Resolution, Disturbance Response and Noise During Constant-Speed Operation

The primary effect of resolution on servo performance is the generation of noise. Lower-resolution devices produce coarsely quantized position feedback, which in turn, produces coarsely quantized velocity feedback. For example, a 2048 line encoder sampled at 4000 Hz produces velocity quantized to about 30 rpm. The quantized feedback signals move through the servo controller and produce current spikes. These spikes, in turn, produce audible noise, heat, and torque perturbations. High-resolution feedback devices allow the servo system to avoid this problem.

Servo performance measures such as command and disturbance response are improved when servo gains are raised to high levels. However, high servo gains amplify the noise caused by feedback resolution limitations. In constant-speed applications, the primary function of servo gains is to limit the effect of disturbance torque. Disturbance torque comes from any number of sources, including load friction, load inertial forces, and lack of eccentricity of rollers. High servo gains reduce the effects of these disturbances and simultaneously exacerbate the noise caused by encoders. Using high-resolution feedback devices often allows the servo gains to be raised to compensate for the disturbances. There are no performance problems caused by high resolution.

Effect of Resolution

A model was used to demonstrate the trade-offs between high servo gains, resolution, and disturbance rejection. The controller is configured as a velocity loop operating at constant speed. This model captures the velocity feedback signal when a disturbance torque swings from +10 Nm to –10 Nm, roughly ±1% of peak torque. Variation in the velocity feedback signal is undesirable.

Figure 1 shows a model of a velocity control system. The velocity control algorithm is a PI (proportional-integral) common in industry today. There are two filters, one in the forward path and one in the feedback path. These filters are adjusted reduce the effects of resolution noise as much as possible for a given set of servo (PI) gains. The motor is shown as KT/J where J is the total inertia of the motor and load. The effects of resolution are realized by quantizing the position feedback device much as a physical encoder does. A digital derivative is used to calculate velocity as is also common in industry. The torque disturbance enters after torque has been produced by the drive (K_T * "Current Loop" output).

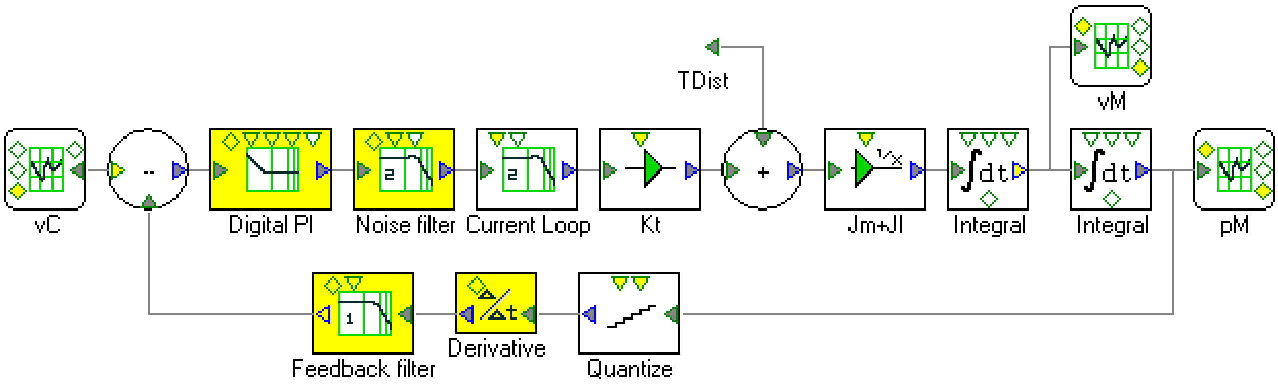

Figure 1: Model Of Velocity Control System

The following system parameters were used:

K_T	9.69 ft-lb/amp
J_L+J_M	12 in-lb-s^2
I_{MAX}	80 Amps
Encoder	2048 lines/rev vs. sine encoder (1 x 10^6 lines/rev)
Operation	Constant speed
Bandwidth[1]	Servo gains were adjusted for several levels of response, characterized by velocity loop bandwidths of 2 Hz, 10 Hz, 35 Hz, and 100 Hz.

