PID

What is PID and how does it work?

Auto tuning PID with the 5400 Controller

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What is PID?

PID control (pronounced P-eye-Dee) stands for **P**roportional-**I**ntegral-**D**erivative, and is a mathematical method for controlling any parameter such as temperature, speed, or pressure. It uses three mathematical parameters to determine the variable amount of input to be applied to a system to achieve the desired output. Once proper values for the three PID constants are determined the desired output can be reached in the minimum amount of time with a minimal amount of fluctuation once the output is reached.

<u>Common Terms and Abbreviations:</u>

Setpoint (SP): The desired output of the system, for controlling temperature this would be the desired preheat or cooking temperature.

Process Variable (PV): The parameter measured by a sensor such as temperature from an RTD or thermocouple probe.

For the remainder of this document we will use 'temperature' as the process variable we are measuring and 'setpoint' is the desired temperature we want to achieve.

Overshoot & Undershoot: Overshoot is when the temperature exceeds the setpoint by a significant amount, undershoot is the reverse. PID minimizes this by varying the output percentage instead of the output being only either fully on or fully off.

<u>Why Use PID?</u>

In a system controlled by an electronic or mechanical thermostat the output is turned on until the temperature reaches slightly above the setpoint and then turns off. Because the heaters have put a lot of energy into the system the temperature continues to rise and then starts to drop. Once the temperature drops to slightly below the setpoint the heat is turned back on. Then the temperature continues to drop until the heaters have put enough energy back into the system and the temperature starts rising again. This amount of overshoot and undershoot can be significant and is dependent on the heater wattage, air circulation, and amount of insulation … standard home ovens can undershoot/overshoot by as much as 50°F.

Using PID control allows the heat to applied to the system in varying amount by cycling the heater on and off on a continuous basis and varying these times to produce the desired percentage. Solid state relays are used instead of electromechanical relays or contactors as the number of on/off operations when using PID would wear the relays out quickly.

