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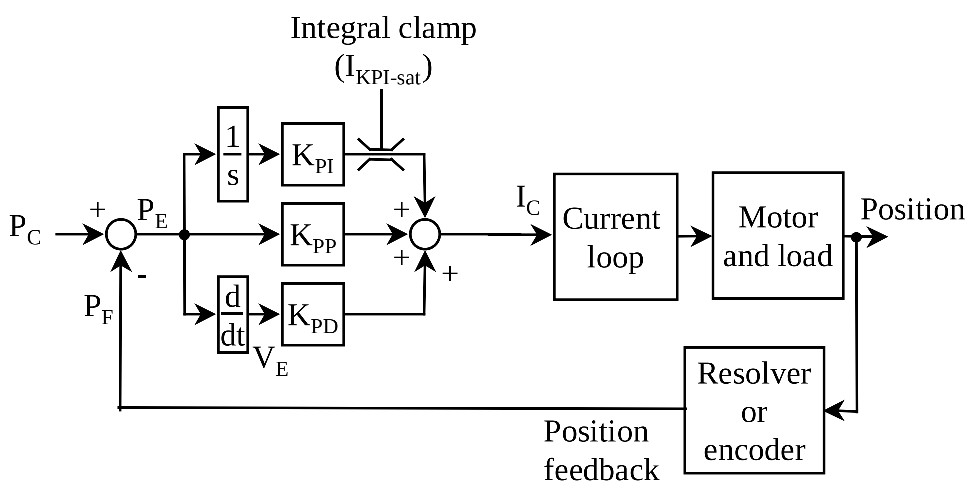
PID position loops

August, 2000

This column is the second a three-part series on position loops. This month we will discuss the PID position loop. Next month we will take up the use of feed-forward in these two loops.

Theory

The velocity loop is the most basic servo control loop. However, since a velocity loop cannot ensure that the machine stays in position over long periods of time, most applications require position control. There are two common configurations used for position control: the cascaded position-velocity loop, as discussed last month, and the PID position controller, as shown below.



Block diagram of PID position loop

<Note to editor: can you replace my “1/s” in the block diagram with an integral symbol followed by “dt?”>

The position loop compares a position command to a position feedback signal, and calculates the position error, P_E. In a PID controller, current command is generated with three gains: P_E is scaled by the proportional gain (K_{PP}), the integral of P_E is scaled by the integral gain (K_{PI}), and the derivative of P_E is scaled by the derivative gain (K_{PD}).

Tuning in Zones

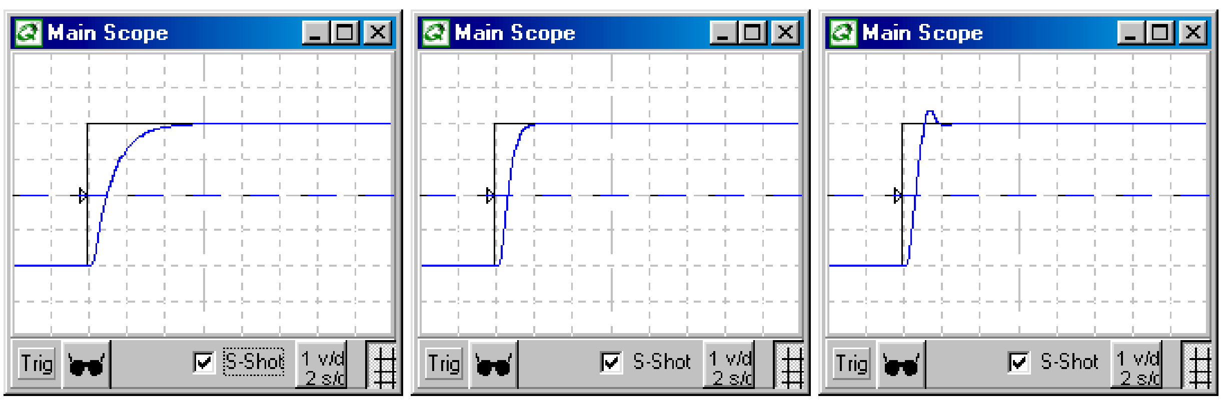
Tuning is the process of setting control loop gains to achieve optimal performance. Higher gains improve responsiveness, but move the system closer to instability. Tuning PID position loops can be challenging because there are three servo gains: K_{PP}, K_{PI}, and K_{PD}. As with the cascaded position-velocity loop, each of the gains plays a different role in the servo system. Once you understand those roles, you can tune the gains independently, saving time and ensuring consistency.

