PF2200-SB

PID TUNING

DOC-001108 / v1.0


PROFIRE
STATUS
READY
BATH (°F)
186.5 [197]
OUTLET (°F)
107.5 [128]
STACK (°F)
557.8 [580]
LEVEL (L)
246.7 [208]
PRESSURE (psi)
45.6 [70]
STATUS
START
STOP
OK
?
+
−
PF2200

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INTRODUCTION

The PF2200 can maintain a desired process temperature by modulating the appliances firing rate via a temperature control valve (TCV). The firing rate has the option to be controlled by a user- selectable simple PID control loop or a cascaded PID control loop.

The PID control loop is useful for most applications that require direct process heat such as modulation on a bath or outlet temperature only.

The cascaded control loop may be useful for processes that require improved outlet temperature regulation along with a controlled bath temperature. Cascaded control can improve outlet temperature stability with processes that have a longer time delay (for example the outlet temperature sensor is located a distance away from the bath).

PID CONFIGURATION SETTINGS

The following lists the settings that are used to configure the PID for the system.

Setting	Value	Description
Process Control Mode	Bath PID control	PID control on bath temperature input
	Outlet PID control	PID control on Outlet temperature input.
	Aux PID control	PID control on Aux temperature input.
	Cascaded PID control	Cascaded PID control using both the outlet and bath temperature inputs. See cascaded control section for details.
Process Proportional Band	Default: 10 °C, 18 °F 0 – 1000 °C, 0 – 1800 °F	This is the proportional Band used for the PID calculation. In cascaded control mode this value applies to the bath PID loop. Value is in temperature units: °C or °F
Process Integral Time	Default: 0 – 1000 min/rep	This is the integral time used for the PID calculation. Value is in minutes per repeat.
Process Derivative Time	Default: 0 0 – 1000 min	This is the derivative time used for the PID calculation.

Setting	Value	Description
		Value is in minutes.
Process Integral Reset Range	Default: 10 °C, 18 °F 0 – 1000 °C, 0 – 1800 °F	This is the boundary of the integral windup range. If the process temperature is outside of this range the integral term will not accumulate. The accumulation range can be calculated by subtracting this value from the process setpoint. Value is in temperature units: °C or °F
Cascade Proportional Band	Default: 10 °C, 18 °F 0 – 1000 °C, 0 – 1800 °F	This is the proportional Band used for the cascaded PID calculation for the outlet temperature. If cascaded PID is not used, this value has no effect. Value is in temperature units: °C or °F
Cascade Integral Time	Default: 0 – 1000 min/rep	This is the integral time used for the cascaded PID calculation for the outlet temperature. If cascaded PID is not used this value has no effect. Value is in minutes per repeat.
Cascade Derivative Time	Default: 0 0 – 1000 min	This is the derivative time used for the cascaded PID calculation for the outlet temperature. If cascaded PID is not used this value has no effect. Value is in minutes.
Cascade Integral Reset Range	Default: 10 °C, 18 °F 0 – 1000 °C, 0 – 1800 °F	In cascaded mode this is the boundary of the integral windup range for the outlet temperature. If the outlet temperature is outside of this range the integral term will not accumulate.

Setting	Value	Description
		The accumulation range can be calculated by subtracting this value from the process setpoint. Value is in temperature units: °C or °F
Output Rate Limit	Default: 100%/sec 0.1 – 100%/sec	This is the limit for the maximum output change of the TCV per second. A larger value allows for a quicker change in output. A smaller value slows down any change in output. This can help prevent fast movements from the TCV. Value is in percent per second.
Ramp Time	Default: 10 seconds 0 – 255 seconds	Once the system enters process control mode after light off delay it will slowly ramp to the requested firing rate over this time. This can prevent the firing rate from jumping hard from the minimum opening position to the maximum firing rate too quickly. Value is in seconds.
TCV Minimum Position	Default: 40% 0 – 70%	This is the minimum position that the TCV will close to in process control mode. The effective range of operation of the TCV is the minimum position on the low end and 100% on the top end. Value is in percentage.
Bath Process Setpoint	Default: 80 °C, 176 °F 0 – 1350 °C, 32 – 2462 °F	The PID will adjust the firing rate to achieve this setpoint if the system is in Bath PID control for its process control mode. In cascaded control this setpoint will be overridden by the one calculated from the outlet PID.