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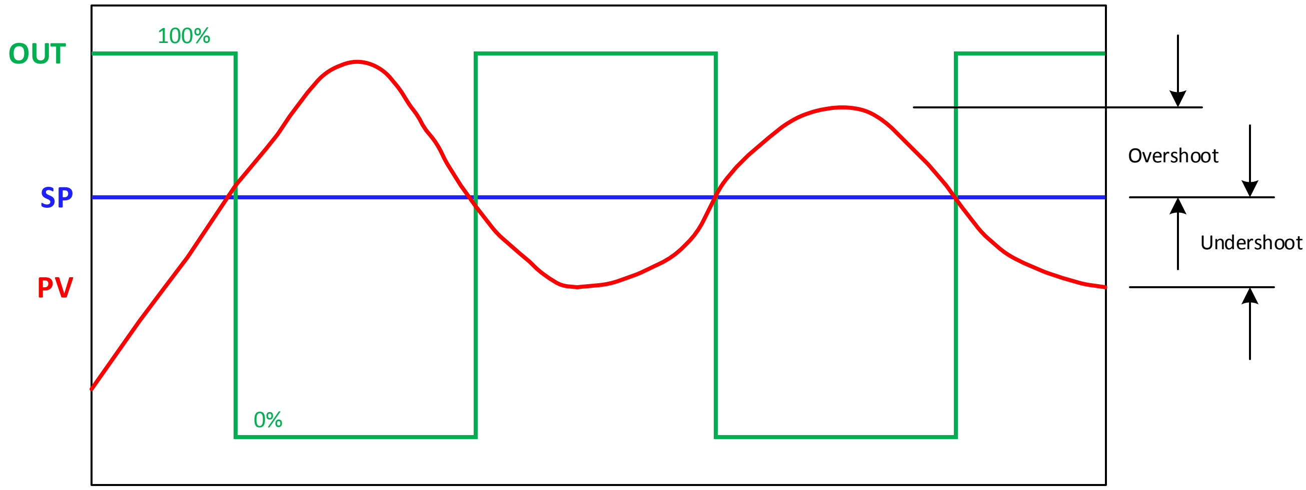
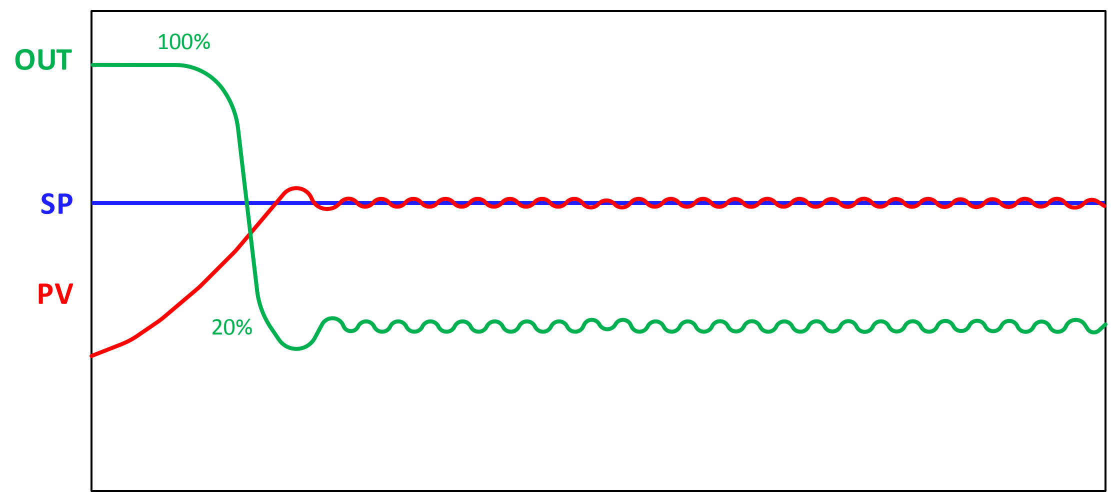
Here are two diagrams showing the difference between thermostatic and PID control:

OUT = Output percentage, SP = setpoint, PV = measured temperature

Thermostatic Control



PID Control



Note how the PID control applies full power until the temperature (PV) starts approaching the setpoint (SP), then starts decreasing the output percentage, this minimizes the temperature overshoot when first heating up. Then as the temperature increases or decreases around the setpoint the output percentage is changed to bring it back to setpoint.

All control systems oscillate around their setpoint, but with properly tuned PID control these oscillations can be minimized and virtually eliminated along with the initial overshoot when starting to heat up.

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P, I, and D Explained

PID stand for the three terms which are used to calculate the output percentage.

P = Proportional
The Proportional term is the *proportion* of output necessary to achieve a certain temperature. For example: 10% output = 200°F, 20% output = 250°F, 30% output = 300°F, etc. The setpoint is used with the P value (K_P) to calculate an initial percentage of output which should result in the desired temperature. You can simply use the P value and set the other terms to 0 but it would take an extremely long time to get to the setpoint. From the diagrams on the previous page the output percentage to get to the setpoint is about 20%, applying only 20% (instead of the 100% shown) would extend the time to achieve the desired setpoint by a huge amount. To remedy this problem the I term is used next …

I = Integral
The Integral term (K_I) is multiplied with the value of the setpoint minus the temperature and the result is *added* to the P term from above. If the temperature is below the setpoint the integral value will be positive and will add to the proportional term (SP - PV > 0), if the temperature is above the setpoint the integral term is negative (SP - PV < 0) so when it is added to the proportional term the result is less. So if the temperature is very low, this term will add a lot of heat to get to the setpoint quicker, and as the temperature gets closer to the setpoint the added value will get smaller and smaller until the setpoint is reached. Once at setpoint the integral term will only add or subtract a small amount, keeping the temperature close to the setpoint.

