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Basic PID Control Loop Theory

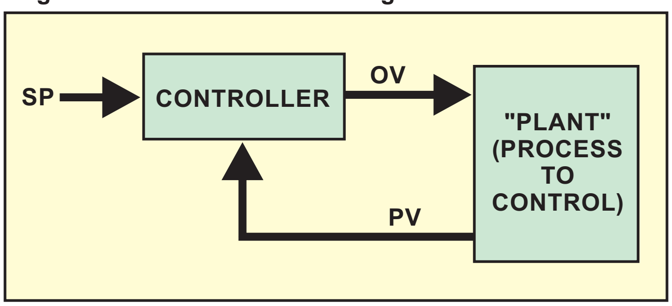
Introduction

PID control is one of several methods used to control a process in a "negative feedback" loop. The roots of the PID method can be traced back to an early period in the industrial revolution. Although PID control is one of the oldest control methods, it still remains one of the most useful methods to control a process. A "process" refers to any "closed loop" system whereby an automation controller (the controller) changes an "actuator" which then changes the process under control. The process "operating point" is measured and fed back to the controller. The controller continuously adjusts the actuator based on the desired operating point and the actual "feed back" operating point.

Terminology

PID stands for **P**roportional, **I**ntegral, and **D**erivative. Figure 1 shows the basic PID control block diagram.

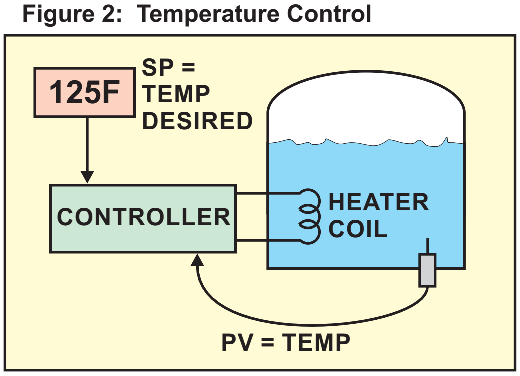
Figure 1: PID Control Block Diagram



The process under control is called the "plant". The operating point of the plant is called the "process variable" (PV) and is fed back to the controller. The "set point" (SP) is an input to the controller which indicates the desired operating point of the plant. The controller output is the "output variable" (OV) which is fed to the plant and controls an actuator. The output variable is also called the "manipulated variable".

For example, figure 2 shows a typical PID control process-maintaining a tank of liquid at a set temperature. In this process, the heater coil is the actuator. The output variable from the controller determines the amount of power provided to the coil. The process variable is the actual temperature of the liquid. The set point is the desired temperature: 125F.

Figure 2: Temperature Control



Theory

The basic equation for a PID controller which samples the process variable and changes the output variable in discrete time intervals is:

$$\begin{aligned} OV(n) = {} & Kp * E(n) + \\ & Ki * [E(n) + E(n-1) + E(n-2) + \ldots + E(0)] + \\ & Kd * [E(n) - E(n-1)] \end{aligned}$$

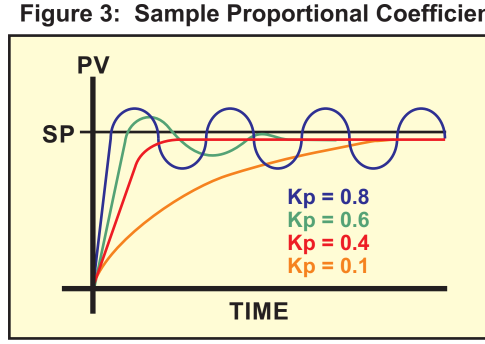
where:
- $OV(n)$ = output variable at the current time sample
- $E(n) = SP(n) - PV(n)$ = error at the current time sample
- $E(n-1)$ = error at the prior time sample
- $E(0)$ = error at the first time sample
- Kp = the proportional coefficient
- Ki = the integral coefficient
- Kd = the derivative coefficient

First, consider the case where Ki and Kd are both zero. In this case the controller acts strictly as a proportional controller with output:

$$OV(n) = Kp * [SP(n) - PV(n)] = Kp * \text{error}$$

A possible graph of the PV output is shown for the proportional only controller in figure 3. The Kp values shown are only for illustration. For any "real world" process, the Kp value will need to be optimized for the process. Notice that the higher the proportional coefficient, the quicker the output approaches the set point. However, if the Kp value is too high, the PV will become unstable.

Figure 3: Sample Proportional Coefficients



In the proportional only controller PV will never exactly match SP because as PV approaches SP the error approaches zero and the output (OV) is turned off. Therefore, PV is slightly offset from SP as shown in the graph. This can be corrected with the addition of the I (integral) term. The integral provides a way to slowly adjust OV based on the accumulated errors. By setting Ki to a non-zero value (typically 0.2) the PV value can be made to approach SP exactly. The integral can be thought of as the "slow adjustment" contribution to OV whereas the proportional control provides instantaneous adjustment.

For fast changing processes the D term (derivative) can be added. The derivative contributes to OV based on the rate of change of the error (i.e. the slope of the error). The derivative acts to "predict" the future error and changes OV so as to minimize the error at the next time interval. The derivative can be thought of as the "fast adjustment" contribution to OV. A typical value for Kd is 0.1.