Effect Of Raising Servo Gains In Low-Resolution Systems

Figure 2 shows the system tuned with very low servo gains. The velocity-loop bandwidth is set at 2 Hz. The motor swings nearly 20 rpm in response to the disturbance. The system requires about 1 second to settle. The total motion due to this relatively small disturbance (±1% peak torque) is large (about 35°). On the positive side, the feedback signal is almost noise-free because of the heavy filtering. Low bandwidth allows heavy filtering, which is a necessity when using low-resolution sensors.

[1] Velocity-loop bandwidth is a common characterization of command response in servo systems, even when the motor is operated in position control. The formal definition of bandwidth is the frequency the command response falls to 3 dB (70%) of the DC response. Most servo systems operate with a velocity-loop bandwidth between 20 and 80 Hz.

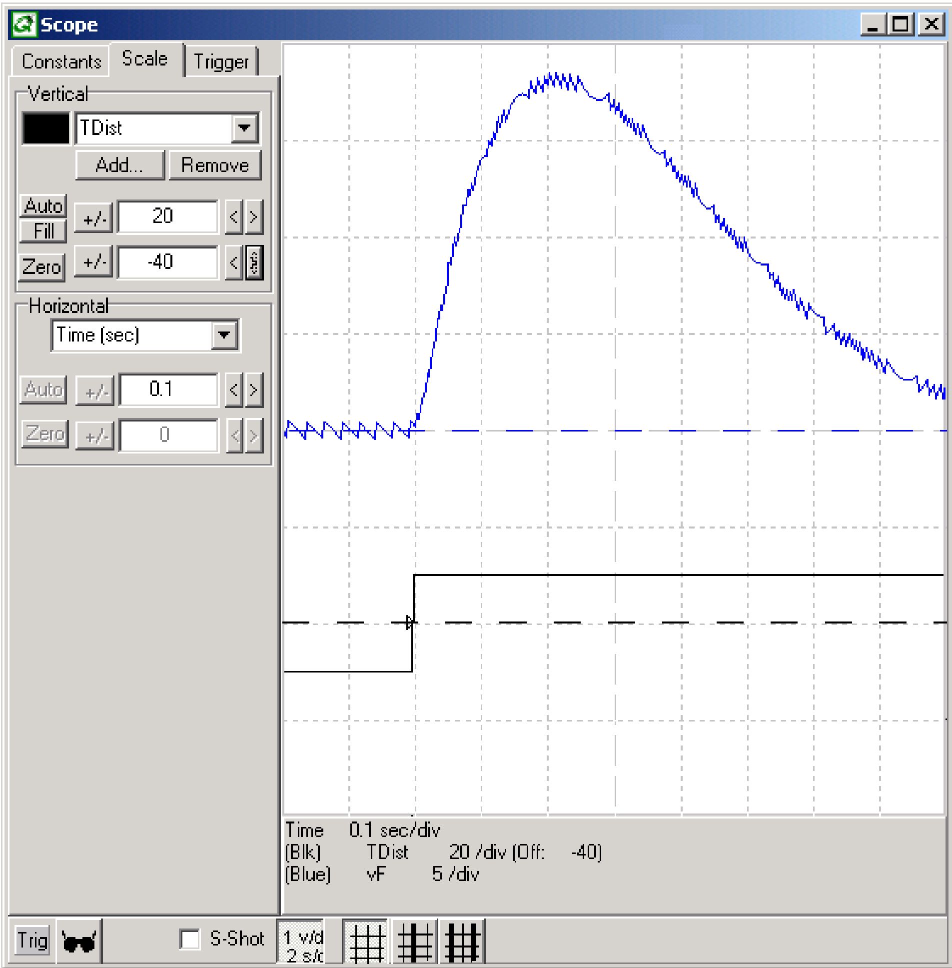

Figure 2: V_F vs. Time, 2 Hz Bandwidth, 2048 Lines

Figure 3 shows the system tuned with modestly increased servo gains. The velocity bandwidth is about 10 Hz. The motor swings about 4 rpm in response to the disturbance. The system requires about 0.2 second to settle. The response is slow, but certainly better. Unfortunately, the feedback signal is becoming noisier, a direct effect of the 2048 line encoder.