The P and I terms do an excellent job of control, but one thing that has not been addressed is how fast we get to the setpoint. Having a significant amount of Integral correction to the Proportional term will allow us to get to the setpoint quickly but can cause the system to overshoot and undershoot (oscillate) to undesirable amounts, that is where the Derivative term comes into play.

D = Derivative
This uses the *slope* of the temperature (how fast it changes), this slope is used with the Derivative term (K_D) and the result is *subtracted* from the P and I results from above. The effect of this will be to control how *fast* the temperature is approaching the setpoint … if the temperature is quickly rising to the setpoint the D value will subtract from the P and I output percentage to slow it down, thus reducing the overshoot when we reach the setpoint. The reverse is true when the temperature is rapidly dropping down to the setpoint, the D value will increase the output percentage to try to prevent the undershoot. Thus larger D term values will slow down the approach to the setpoint, smaller values will allow the temperature to reach the setpoint quicker.

For the mathematicians: $Output = (K_P \times SP) + (K_I \times (SP-PV)) - (K_D \times PV/t)$

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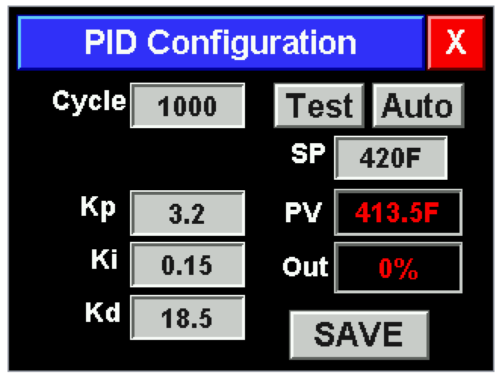
Determining P, I, and D

You can manually tune your system, trying different values of the PID terms, but this can be a long and extremely frustrating experience with questionable results. Artisan provides PID auto-tuning to get you to the optimal PID values with a reasonable amount of effort. Once the auto tune feature has been ran a few times a small amount of manual adjustment with the understanding of their affects can provide the temperature control you need for your application.

Auto Tuning the PID
In order to calculate the PID constants the controller needs two pieces of information: the gain of the system (how much a change in the output will affect the temperature) and the period (the time it takes for system to respond to a change in the output). Artisan's auto tune software determines these by running the controller in thermostatic mode. The output is changed between a low percentage and a high percentage as the temperature goes above and below a setpoint and the high temperatures, low temperatures, and time between the high and low temperatures are measured and the averages calculated. From these values the P, I and D constants can be calculated.



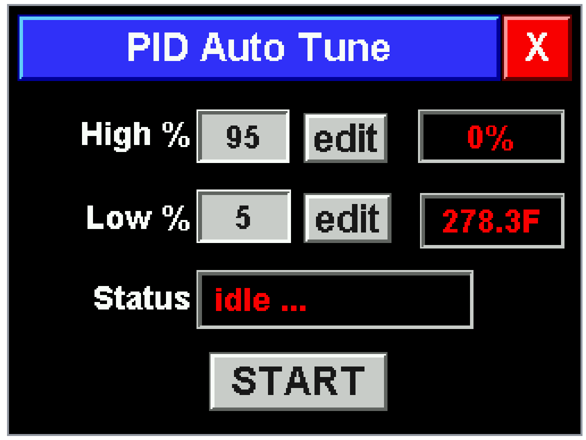
To the right is the PID configuration screen, please refer to the users manual to access this window. This screen shows the output on/off cycle time for PID control in milliseconds, this should be left at 1000 (1 second) and does not need to be changed under normal circumstances. *This screen may also show a Depth value (in custom versions) which allows the history of temperature values to be changed for slow or fast response systems.*

The PID values (K_P, K_I, K_D) are shown, this screen is from after an initial PID auto tune was performed, the default values are 1.0, 0.0, and 0.0. Also shown is a setpoint (SP) box, a temperature box (PV), and a box showing the current output percentage. In this case the PID control is not running so the output shows 0%.

