Understanding PID Temperature Control As Applied To Vacuum Furnace Performance

INTRODUCTION

Proportional-Integral-Derivative (PID) control is the most common control type algorithm used and accepted in the furnace industry. These popular controllers are used because of their robust performance in a wide range of operating conditions and because of their simplicity of function once understood by the processing operator. The purpose of this paper is to further define and thoroughly explain the basics of the PID controller.

It should be noted that many current instruments incorporate what is called an "Autotune" feature which can automatically set the PID variables for a given temperature setting allowing the operator to bypass much of the initial manual requirements. However, Autotuning was not introduced until the late 1980's and there still exists many instruments in use which do not have this tuning feature and must still be manually set-up. Also, Autotuning often requires additional tuning or tweaking to reach final acceptable results. By understanding fully the basics of the PID functions as described below, it is hoped that any final adjustments or tuning will be simplified. Further discussion of the Autotune feature follows below.

As the name suggests, the PID algorithm consists of three basic components: proportional, integral and derivative which are varied to get optimal response. If we were to observe the temperature of the furnace during a heating cycle it would be rare to find the temperature reading to be exactly at set point temperature. The temperature would vary above and below the set point most of the time. What we are concerned about is the rate and amount of variation. This is where PID is applied.

DEFINITIONS

1) Closed Loop System – In a typical control system, the process variable is the system parameter that needs to be controlled, such as temperature for the vacuum furnace. The control T/C is used to measure the process variable and provide feedback to the control system. The set-point is set for the desired temperature for the process, such as 1500^{o}F. At any given moment, the difference between the process variable and set point is used by the control system algorithm to determine the furnace power output required to reach and maintain set-point.

2) Proportional (GAIN) – means a value varying relative to another value. The power output of a proportional controller is relative to the difference between the temperature being controlled and the set-point. The controller could be full ON at some temperature which is well below the set point or full OFF at some temperature above set-point. This creates a Proportioning Band above and below set-point and the power within the band adjusting proportionately to the set-point. See Figure 1

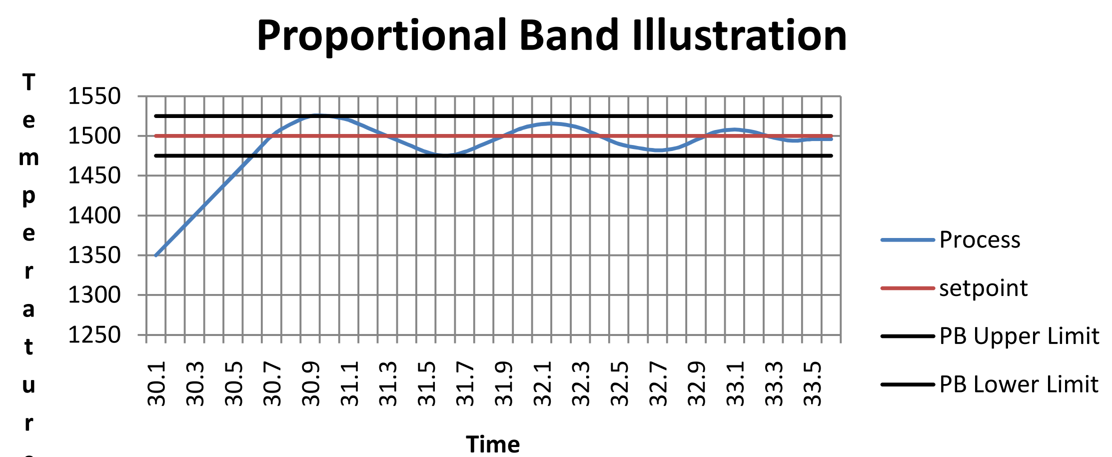

Figure 1

3) Integral (RESET) – this component will provide automatic and continuous elimination of any offset between final settling temperature and set-point. After monitoring and averaging the actual temperature over a period of time, this feature shifts the Proportional Band upscale or downscale until the system temperature and set-point coincide. See Figure 2 where the Blue process will eventually be corrected to Red set-point.

