APPLICATION NOTE

YASKAWA

Title: Custom Delta Robot Motor Tuning	
Product(s): MP3200iec-RBT, MP3300iec-RBT, MotionWorks IEC	**Doc. No.** AN.MP3300iec.02

Application Overview

This application note provides an overview of steps and an example to tune the three arm motors for a custom delta robot. Before using this application note, it is assumed that the user has properly configured the delta robot in Hardware Configuration, homed the motors, and is able to move the robot in Machine Coordinate System (MCS) properly. The main goal of tuning the motors should be to minimize vibration (hardware vibrations, motor torque ripples) since it is typically the limiting factor in getting higher throughput.

The main strategy has the following steps to tune the three arm axes:

- Use SigmaWin+ to find the inertia ratio
- Use SigmaWin+ autotuning to find tuning gains as starting point.
- Manual tuning of gains after getting initial values from SigmaWin+
- Find a suitable torque feedforward using Torque Passthrough delta parameter.
- The theta axis is much easier, and can typically be tuned like a regular motor.

This is meant to be a general guide of possible steps, and the user may need to slightly deviate from it depending on the needs of their mechanism and application.

Products Used

Component	Product and Model Number
Servopack	Sigma5 or Sigma7
Motor	Sigma5 or Sigma7
Controller	MP3300iec-RBT, MP3200iec-RBT
Firmware	3.3 or higher
Delta Robot	Any simple delta robot with kinematics supported by Hardware Configuration

Title: Custom Delta Robot Motor Tuning	
Product(s): MP3200iec-RBT, MP3300iec-RBT, MotionWorks IEC	**Doc. No.** AN.MP3300iec.02

Implementation

⚠ CAUTION
• **When using SigmaWin+ for inertia finding or auto tuning, the motor controlled by SigmaWin+ will move as specified by the inputs to the SigmaWin+ routines. Ensure that the mechanism will have enough space to not crash.** • **When doing manual tuning using a defined path, ensure that the application in MotionWorksIEC commands a path that the mechanism can follow without crashing.** • **This tuning procedure assumes homing of each axis and is already done and delta mechanism is configured properly in Hardware Configuration in MotionWorksIEC.** • **Yaskawa is not responsible for damange to mechanism or damage caused by mechanism during this procedure.**

Before starting, make sure the robot motors are in a good position to avoid obstacles or collisions. The inertia ratio finding and auto tuning routine typically require less than two motor revolutions of movement. Typically, motor positions of 0 degrees is a good starting point. Open SigmaWin+, and connect to S L or U motor

☐ Suggested Non-Tuning Parameters

The following is a list of parameters not related to tuning, that may help the robot run smoother.

- **Pn109 Feed Forward Gain** – Setting to 100 may help for, especially with 1310 disabled
- **Pn10A Feed Forward Filter Constant** – Setting to mechatrolink rate may help especially with 1310 disabled.
- **Pn30C Torque feedforward average moving time** – Only available for Sigma7 servopacks. Set to Mechatrolink cycle.
- **Pn426 Speed feedforward average moving time** – Only available for Sigma7 servopacks. Set to Mechatrolink cycle

- **Pn506 Brake reference servo OFF delay time** – When servo off is commanded, keep power on for some time until brake is engaged. Set to 150ms
- **Pn600 Regenerative resistor capacity** – Set to external regenerative resistor if necessary
- **Pn812 Moving average time** – Set to Mechatrolink cycle
- **1300 Moving average filter 1 enable** – Sets a position moving average filter on axis command positions. Set to TRUE.
- **1301 Moving average filter 1 time constant** – Time constant of the position moving average filter. This effectively causes a time delay on all move commands, but will smooth out jerk and vibration. Set to 0.05.
- **1310 Velocity feedforward enable/disable** – Enable for Sigma7, disable for Sigma5
- **1311 Drive motion command option Accfil value** – Subinterpolation of position commands by drive. Set to 2.

☐ Find Inertia Ratio

The inertia finding tool in SigmaWin+ can provide an estimate of inertia ratio for Pn103.

- It is sometimes helpful to increase **Pn520** to a large value in order for the automatic calculations to complete. Go to the **Edit Parameters** window from the menu.

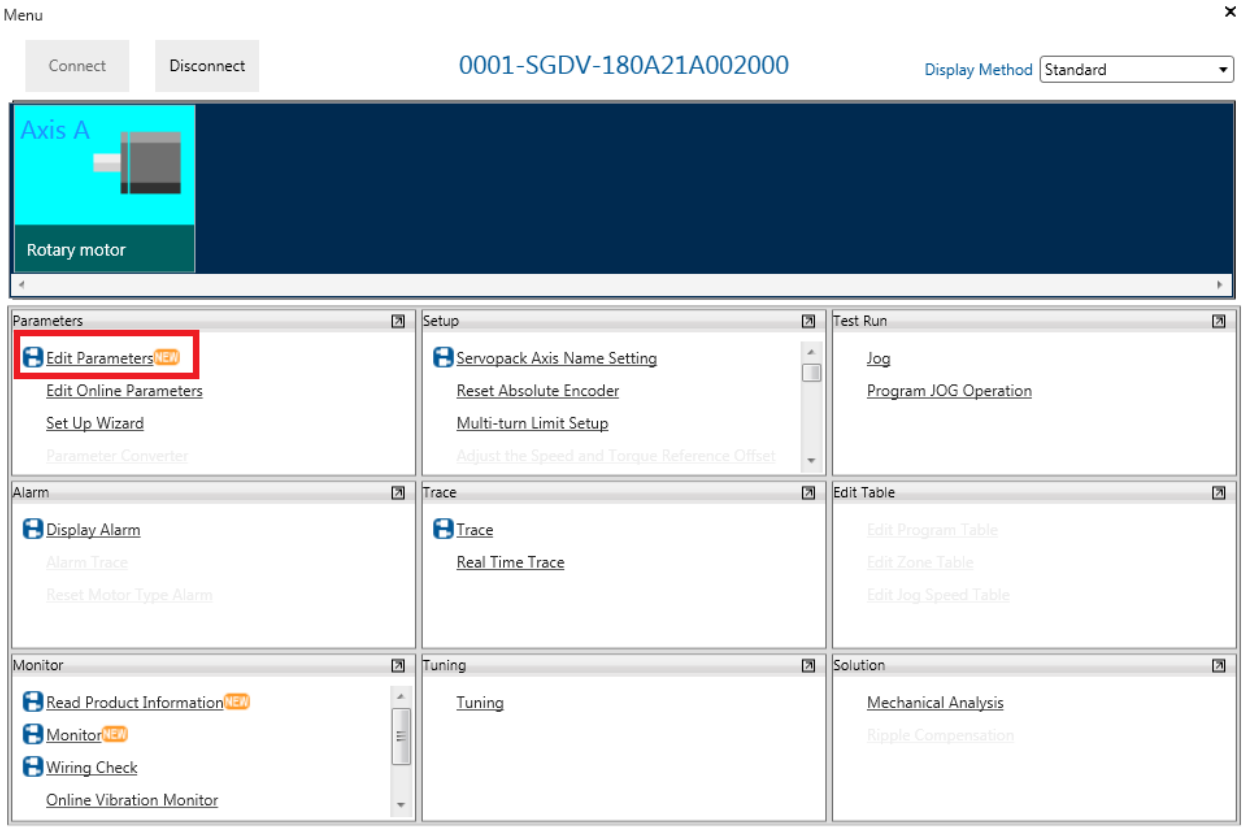

FIGURE 1 EDIT PARAMETERS MENU IN SIGMAWIN+

- Edit **Pn520** to some large value. Default is 5242880 units, which should be fine for a SigmaV motor. For a Sigma7 motor, a larger value like 15000000 units may be necessary. Select the **Write Edited Parameters From the SERVOPACK** to save the new value.

