PID Control - - What, Why, How ?

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Open and Closed Loop Control

The typical residential sprinkler system is controlled by a simple timer that turns the system on at some preset time and then turns it off at some other preset time. And, it doesn't matter if it is raining cats and dogs - - it will turn on and off based on the timer settings. In the "process" environment, this control scheme is known as "open loop" control. Open loop control works well as long as the event it controls is repetitive and no damage could result from its action. If our sprinkler activates during a rainstorm, the water is wasted but no damage occurs. Open loop controls are also simple and inexpensive. The key characteristic of open loop control is that the controller has no clue what is going on within the system. It simply follows its instructions, to the letter, regardless of its surroundings. You probably know some people who fall into this category!

It is a bit different when it comes to your home heating system. Although open loop control could be used, the results would be less than satisfactory. You would experience periods when it is too warm and others when it is too cold as the heater would start and stop based on a simple timing cycle. A better control method would provide some "feedback" to the heater based on the desired temperature and the actual measured temperature at any point in time. It could then make its own decision as to when it should start and how long it should operate. In the typical home heating system this is accomplished with a thermostat. When the temperature drops below a certain predetermined level, the thermostat starts the heating system and runs it at its full capacity until the temperature rises to some maximum. The thermostat then stops the heating system and waits to begin another cycle. This is an simple example of "closed loop" control. More specifically, it is known as "on/off, closed loop control" as the heater is either fully on or fully off and there are no intermediate settings. The key characteristic of the closed loop controller is that it receives some form of feedback as to what is going on within the system and can therefore make more "intelligent" decisions.

Proportional Control

Now, suppose, for a moment, that our home heating example does not use an on/off thermostat but, instead, uses one that can transmit the actual measured temperature in the room back to the heating system controller. Lets also suppose that the heating system can vary its output based upon the temperature it receives from the thermostat. (For example, a gas system can accomplish this by varying the number of burners that are active at any point in time and an electric furnace can vary the current seen by the heating element.) As the temperature in the room approaches its "set point" the heater would not necessarily turn off but, instead, reduce its output and attempt to keep the room at the desired temperature. If the temperature drops, it would increase its output and if the temperature increases it would either reduce its output or shut off completely. Furthermore, these changes in output would be in "proportion" to the change in temperature. A small change in temperature results in a small change in output while larger changes in temperature would lead to proportionally larger changes in heat output.

The example above is one of "proportional, closed loop" control and is the "P" in "PID". Proportional control is used in systems where the feedback measurement tends to change slowly. Your car's cruise control also operates by proportional control. The controller monitors speed and changes the throttle setting in proportion to the change in speed it sees. These devices work very well on level and slightly inclined roads but you have probably noticed that they do not work as well on a steep incline. A steep incline will decrease your speed quickly but the controller reacts in its normal fashion and speed will remain well below the set point until, ultimately, the transmission drops into a lower gear and the speed set point is once again reached. If the steep incline continues this cycle will repeat itself a number of times. The proportional controller uses an "algorithm" to accomplish its mission. An algorithm is simply a set of rules for solving a problem in a finite number of steps. In the past we used relay logic to carry out the various steps but, today it is accomplished by a software program that is executed by a PLC (programmable logic controller) or some other computer like device.

In the pumping environment proportional control is seen daily. Multiple pump booster booster systems use multiple pressure switches to bring additional pumps on line based upon changes in system pressure. Proportional control is also used in some simple VFD pumping applications where a finite number of different flows or pressures are required by some process. For example, a process may require three different flow rates based upon the number of machines operating at a given time.

If a single pump can provide all three flows at different speeds, the VFD can use proportional control to vary its output frequency and satisfy the application's requirements.

PID Control

There are, however, times when proportional control, by itself, cannot provide the accuracy required by a process. Take, for example, a constant pressure booster system under VFD control. If changes in flow and the resulting change in pressure occurred gradually over a long period of time, the VFD could use proportional control to keep pressure constant. But this is seldom the case. Abrupt flow changes are the norm and their duration can vary substantially depending upon the application and time of day. When a proportional control system is forced to act on a rapidly changing event, it tends to over react. Once it has over reacted in one direction, it will probably over react in the other. These "oscillations" can cause instability and, in some cases, a total loss of control. Therefore, these types of systems will require some "tweaking" (fine tuning) of that proportional algorithm if the drive is to maintain constant pressure under a host of differing conditions.

