StepSERVO™ Tuning Guide

Goal: Using the Step-Servo Quick Tuner software, this guide will walk the user through the tuning parameters to assist in achieving the optimal motor response to a target move profile. While it is important that the motor position tracks the target position closely when the position loop tuning has been completed, it is also important that there is little to no audible noise coming from the motor during the accel/decel, constant velocity, and stationary sections of the move profile. Position errors can be minimized by using this procedure, with an expected position error range of ±10 encoder counts or less under many common conditions.

Servo Tuning Background and Overview: Servo tuning is the process by which tuning parameters are adjusted while the motor is installed within the machine for which it has been selected. The load must be coupled to the motor shaft and the move profile must be simulated as closely as possible to the actual operating conditions during the tuning process. This includes tuning with sample moves that have the same acceleration, deceleration and target velocity while the motor is driving the load as it would be in the actual application. To a large extent, gain and filter settings will be dependent upon these conditions. Therefore, it is important to keep in mind that changes to the load and move profile will cause a change in the motor's response for a set of tuning parameters arrived at under a different set of tuning conditions. Finally, the desired results of tuning (i.e. amount of position error, velocity profile tracking, etc.) are directly related to the desired performance of the motor. In general, a mismatch greater than 10:1 for the load-to-motor inertia can make the tuning process more difficult, while lower inertia mismatches will allow for easier tuning. Compliance in the mechanical transmission from the motor to the load may also complicate the tuning process. Use of the Notch Filter feature may be required in these cases.

Tuning Parameters

Velocity Loop:
> **Gain (VP)** – Proportional gain term used to increase stiffness of motor response in direct proportion to the velocity error
> **IntegGain (VI)** – Integral gain term used to increase stiffness and reduce steady-state velocity errors
> **FF Gain (KK)** – Inertia Feedforward gain term used to improve acceleration control by compensating for the load inertia
> **Filter (KC)** – Overall servo filter; simple one-pole, low-pass filter intended for attenuating high frequency oscillations

Position Loop:
> **Gain (KP)** – Proportional gain term used to increase stiffness of motor response in direct proportion to the position error
> **Deri Gain (KD)** – Derivative gain term that acts on the rate of change of the position error to provide system damping and increased stability
> **Deri Filter (KE)** – Derivative filter that is used to limit the high frequency noise often caused by increased derivative gain; makes the system quieter and more stable

Tuning Process

This tuning process is intended to give the user only the steps necessary to complete the tuning; for more details on the gain terms and filters, consult the software user's manual. In many cases, arriving at the "ideal" tuning values is an iterative process. This step-by-step guide shows the process of building up a tuning file from low gains in order to better understand the influence of each tuning parameter.

If the motor vibrates and makes noise when it is first powered on while coupled to the load, this indicates system instability and the need to adjust the tuning parameters. To quickly eliminate this problem, reduce each tuning parameter that contains the word "gain" on both the V Loop and P Loop tabs and click the large 'Download All to Drive' at the top right in the Step-Servo Quick Tuner software.

Use caution while tuning and always be ready to disable the StepServo motor in the event that something goes wrong (i.e. motor instability, motor stall, etc.).

The Velocity Loop (V Loop) must be tuned before the Position Loop (P Loop).

Operation 1 – Set V Loop gains to low values to start
   a) Leave the Filter (KC) set at the default value of 15000
   b) Reduce IntegGain (VI) and FF Gain (KK) to ZERO
   c) Set Gain (VP) to a value in the range of 1000 – 1500 for low inertial loads and low accel/decel rates (see Tips #1 & 2 below)

Tip #1: Hit <Enter> after typing a number into a tuning parameter field; pressing the Tab key after typing in a value will cause the field to revert back to its previous value. The slider bar and up/down buttons may also be used to adjust values.

Tip #2: The initial recommended VP gain setting shown in **operation 1c** above will allow for the sample move to be completed without any faults when tuning at low accel/decel settings (up to ~200 rev/sec²) with inertial loads that are less than 5x the rotor inertia. If the accel/decel setting required and/or the load inertia is over 5x, however, then Position Errors will likely be seen when executing the sample move. These Position Errors can be eliminated during tuning by selecting the ***Not Used*** radio button on the Configuration tab next to the *Position Fault Limit* setting as shown in **Figure 1** below. Be sure to click on 'Download All to Drive' after making this selection. After tuning is complete, it is recommended that this setting be changed back so that a fault will occur when the motor is off from its commanded position.