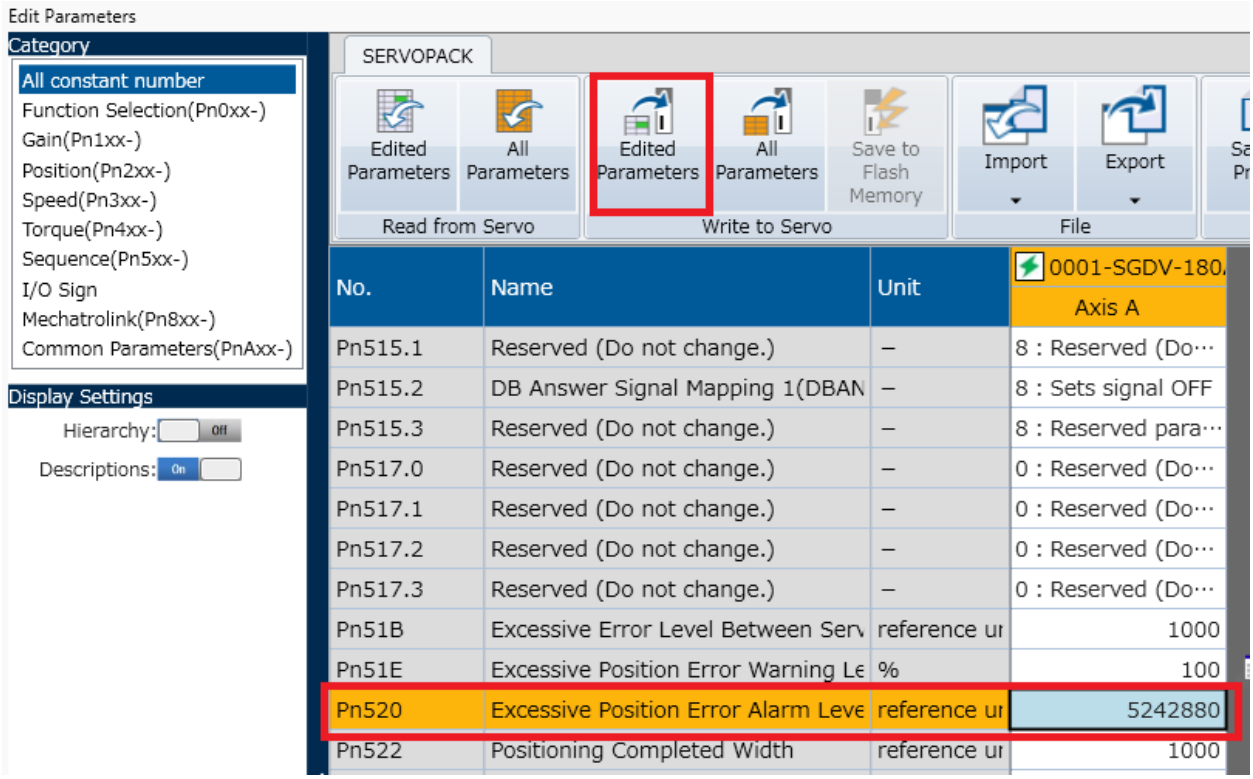

FIGURE 2 EDIT PN520

- Go to the **Tuning** menu.

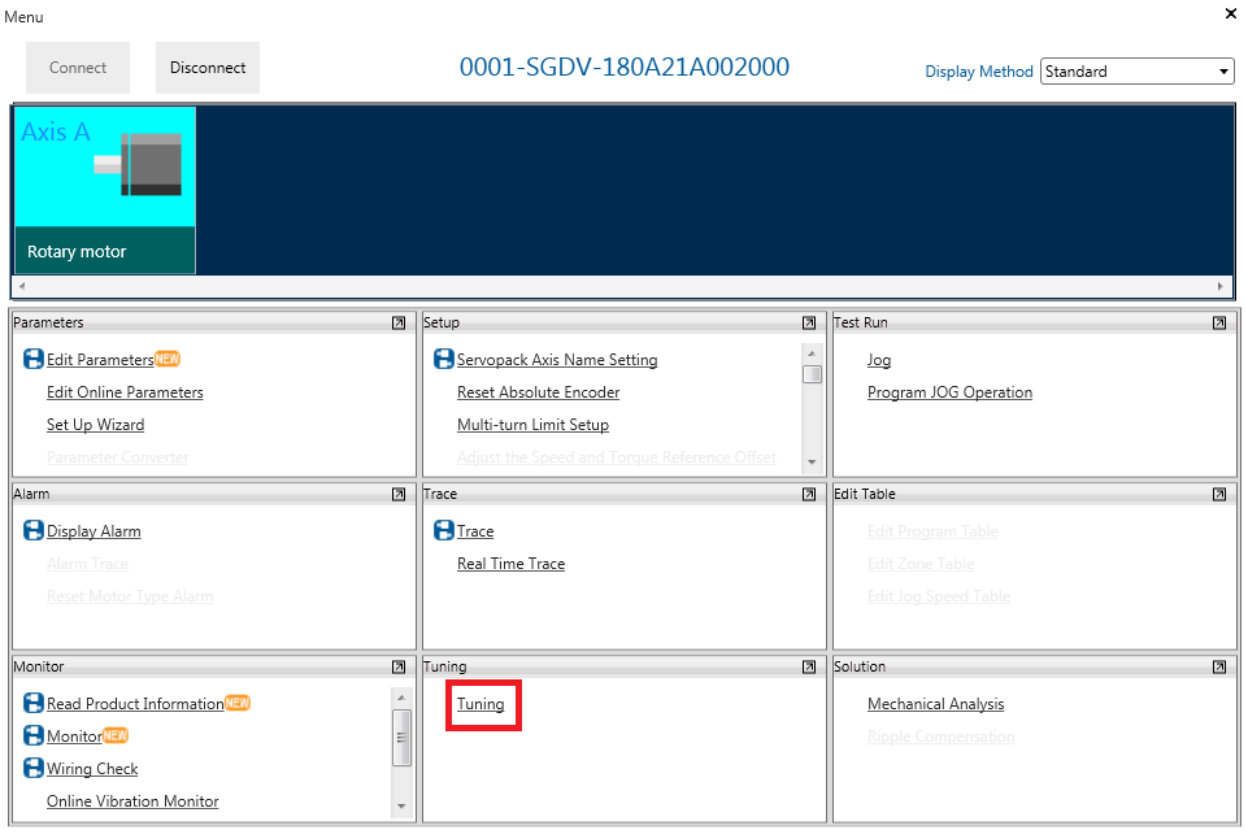

FIGURE 3 TUNING MENU IN SIGMAWIN+

- **Execute** the inertia ratio identification routine.

