Tuning Rules for PI and PID

Data Sheet

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PUBLICATION DS501C-EN

About this Publication

This data sheet covers various strategies for choosing the correct controller for your process.

Determining Which Controller to Use

A key challenge in setting up a control system is determining what type of controller to use. The PID controller is generally accepted as the standard for process control, but the PI controller is sometimes a suitable alternative. A PI controller is the equivalent of a PID controller with its D (derivative) term set to zero.

It is important to understand how controllers interact with each different type of process. For details, see Table 1.

Table 1 – How PI and PID Controllers Interact with Different Kinds of Processes

Controller	PI Controller	PID Controller
Effective for These Processes	Fast processes, such as flow, pressure, and some temperature loops.	Slower processes, such as level and insulated temperature.
Tuning Parameters	P = Proportional I= Integral PI controller is the equivalent of a PID controller with its D (derivative) term set to zero.	P = Proportional I= Integral D = Derivative The derivative term is particularly important for integrating processes, such as level, position, & well-insulated temperature. In general, using a derivative term can significantly increase the speed of the response of a non-integrating process and suppresses overshoot.
Response Speed	Response is slower, thus enabling a smooth and accurate PV change.	Response is faster, thus enabling setpoint to be reached more quickly.
Overshoot	Overshoot will likely occur.	Reduced or no overshoot.

Integrating vs. Non-Integrating Process

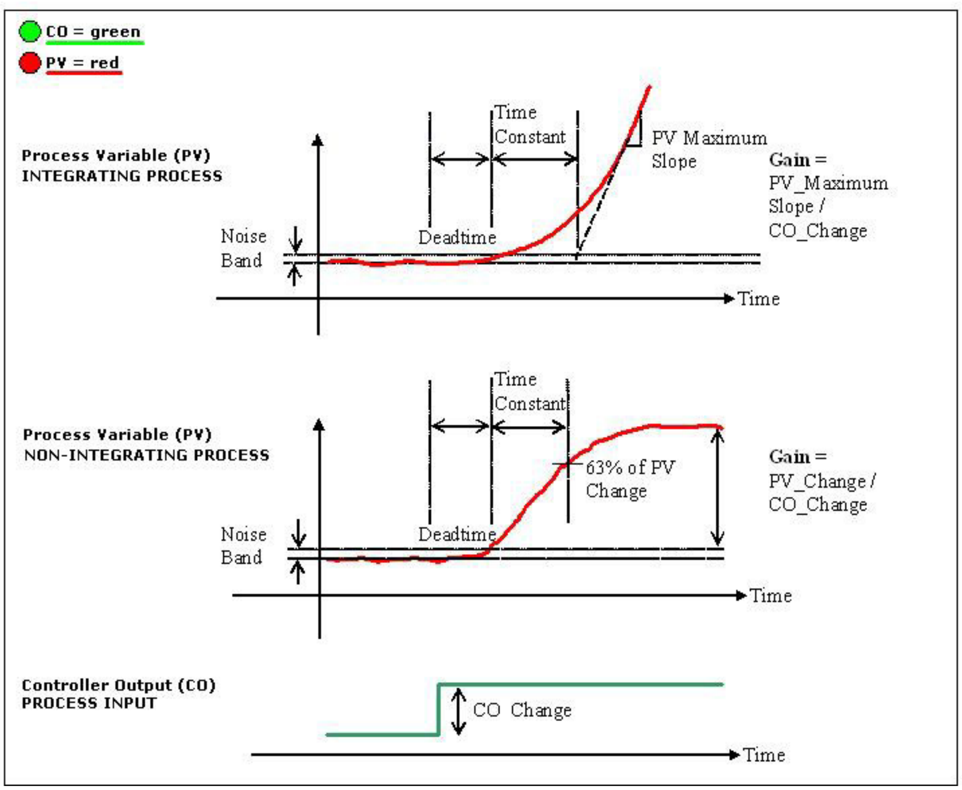
Understanding the process type is a basic step in tuning. Integrating and non-integrating processes are the two most common types of process applications.