Each of the gains operates in one of three frequency "zones." The highest frequency zone is covered by the derivative gain (K_{PD}); typically, this zone ranges from about 30 to 100 Hz, although it can be much higher. The proportional gain (K_{PP}) is most important for frequencies between about 10 and 30 Hz. The position loop gain covers all frequencies below that.

Zone 1: Derivative gain

Begin tuning the highest frequency zone. Start by eliminating the lower zones: zero K_{PI} and, if possible, K_{PP}. Many PID controllers do not allow K_{PP} to be zeroed. If that's your case, fix K_{PP} at a fairly low value while tuning K_{PD}. Now, prepare a trapezoidal point-to-point move. These commands have three segments: acceleration, cruise, and deceleration. When tuning Zone 1, you should set the acceleration and deceleration rates as high as the controller will allow. In fact, a square velocity command (unlimited acceleration) is ideal.

If the commanded move puts the current controller in saturation (that is, commands more than the controller can produce), reduce the peak velocity of the move. Usually a peak velocity of 0–250 RPM works well. Now, raise the derivative gain as high as possible without generating overshoot in the velocity response. The three figures below show the servo system response to a square-wave command when K_{PD} is a) too low, b) about right, and c) too high. Note that if you cannot zero the proportional gain (K_{PP}), expect some overshoot to a square wave. Overshoot due to K_{PD} occurs on a much shorter time scale and so is easily distinguished from overshoot caused by K_{PP}.



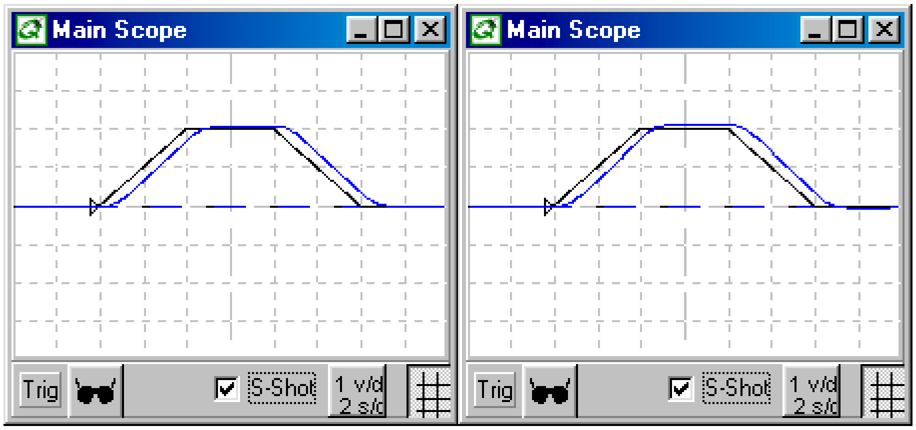
a) b) c)

Zone 1: Velocity step command (black) and response (blue) with K_{PP} and K_{PI} = 0, and K_{PD} a) low (0.6), b) about right (1.1) and c) high (2.0). Horizontal scale is 5mSec/div and vertical scale is 50 RPM/div.