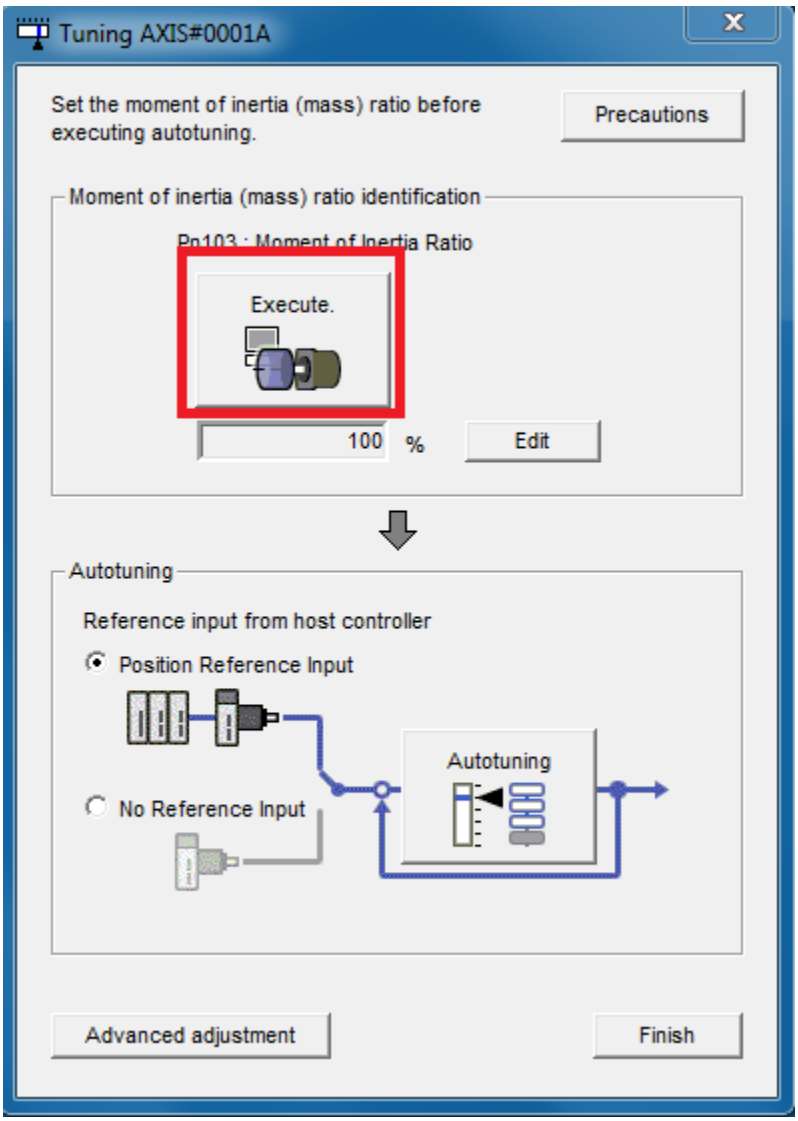

FIGURE 4 TUNING FUNCTION IN SIGMAWIN+

- Edit the **Condition Settings** of the inertia ratio finding routine. Typically a low **Acceleration** and **Speed** has a higher chance of completion. A higher than default value (400) of **Pn100** may also need to be used. Click **Next** to go to Reference Transmission.

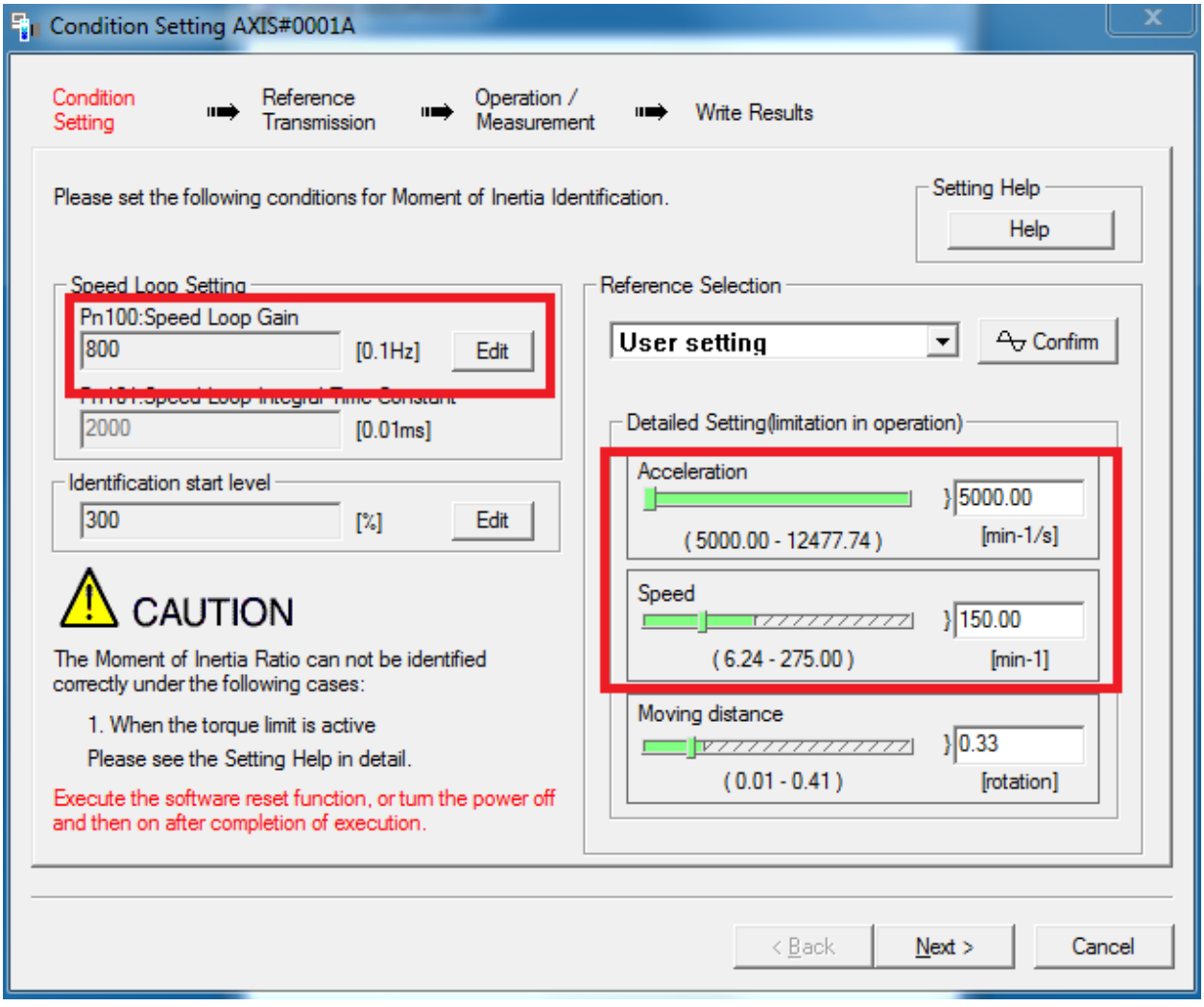

FIGURE 5 SETTINGS FOR INERTIA RATIO ROUTINE

- On **Reference Transmission**, click **Start**, then **Next**.