Tip #3: When the StepSERVO motor is connected and communicating with the Step-Servo Quick Tuner software, it will automatically be put in "connected mode" causing the following default settings to take effect:

   Baud Rate set to 115,200 bps (command: BR5)
   Immediate Format set to hexadecimal (command: IFH)
   Transmit Delay set to 2 ms (command: TD2)
   Protocol settings for model-specific values: PR13 (for RS-232 models)/PR15 (for RS-485 models)

There is no need to be concerned with any of these settings while connected with the software. These settings may change when disconnected from the software; they will be based on the configuration that was last downloaded. For more information on the commands above, please consult the Host Command Reference manual.
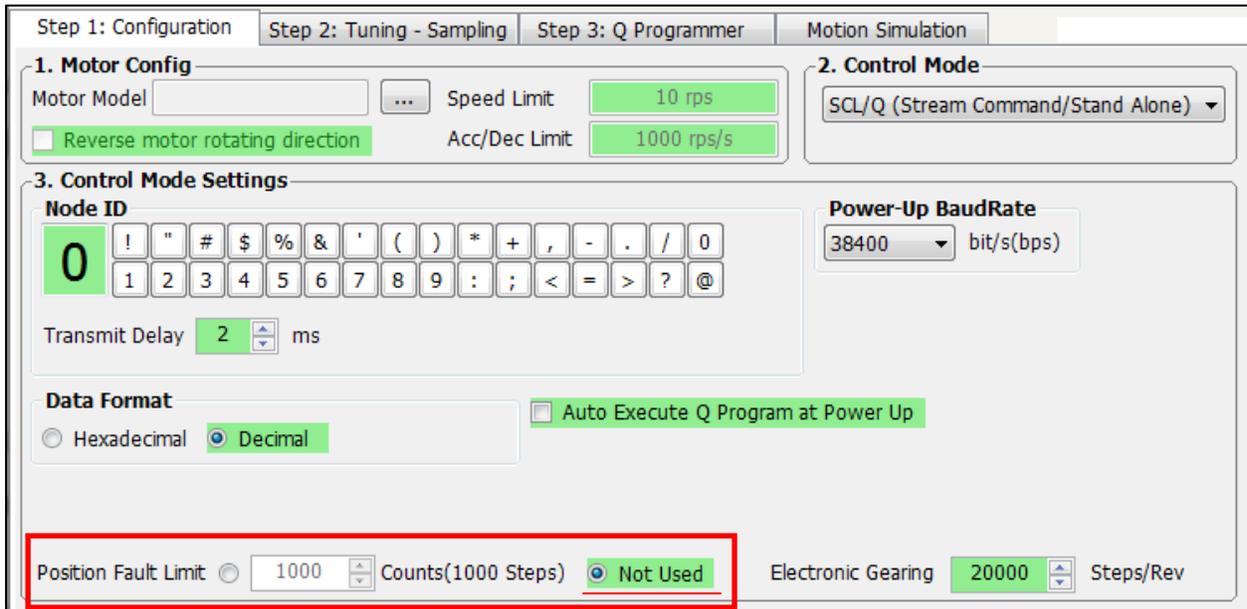
Figure 1: Turning off Position Fault Limit will eliminate Position Errors during tuning

Operation 2 – Run a sample move and adjust Gain (VP)
   a) Plot Actual Speed vs. Target Speed
   b) Set Direction to CW and select Sample Once
   c) Observe response (Actual Speed); see **Figure 2a** below
   d) Repeat sample move and adjust Gain (VP) until the Actual Speed is between 80-90% of the target speed. Depending on the load coupled to the motor shaft and the Speed Limit set for the sample move, this final VP gain setting will vary.

