Understanding PID Loops

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Understanding PID loops can be frustrating and seemingly difficult, but it doesn't have to be this way. What you may not realize is that we all use PID control in our everyday lives. We often don't notice because our brains are programmed to perform these complex calculations hundreds of times per minute with relative ease. Raising our arms, pouring our coffee, walking and driving all require continuous adjustments to achieve the desired results. In our plants, we do not expect to see changes in environmental conditions. Once our controllers have been tuned, they will usually run for years without any significant adjustments.

A PID controller is a control-loop feedback mechanism. It is expected to control a process using only a process variable. Every application is different and requires specific settings and approaches. PID stands for Proportional-Integral-Derivative, and the response of the control loop is entirely dependent on three terms:

- **Proportional.** The proportional term looks at current error (difference between setpoint and process variable) of the system. Depending on the controller, the proportional term is expressed as either proportional band (PB) or gain. Knowing what your controller is using is critical in correct tuning. These functions are simply the inverse of one another (1/X). For example, a 20% proportional band equates to a gain of 5.
- **Integral.** This term is related to the accumulated past error of the system. Integral is typically expressed in repeats per minute or minutes per repeat. The "repeat" is the current (proportional) error. The integral is the sum of error over a period of time.
- **Derivative.** The derivative term looks at the expected future error of the system. The derivative is applied based on the rate of change of the process variable. Most heating applications can function quite well with just the PI terms being used. The derivative term can help when you have a process that has a quick and sudden change like opening an oven door and closing it. Derivative works in the opposite direction of the proportional term and acts as a dampener.

Verifying that all of the feedback and control devices are functioning properly is critical to having a system that is efficient, repeatable and stable. We will focus on temperature control for this discussion. The process variable (PV) is what is being measured and is the input to the PID loop. The control variable is the output of the PID to a physical device.

For heating systems, the most common control variable is either a gas valve or electric heating elements. Both of these systems can have on/off control (a heating contactor applying full power when engaged or a gas valve fully opening when called for). Controlling this type of system is typically a time-proportioned output of the PID loop. With a time-proportioning signal, a cycle time is applied to the control loop.

The control loop will multiply the control variable output by the cycle time to calculate the control signal's total on time. For example, if the control output is 50% and the cycle time is 30 seconds, the control output on time will be (30 x 0.50), or 15 seconds. For a heating contactor, cycle times of 30 to 45 seconds are typically used. For a gas control valve, the cycle time should be twice the time it takes for the valve to fully open from the closed position.

If the system has a 4-20 mA control valve or a silicon-

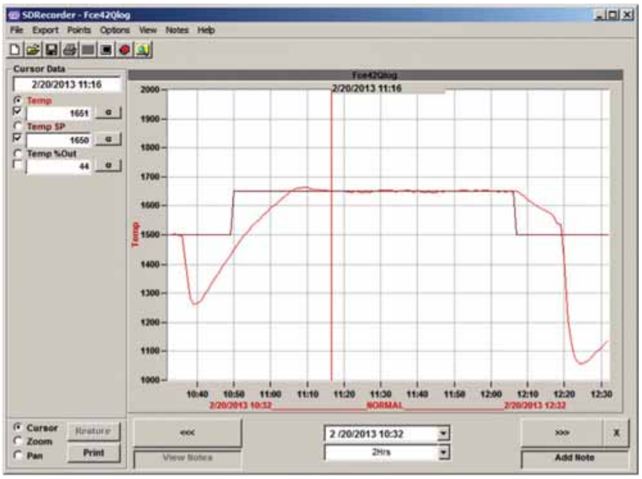

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Fig. 1. Overshoot and general instability

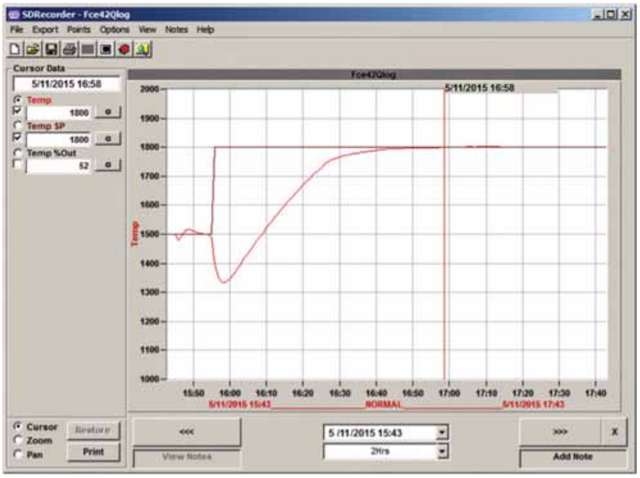

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Fig. 2. Case study #1 with corrected PID

controlled rectifier (SCR), then it is a full proportional-control system. With full proportional control, the control valve/elements will be adjusted to a level that corresponds to the control output. Full proportional control will provide for the tightest tolerances and the least amount of process variable changeability at setpoint.