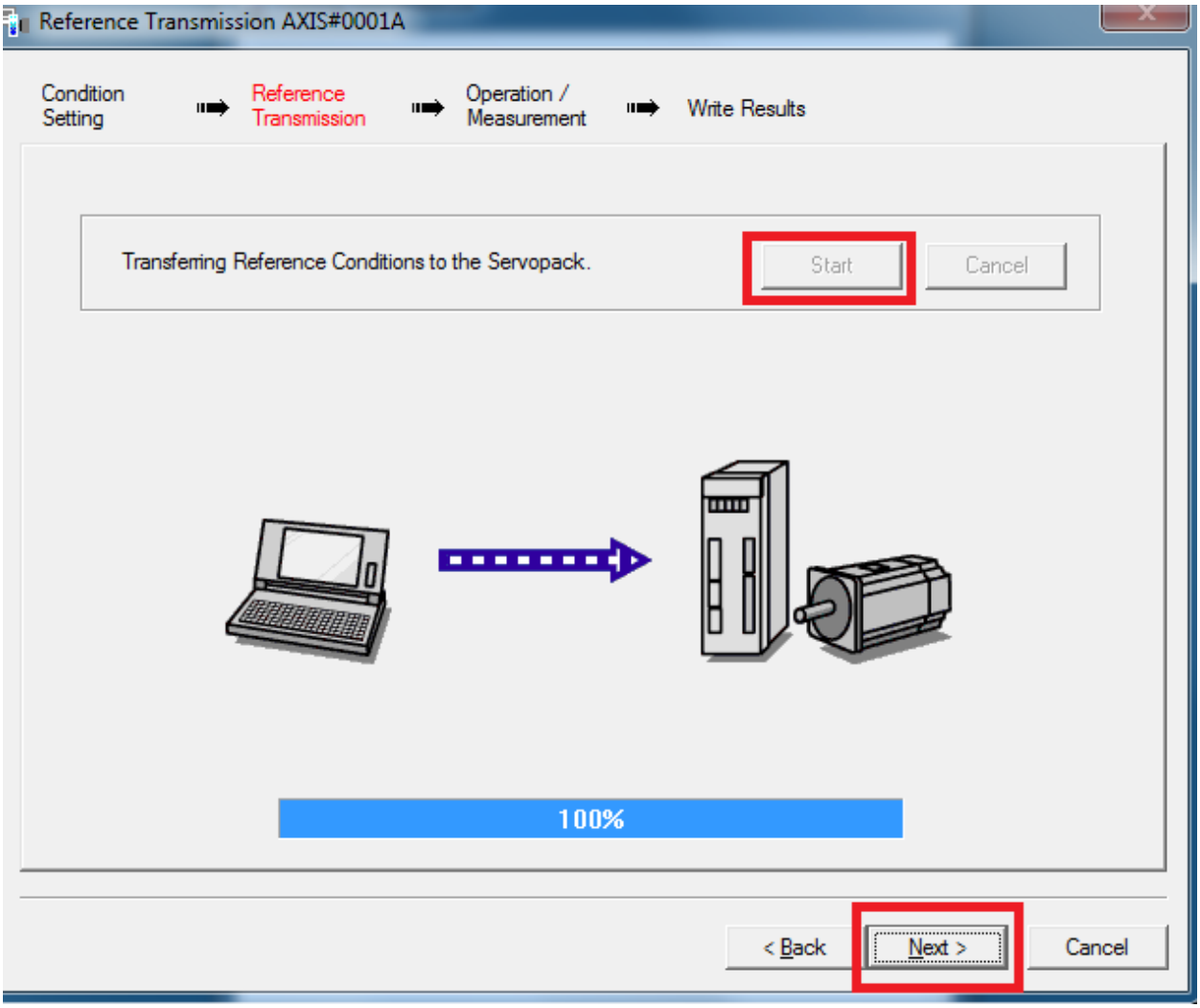

FIGURE 6 BEGIN INERTIA RATIO ROUTINE

- In **Operation/Measurement**, click **Servo On**, then **Forward**, and **Backward** until inertia ratio is found, then click **Next**

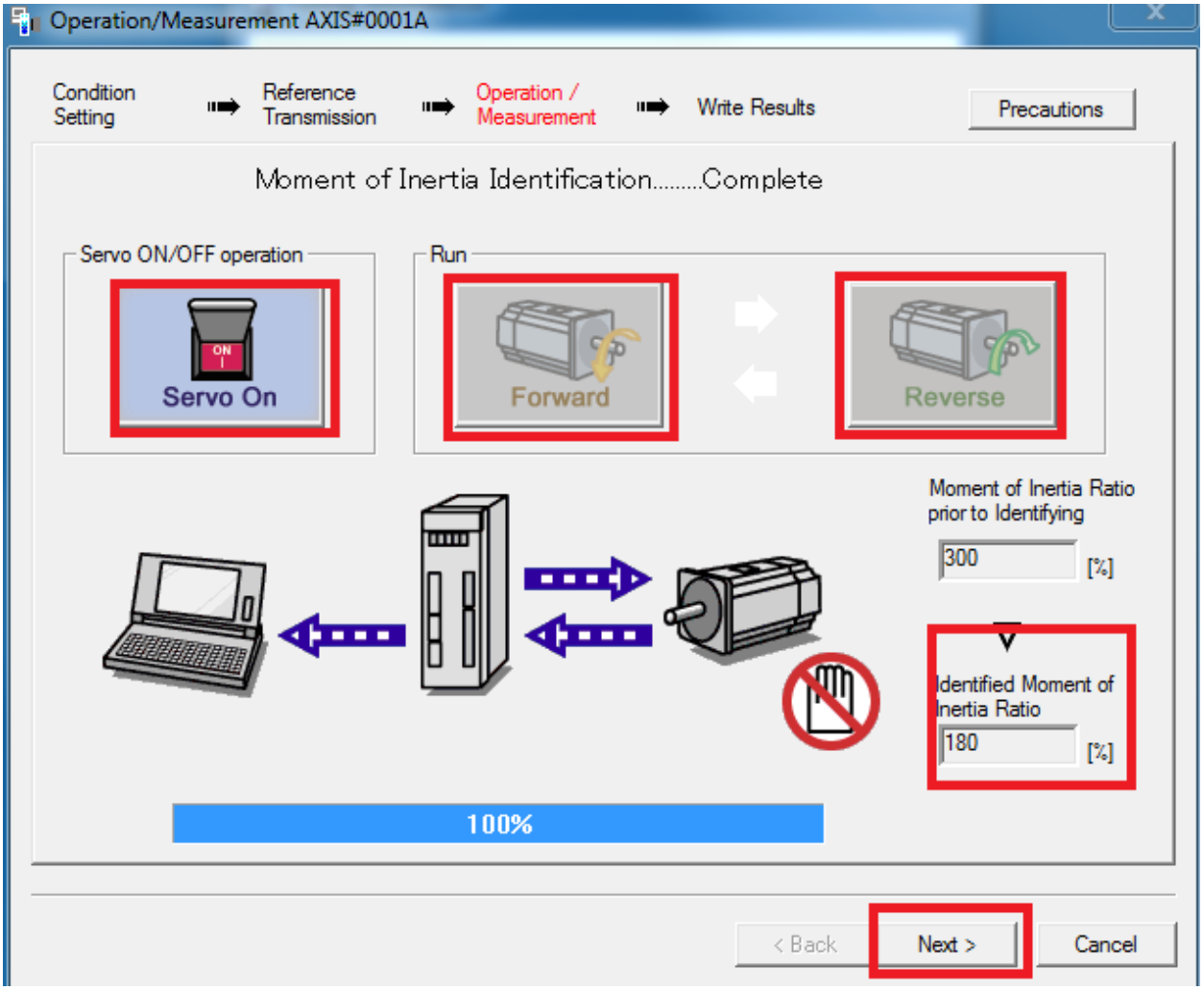

FIGURE 7 OPERATION OF INERTIA ROUTINE

- In Write Results, Select **Write Results**, then **Finish**.