- In non-integrating processes, when the control valve is manually put in any fixed position, the process variable (PV) will reach a steady state value. These are also known as self-regulating processes. Non-integrating processes are those such as temperature, flow, velocity, and pressure.
- In integrating processes, when a valve position changes, the PV tends to increase or decrease continuously without stopping. Common integrating processes are level, position, well-insulated temperature, or others with similar characteristics.

To better understand the two types of processes, let's consider how the PV behaves when we make a positive change to the controller output (CO) of a system. For positive gain processes, Figure 1 shows the difference in the two processes in response to a step change in CO.

- Looking at the integrating process, we notice that this system is not inherently self-regulating. If we make a step change in CO, the PV will begin to increase, and will continue to increase at a constant rate.
- In a non-integrating process, a change in CO causes the PV to eventually taper off to a new steady-state value.

Figure 1 - How the two types of processes respond to a step change in CO.



[TOP]
In an integrating process, CO step change causes the PV to increase and continue to increase at a constant rate.

[MIDDLE]
In a non-integrating process, PV eventually tapers off to a new steady state value.

[BOTTOM]
The CO step change magnitude is the same in both instances.

PI vs. PID Tuning in a Non-Integrating Process

The non-integrating process is the most common type of process, and it is also the easiest to control. Tuning a non- integrating process can be done manually with great difficulty or automatically with great ease using a good software package.

EXAMPLE 1: TEMPERATURE CONTROLLER

Let's look at how both PI and PID controllers operate on a non-integrating process.

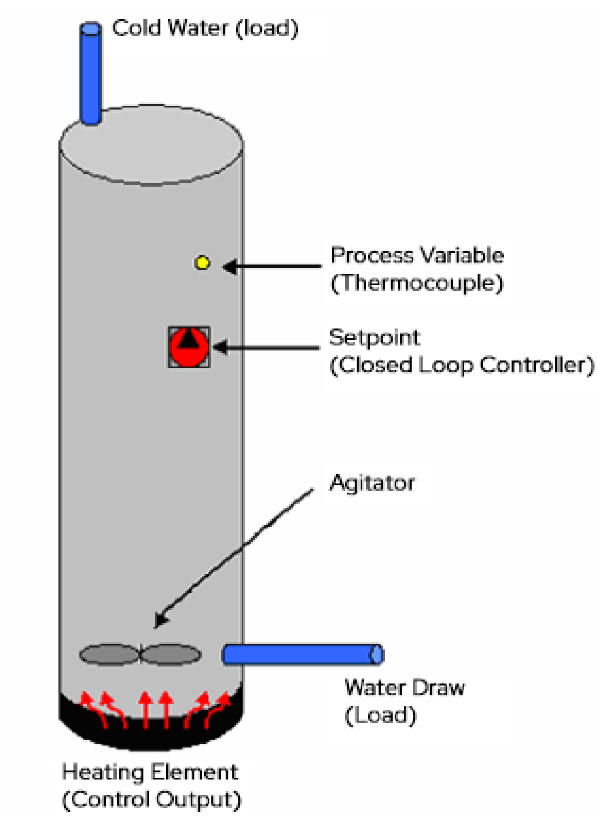
A common application of a first order model is a temperature controller for a hot water heater. Example 1 focuses on the temperature controller.

We have ignored the specifics of the inflow and outflow of water so that we can more easily see the impact of an instantaneous temperature disturbance.

For this example, we used a computer simulation to model and analyze the behavior of this system and the specifications for the water tank and heating element, as well as some estimated parameters for the process. (The system characteristics can be seen in Figure 2.)

A first order system was simulated using the PID simulator function of the INTUNE software.

Figure 2 - Hot water heater system characteristics.