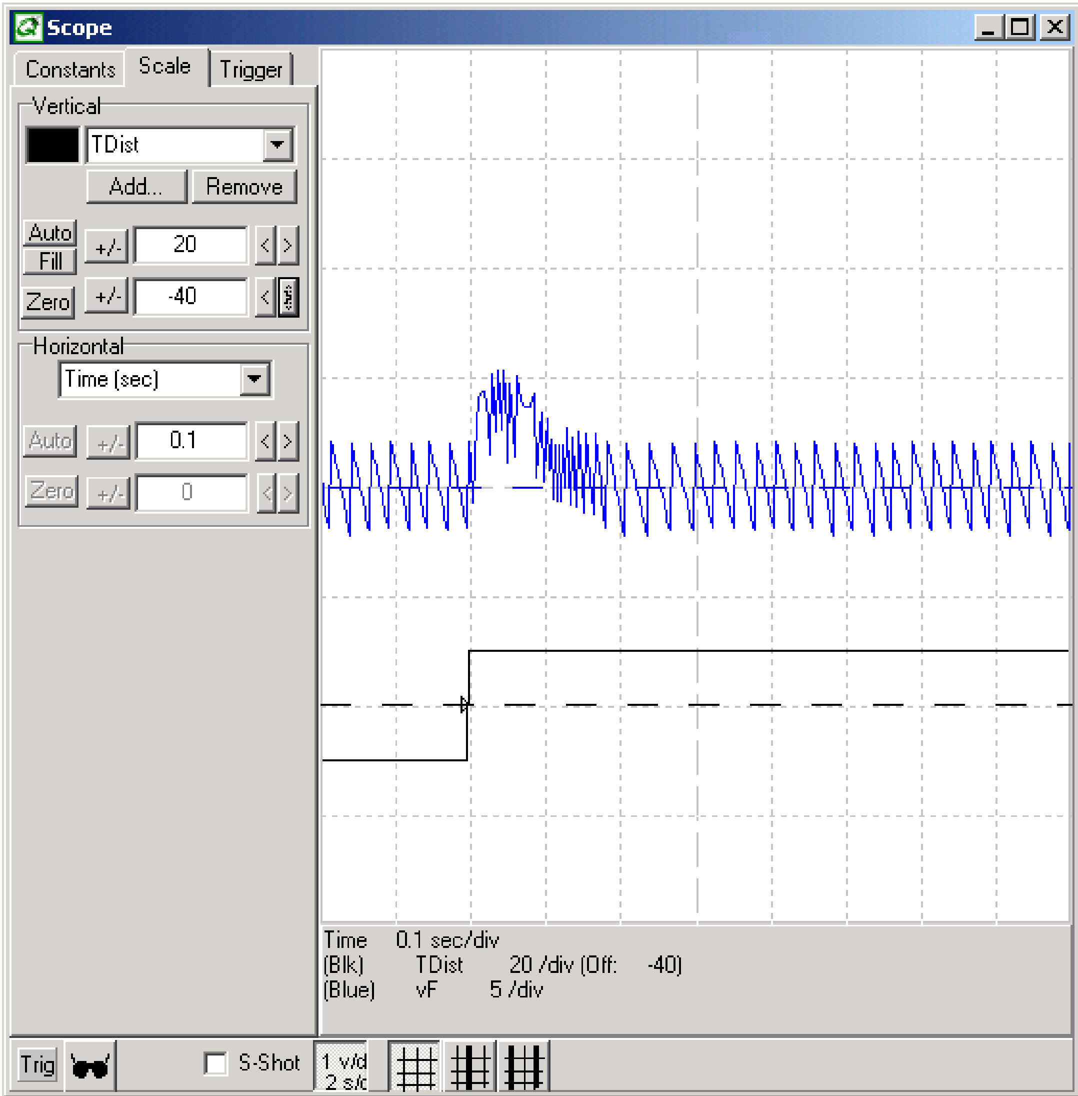

Figure 3: V_F vs. Time, 10 Hz Bandwidth, 2048 Lines

Figure 4 shows the system tuned with typical servo gains, about 35Hz velocity loops. The motor swings less than one RPM in response to the disturbance. The system settles in well under 0.1 second. The response is improved, but the noise is so large, the feedback signal is difficult to read. Such a signal would be expected to generate significant current ripple due to the coarse resolution.