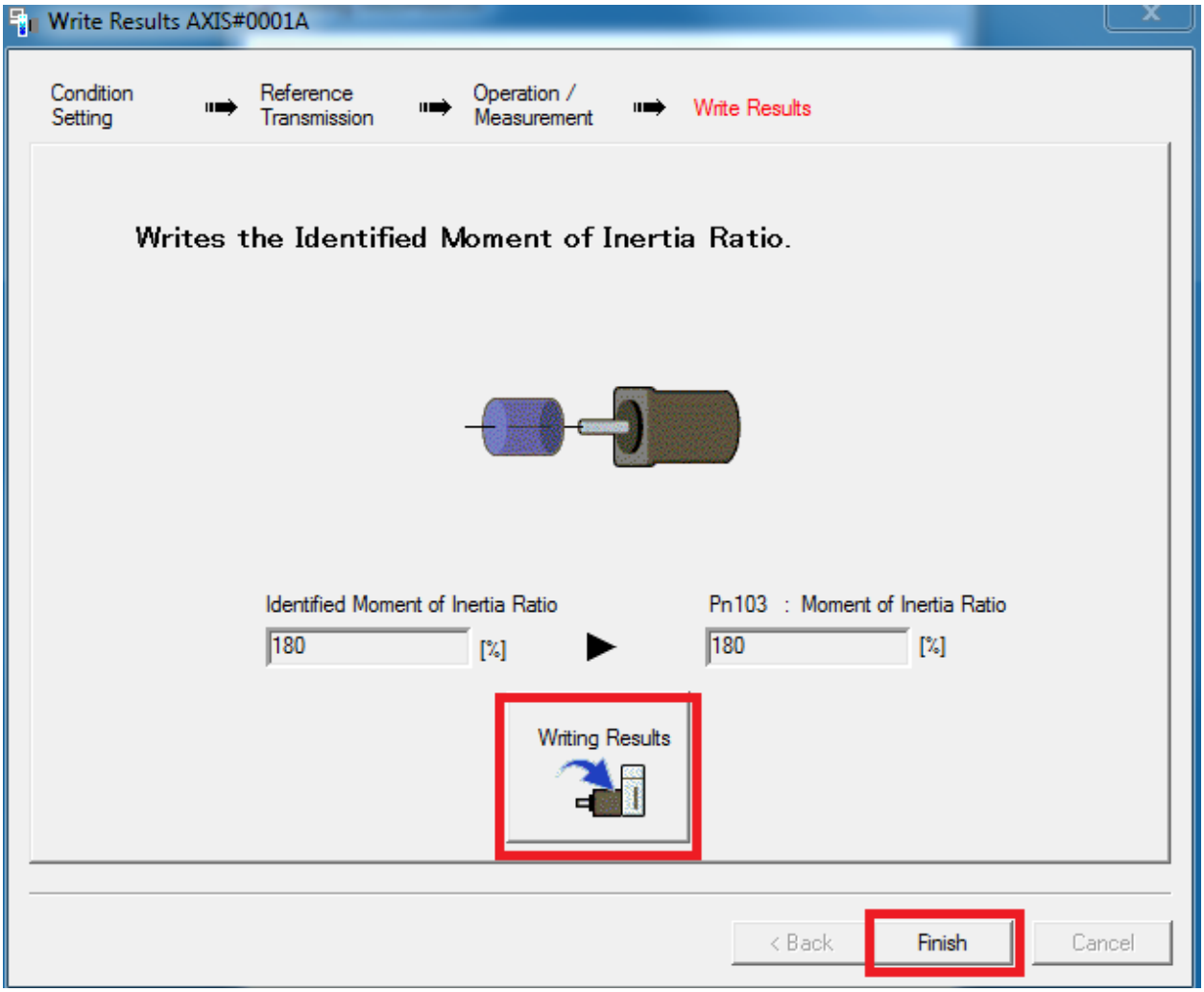

FIGURE 8 WRITE RESULTS OF INERTIA ROUTINE WHEN FINISHED

- Follow prompts to do a SERVOPACK soft reset.

- When clicking Forward or Backward, an error may be encountered. If this error comes up, either increase the torque limit of the motor (**Pn402/403**) or lower the Acceleration and Speed on the Condition Setting before repeating.

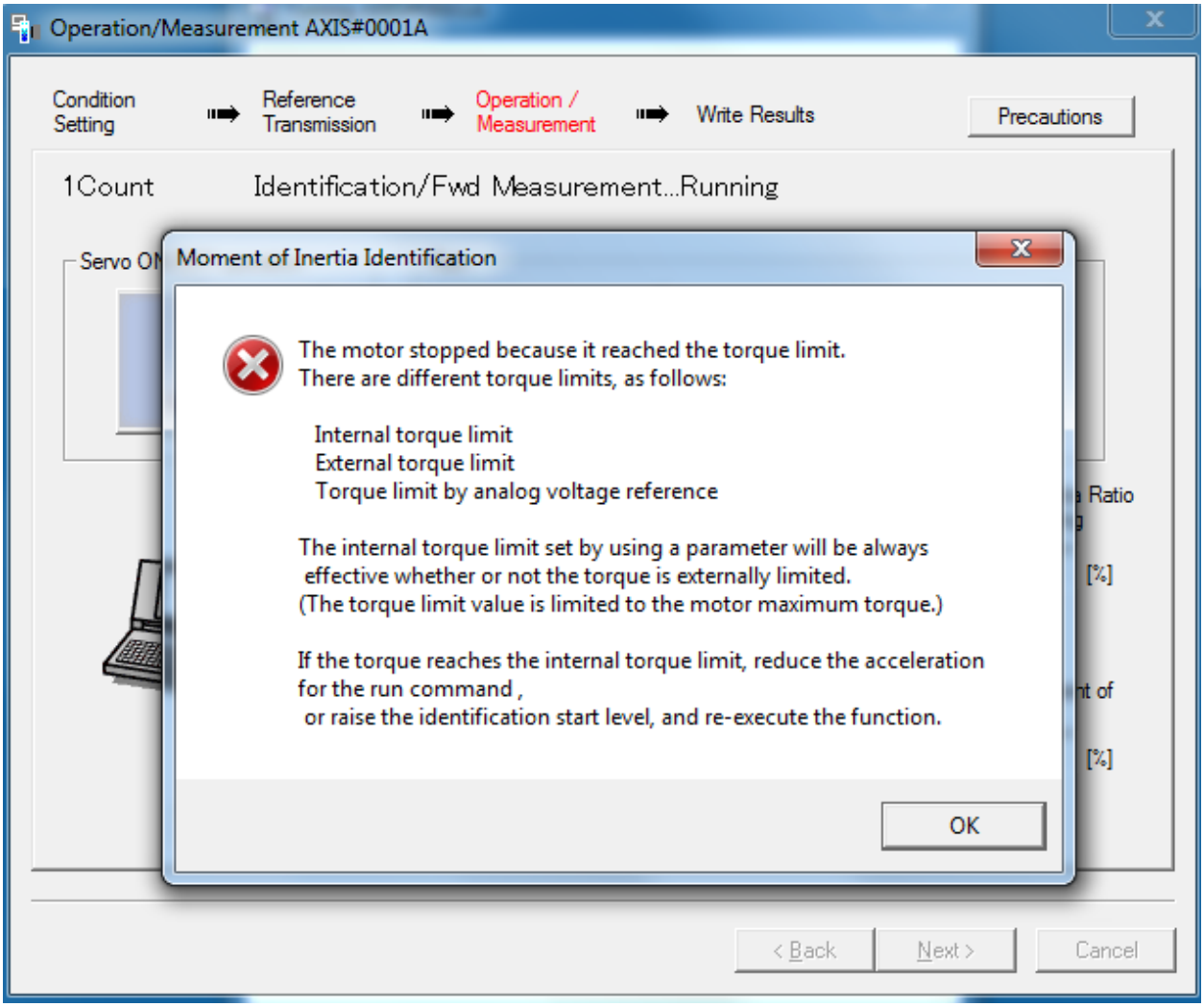

FIGURE 9 POSSIBLE ERROR MESSAGE DURING INERTIA ROUTINE

☐ Autotuning

After finding an inertia ratio, the autotuning function in SigmaWin+ provides a good starting point for motor gains and tuning parameters.

- To go the Tuning menu in SigmaWin+. Select **No Reference Input** then **Autotuning** button. Using a reference input is fine too, but it was not used in this example.