Remember, that unlike we humans who might monitor several conditions within a system at the same time, the VFD usually monitors only one. It could be the output of a pressure transducer, a flow meter, or that of an ultrasonic level device. Regardless of the input it is always one dimensional - - just a stream of varying electric current that equates to PSI, GPM, or Feet. Now, if you were controlling that pump your multitasking brain would allow you to add another dimension to these data (assuming, of course, you are not one of those open loop people we mentioned earlier).

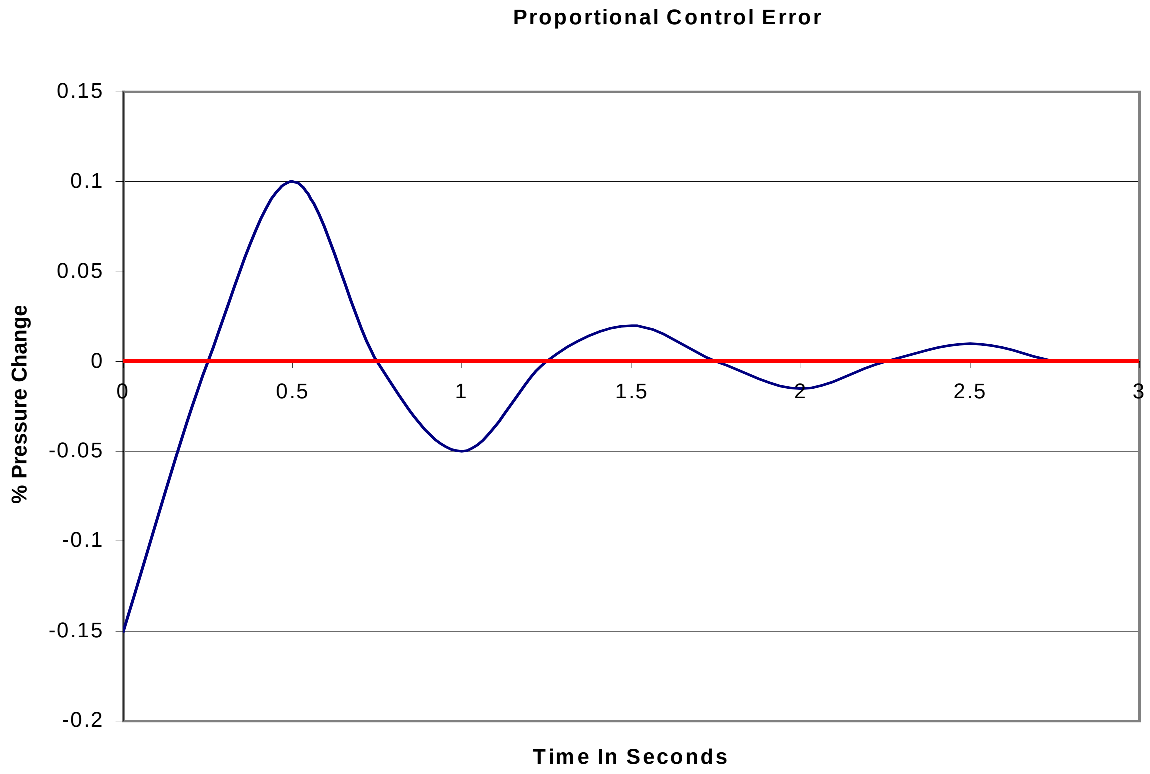
Suppose that you have been tasked with controlling the speed of a centrifugal pump in order to maintain some constant pressure. You know nothing about the flow and head characteristics of the pump and you have never heard of the affinity laws. You have only two tools - - a joystick that will allow you to increase or decrease speed and a pressure gauge that shows the system pressure. If the pressure drops, you would move the joystick in a direction that increases speed and try to get the pressure back to the set point. If pressure rises past the set point your hand would react in the opposite direction. In the beginning, you will probably over react to the changes in pressure displayed by the gauge. This is human instinct at work - - if some is good, more is better! But, as you gain experience, that simple pressure gauge will provide you with additional information that will allow you to better control pump speed and the resulting pressure it produces.

One of the first things you will notice is that the range and duration of the pressure drops are not the same. Some will be very small (1 – 2 PSI) and last for just a few seconds. Others may also be small but last for minutes. And some will be much larger and last for varying amounts of time. Another piece of information the gauge will provide is how quickly these changes occur. Some changes in pressure may be large but occur slowly while others can occur in the blink of an eye. Interestingly enough, your analog brain will begin to incorporate this additional information into your control scheme and your ability to control speed and pressure will increase significantly. And, it is this ability to add an additional dimension that allows your foot to do a better job than the cruise control on a steep incline. The difference is that you can see the hill and react accordingly to its steepness and duration. That simple proportional cruise control cannot. The I and D values of PID attempt to do exactly what your human brain did - - add an additional dimension to the rather limited information received by the controller. Basically, they add new dimensions to the algorithm and help the controller decide upon how much and how quickly it reacts to a particular change in pressure.