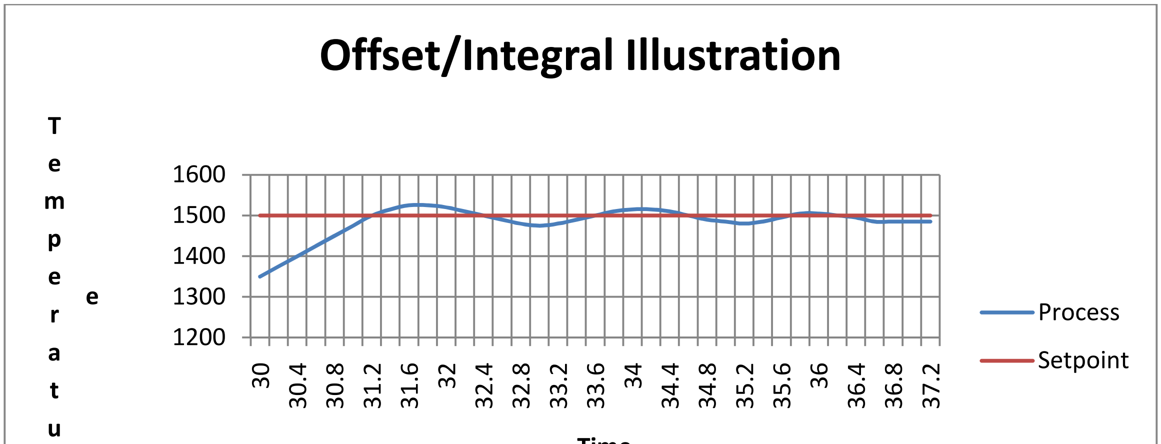

Figure 2...

4) Derivative (RATE)– this component when combined with proportional action improves control by sensing either positive or negative changes and correcting them more quickly. The proportional is effectively intensified (its gain increased) to achieve a quicker response. As illustrated in Figure 3, the process temperature is rapidly corrected (Green Line) with the derivative active as compared with the slower correction (Red line) without the derivative active.

