PROFIRE PID Tuning Guide

PROFIRE
1.855.776.3473
solutions@profireenergy.com

1. Introduction

Functional Description

The PID control system is used to maintain a stable process temperature by adjusting the signal to a proportional control valve, which in turn will control the flow of fuel to the burner.

In the PF3100 system, PID settings can be accessed in two ways:

1. From the controller Status screen: select **Settings**, **Process Control** and then **BMS PID** to access the PID settings for temperature. (See PROFIRE Operator Guide for details).
2. From the **I/O Wizard**: select the appropriate appliance, and then select the **I/O Wizard** tab. Select **4-20 Output**. This allows changes to be made to temperature, fuel air ratio control, or 4-20 input based PID, depending on system requirements. (See PROFIRE Operator Guide for details).

2. PF3100 – PID Parameters

Proportional Band (PB)

The **Proportional Band** setting affects the speed with which the system reacts to changes in temperature. Please note that this setting affects the gains of the proportional, integral, and derivative terms.

Under-Damped System

A smaller proportional band increases gain, therefore a small change in temperature will yield a large response in output. As the proportional band decreases, the system becomes under-damped. This means that the temperature will oscillate and will swing above and below the setpoint. A very low proportional band will cause the system to behave similarly to an on/off control setup without a proportional valve.

Over-Damped System

A larger proportional band decreases gain, therefore a large change in temperature will yield a smaller response in output. As the proportional band increases, the system becomes over-damped. This means that the temperature returns to the setpoint without oscillating. However, if it is too large, it will return to the setpoint slowly and will be very slow to react to changes in the temperature.

The output is limited to a range of the minimum temperature control valve (TCV) opening and 100%.

Integral Time (Ti)

The integral term accelerates the movement of the process temperature towards setpoint and eliminates the residual steady-state error that occurs with a pure proportional controller.

The larger the input error (error = setpoint – temperature) the greater the effect of the integral term.

The smaller the integral time, the quicker the system will increase the output. The larger the integral time, the slower the system will increase the output.

Derivative Time (Td)

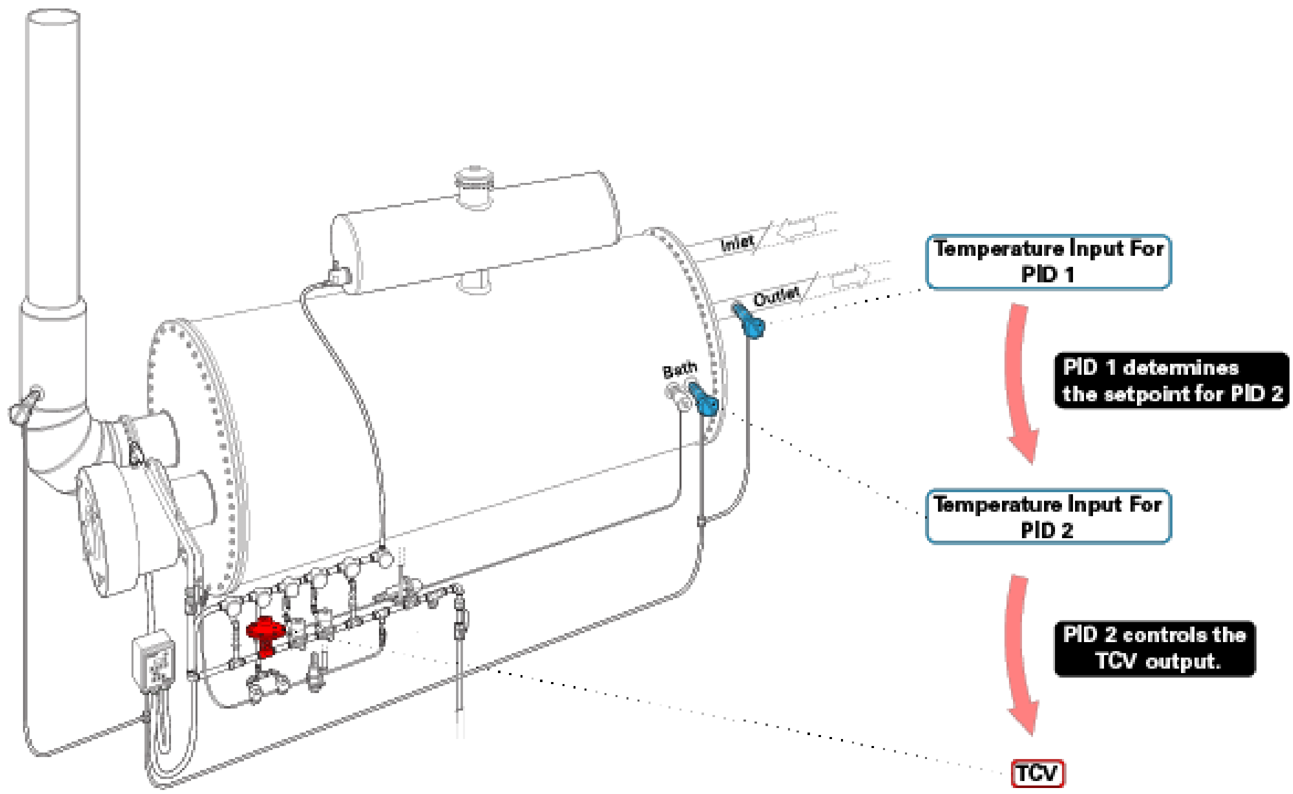
Derivative action is seldom used in practice because of its variable impact on system stability in real-world applications.