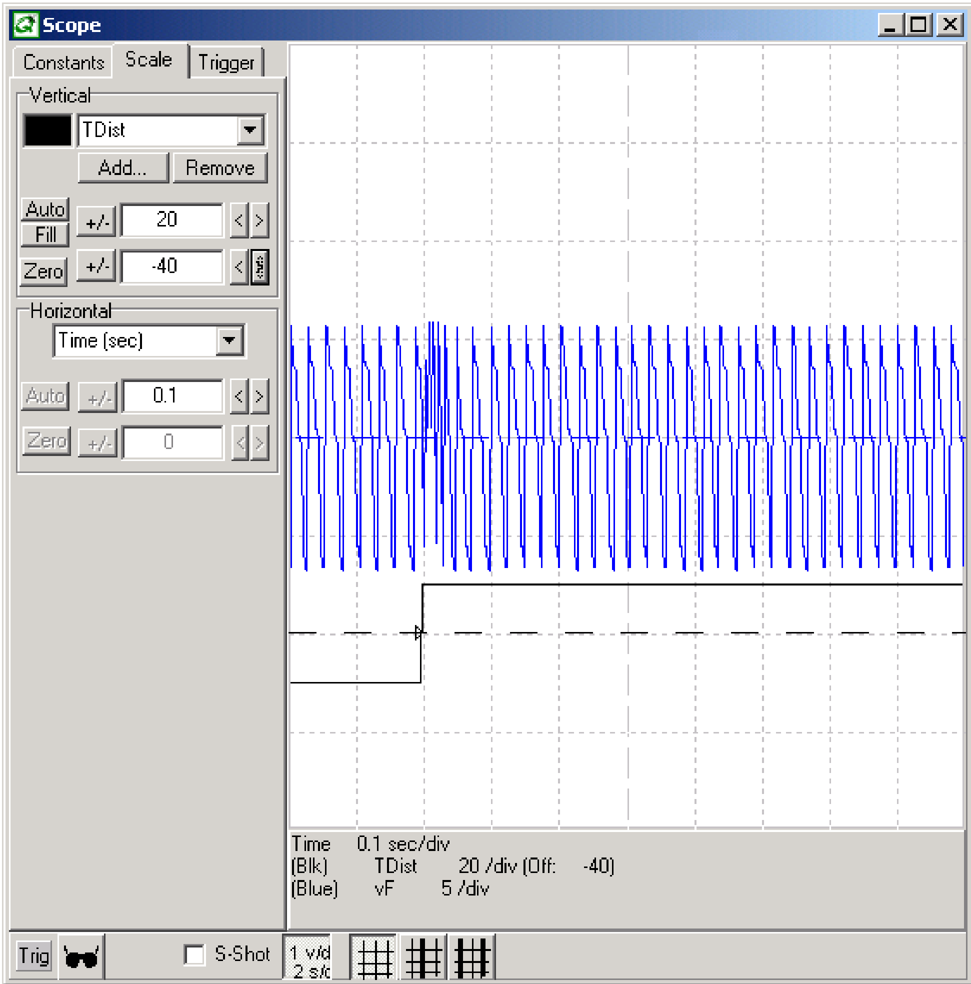

Figure 4: V_F vs. Time, 35 Hz Bandwidth, 2048 Lines

Benefit Of Higher Resolution

Figure 5 shows the system of Figure 4 tuned with the same gains, but this time, based on sine encoder feedback. The resolution of such a device, about 10^6 lines/revolution is dramatic. The motor speed is clearly readable. The perturbation in response to the torque disturbance is about the same as it was in Figure 4, as would be expected since both systems have the same servo gains.