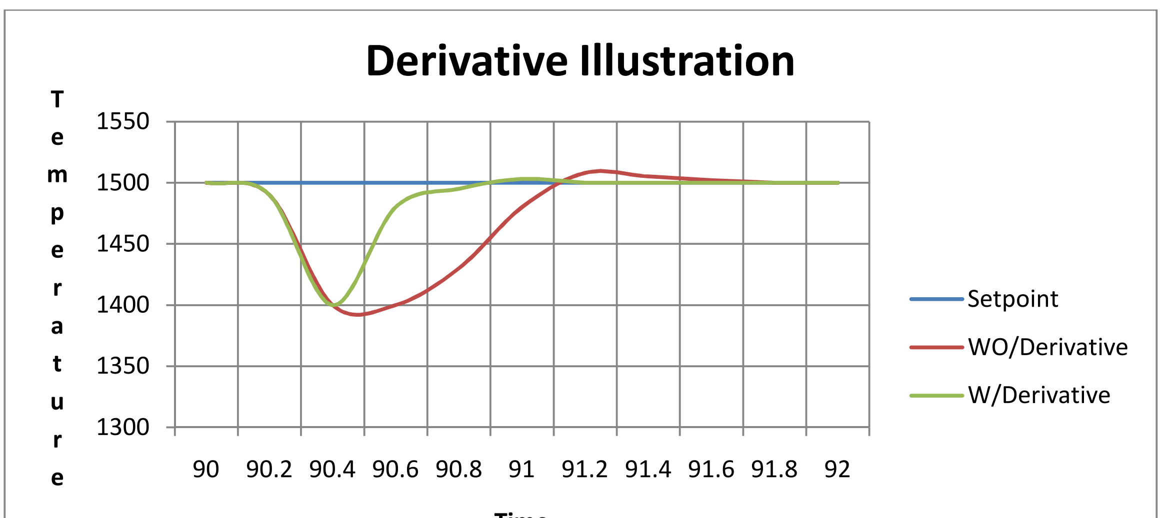

Figure 3

ACTUAL OPERATION

1) UNDERSTANDING PID DIMENSIONS AND VALUES
   Although instruments can vary in how each PID value is expressed, most controllers would use the following units:
   a) Proportional Band – usually expressed as a percentage of full scale range where the proportioning action takes place. The wider the proportional band, the greater the area around the set-point in which the proportional action occurs. Proportional band is sometimes referred to as GAIN which is the reciprocal of the proportional band number.
   b) Integral – This value, also known as RESET, is usually expressed in time (seconds). This component sums the error between the process value and the set-point over the set time period and makes an adjustment accordingly.
   c) Derivative – This component is also expressed in time (seconds) and usually ends up being about 1/4 to 1/6 the value of the Integral time. The derivative response is proportional to the rate of change of the process variable. The time setting represents the period over which the derivative reacts to the process conditions.

2) GENERAL RULES FOR MANUALLY ADJUSTING PID
   The following rules define what happens with each component adjustment:
   a) Proportional Band – Configured as % of range
      1) Low Numbers – More Responsive
      2) High numbers – Less Responsive

   b) Integral – Configured as time constant (seconds)
      1) Low numbers – More Integral action
      2) High numbers – Less Integral action

   c) Derivative – Configured as time constant (seconds)
      1) Low numbers – Less Derivative action
      2) High numbers – more Derivative action

As stated above, most modern PID controllers have the autotune capability which will often work very satisfactorily, so why even need to understand how to tune the PID? However, keep in mind that that autotuning functions are based on assumed dampening values which may or may not be perfect for your furnace system. Also, if you have an instrument which does not have Autotuning such as the Allen Bradley PLC used on many furnaces or even if you have Autotuning, being skilled in the art of tuning allows you to consider trade-offs in the performance of your controller which would not be apparent if you relied solely on an autotune feature.

In general, the most popular method of tuning involves the close loop type of tuning, primarily because they are the easiest to do and the least time consuming. Begin by placing your controller in the ON-OFF mode (turning off the PID). If your controller does not have this capability, set the proportional band as low as possible (1 or 2%). Turn the Integral function off or set it to zero. If you cannot set it to zero and it is configured as a time constant as with most modern instruments, setting it as high as possible will disable the Integral function. Finally, turn the Derivative to OFF. If this is not possible, set it to zero or as low as possible. It is understood that a chart recorder is part of the control panel.

Start with an empty furnace and establish what set point is to be reached. Let us say this is 1500^{o}F. Allow the furnace to time to reach set-point. The chart recorder should show something as shown in Figure 4.