Increasing the derivative time increases the output contribution. Decreasing the derivative time decreases the output contribution.

3. Cascaded PID

Two PID controllers can be used together to yield better dynamic control. In cascade control, one PID controls the setpoint of another. One controller (PID 1) acts as an outer loop (primary temperature) controller, which controls the setpoint of the second controller (PID 2). The second controller (PID 2) acts as an inner loop (secondary temperature) controller, which controls the primary process temperature (via the temperature control valve or TCV output).

PID 1 should be slower to respond than PID 2. This is necessary so that PID 1 does not request a different setpoint before PID 2 has had time to achieve the previous setpoint.



How to Set-up a Cascaded PID

1. Understand the process that will be controlled, and the requirements of the process.
2. Allocate the primary process temperature to the process temperature that is directly heated by the fuel gas. This is often the bath.
3. Run the system to a steady state (this is usually low fire).
4. Allocate the secondary process temperature to the control process. This is often an outlet temperature from the tank. Select this temperature input for cascaded control in the **Secondary Temperature** setting (please see the PROFIRE PID Operator Guide for details).
5. Enable the **Cascaded PID** function.
6. Determine an allowable operating range of the primary process temperature. This is the range the tank temperature will adjust between in order to meet the secondary setpoint.
    a. Set the primary setpoint maximum to the maximum temperature you want the tank to achieve during process control. This value must be below the low fire setpoint.
    b. Set the primary setpoint minimum to the minimum temperature the tank should achieve during process control. Depending on the application, this value will often be very close to the secondary temperature setpoint.
    c. Set the primary setpoint to a value between the minimum and maximum setpoint limit. During cascaded control, this setpoint value is arbitrary; however, if the secondary temperature is ever lost or loses communication, the system will fall back to operating from the primary temperature. This means that it should be set to a reasonable value.
7. Adjust the primary PID tuning values as needed. (See Section 4 – PID Tuning below for details).
8. Once the primary is stable and controlled, adjust the secondary tuning parameters as needed. (See Section 4 – PID Tuning below for details).

How to Set-up PID Staging

PID staging simply switches process control between two different temperature inputs depending on the defined conditions. The following modes can be set according to system requirements and are defined below:

High Input

When the IO expansion input is high, the system will control from the secondary temperature.

Low Input

When the IO expansion input is low, the system will control from the secondary temperature.

For both High Input and Low Input: the expansion input must be selected through use of the **Staging Input** setting and setpoint ranges are ignored unless cascaded PID control is also used.

Primary In Range

When the primary temperature is above the primary setpoint minimum, the system will control from the secondary temperature. In this case, the primary setpoint maximum is ignored because the low fire setpoint handles the high side.