To optimize response and minimize difficulties in tuning, the control system should be checked for integrity and linearity on a regular basis. Focusing on heating systems, the systems to review are as follows.

- **Control valve.** Most control valves have a motor and linkage. The linkage and valve should be adjusted to maximize the linearity over the full stroke of the motor. Set the control-loop output to 0% and verify that the valve is in the closed position. Then set the control loop to 100% to confirm that the valve is fully open. Verify that the valve moves to the corresponding position for 25%, 50% and 75% output and that the valve does not fully close before arriving at 0% or fully open before arriving at 100%.
- **Regulators.** Gas regulators and air/gas ratio regulators should be checked for leakage as well as inlet/outlet pressure. On ratio regulators, verify that the impulse lines are tight and leak free.
- **Combustion air blowers.** Verify that a filter is installed and that it is cleaned or replaced on a regular preventive maintenance (PM) schedule.
- **Burners.** It is critical to monitor and adjust burners. A properly adjusted burner will provide the most efficiency and linearity.
- **SCR.** As with control valves, the SCR should be checked for linearity. Zero and span adjustment potentiometers are provided to make adjustments to the SCR output.
- **Elements.** Heating elements degrade over time. Shorts and open circuits will have a large effect on the performance and uniformity of the control system. A check with a multimeter and clamp-on current meter will verify that the elements are within the manufacturer's specifications.
- **Thermocouples.** Thermocouples will degrade over time. Cycling the thermocouple from hot to cold or running thermocouples close to their maximum temperature will accelerate the degradation. Thermocouple placement within the oven also plays a critical role in the response of the control system. On commissioning an oven or furnace, the placement and insertion depth of the thermocouple is often a trial-and-error process in an effort to find a hot zone to prevent survey thermocouples from overshooting. Using an exposed-tip versus a closed-ended thermocouple can dramatically change the system response. An open-tip thermocouple may provide for the fastest response to changes but can also be a challenge on open-burner furnaces, where heat input can be very fast.
- **Insulation and refractory.** The insulation and refractory must be in good condition, and the correct amount should be present for a properly operating system. Circulation fans can have a surprising amount of heat input on a furnace system. This heat input, especially at low temperatures, can make tuning impossible. To determine how much heat the fan is adding, turn off the heating system and let the fan run for a few hours. Adding a two-speed motor or variable-frequency drive (VFD) to the fan helps reduce or eliminate the effects of the fan on the heating system.

Steps for Proper Tuning

When tuning a PID, small adjustments should be made to the PID constants, and only one parameter should be changed at a time. Viewing and comparing results using a capable data-logging instrument is also imperative. On each test, write down the PID parameters so that comparisons of the effects of each change can be made. The system should be tuned using the same method that the furnace will use for operation. If the system will be ramped to setpoint, then tuning tests should be done employing the same ramps and rates. It is possible that the

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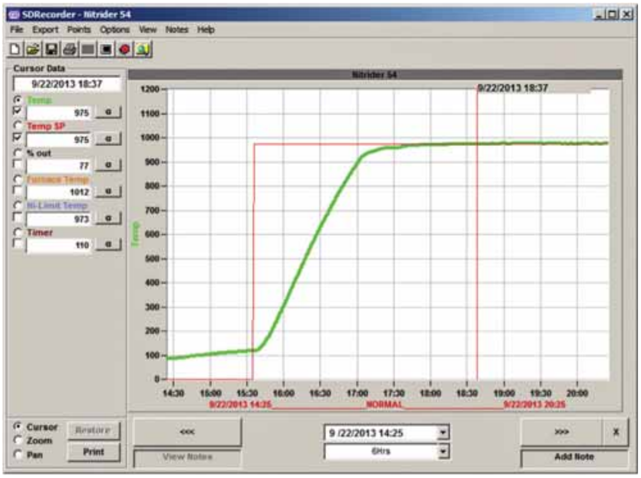
Fig. 3. Slow approach and late overshoot



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9 /22/2013 14:25
6Hrs

Fig. 4. Case study #2 with corrected PID

ramp, especially if it is lengthy, will introduce more accumulated error than a traditional step-change approach would. The accumulated error will affect the I (integral); without accounting for this possibility, large overshoot can occur.

