mixed volumes. For temperature loops on columns, evaporators, crystallizers, and reactors, the process time constant is typically 10 times larger than the dead time. The user has a choice of a very high controller gain and tight control. However, this assumes the rapid movement of the controller output doesn't upset the operator or other loops. If one chooses to not tune the controller gain as aggressively as dictated by these equations, it is equivalent to additional dead time in the loop. If you set the above equation for maximum controller gain equal to the equation used by your current tuning rule, you can solve for the effective dead time you have dialed into the loop. For example if you use a Lambda factor of one (Lambda equal to the process time constant) and set the equation for Lambda tuning of self-regulating processes equal to the first expression in the equation above for maximum controller gain and solve for process dead time, you find that you have effectively created a loop that performs like it had a dead time that is 50% of the process time constant. In other words, money and time spent to improve piping and mixing or reduce communication or control execution delays so that the total dead time is below 50% of the process time constant has a negligible effect on disturbance rejection by a PI controller. Appendix C in the ISA book titled *New Directions in Bioprocess Modeling and Control* provides the derivation of the equations showing these relationships

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It is important to remember that the integrated absolute error (IAE) for a disturbance is proportional to the integral time divided by the product of the process gain and controller gain for a non oscillatory response. If you tune the controller for maximum load rejection, you can show that the IAE is proportional to the dead time squared divided by the process time constant.

A large time constant in the process slows down the excursion rate of the actual process variable disturbances and gives a change for the controller to catch up with the disturbance. The discussed relationships for controller tuning and performance work no matter where the largest time constant is located. If the largest time constant is in the measurement, the measured process variable looks good but the actual process variable is gone off to parts unknown. A big time constant in a sensor, transmitter, or signal filter gives the illusion of good control but what you are seeing is an attenuated version of the real world. Also, a large time constant in the measurement converts part of the next smaller time constant in the loop into dead time. Dead time slows down the ability of the controller to see and compensate for disturbances (see the August issue of Control Talk for a spirited discussion of these terms).

Part of the confusion is the large variety of nomenclature and lack of detail for the three parameters (process gain, time constant, and dead time) used for a first order plus dead time model of a self-regulating process response. The process gain for controller tuning is a dimensionless static or steady state gain that is really the product of the final element gain, process gain, and measurement gain (100%/span) for the controller in manual. It is the final change in the process variable in percent divided by the change in manual controller output in percent assuming no disturbances. I prefer to call it an open loop gain (K_o). The process time constant is the largest time constant in the loop for a change in manual controller output. I prefer to call it the open loop time constant (τ_o) to distinguish it from the closed loop time constant, which is the time constant for a set point change with the controller in automatic. A time constant is the time to reach 63% of the final change after the loop dead time. The process dead time is the total dead time in the loop, which is the sum of individual delays and small time constants acting as equivalent dead time. The dead time is the time to the start of a distinguishable response in the process variable after the change in controller output. Sometimes the total loop dead time is called the "delay" and the open loop time constant is called the "lag." Note that the term "dynamic gain" employed by control specialists includes both the effect of both the open loop gain and time constant and is function of the frequency of the perturbation and is generally not used for process models for PID tuning or model predictive control.

The open loop response for a step change in the controller output with the controller in manual for a self-regulating and integrating process is illustrated in the following PowerPoint file. Note that the term controlled variable (CV) in percent is used in these plots that is the process variable (PV) in engineering units converted to percent of scale.