Secondary In Range

When the secondary temperature is above the secondary setpoint minimum and below the secondary setpoint maximum, the system will control from the secondary temperature.

Primary & Secondary In Range

Both the primary and secondary must be within their valid range in order to transfer control to the secondary input.

Primary or Secondary In Range

Either primary or secondary can be within their valid range in order to transfer control to the secondary input.

In every case, if the system has not transferred control to the secondary temperature input, the system will be controlled from the primary. PID staging can work in conjunction with cascaded PID mode. When they are both enabled, the system will enter cascaded PID control when transitioning to secondary control.

How to Set-up Integral Jacketing

Integral jacketing may be enabled at any time during control by navigating to the **Settings** tab and selecting **Advanced PID Config**. This will display the option to **Enable** or **Disable** the **Integral Jacketing**. When it changes state, the integrator will be reset. PID performance will generally be improved with jacketing enabled.

Jacketing will speed up process convergence on the setpoint during startup, and significantly reduce overshoot of the burner. It may increase oscillations around the setpoint during temperature transitions, but quite often these oscillations are acceptable as they help to achieve convergence more quickly.

Jacketing has no effect when the process is operating without hitting its limits, so that the TCV output is operating between its minimum and maximum position.

How to Set-up PID Ramp Time

The PID Ramp Time setting is accessed by navigating to the **Settings** tab and selecting **Advanced PID Config**. This will display the **PID Ramp Time** setting.

When the burner transitions from pilot to low fire, it will open the TCV to the minimum TCV opening. The system will then wait for 30 seconds before entering PID control. A common problem occurs when upon first entering PID control, the TCV will slam open to 100%, often snuffing the pilot.

The PID Ramp Time slows the TCV opening when transitioning into PID control. The time may be adjusted from zero (0) seconds (off) to a maximum of 60 seconds. The PID will ramp from the low fire position to the currently requested position (this could be anything from the low fire to 100% on) over this period of time.

4. PID Tuning

General Information

Selecting Proportional Band

The appropriate proportional band completely depends on the application.

For instance: a large heater with an undersized burner may only need a PB of 2°C or 3°C, because even at 100% output, the temperature control valve (TCV) has a difficult time heating the process fluid to its setpoint. Clamping at 100% until very close to the setpoint will not be an issue. On the other hand, if the burner is oversized and is heating something with a low heat capacity (e.g. – air), the PB may need to be 20°C or 30°C to avoid excessive overshoot.

The best way to select an appropriate proportional band is to ask someone familiar with the process. Describe what the proportional band term means – the distance away from the setpoint where the output starts backing off from 100%. This will allow someone familiar with the process to provide a credible baseline to work from.

Upper and Lower PB Boundaries

Once you have an estimate for your PB term, you should tune the term to provide ideal proportional control. The objectives are to get to the setpoint relatively quickly, and keep overshoot at an acceptable level.

Upper Boundary

If the PB is too large, the output will back off too early, resulting in the input never reaching its setpoint, or in taking an unacceptable amount of time to do so. This provides you with an upper boundary on the PB parameter.

Lower Boundary

The lower boundary for an appropriate PB is based on overshoot. Acceptable overshoot might be 10% of the setpoint or it might be 0.5% of the setpoint. This will depend entirely on the process and the application in question.

For the BMS TCV output, the Low Fire Setpoint (LF SP), Pilot Off Setpoint (PO SP) and High Temp ESD (HT ESD) provide a decent guideline if already configured. If the current PB results in an overshoot past these setpoints and results in BMS state transitions, it is safe to assume that this overshoot is unacceptable and the PB is too small.

Sometimes the setpoints are packed tightly together (e.g. – SP = 80, LFSP = 81, POSP = 82) and the rules are the same here, but the window for acceptable overshoot is much smaller. The only way to prevent a 1°C overshoot under these circumstances may be to select a large PB and crawl up to the setpoint over several minutes.

Integral Time

The actual “strength” of the integral term is defined by the Integral Time parameter. With a fixed input and proportional band, it will take one Integral Time period for the integral term to accumulate a value equal to the proportional term. The lower the Integral Time, the quicker the integral term will accumulate.