Parameter	Estimated Value
Ambient (Base) Temperature	20 deg C
Heatiing Ellement Power Rating	5500 Watts
Max Temp Disturbance	20 deg C
Process Deadtime	6 seconds
Process Gain	0.45 deg C per %CO
Process Time Constant	9.25 seconds
Tank Capacity	295 lliters
Temperature Setpoint	55 deg C
Inflow & Outflow	Constant

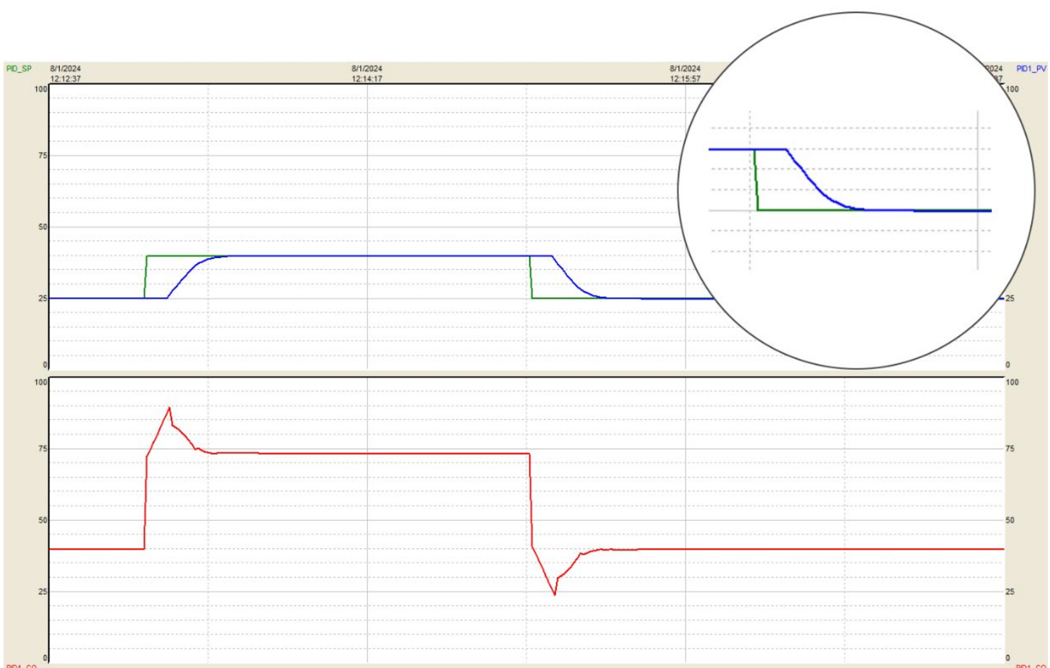
Important: In this example of a non-integrating process, we use dynamics, deadtime, and time constant that are too fast to be real. The simulation results, therefore, are more dramatic, and make it easier to see the differences.

We have simulated a first order system using the PID simulator in our INTUNE PID Loop Tuning software. Figure 3 and Figure 4 show the first order system responses for both PI and PID tuning.

Both PI and PID controllers are tuned to ensure optimal results using INTUNE's Auto Tune function. P terms and I terms are identical in both figures, and the D term is set to zero in Figure 3. Both tests were simulated identically using a setpoint (SP) change of +15 degrees followed by a SP change of –15 degrees.

Figure 3 - PI response does not react to the rate of change of the error. The result is overshoot.

Figure 4 - PID response shows that the PID PV reaches the desired SP with minimal overshoot.