It is important to look at the quality of the response (i.e. Actual Speed curve plotted). The curve should be smooth at the top without any visible oscillations (See **Fig. 2b & 2c**) and the motor should not be making any noise or vibrating when the move has completed.
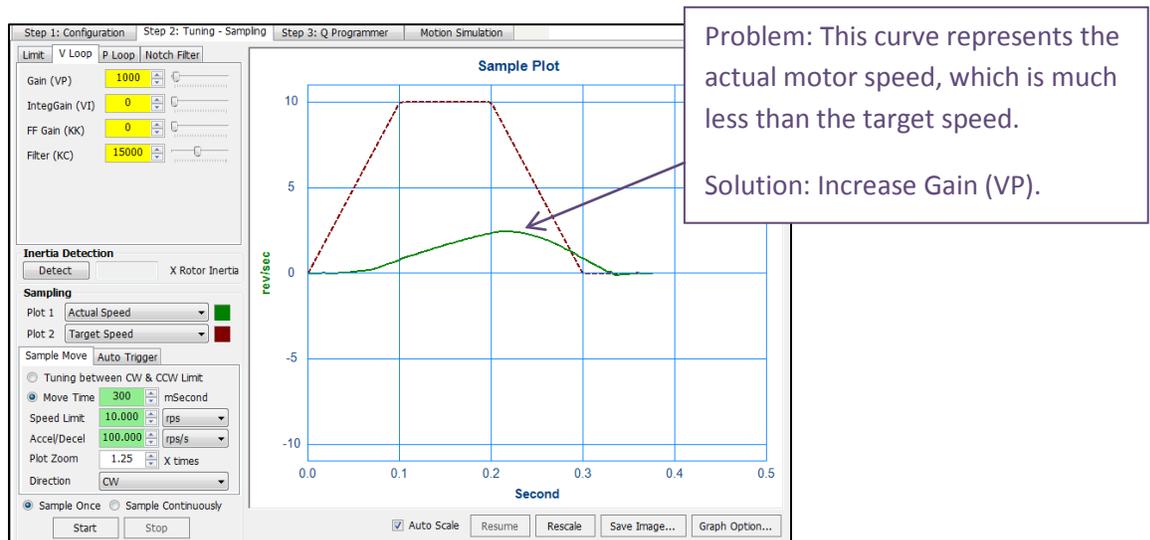

Figure 2a: Sample move with Actual vs. Target Speed plotted
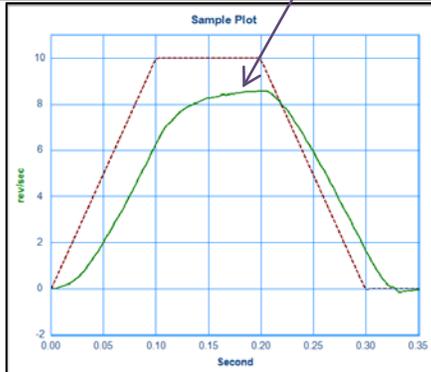
GOOD = smooth curve

BAD = rough curve

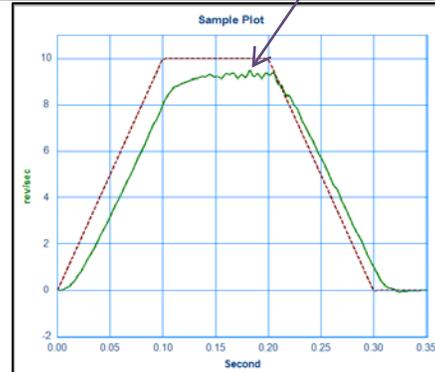| **Fig. 2b:** VP=6000 (acceptable) Smooth Actual Speed curve (green)	**Fig. 2c:** VP = 12000 (too high) Actual Speed curve showing instability