Rather than worrying about the actual integral gain, it’s best to set an appropriate Integral Reset Range (IRR). The main benefit of the integral term comes once the input is oscillating around the setpoint. If the input is well below its setpoint and the output is railed 100%, then using the integral term will do more harm than good. Ideally, the integral term should only “activate” when it is needed. This behavior is what the integral reset feature enables. It allows then integral term to only become enabled when it is time to eliminate the steady state error.

The IRR is a band that surrounds the setpoint in positive and negative directions. If the input is outside this band, the integral term is reset to zero and the PI controller acts like a P controller.

Logically, this setting should be slightly larger than the oscillations that result from a P controller. If the setpoint in 80°C, and the oscillations are +/- 10°C, then 20-30°C might make sense. The important point here is that the integral term only activates when the system is in a steady state.

Derivative Term

The derivative term allows for a PID controller to predict future error by calculating derivatives of the error or input.

PF3100 PID controllers take the derivative of the input measurement rather than the error. This is a standard PID feature which prevents large output swings when the setpoint is changed. When the setpoint increases, the error term increases instantaneously. If the derivative of the error term was used for the derivative term, the output would spike in response to the setpoint change, even though the state of the system didn’t really change.

PROFIRE recommends avoiding the derivative term. A well-tuned derivative term allows the controller to respond quickly with minimal overshoot, but a well-tuned PI controller can also achieve this with a slightly slower response time. Unless the application requirements are very tight, there's no need to involve the derivative term.

PID Tuning Key Points

The goal of PID tuning is to achieve acceptable stability of the system. This is a balance between unstable oscillations and over-dampening of the system. A system can be considered stable if it settles within 4 oscillations (1/4 decay) after a disturbance. A disturbance may be a step in setpoint (e.g. – from 50°C to 51°C) or a rapid change in process (inlet temperature). It is therefore important to understand how the different variables that comprise the PID controller will affect the system before any tuning of the system can be performed.

Proportional Band

This number represents the overall gain. An increase of this value slows the system's response to change. A decrease in this value will speed up the system's response.

Integral Time

This number represents how long a system will accumulate error, which is vital for balancing a PID system. An increase of integral time will reduce the error accumulation.

Derivative Time

This setting should be avoided in all but the most specialized cases.

Sample Time

This setting is used in conjunction with derivative time and should be ignored.

Integral Reset Range

This is the range around the setpoint at which the integral portion of the PID will start to accumulate error.

PID Deadband

This is the range where the actuator will take no action around the setpoint. It can reduce driver wear at the cost of reduced precision.