This screen is where you can manually change the PID values, test them by pressing the [Test] button, perform the auto PID tuning by pressing the [Auto] button, and permanently save the PID terms for use in your system. The PID values can be exported by using the USB port so that once you have determined your best values they can be easily imported into your production controllers.

Before you use the [Auto] button you must set the SP value in this window as it is used in the auto tune windows, it should be the typical temperature used in your application. Touch the SP box and the screen changes, enter your typical setpoint value and touch [SAVE] to save that value and return to this screen.

This is the PID auto tune window, showing the high and low output percentages, output percent, current temperature, and the status of the auto tune process. The [edit] buttons allow for changing the output percentages.



Output values of 5% and 95% are appropriate *only* for the first time running the auto tune, subsequent tuning cycles should use adjusted values to obtain optimal PID constants.

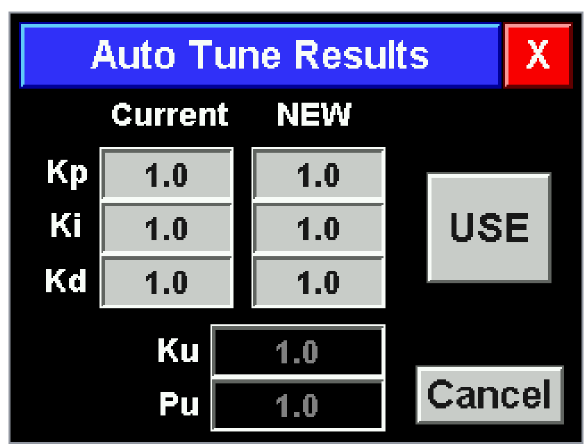
Performing An Auto Tune

With the percentages set at 5% and 95%, press the [START] button to begin the cycling of the heat. The setpoint used with the auto tune is 2/3 of the setpoint entered on the configuration screen, the trip points for turn the heat output up or down are set at ±1% of this calculated setpoint. The system will cycle the heat up and down three times to ensure stability (displaying “Cycling 1”, “Cycling 2”, etc) then it will start measuring the temperatures and timing values.

During the measurement part of the process observe the high and low temperatures, after this initial tuning you will need to adjust the percentages in order to do a second auto tune for the best tuning values.

If it is taking an extremely long time to get through the cycles stop the auto tune, move the percentages closer to each other, and start again. If the system is spending too much time above setpoint drop the upper percentage, or spending too much time below the setpoint raise the lower percentage. The converse is also true, raise the upper percentage of it is taking a long time to heat up, and drop the lower percentage if the system is taking a long time to cool down

The ideal PID auto tune is when the controller spends equal time above and below the setpoint, stopping the auto tune cycle and adjusting the output percentages to minimize the time cycle and undershoot and overshoot will yield the best results.



Once the auto tune cycle is complete the results window will show the old and new PID constants along with the calculated system gain (K_U) and system period (P_U). Touch the [USE] button to accept those values and return to the configuration window.

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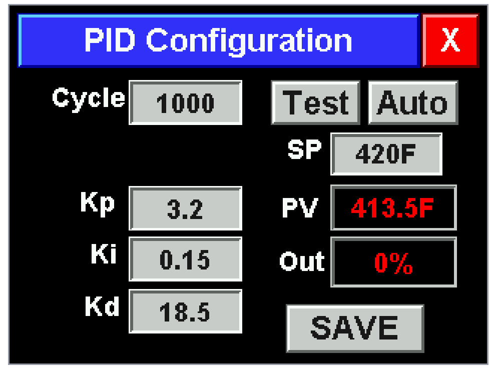

After an Auto Tune

Once new PID values have been calculated the configuration window will show these new values *but they are only temporary and have not been saved.*

You can save them immediately or use the [Test] button to verify their performance before saving.

The [SAVE] button saves the new PID values, the setpoint, and the percentages used in auto tune. When the system configuration is exported to a USB drive these values are in the "PID.CFG" file and are automatically imported when performing a configuration import.

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