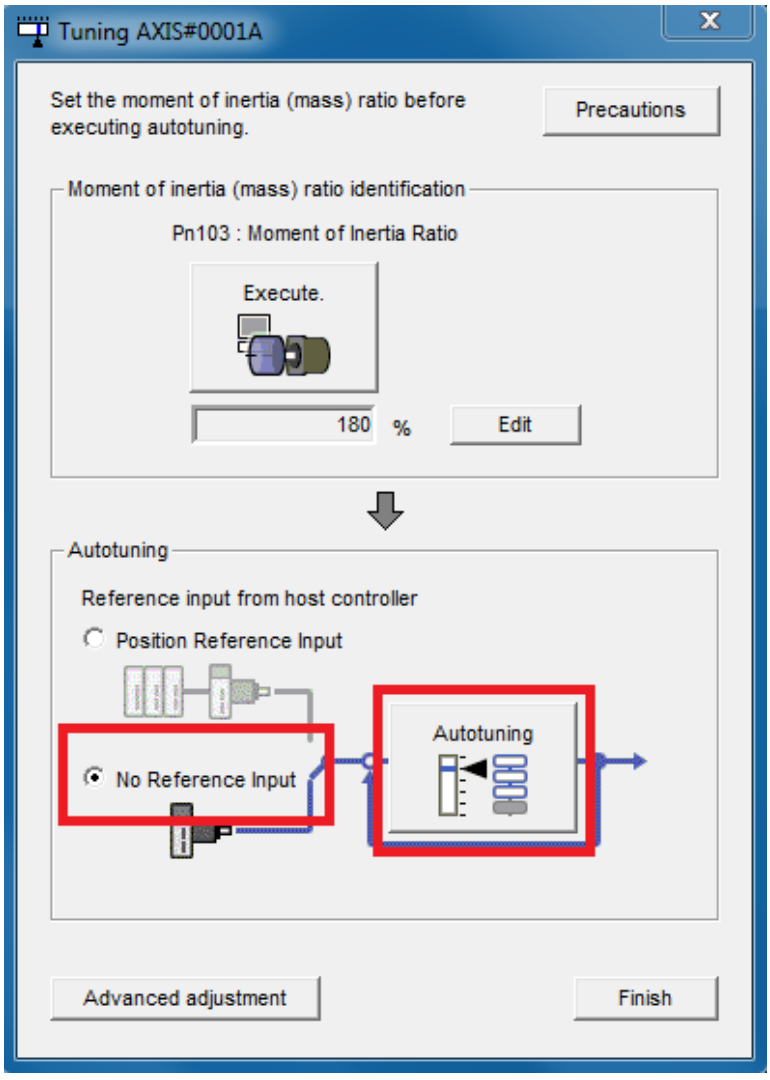

FIGURE 10 TUNING FUNCTION FOR AUTOTUNING

- In the **Autotuning – Settings Conditions** window
  - Select **1: A moment of inertia ratio is not presumed** for Switching the load moment of inertia (load mass) identification. This is because inertia was already found in a previous step.
  - Select **1: Standard** for Mode Selection.
  - Select **1: Belt mechanism** for Mechanism Selection.
  - Set a **distance**. 20000 was used in this example using a Sigma7 motor. Make sure the distance set will not crash the robot. In this example, there is much more free space than 1.2 rotations of motor.
  - Click **Next** when done

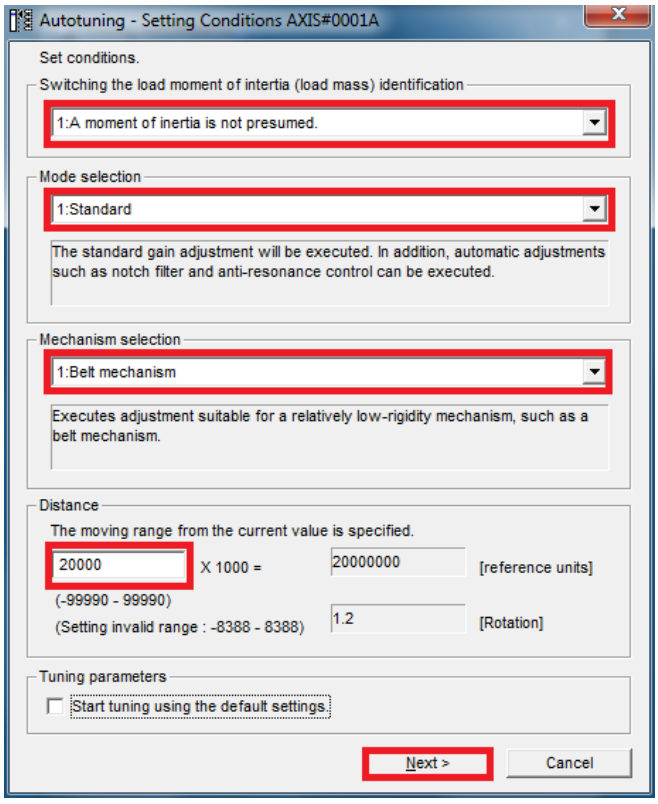

FIGURE 11 AUTOTUNING SETTINGS

- In the **Autotuning – Automatic settings** window, click **Servo ON**, then **Start tuning**. Click **Yes** on warning for Please check safety near an operation part to begin autotuning.