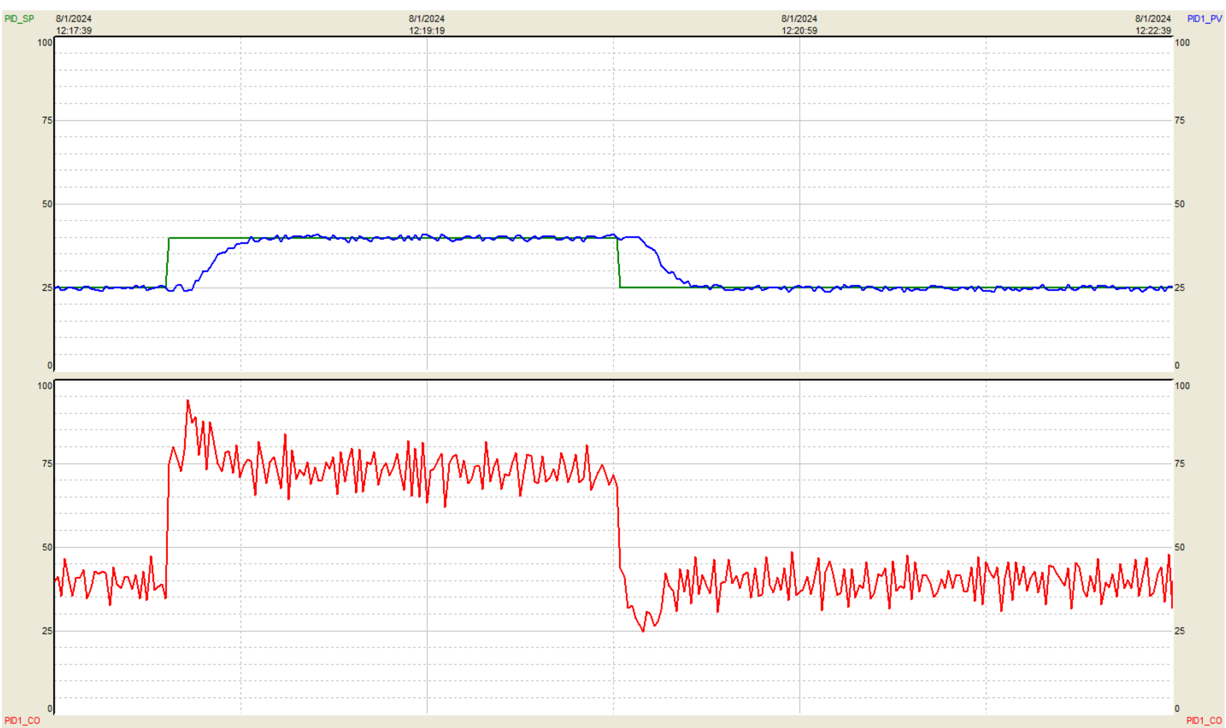
- The system response for the PI results in an overshoot of about one degree.
- The system response for the PID, adding a derivative component of 2, reduces the overshoot to less than 0.05 degrees.
- In some processes, overshoot is unacceptable or not desired.

In general, optimally tuning the derivative action of PID makes the controlled system to respond more quickly with reduced level of overshoot than the same system without derivative. For a fast-acting system, the overshoot may not be significant enough to warrant the use of derivative as the transient of the overshoot will be relatively brief. There is also a potential issue with the process's response to noise which we will evaluate next.

Now we will add some noise to the Process Variable signal. Additional noise of around +/-2 degrees was added to the simulation.