Setting	Value	Description
Bath Main Off Setpoint	Default: 85 °C, 185 °F 0 – 1350 °C, 32 – 2462 °F	This setpoint is the upper end of the process control range for the bath temperature. If the temperature goes over this setpoint the system will go to pilot. Value is in temperature units: °C or °F
Outlet Main Off setpoint	Default: 85 °C, 185 °F 0 – 1350 °C, 32 – 2462 °F	This setpoint is the upper end of the process control range for the outlet temperature. If the temperature goes over this setpoint the system will go to pilot. Value is in temperature units: °C or °F
Outlet Process Setpoint	Default: 0 °C, 32 °F 0 – 1350 °C, 32 – 2462 °F	The PID will adjust the firing rate to achieve this setpoint if the system is in Outlet PID control for its process control mode.
Aux temp main off setpoint	Default: 85 °C, 185 °F 0 – 1350 °C, 32 – 2462 °F	This setpoint is the upper end of the process control range for the aux temperature. If the temperature goes over this setpoint the system will go to pilot. Value is in temperature units: °C or °F
Aux temp process setpoint	Default: 0 °C, 32 °F 0 – 1350 °C, 32 – 2462 °F	The PID will adjust the firing rate to achieve this setpoint if the system is in Aux PID control for its process control mode.

CONFIGURATION of PID CONTROL LOOP

This PID will modulate to maintain a single temperature setpoint. Other system temperatures will inherently follow the controlled temperature based on the process heating method of the appliance.

CONFIGURE SETPOINTS

First, determine the **operating range** of the desired process temperatures. We'll use these values to configure the **High temp setpoint**, **Main off setpoint**, and the **Process setpoint**. Not all temperature inputs may be used, or enabled for process control.

The **shutdown temperature** is the setpoint where the system will shutdown and lockout if it's reached. The **operating temperature** must be below the shutdown temperature with a bit of a headroom in case of overshoot during normal operation.

The **process temperature** will be the **control temperature** of the PID. This should be the setpoint that the system will maintain.

The **process load**, or **head demand**, will affect how quickly the process heats up and cools down. An appliance's burner is usually sized for the maximum load and has a limited **turn down ratio** (**minimum firing rate**). This means that under light loads the burner may produce too much heat even at the lowest firing rate. In this case it's expected that the PID cannot effectively control the process temperature, and it will gradually increase until it reaches the **Main off Setpoint**.

A main off setpoint should be selected with a few points in mind:

- It should be high enough above the process setpoint to allow for a small amount of overshoot during normal operation and system startup. This is the upper range of where the PID can effectively control the process temperature. If the setpoint is too close to the process setpoint the PID will not have enough working area to effectively maintain temperature before the mains cycle. Each system will be different, however, headroom of 5 °C is usually sufficient.
- During light loads, the process temperature will likely bump this setpoint. Make sure this is a safe operating temperature for the process fluid.
- If the system is continually bumping this setpoint even under medium to heavy loads it is likely that the burner is oversized or the PID is not tuned correctly and is overshooting.

The table below can be used to record the **High Temp**, **Main Off**, and **Process** setpoints for the **Bath**, **Outlet**, and **Auxiliary** temperatures. This will help in the configuring of the PID by knowing each setpoint described above.