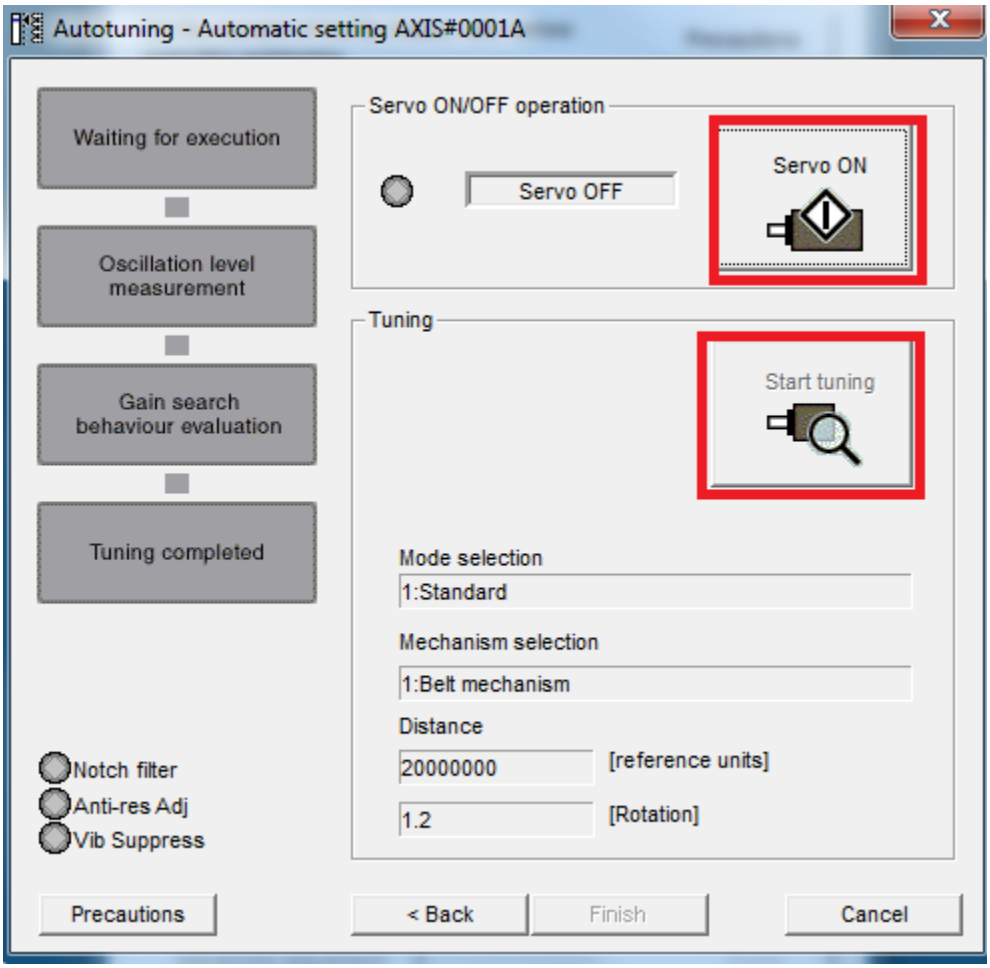

FIGURE 12 AUTOTUING OPERATION

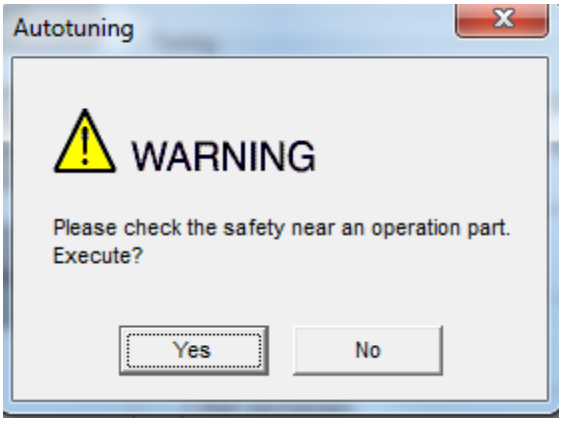

FIGURE 13 WARNING WHEN STARTING AUTOTUNING

- Autotuning may be aborted due to some possible causes, and there may be an alarm on the drive. Deal with and clear the alarm. It may be necessary to increase the value of **Pn520** (Excessive Position Error Alarm Level), **Pn522** (Position Completed Width), or **Pn402/403** (Torque limits). In this example, **Pn520 = 15000000 and Pn522 = 1000 was used for a Sigma7 motor. Pn520 = 5242880 and Pn522 = 70 be used for a Sigma5 motor.** Other values may work as well.

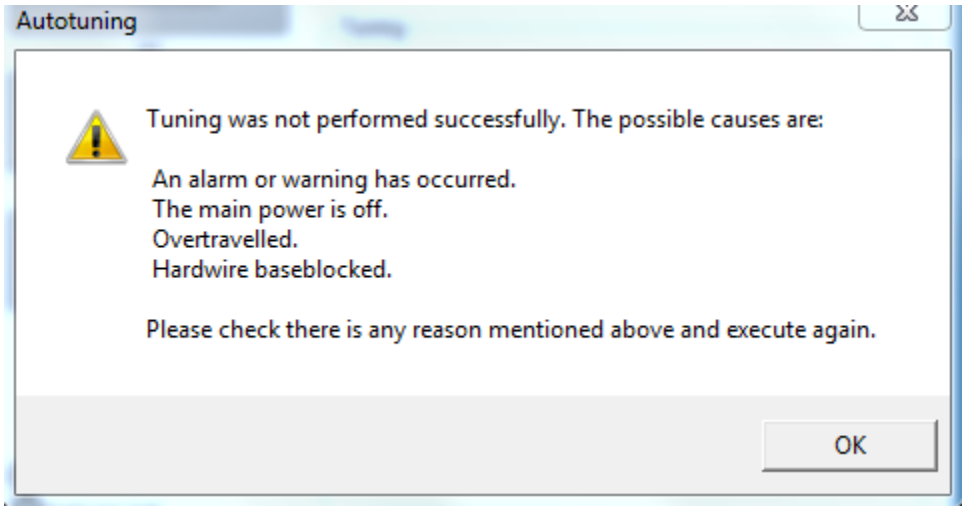

FIGURE 14 POSSIBLE ERROR MESSAGE WHEN AUTOTUNING

- Restart the autotuning routine with the same settings as before. Allow the tuning routine to complete. Click **Finish** to exit. The tuning parameters are now saved.

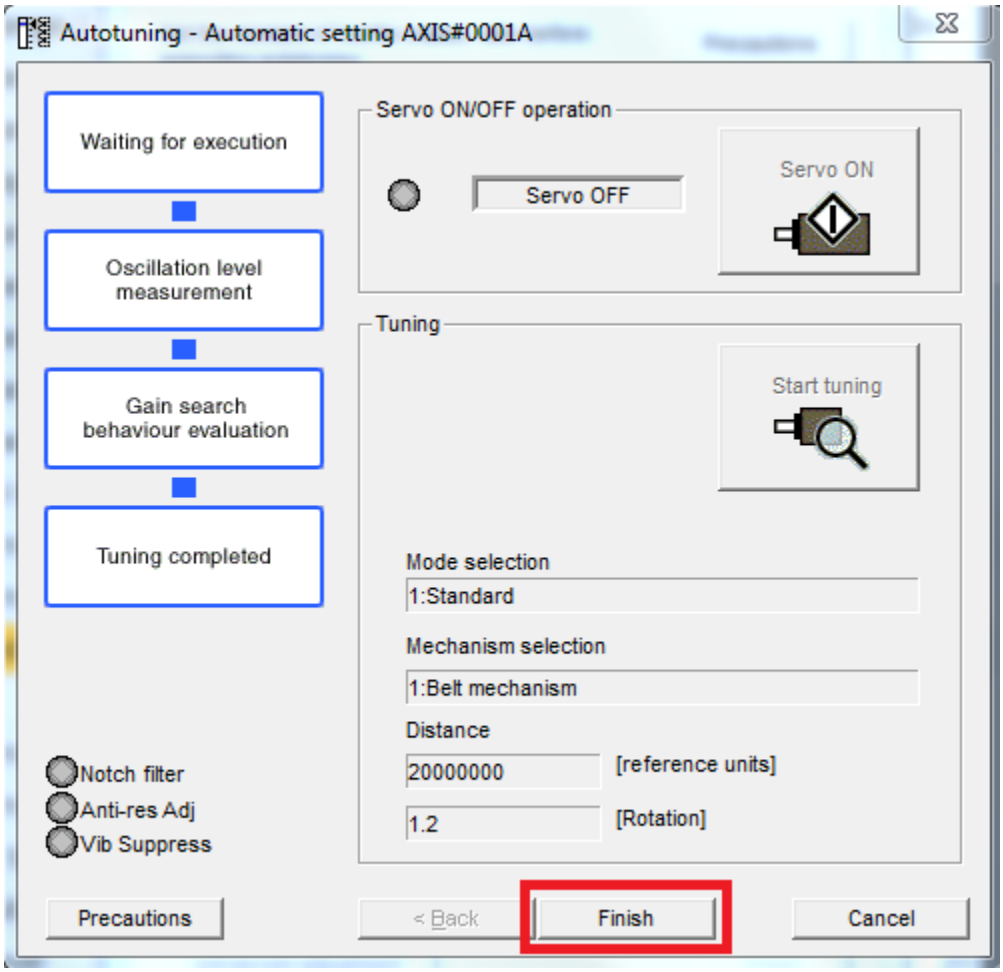

FIGURE 15 AUTOTUNING ROUTINE FINISH SUCCESSFULLY

- Reset **Pn520** and **Pn522** back to something reasonable. **For Sigma7 motors, Pn520=500000 and Pn522=100** can be used. For **Sigma5 motors, Pn520=30000 and Pn522=7** can be used. Note that Pn520 may need to be increased later on if accelerations are high.
- Power cycle the controller and drives.

- Copy the parameters of this arm motor into the other 2 arm motors. Can do it though SigmaWin+ or MotionWorksIEC.

☐ Manual Tuning

After finishing autotuning, some manual tuning may be required to get rid of excess vibration or torque ripples.

- Create a program in MotionWorksIEC to run a cyclic sample path at a slow speed. It is recommended to have this path be similar to expected operation with some payload attached. This example ran a simple pick and place path through [200 200 950] -> [200 200 1050] -> 100ms Dwell -> [200 200 950] -> [-200 -200 950] -> [-200 -200 1050] -> 100ms Dwell -> [-200 -200 950] -> repeat. All the moves are blended, and with Velocity=1000mm/sec and Acceleration=10000mm/sec^2
- Open **SigmaWin+** and connect to an arm motor. Go into the **Trace** menu.