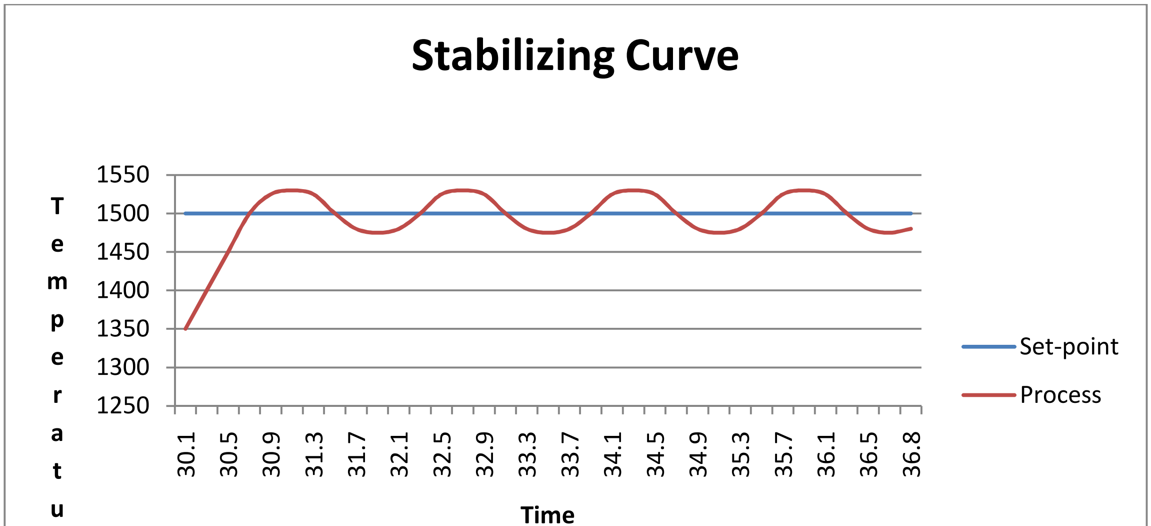

Figure 4

This curve allows us to establish two important values –

1) The Amplitude which is the difference between the highest and lowest temperature achieved during stabilization.
2) The Period which is the time after settling between peak to peak or valley to valley. This time should be recorded in seconds if your Integral and Derivative functions are typically in seconds.

The range of a controller is usually defined by the specific type of thermocouple used for the process. Go to the configuration section of the controller to help determine the range.

Based on the above, we can now use the following formulas to determine a preliminary value of each PID component:

1) % Proportional Band = Amplitute X 100/ Input Range

2) Integral Time (Seconds) = Period

3) Derivative Time (Seconds) = Period/6

Put these PID calculated values into your controller which should represent an excellent starting point. Most likely some tweaking will be required which is covered in the next section.

AUTOTUNING

As stated above, many instruments today incorporate an autotuning feature that provide for being able to determine PID settings automatically for different temperature settings. With the autotuning function, PID values are measured, computed, and optimum PID constants are set. This allows for deriving accurate PID values to achieve stable and more accurate control. The autotuning feature of the instrument is normally activated when the system has reached desired furnace temperature set-point and stabilized for at least 15 minutes. The PID parameters are derived via the software of the microprocessor in the controller. Most instruments allow for establishing and automatically storing PID setting for various temperature settings as they will be different for each final stabilizing point.

TWEAKING THE FURNACE PID CONTROLLER

We should define tweaking as minor adjustment of the PID parameters in pursuit of control perfection whether following an Autotune or Manual set-up.

One of the most important concepts to keep in mind when doing tweaking is to understand the potential for harmful interaction between the three PID functions. For example, if the integral function is set to a time which is shorter than the natural period of the process, it could start erroneously applying correction which might be easily mistaken as a problem with the Proportioning function. Similarly, too long a Derivative time could cause your system to oscillate unnecessarily. We should remember that the principal function of the PID is to better control the P.

Some basic rules in tweaking PID parameters would include: when fine tuning the PB, keep in mind that excessive oscillation or swing can result in either too high or too little Amplitude (Bandwidth). This could result in pronounced period length which would mean generally sluggish response when set too high or shorter period length accompanied by greater amplitude when set too low. Finally, be sure to change only one value at a time. Remember, Integral and Derivative values which are set too long will cause oscillation or swing while setting them too short could make them essentially ineffective.

OTHER FACTORS

1) It should be noted that if Autotune is done at several temperatures, resulting PID parameters will be high at the lower temperatures and will be decreasing in value as the temperature values are increased. This is why the autotune process is valuable in that it can establish and store each PID functional values at several different temperatures and implement those values when operating in each range. See Figure 5

Temperature	Proportional Band	Integral	Derivative
600	17.5	653	163
900	12.3	408	102
1500	4.4	225	56
2100	3.5	170	42

Figure 5

2) When initiating an Autotune function, the operator should determine the % of output power being used to hold stabilizing temperature and set the Autotune Hi Limit to 3-5% above this number. This input will expedite the system in establishing the PID parameters.
3) When multiple PID parameters have been established for various set-points using Autotune, the operator enters at what temperature cross-over occurs between one set of PID values and the next set of values.
4) Overshoot is a critical component of any process and must be minimized. By properly programming any heating cycle and having the proper Proportional Band and Derivative value established, this can be controlled within acceptable limits.
5) Many furnace users consider limiting power output so as not to overdrive the hot zone of the furnace. This is especially important at lower temperatures (under 1000^{o}F) and users should consider minimizing power output to the 15-30% range.

TYPICAL PID CONTROLLERS –

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