Operation 3 – Plot Velocity Error while adjusting FF Gain (KK) and IntegGain (VI)
   a) Select "Velocity Error" for Plot 2 and make sure that "Auto Scale" is checked
   b) Run sample moves while increasing FF Gain (KK) first (see **Fig. 3a**)
   c) When the Actual Speed curve starts to have sharpened corners, then begin to increase KI along with KK gradually in an effort to minimize *and* stabilize the Velocity Error (see **Fig. 3b & 3c**)
      i. Uncheck the "Auto Scale" box to lock the units on the vertical axes; this helps visually to see the reduction in Velocity error
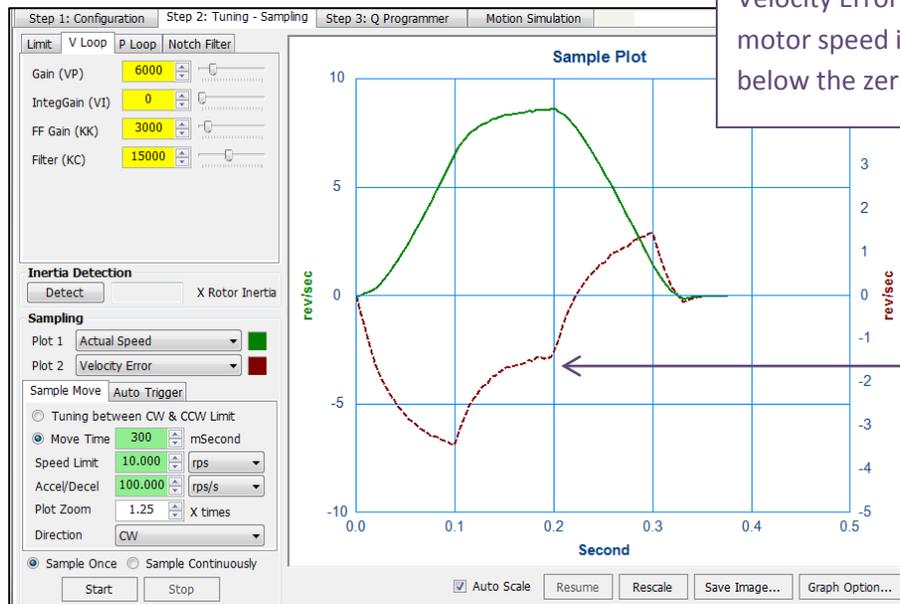   ii. Reduce the Filter (KC) value if the motor begins to make noise

Velocity Error (dashed line) shows motor speed is lagging when below the zero rev/sec line.