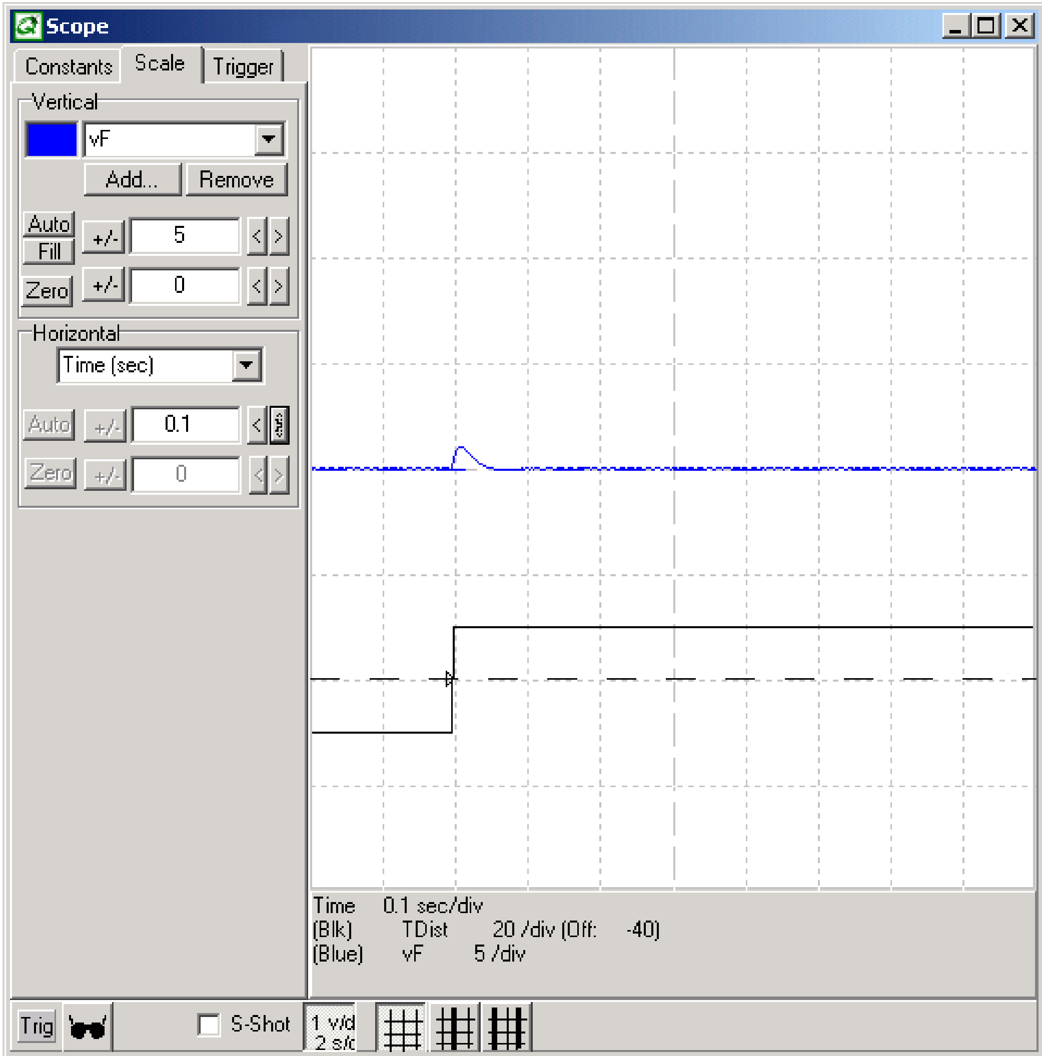

Figure 5: V_F vs. Time, 35 Hz Bandwidth, Resolution $1x10^6$

High resolution allows very high servo gains, which, in turn, can produce excellent disturbance rejection. Figure 6 shows the system tuned with high servo gains—about 100 Hz. Again, the feedback device is the sine encoder. The motor perturbation is nearly undetectable at this scale, and the effects of resolution are still unseen. Such high gains would not be practical with the lower resolution device.

