Tuning the PID Controller

The very nice thing about tuning a PID controller is that you don't need to have a good understanding of formal control theory to do a fairly good job of it. Ninety percent of the closed-loop controller applications in the world do very well indeed with a controller that is only tuned fairly well, so you're in luck. I have received a number of emails from people who have used the techniques described here and who were quite satisfied with their results. These techniques don't always work, of course: in some cases you need to gain a deeper understanding of control system theory, such as you would get from my book or from attending one of my longer seminars.

If you can, hook your system up to some test equipment, or write in some debug code to allow you to look at the appropriate variables. If your system is slow enough you can just spit the appropriate variables out on a serial port and graph them with a spreadsheet. If you are tuning something motorized you may be able to just watch it's behavior. Ideally, you want to be able to look at the drive output and the sensor output, to get graphs similar to the ones earlier in this paper. In addition, you also want to apply a changing command—preferably a square-wave—to your system. It is fairly easy to write some test code that will generate a suitable test command.

Once you get the setup ready, set all gains to zero. If you suspect that you will not need differential control (like the motor and gear example or the thermal system) then skip down to the section that discusses tuning the proportional gain. Otherwise start by adjusting your differential gain.

Adjusting Derivative Gain

The way the controller is coded you cannot use derivative control alone. If you can, set your proportional gain to a value that's low enough to prevent oscillation, or at least so that the system is oscillating much more slowly than you want it to react when it is tuned. Check to see how the system works. If it oscillates with proportional gain you should be able to cure it with differential gain. If it doesn't oscillate, but it appears that the proportional control term is working, consider yourself lucky.

Now put in some derivative gain. Start with about 100 times more derivative gain than proportional gain. Watch your drive signal while you stimulate the system. If the system oscillates under derivative control when it did not oscillate under proportional control alone, or if the system oscillates much faster when you dial in some derivative gain, back the derivative gain off by factors of two until it stops.

If you did not need to decrease the derivative gain to make the system stop oscillating, start increasing it gain until you do see oscillation, excessive noise or excessive (more than 50%) overshoot on the drive or plant output. Note that the oscillation from too much derivative gain is much faster than the oscillation from not enough, or from too much proportional gain. I like to push the gain up until the system is on the verge of oscillation, then back the gain off by a factor of 2 or 4. Make sure the drive signal still looks good. At this point your system will probably be settling out very sluggishly, so it's time to tune the proportional and integral gains.

Adjusting Proportional Gain

If you have nonzero derivative gain in your system, a good starting value for the proportional gain is 1/100 of the derivative gain value. This may cause the system to oscillate, it may leave the system very sluggish, but it should be a starting point.

If you are not using derivative action in the system, find a starting value for the proportional gain. In most control systems, a gain of between 1 and 100 is a good point to start.

With this initial value your system will probably either show terribly slow performance or it will oscillate. Now that you have an initial guess for the proportional gain, see if you have oscillation. If you see oscillation drop the proportional gain by factors of 8 or 10 until the oscillation stops. If you don't see oscillation, increase the proportional gain by factors of 8 or 10 until you start seeing oscillation or excessive overshoot. Once you are close, fine tune the proportional gain by factors of two until you see oscillation, then back the gain off by a factor of two or four.

Adjusting Integrator Gain

Once you have your proportional gain set, start adjusting integral gain.
If you are using derivative gain, a good starting value for the integrator gain is to set it smaller than the proportional gain by the same ratio as proportional gain to derivative gain. For example, if you have a derivative gain of 1000 and a proportional gain of 10 (a 100:1 ratio), set the starting integrator gain to 0.1.
If you are not using derivative gain, a good starting value for the integrator gain will be around 1/100 of the proportional gain. Try this gain. If you see oscillation, decrease the integrator gain by steps of 8 or 10 until the oscillation goes away. If you don't see oscillation, increase the integrator gain by steps of 8 or ten until you do. From this point, try to find the gain where the system just breaks into oscillation, and then back the gain off by a factor of 2 or 4.

The hardest part

When you have gone through this sequence exactly once: find the derivative gain, find the proportional gain, and then find the integrator gain, you must stop. Do not go back and tweak the gains. Doing so is a very good way to fool yourself into thinking that you've improved performance, while actually shoving the system into a corner of it's operating envelope that may well render it a "lab queen" that will only work under the best of circumstances.