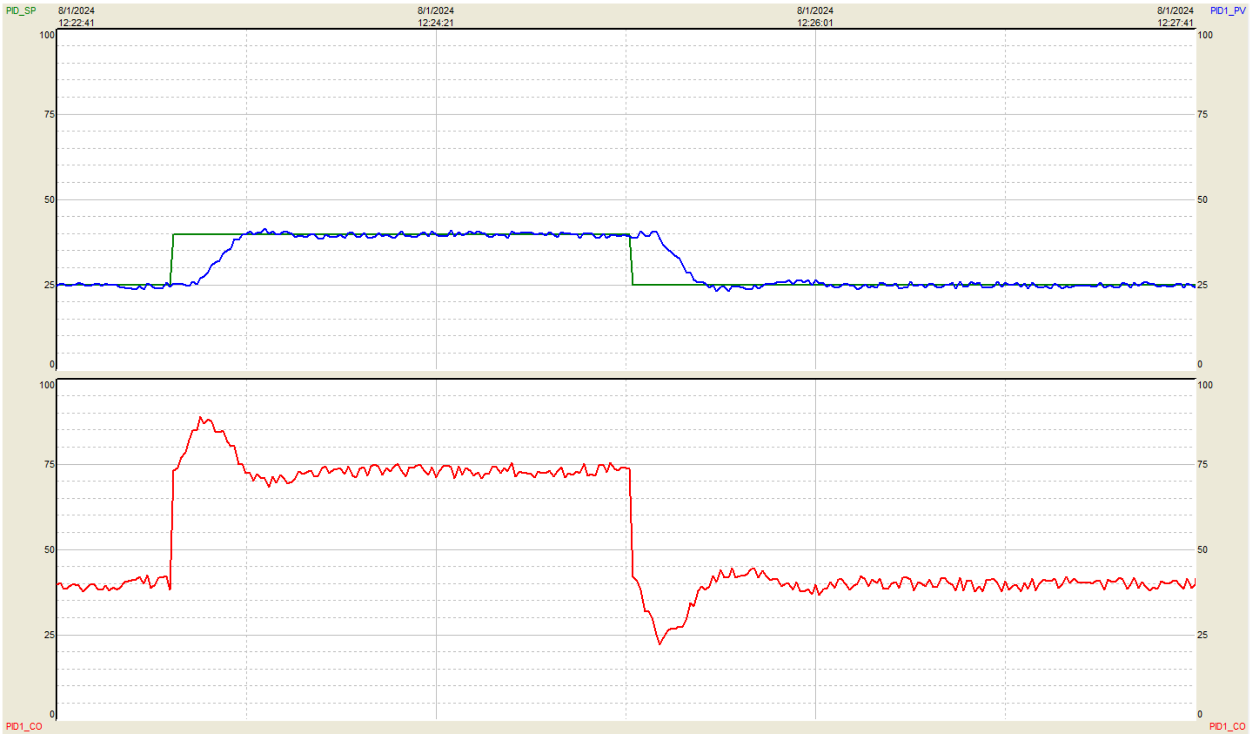
Figures 5 and 6 show the first order system responses for both PID and PI tuning. Both PI and PID controllers are tuned to ensure optimal results using INTUNE's Auto Tune function. P terms and I terms are identical in both figures, and the D term is set to 2 in Figure 5. Both tests were simulated identically using setpoint (SP) change of +15 degrees followed by SP change of –15 degrees.

Figure 5 - PID response with noise.



The CO response reacts to the noise.

Figure 6 - PI response with noise.



The CO response does NOT react to the noise as much as it did with derivative action.

- The system responses for the PID results in the controller output responding to the noise of the process.
- The system response for the PI, removing the derivative component, significantly reduces the reaction of the Controller Output to noise.
- If Derivative is used, the controller element may wear down or break pre-maturely as it moves more than necessary, for a system with significant process noise.
- Filtering should be considered for a process with significant noise that could benefit from derivative.

PI vs. PID Tuning in an Integrating Process

An integrating process requires tuning that is different than the tuning of a non-integrating process. For instance, using the derivative term (D term) is much more important for an integrating process, and it provides a greatly improved and more stable response.

To better understand how the PI/PID controller operates on an integrating process, in Example 2 we will take look at a liquid level controller in a hot water tank.