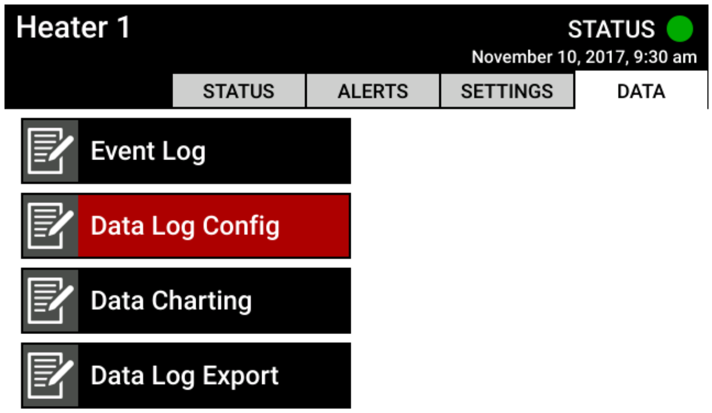
Rate Limit

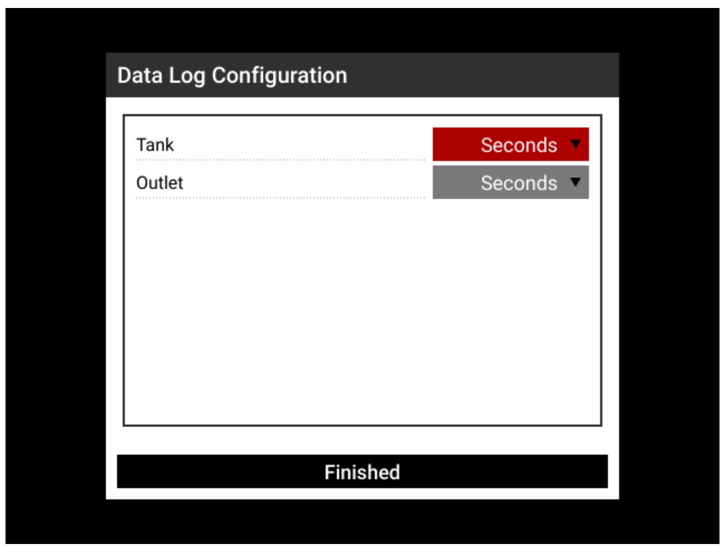
This setting is used to smooth the actuator output. It affects the maximum speed the actuator can move in a given time.

In order to tune a PID system, the proportional portion must be tuned first by zeroing out the integral and derivative times. After running the system, it will be possible to observe how the proportional performs, and from that point adjustments can be made to the integral term for a fully tuned. PID.

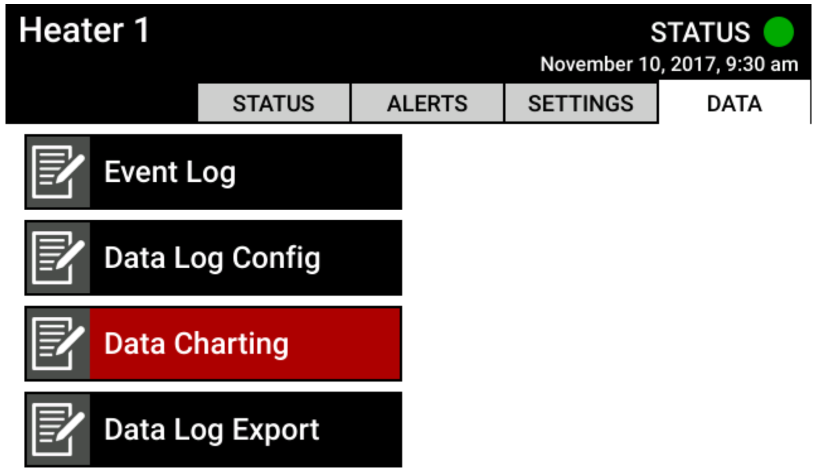
Tuning P & I Parameters for a Single Loop

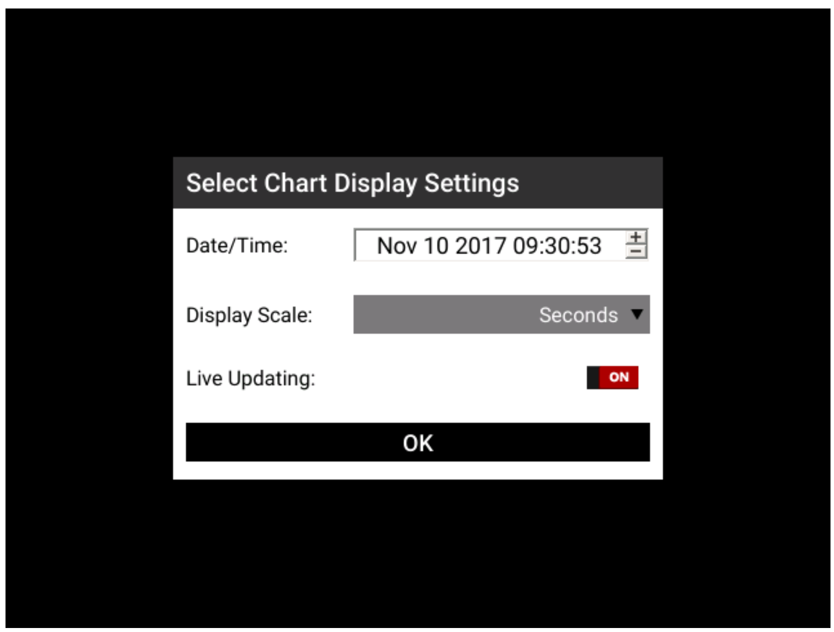
1. Start with a proportional band of 5°C, keeping the integral and derivative times set to 0, and run the system to a steady state near the desired setpoint.
2. In the **Data** tab under **Data Log Config** set the units of time for the process variables.