Figure 3a: Actual Speed & Velocity Error plotted; FF Gain (KK) being adjusted
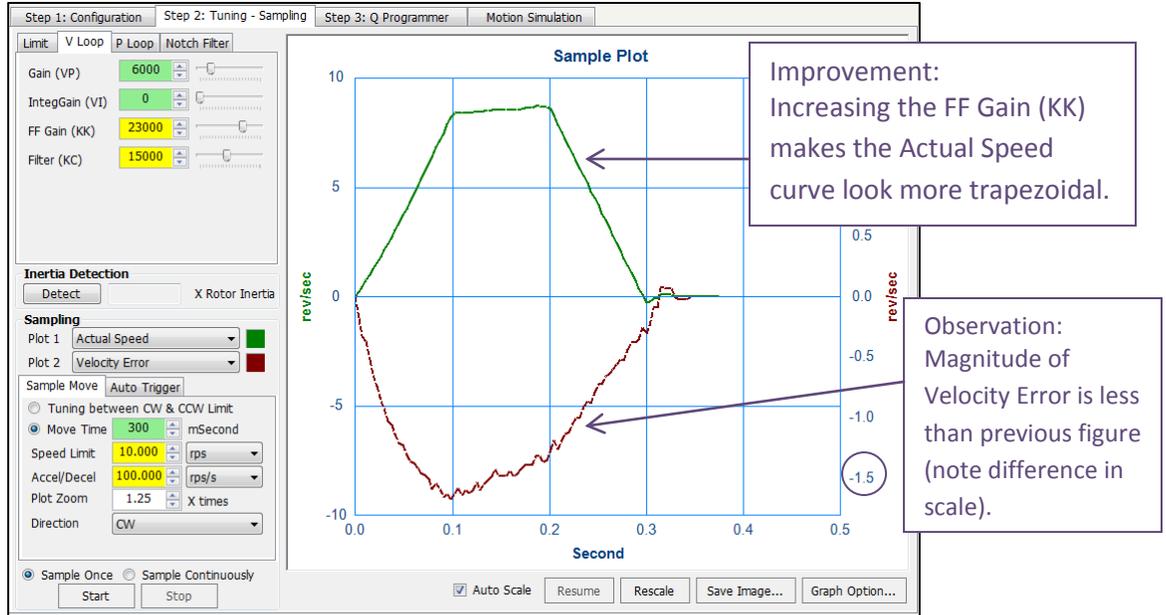
Figure 3b: Actual Speed profile looks more like a trapezoid shape with increased FF Gain
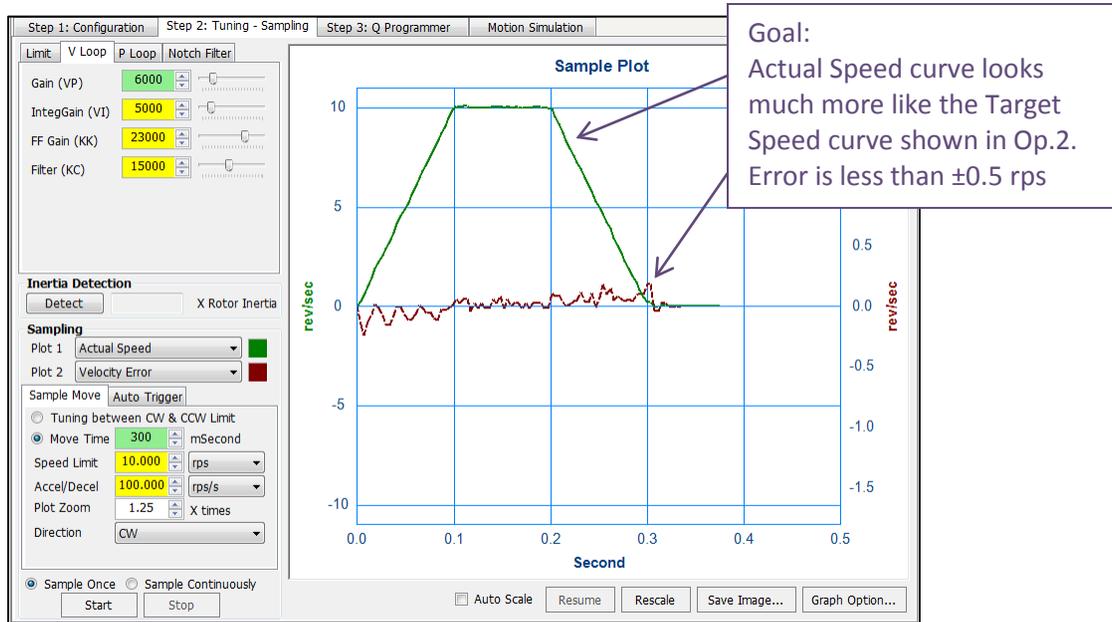

Figure 3c: Velocity error minimized with Integral Gain (VI) and FF Gain (KK) adjustments

If the application requires only speed control (not positioning), then stop here.
If the application requires position control, then continue.

Operation 4 – Switch to P Loop (Position Loop) tab and change Plot 2 to Position Error