The Integral and Derivative

The "tweaking" I referred to earlier involves the integral and derivative. These functions are two essential components of the mathematics known as calculus and although they can seem complex their function is pretty straight forward. (If you are interested in learning a little more about calculus download "Why Newton Invented Calculus" at Pumped101.com. You will find under the VAST category.) In calculus, the derivative is used to illustrate the rate of change of some other value. The integral does the exact opposite and converts the derivative back into its original value. So, if the derivative of distance is velocity, the integral of velocity is distance. It follows then that the derivative of a 5 PSI pressure reduction is the change in pressure per unit of time. And, the integral of that change over time is the total change itself. Integration allows us to measure the area of a complex curve that is continuously changing over time and differentiation allows us to calculate the rate of change at any point on that curve. OK, maybe that was not an adequate explanation. Perhaps if we expand on it a bit and see how these two functions affect the proportional algorithm, it will become clearer.

I mentioned earlier that the feedback seen by the VFD is one dimensional, and it is. But, it is also a continuous stream of information and, depending upon the processing power of the controller, it might be monitored anywhere from 10 to 100 times each second. The point here is that the controller is continuously updated with new pressure or flow information. That said, the integral function is the traffic cop for the proportional algorithm and tries to keep it from speeding off in one direction or another. I like to refer to it as the "how much function". It does this by keeping track of the errors that occur and using that information to correct those errors in the future. Almost every time a VFD attempts to bring a change in system pressure back to the set point, it makes a mistake. By mistake, I mean that it initially misses the set point. Part of the reason for this is that, even today (2006), the proportional control algorithm used by the VFD does not take into account the affinity law that governs centrifugal pump pressure - - the one that says pressure changes as the square of a change in speed. Because of this the proportional algorithm tends to over correct pressure changes. The chart below illustrates this point.



The blue curve on the chart plots the % change in system pressure over time. The red, horizontal line at zero on the Y axis is the set point pressure. Here is what happens. At time 0, the controller receives a message that the system pressure has dropped 15%. It immediately initiates an proportional speed increase and it takes about 0.25 seconds to get pressure back to the set point but, unfortunately it doesn't stop there. Pressure increases for another 0.25 seconds and hits its max at 10% over set point. By this point the proportional controller realizes that it has made a mistake and instructs the drive to slow the pump. But, yet again, it over corrects in the opposite direction. Over the next 1.5 seconds it continues to adjust speed until pressure finally remains at the set point.

This curve represents the total error that occurred during the pressure correction and it can broken down into three pieces of information. The first is the "rise time" which is the time it takes for the pressure to increase from its low point to the set point. The second is "overshoot" and represents the maximum pressure that occurred. And, the third is "settling time" or the time required for pressure to settle about the set point. The beauty of the integral function is that it can calculate the area under this complex curve and come up with a numerical value that describes the total error that occurred. It can then use that quantity to police the proportional controller the next time a pressure change occurs. For example, if the controller sees a 10% drop in pressure and decides to increase speed by 10% the integral will say - - "nope, can't let you do that. Based on your past performance I am going to limit your increase to 7%." The integral tracks the error quantity continuously and its response will continue to increase until the error is reduced to zero. This probably never happens but it does reduce, substantially, the total error that results from proportional control alone. In fact many VFD processes, including some pump applications, find PI control more than adequate and don't even use the D in PID.

OK, lets end our discussion with D. As I said earlier, the derivative function of calculus allows us to calculate the rate of change of some quantity that is undergoing some nonlinear increase or decrease. In our example this quantity is pressure and, pressure seldom changes in a linear fashion. Its changes are almost always in the form of a complex curve and the changes cannot be calculated by a simpler mathematics such as algebra. The derivative continuously monitors the rate at which pressure is changing and informs the controller as to how quickly it should react to some change. For example, if pressure is dropping at 0.1 PSI per second there is no need to react too quickly but, if that change is 2 PSI per second a quick fix is definitely required. You can think of the derivative as the "how quickly function".

Well, there you have it - - PID control explained in layman's terms. Essentially it is Proportional Control (P) that is tempered by the additional knowledge provided by the Integral (I) and the Derivative (D) functions.

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