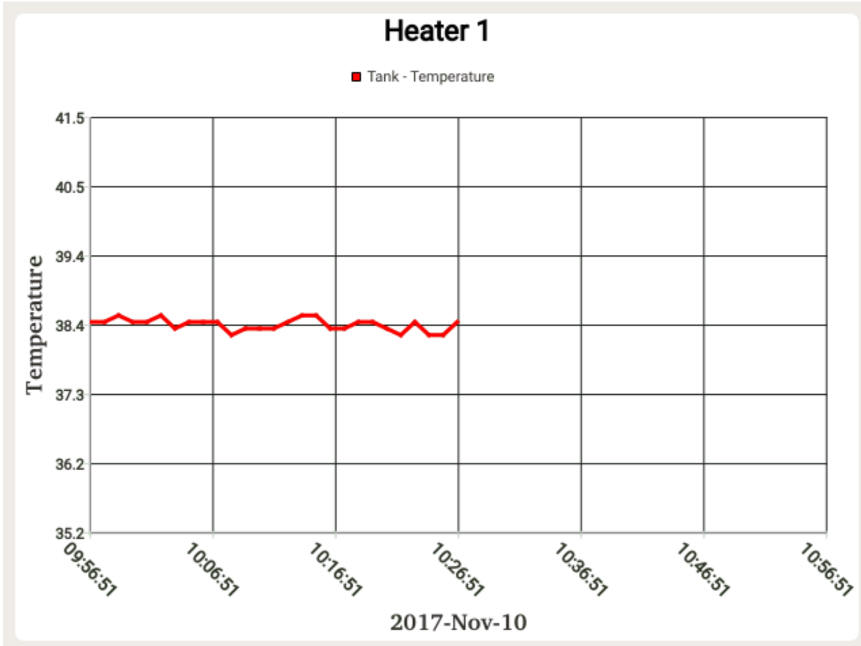


3. In the **Data** tab under **Data Charting**, enable live updating and select **OK**.

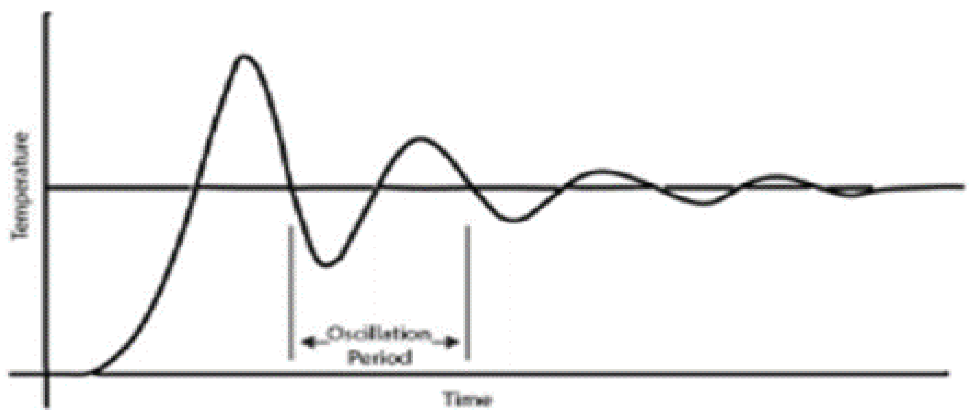




4. From this screen:



Use the +/- keys to size the graph. Ideally, the system should oscillate four times before stabilizing. If the process does not oscillate at all then the proportional band will need to be increased. If the process oscillates too much, then the proportional band should be decreased. A good rule for this process is to adjust the proportional band by roughly 20% each time.



Note: at this point the output should be relatively stable, but still below the desired setpoint.

5. The **Integral Reset Range** can be set next. It is important that the range spans the heating effect granted from the proportional control (e.g. – if the setpoint is 50°C and the steady state brings it to 45°C, then the reset range must be above 5°C). This is usually a value between 3-5 degrees.
6. Integral time should be set to roughly one oscillation period (as noted in the previous step) divided by 1.5.