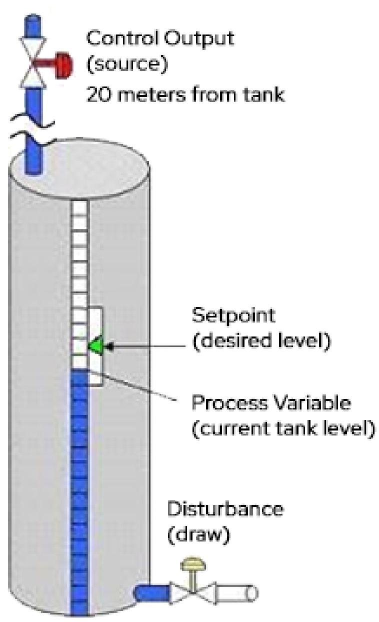
- If the level in the tank is constant, the inflow is equal to the outflow, and the system is stable.
- If the control output (CO) is increased, allowing more water to flow into the tank, the tank will begin to fill up and the tank level (process variable, PV) will increase at a constant rate.

EXAMPLE 2: LIQUID LEVEL CONTROLLER

For this example, we will use a different computer simulation to model the behavior of the liquid level controller.

For the integrating process simulation, we will model a disturbance in the system. Initially, we will assume that there is no load on the water tank and that the water level is static. When the simulation time reaches 300 seconds, we will introduce a load to the water tank, and examine how our controller behaves. We expect an initial drop in water level, after which the controller should compensate.

Figure 7 - Liquid level controller system characteristics.

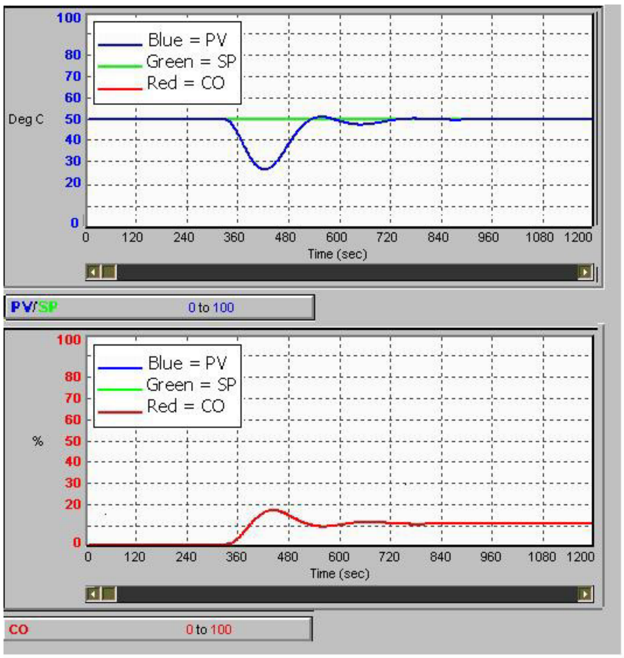


The blue metric represents the current water level.
The green arrow points to the desired level SP.

Parameter	Estimated Value
Tank Capacity	295 Liters
Tank Height	1.5 m
Influent {CO}	0 to 5 Liters / second (L/s)
Effluent {Disturbance}	1 to 3.75 L/s
Liquid Level	0 to 1.5 meters
Level Setpoint	1 meter
Tank Containment	197 Liters/meter
Process Gain	0.05 L/s per %CO
Process Time Constant	10 seconds
Process Deadtime	25 seconds
Distance from Control Output Valve to Tank	20 meters

A quick glance at Figure 8 and Figure 9 tells us that the responses are similar. However, it is important to note that what looks like a small difference carries big implications.

Figure 8 - PI response for integrating process.