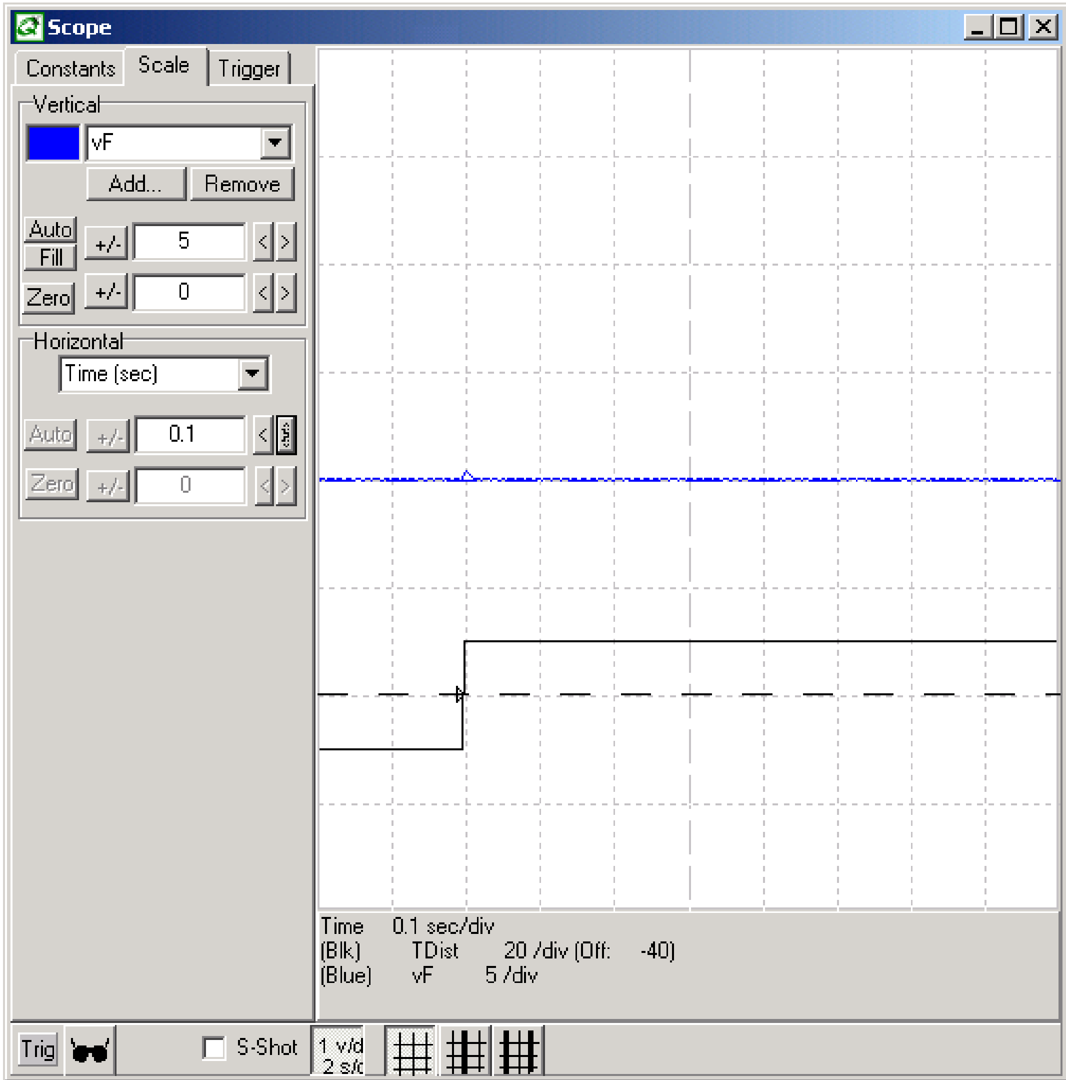

Figure 6: V_F vs. Time, 100 Hz Bandwidth, Resolution 1x10^6

Conclusion

This sequence of figures demonstrates the primary advantages of high resolution: servo gains can be raised to improve performance with less concern for generating noise.

In general, the best alternative is for applications to use high-resolution devices in early prototypes. High-resolution feedback offers designers more options as they integrate and debug the machine. It is difficult to tell early in a project whether high gains will be advantageous for the application. By relying on the high-resolution device early, engineers maintain the option of raising servo gains to correct problems seen on the machine. Later, as the machine moves into production and if the application does not need the high resolution, a lower resolution sensor can be substituted.