Zone 1 is the hardest zone to tune. This is because two common problems seen in servo systems, resonance (20-minute tune-up, October, 1999) and audible noise (20-minute tune-up, July, 1999), are excited by this gain. You may need to use low-pass filters to reduce these two problems. While low-pass filters are helpful, you should always minimize the their use because they cause instability and force lower value servo gains.

Zone 2: Proportional gain

Now that the derivative gain is set, it's time to tune the proportional gain. First, modify the position command. Lower the acceleration and deceleration to the highest rates that will be seen in the application under normal operation. Raise the integral gain until a slight amount of overshoot appears, and then reduce the gain to remove the overshoot. The responses for two proportional gain values are shown below with K_{PP}: a) about right and b) too high.

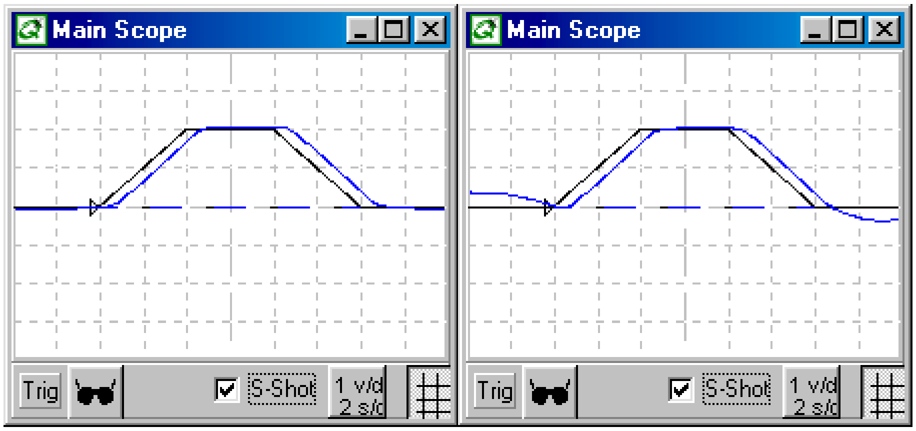


a) b)

Zone 2: Trapezoidal position profile with K_{PD} = 1.1 and K_{PP} a) about right (20.0) and b) a little high (40.0). Horizontal scale is 5mSec/div and vertical scale is 50 RPM/div.

Zone 3: Integral gain

The final zone to tune is the position-loop gain. Tuning integral gain is difficult because even a small amount causes overshoot. Several methods have been developed to deal with this shortcoming. First, most controllers allow you to clamp the maximum current the integral term can command. This makes sense because the primary reason to use integral gain in many applications is to overcome frictional loads; when that it the case, there is no need to allow current generated by the integral term to be much larger than the maximum friction load. Another technique is to force the integral to zero anytime the motor is commanded to move. Both of these techniques allow the integral gain to be raised to higher values than it otherwise could be. The figures below show the integral gain set to a level just below causing overshoot (K_{PI} = 5) and to value so high (K_{PI} = 10) that it causes oscillations at zero speed. Both figures depict a system with the integral zeroed when motion is commanded, and a clamp on the integral output of 2 amps.



a) b) c)

Zone 3: Velocity trapezoid response with K_{VP} = 1.1, K_{VI} = 2.0, and K_P a) about right (5.0) and b) high (10.0). Horizontal scale is 5mSec/div and vertical scale is 50 RPM/div.

Laboratory

Want to tune a PID position loop yourself? Then log onto www.motionsystemdesign.com and download this month's ModelQ simulation program. Launch the program, select August's model, and click "Run." You should be looking at the square-wave response with just the derivative gain (K_{PD}). The value is set a little low (0.6), so raise it until the square wave response just overshoots, and then reduce the gain to eliminate the overshoot (K_{PD} = 1.1).

Now select a trapezoidal velocity command by choosing "Trapezoid" in the waveform generator at bottom left. Now raise K_{PP}, adjusting to the highest value that does not cause overshoot (K_{PP} = 10). Finally, raise K_{PI} to 5 to get a complete set of PID tuning gains.

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