	Shutdown temperature (High Temp Setpoint)	Maximum temperature during normal or light load operation (Main off Setpoint)	Desired process temperature (Process Setpoint)
Bath Temperature			
Outlet Temperature			
Aux Temperature			

CONFIGURE PROCESS CONTROL MODE

Determine which **Temperature Input** will be used for the **Process Control**, and set the appropriate Process Control Mode setting. This will be based on the type of appliance. The system will attempt to maintain this temperature by changing the other temperatures in the system. The other temperatures can increase up to their respective **main off setpoints** (**if configured for process control**), and if bumped the system will turn off the main burner to cool the appliance.

- If the appliance only has a bath temperature to maintain, use Bath PID control.
- If the appliance has an outlet temperature of the process fluid, use Outlet PID control.
- If the appliance has an outlet temperature that has a longer time delay to heat up and cool off, use the Cascaded PID control.
- If the appliance has an auxiliary temperature that requires regulation, use Aux PID control.

CONFIGURE the TCV MINIMUM OPENING

This should be set to the **lowest value** that the burner can remain **stable** at. Each appliance will be different so this value should be optimized by a burner technician. If an acceptable **turndown cannot be achieved**, and the **process heats up even when at this minimum firing rate**, the burner may need to be **de-tuned to reduce its heat output**.

CONFIGURE the RAMP TIME

For most systems, the **ramp time** can be left at the default 10 seconds. **Increasing** this time will force the burner to slowly open the **TCV** when coming from a **pilot state**. This can help prevent the pilot from snuffing out from a sudden change in firing rate.

CONFIGURE the OUTPUT RATE LIMIT

For most systems, the **output rate limit** can be left at the default of 100%/ second. If the system uses a **mechanical linkage**, or **alternate actuator** that requires a slower rate of change, this value can be **decreased**. The **ramp time** setting takes effect when the system first enters the **process control state**. The **rate limit** is effective in all states. **Decreasing** this value prevents quick changes to the **output**, however, it also **dampens the response time of the system**. This can hinder the ability of the PID to properly control the temperature in quick changing systems.

CONFIGURING PID PARAMETERS

for a NON-CASCADED SYSTEM

The following steps will be used to tune the PID:

1. Determine a stable proportional band.
2. Determine an integral reset range that will work for our proportional band.
3. Determine a stable integral time.
4. Evaluate and tune our results.

To determine a stable proportional band, the following PID parameters can be used as a starting point:

- Set the proportional band to 10 °C or 18 °F.
- Set the integral to 0.
- Set the derivative to 0.
- Set the process integral reset range to 10 °C or 18 °F.

This configuration allows us to control the system with **proportional** only without effects from the **integral term**. Our expectation is that the system will stabilize at a temperature a few degrees below the setpoint. Later we'll use the integral term to pull the temperature up to the setpoint.

Start the system and **monitor the process temperatures**. If the process is **cold**, we will expect the firing rate to fire at 100% until we reach the setpoint **minus the proportional band**. The **firing rate** will decrease proportionally from this point up to the setpoint. The system will naturally settle at a firing rate between **100% and the minimum opening**.

Once the heater has warmed up continue to monitor the **temperature** and the **firing rate**. The goal is to maintain a **steady firing rate** and **temperature** just below the setpoint and to also find the point where the proportional causes the system to become unstable.

- If the firing rate is continually oscillating than double the proportional band. This will dampen and stabilize the oscillations. Continue to increase the proportional until the oscillations stop.
- If the firing rate is not oscillating and seems stable, we may already have a good proportional value, or we may be overly damped. Check the stability by reducing the proportional by half. Continue to reduce the proportional until the system starts to oscillate.
- After testing you will have found a proportional setting that causes the system to oscillate. Set the proportional value a few degrees greater than the oscillating value.

We will now verify the stability of the proportional effect by causing a system disturbance and evaluating the response.

- Once the process has stabilized at the selected proportional value increase the process setpoint by 1 degree.
- The firing rate will jump immediately. As the process heats up the firing rate will decrease. After the setpoint change if the system continues to oscillate for more than 4 oscillations increase the proportional. The system is unstable.
- If the process oscillates for 4 or fewer oscillations the system is close to where we need it. Our goal is to have slight oscillations after a disturbance with the system moving towards a stable temperature.