7. At this point there will be a waiting time for the system to run during which the chart should be observed. If the process is unstable, then increase the proportional band by 20%. If after adjustments have been made the system is still unstable or too sluggish, the integral can be adjusted. Increasing the integral time will dampen the system and decreasing it will speed up the response.

   Once the system is stable, test for overshoot. To test for this, allow the system to cool or heat it up. The goal here is to get it to a temperature that is outside the bounds of the integral reset range (e.g. – if the reset range is 5°C then the system should be greater or less than the setpoint =/- 5°C). Once the system is outside the reset range, start it and monitor the chart. If the overshoot is acceptable then the PID system is finally tuned. If the overshoot is too high, increase the proportional band and try again.

Tuning P & I Parameters for a System with PID Staging

In a PID staging system there will be two sets of PID parameters to tune (primary and secondary). Begin by tuning the primary system (this is often the tank). Once the primary is satisfactorily stable, tune the secondary process. Test the transition between the primary temperature and the secondary temperature to ensure that the system is stable between large setpoint transitions.

Tuning P & I Parameters for a System with Cascaded PID

In a cascaded system the secondary temperature controls the primary temperature's setpoint. Tune the system as follows:

1. First, tune the primary temperature PID. This is the temperature that is most often coupled with the TCV (for example, the tank). For now, disable cascaded control and run the primary temperature to a setpoint midway between the minimum and maximum setpoint limits. The setpoint or high temperature of the secondary process should be set to prevent high temperatures, but there should be enough headroom left so that the setpoints do not interfere with tuning.
2. Tune the primary process following the guide above for Single Loop P & I Tuning. The primary should be faster and more reactive than the secondary. It may be advantageous to run this PID with proportional only (keeping integral time at 0). This is because it is not as important that the primary PID reaches its setpoint, only that it is stable since that setpoint will be adjusted by the secondary PID.
3. Enable the **Cascaded PID** tab and tune the secondary PID parameters. Start with the proportional band of the secondary being 2-3 times that of the primary proportional band.
4. Test the setpoint response of the system to ensure that the secondary is slower than the primary. When looking at the chart, the primary system should stabilize before its setpoint is changed. The primary system should never be responding to a setpoint before that setpoint is changed again.

5. Similar to tuning a single loop, the system must be tested for overshoot. To test for this, the system must be allowed to cool, or heated up. The goal is to obtain a temperature that is outside the bounds of the integral reset range (e.g. – if the reset range is 5°C then the system should be greater or less than the setpoint +/- 5°C). Once outside the reset range, start the system and monitor the chart. If the overshoot is acceptable then the PID system is finally tuned. If the overshoot is too high, increase the proportional band and try again. Implementing **Integral Jacketing** may help to correct overshoot under these circumstances. Integral jacketing is not always enabled, but is almost always a benefit when it is.

5. Troubleshooting PID Tuning

Below are a common list of problems and how they can be resolved. If you have any further issues that are not listed here, please contact PROFIRE directly.

Verify Wiring

The first step in resolving any issue is to confirm the fundamentals by verifying the wiring of the system. More specifically, it is important to ensure that each of the valves are wired to their respective places.

Check Valves

Sometimes valves get stuck and don't respond as expected. If the system has been tuned and is behaving abnormally, take some time to ensure that the valves connected to the PF3100 are at the positions they are being set to by the system. If there is a disparity between two, try power cycling the valves.

Check Derivative Term

The derivative term can have unexpected results on the system. If the system is behaving abnormally and the derivative settings are non-zero values, it can sometimes be beneficial to zero them. After the values are zeroed, the system should behave more predictably and can again be tuned.

6. PROFIRE Contact Information

If you have any concerns or questions about this information, please contact PROFIRE as follows:

U.S.

1.801.796.5127
321 South, 1250 West Suite 1
Lindon, UT
84042, USA

solutions@profireenergy.com

CANADA

1.780.960.5278
Box 3313, Bay 12, 55 Alberta Ave
Spruce Grove, AB
T7X 3A6, Canada

solutions@profireenergy.com