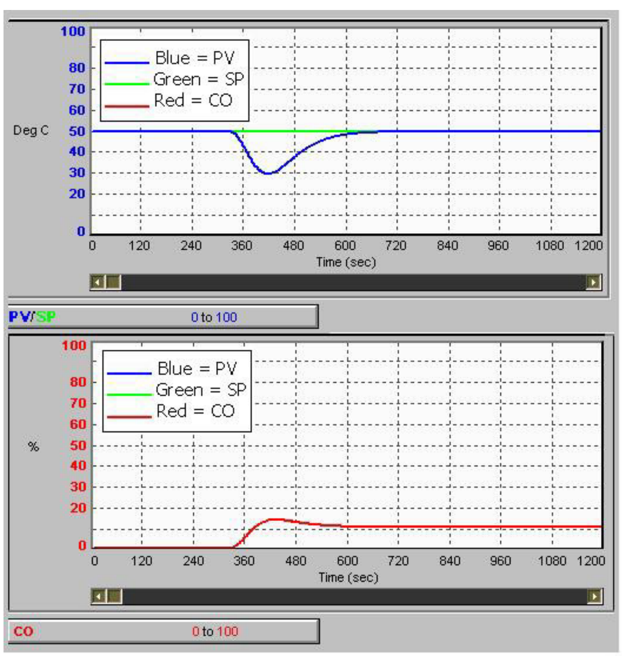


In Figure 8, we see the response that PI tuning alone can achieve. For the PI simulation, the tuning parameters were P= 0.47, I = 132, and D = 0.

The disturbance causes the PV to drop down to approximately 25.

We notice that a second minor disturbance happens following the main one. This is caused by the behavior of the CO, which is somewhat oscillatory.

Figure 9 - PID response for integrating process.



For the PID simulation shown in Figure 9, the tuning parameters used were P = 0.47, I = 132, and D = 11.

After generating the best response possible using just the P and I terms, the D term was added.

A closer comparison of the two responses shows that the disturbance in the PID simulation causes the PV to drop to about 20.

Simply tuning with the D term reduced the effect of the disturbance by about 20%.

An additional important consideration is the amount of time needed to recover from the disturbance.

For this example, we define the end of the disturbance to be at the time when the PV maintains at SP.

- Without using the derivative action, the disturbance affects the PV for 500 seconds (t= 300...t=800).
- When we add the derivative action, we reduce this time to 300 seconds (t = 300...t=600). This is approximately a 40% reduction in the total recovery time.

Other factors to consider when choosing a PI or PID controller:

- How much does the CO change during the disturbance? For the water tank example, this equates to valve travel. Valve travel increases the wear on the valve and decreases its lifespan.
- For integrating processes with higher gains and longer deadtimes, tuning the derivative action is virtually a requirement to achieve optimal process response and control. For the controller in this example, using the D term significantly improves the response of the PV.
- Applications with significant amounts of electro-magnetic interference (noise) affecting their process can be problematic. Excessive noise often makes PI the better choice. It is very important to identify noise in a process and adjust the tuning as needed.

Summary

The decision to use the derivative action to control a process depends on many factors, including the process type, desired response, and system dynamics.

In general, using the D term in your controller can speed up the closed loop response. However, one might want to be cautious with the existence of noise, as the derivative term amplifies the noise in the PV signal.

Generally, it is advantageous to use a PID controller (rather than PI) in slow processes such as a hot water tank or a rotary motor controlling a rotational shaft position, where the application requires a fast and stable response. To help decide whether to use PI or PID, we recommend using tuning software, such as ControlSoft's INTUNE PID Loop Tuning Tools, to generate parameters for all types of processes and both types of tuning.

Additional Resources

DOCUMENTATION

Refer to these documents for more information on INTUNE Software:

Publication No.	Document
DS401G	PID Loop Tuning Pocket Guide: **https://www.controlsoftinc.com/pid-tuning-pocket-guide/**

TRAINING

We offer individual and group training for additional assistance with PID loop tuning and advanced process control techniques. See our website for more details: **https://www.controlsoftinc.com/training/**.

TECHNICAL SUPPORT

Contact us for technical support:

By	Details
Phone	Monday – Friday: 8:30 am - 5:00 pm ET 1 (440) 443-3900 After-hours support available for maintenance agreement customers.
Email	Send email to: **tech-support@controlsoftinc.com** We'll respond within two hours during business hours.
On-site	Arrange for our engineers to come to your location for: • Troubleshooting • Optimization • Control Loop Performance Monitoring Send email to: **sales@controlsoftinc.com** Or call: 1 (440) 443-3900

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