We will now set our **integral reset range**. The process will settle at a temperature below the setpoint. We want our integral reset range to take effect below this temperature. Set the **integral reset range about 5 to 10 degrees lower than the settled point of the process temperature**. For example, if the setpoint is 100 degrees and the stabilized process temperature is 95 degrees, set the reset range to 10 degrees.

- The integral reset range primarily affects system startup. It prevents the integral from winding up when the process temperature is cold and takes a while to heat up.
- If the reset range is too tight (too close to the setpoint) the process may never reach temperature because it will settle below the range where the integral takes effect. If it seems like the process gets "stuck" at a temperature below the setpoint, and the firing rate does not start increasing, then increase the integral reset range.
- If the reset range is too large the system will overshoot on startup as it takes the firing rate as much time to wind down after winding up.
- It is common to adjust the integral reset range over a few weeks as the load on the system changes to find a value that achieves an acceptable overshoot, and doesn't prevent the integral from accumulating during heavy loads.

The **process temperature** will settle to a value lower than the **process setpoint**. To pull the temperature up to the setpoint we will add the **integral term**. A good starting point is about **4 min/repeat**. What this means is the integral term will double (repeat) every 4 minutes. Increasing the integral term will slow down its effect. Decreasing the integral term will speed up its effect.

- After adding the integral term, the system may begin to oscillate. If the system begins to oscillate continually, try to increase the proportional band a few degrees.
- If the system continues to oscillate increase the integral term to slow it down.
- Both an integral that is too long and an integral that is too short can cause oscillations, so we're trying to find a stable value that allows for quick system response. The integral term should lean more towards a lower value (faster value) that still maintains system stability.
- Once the integral term seems stable on its own. Introduce a step change by increasing the system setpoint by 1 degree and analyzing the response. The system should stop oscillating within 4 oscillations. If the system becomes unstable, gradually increase the integral term (and possibly the proportional term as well) until it stabilizes.

The **derivative** term is rarely required for **heat process control applications**. Most systems can achieve the required stability with proportional and integral alone. It is recommended to use the derivative term only if its implications are understood and the operator has experience in tuning derivative systems.

- Increasing the derivative term will reduce its effect. A larger derivative means a change in temperature produces a smaller counter-response.
- Decreasing the derivative term will increase its effect. A smaller derivative means a change in temperature produces a larger counter-response.

CONFIGURATION of CASCADED PID CONTROL LOOP

A similar process to tune the basic PID control loop will be used for the cascaded configuration. In the cascaded control mode, there are two separate PID loops, where the output of one feeds the input of the other.

The first control loop measures the outlet temperature and modulates to maintain the outlet temperature setpoint. The PID settings for this loop are prefixed with the term **"cascade"**. **The output of this PID calculates the setpoint of the bath temperature**.

The second control loop measures the bath temperature and modulates to maintain the bath temperature setpoint received from the first loop. The PID settings for this loop are prefixed with the term "**Process**". **The output of this PID calculates the firing rate for the TCV**.

The reason for this configuration is to allow for two separate control loops to act quickly on elements they can control. The bath temperature is directly, and immediately affected by the **TCV firing rate**. The smaller the time delay between action and response of the PID input, and output, the more stable the system can be. The **outlet temperature** is directly affected by the **bath temperature**. For example, by changing the **bath temperature** via its **setpoint**, the **outlet temperature** will also change in quick response. By combining these two control loops we can reduce the overall time delay of the system and create a more stable process.

We will perform the following steps to tune the cascaded system:

1. Select a Bath process setpoint range.
2. Select a stable bath temperature proportional band.
3. Select a stable cascaded proportional band.
4. Select a stable cascaded integral reset range.
5. Select a stable cascaded integral.