In the following examples, we will be using an inverse proportional PID controller that expresses the integral term in repeats per minute and the derivative in time. In this scheme, a smaller P term will result in higher output for lower error. A higher integral term will result in more wind-up (accumulated error while approaching setpoint). A higher derivative term will increase the decay time of the derivative action.

When tuning a furnace, it is important to assess the capabilities of the furnace and control system and to try working within those parameters. Begin by setting up the PID with sluggish parameters, such as a P of 5.0, I of 0.01 and D of 0.00. Heat the furnace to the lower end of its operating range and observe control when the PID is at setpoint. Note that the minimal I term will make the approach extremely slow, but we only want enough integral influence to provide us with the power we need to maintain temperature. If the furnace is oscillating, increase the P term by a factor of 1.5 and observe control. Continue to increase the P term by a factor of 1.5 until the PV is steady. If the furnace was steady initially, divide the P term by 1.5 until the furnace begins to oscillate. When that happens, revert to the previous P term.

Establishing the proportional term is critical because it directly affects every other term. It is usually advisable to have the furnace operating as fast as possible from an efficiency standpoint, and it normally makes the furnace easier to tune. A fast PID not only approaches setpoint quickly but also has stronger action to resist wandering when the furnace is at setpoint.

You can work out the appropriate integral term by introducing a setpoint change. Set the integral term to a larger value – 0.10, for example. Cool the furnace to create significant error – enough to force the furnace to provide more than its maximum control output – and then return to the previous setpoint. Wait for the PV to settle from the initial approach. If the PV comes up short of setpoint, then more integral is needed. If the PV exceeds setpoint and then falls back, less integral is needed. Integral is often described with the terms wind-up and unwind. Wind-up is the accumulated error during setpoint approach. Unwind occurs when setpoint is exceeded and the integral is reduced.

The derivative term often creates the most confusion in PID control. Derivative acts as a dampener, working the control output against the movement of the PV. When the PV is moving very quickly, the derivative action is stronger. For this reason, derivative should be considered as a method of improving stability and not as a way to inhibit overshoot.

Case Study #1

This example features a fairly quick batch furnace that suffers from initial overshoot and general instability at setpoint (Fig. 1). The original PID is 1.0/0.05/1.10.

What went wrong, and how do we correct it? The initial overshoot is a result of the small (fast) PB. The PV falls back to setpoint fairly quickly, but the control is relatively unstable, which suggests that we may have applied too much derivative in conjunction with our too-strong PB. Because we know we first need to establish the PB, this is the focus of fixing this PID. Slowing down the PB immediately improved the overshoot, and the stability was brought under control as well. The PID settled on is 1.8/0.06/1.00 (Fig. 2), and this is about as slow as the furnace can tolerate.

There seems to be very little difference in the PID, but the key element is in getting the PB right. We have only added 0.8 to the PB in this case, but the net result is that the PB is almost doubled. Adding so much PB to the tuning parameters slows down the integral and reduces the effect of the derivative. In this case, only a slight change in the integral was made to counteract the larger PB because the slower approach will increase wind-up on its own.

Case Study #2

In this example, the furnace requires no overshoot with stable steady-state performance. The initial PID parameters selected were very slow for a temperature loop: 6.1/0.04/5.94. The result was a PID that did effectively prevent initial overshoot but at the expense of increased heating time and late overshoot (Fig. 3).

What went wrong, and how do we correct it? Because the furnace operates relatively slowly, the integral is probably going to need to be small and we probably need some derivative action. In the case of the integral, because the furnace's approach is slow, we expect a sizeable error term for a relatively long period of time. That means the integral will have plenty of time to wind up – an effect we counter with a smaller term. Because the temperature changes are slow, it is likely we will need some dampening action for stability since we do not expect to see rapid changes in the PV. In an effort to avoid initial overshoot, however, the proportional term has been increased significantly with the intention of creating an earlier cutback in power. As a result, there is more error for a longer period of time than the integral can deal with, and when the PV finally arrives at setpoint, it does so with too much integral.

In this case, the plant manager first reviewed the furnace's heating system and made slight adjustments to the control-valve linkage to maximize the system's linearity. Once the adjustments were made, a much smaller PB was settled on first, and further adjustments were made to the integral and derivative to bring them in line with the much-stronger proportional term. A PID of 2.1/0.02/3.79 was settled on, putting the system at the slowest possible state of tune to avoid overshoot from load thermocouples during survey. This effect is shown in Fig. 4.

Conclusion

There are many variations in closed-loop heat-treating control applications. These variations can be based on the control parameters, the type of furnace, the controllers and PID logic. Knowing the fundamentals of PID settings and how PID loops work allows us to tune a furnace for optimal performance, which increases production efficiency and helps us meet industry furnace classification requirements.

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