a) Change Plot 2 to "Position Error" and set up sample move similar to V Loop
b) Set Deri Filter (KE) at default of 15000 and reduce Gain (KP) & Deri Gain (KD) to 1
c) Increase Gain (KP) while running sample move in an effort to minimize Position Error (see **Fig. 4a**). Increasing KP too much will lead to instability (see **Fig. 4b**).
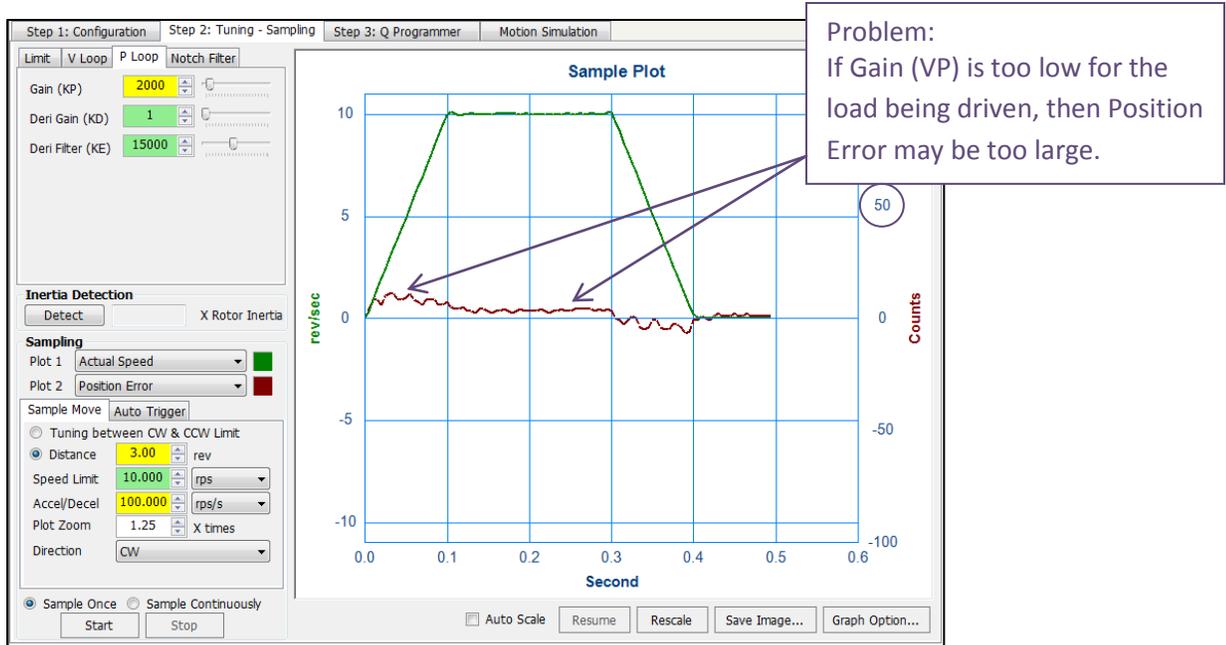
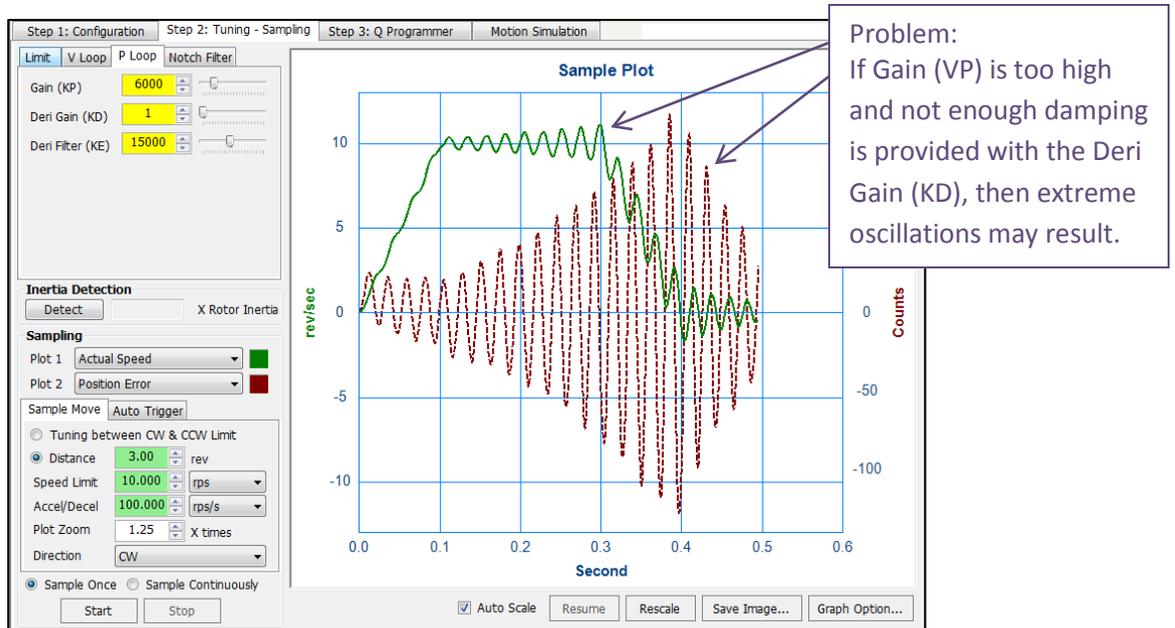**Figure 4a:** Position Loop tuning; plot of Actual Speed and Position Error