In the cascaded configuration the **bath setpoint** can change within a specific range. The low end of the range is the **Bath Process setpoint**. The high end of the range is the **bath main off setpoint – 1**. By forcing a known operating range for the bath temperature, the cascaded system can operate in a reliable manner without requiring to "hunt" for the correct bath temperature. The **main off setpoint** should already be selected according to the process. Select the **bath temperature setpoint** to be near the minimum expected bath temperature during operation. This will be the **bath temperature during light loads** or near the **minimum flow rate** of the process. The bath temperature will usually settle just a few degrees above the outlet temperature during normal operation.

In most cascaded PID configurations, the Bath PID will only use a proportional band. The reason for this is because it's the quickest and most stable control loop for the bath temperature.

Configure the process control mode as Bath PID control. Perform the PID loop configuration from the last section for the bath temperature, but only set the proportional band. The integral, integral reset range, and derivative can remain at zero. The goal is to tune a stable, but quick reacting proportional band. **Integral should not be added to the bath loop, as it will add a delay in system response**. The offset that the integral normally removes will be compensated for by the outlet PID loop.

Change the process control mode configuration to Cascaded PID control.

To determine a stable outlet proportional band, the following PID parameters can be used as a starting point:

- Set the cascaded proportional band to 10 °C or 18 °F.
- Set the cascaded integral to 0.
- Set the cascaded derivative to 0.
- Set the cascaded integral reset range to 10 °C or 18 °F.

Start the system and monitor the **outlet temperature** and the **cascaded setpoint (shown as the bath setpoint on the status screen)**. The goal is to determine a **stable proportional band** for the **outlet temperature**. The outlet temperature should stabilize a few degrees below setpoint with the caveat that the cascaded setpoint will also remain stable. The o**utlet temperature PID** in the cascaded configuration is often more stable when tuned to be over damped. This means that the **proportional band** is larger than what may be tuned for a normal PID loop. The reason for this is to allow more time for the bath temperature to heat up and reach its requested setpoint before the outlet requests a setpoint change.

- If the outlet temperature or the cascaded setpoint (bath setpoint) is oscillating, increase the proportional band. Also check that the bath setpoint (the low end of the cascaded setpoint range) is low enough to prevent overheating of the outlet temperature. The bath setpoint should be set to a value that will allow the outlet to cool off at during a minimum load.
- If the outlet temperature and cascaded setpoint seem stable bump the outlet setpoint up by 1 degree. Observe the response of the system. The bath temperature should slowly increase and stabilize along with the outlet temperature within 4 decaying oscillations.
- The cascaded proportional band may be decreased to speed up the response of the bath temperature change. However, the key point here is to not allow the cascaded setpoint to change to a different setpoint before the bath has had time to react to the initially requested value. We want the outlet PID to be just slow enough to request a bath setpoint and for the bath to achieve that temperature before the outlet requests a different bath temperature.

Once the **outlet temperature has stabilized** with the **proportional band only**. Select a cascaded integral reset range about 5 degrees below the outlet temperature offset from the outlet setpoint. For example, if the **outlet setpoint is 100 degrees** and the **outlet temperature has stabilized at 95 degrees**, select an **integral reset range of 10 degrees**. This value may be decreased if the overshoot of the outlet temperature during startup is too large or increased to compensate for heavier loads that may require a larger reset range region.

The **cascaded integral term** may now be added to **remove the outlet temperature offset**. A good starting point is about 4min/repeat. The goal is a stable outlet temperature that requests a cascaded setpoint change just slower than the bath reach the request.

- Increase the integral term if the system becomes unstable and oscillates.
- Decrease the integral term if the system takes too long of time to achieve setpoint after a change in process flow or disturbance. This can be tested by bumping the temperature up by 1 degree and observing the system response. Optimally the system will stabilize after 4 oscillations.
- If the outlet does not stabilize by increasing the integral term then also try to increase the cascaded proportional term.

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