Figure 4b: Instability created by high KP setting while tuning P Loop

Operation 5 – Add in Derivative Gain (KD) and adjust KP and KE (see **Fig. 5a**)
   a) Continue running the sample move while adding in the KD gain term
   b) If high pitched noises are heard from the motor, reduce KE
   c) When position error and settling time meet requirements, tuning is complete
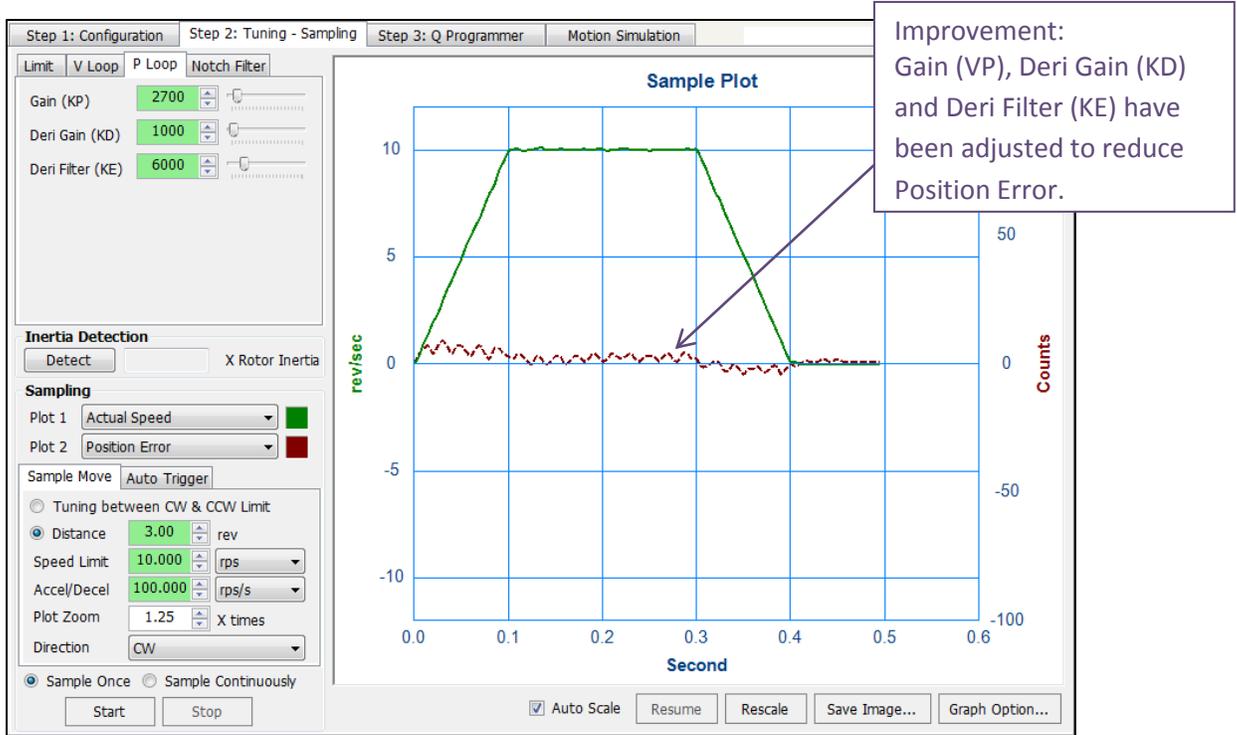   d) Zoom in with cursor to view position error (see **Fig. 5b**)

Figure 5a: Position error has been minimized by adjusting the P Loop tuning

Improvement:
Gain (VP), Deri Gain (KD) and Deri Filter (KE) have been adjusted to reduce Position Error.

Goal:
This zoomed-in view shows that further adjustments have greatly reduced Position Error (note scale change).
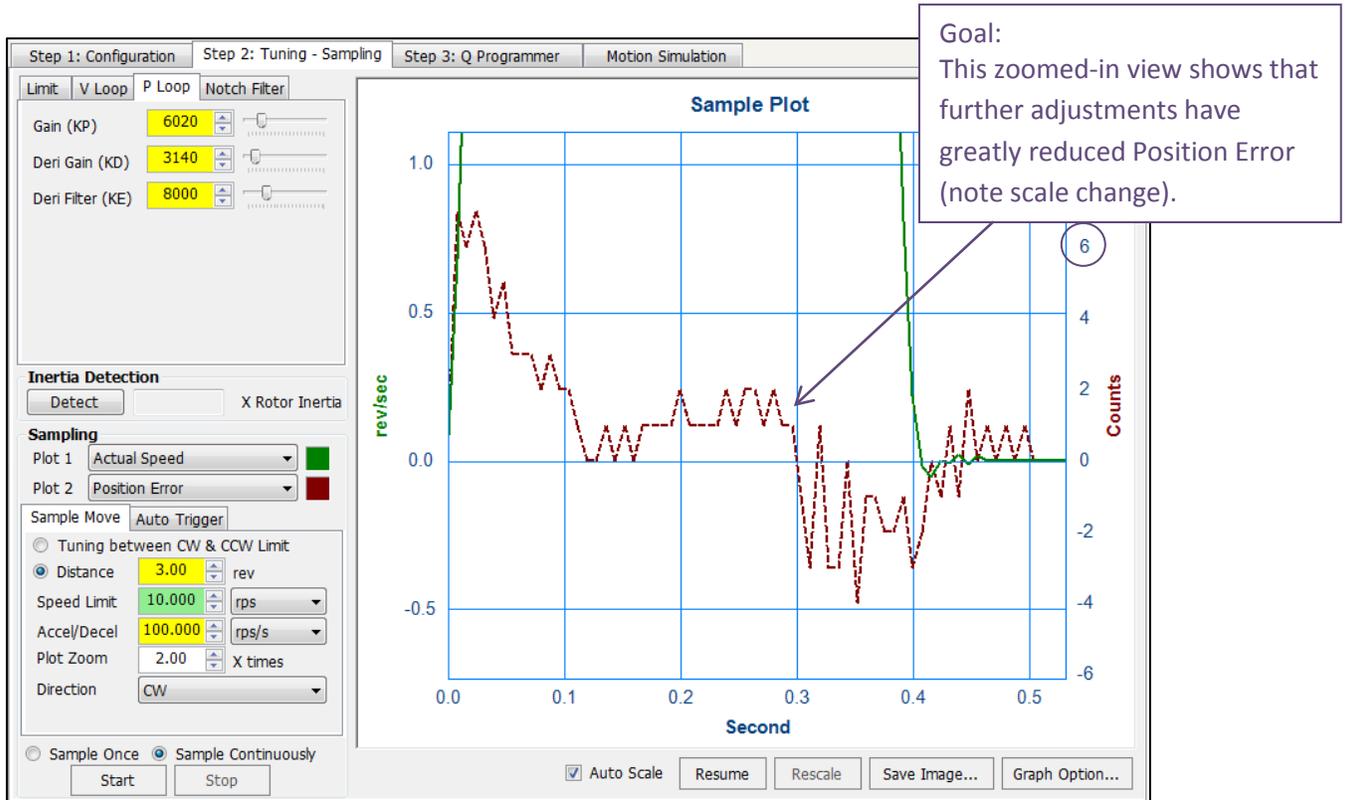
Fig. 5b: Zoomed in view of Position Error plot, showing range of less than ±10 encoder counts

Operation 6 – Finalizing settings, downloading and saving

 a) If the Position Fault Limit feature was set to 'Not Used' in Step 1, be sure to set it back to its previous setting
 b) Make sure to click 'Download All to Drive' so that the final tuning values will be retained in non-volatile memory
 c) Save a project file by selecting 'Save Project' from the *Project* pull-down menu

It's important to keep in mind that the images shown above represent just one system and that the curves shown may not look the same for your motor and load. If this is the case, then it will be necessary to focus on the relative impact of the adjustments made.

The StepSERVO motor model used to develop this guide was: TSM23Q-3AG. The load inertia was simulated with a flywheel (5x the motor's inertia) directly coupled to the motor shaft.

For additional information on the StepSERVO integrated motors, please refer to:
http://www.applied-motion.com/products/series/integrated-stepservo%E2%84%A2-products

For additional information on the Step-Servo Quick Tuner software, please refer to:
http://www.applied-motion.com/products/software/step-servo-quick-tuner