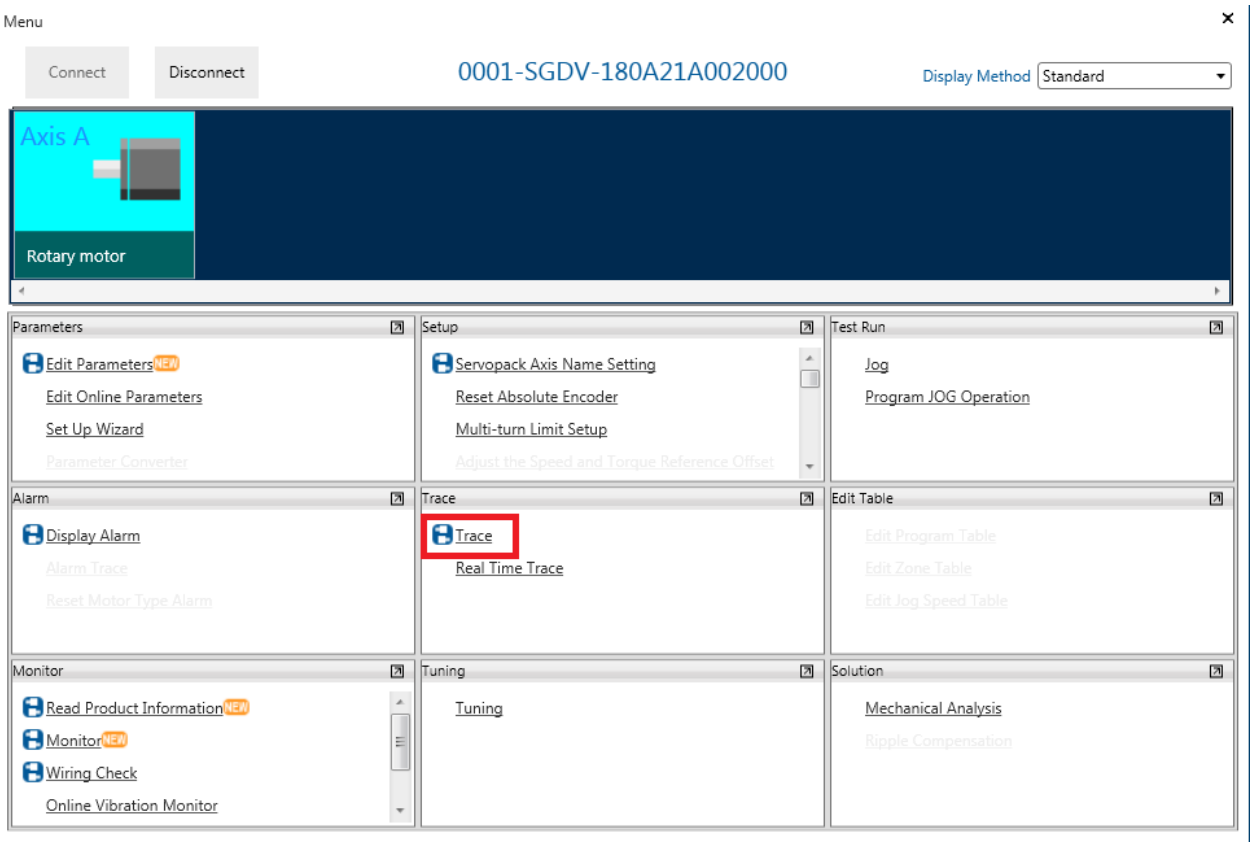

FIGURE 16 TRACE FROM MAIN MENU

- On the Trace window, click **Setup**, then configure settings to record **Feedback Speed**, **Torque Reference**, and **Position Error**. Set **Sampling Time** to something that will capture a cycle of the move, with **High-precision trace** checked. Use a **Trigger** based on rising edge of Feedback Speed. Click OK to continue. On Trace window, Click Start to collect data.

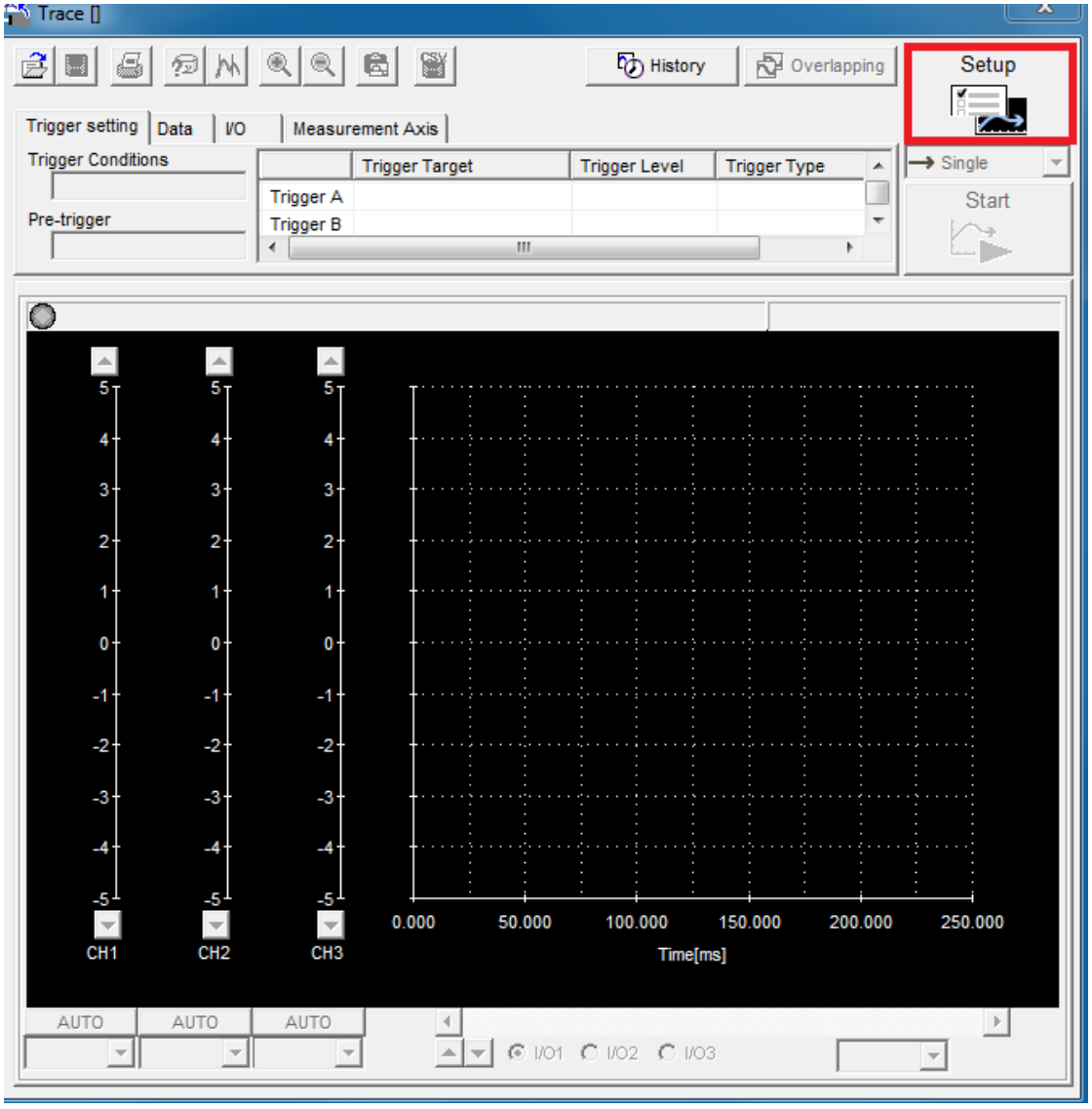

FIGURE 17 TRACE WINDOW

Title: Custom Delta Robot Motor Tuning

Product(s): MP3200iec-RBT, MP3300iec-RBT, MotionWorks IEC

Doc. No. AN.MP3300iec.02

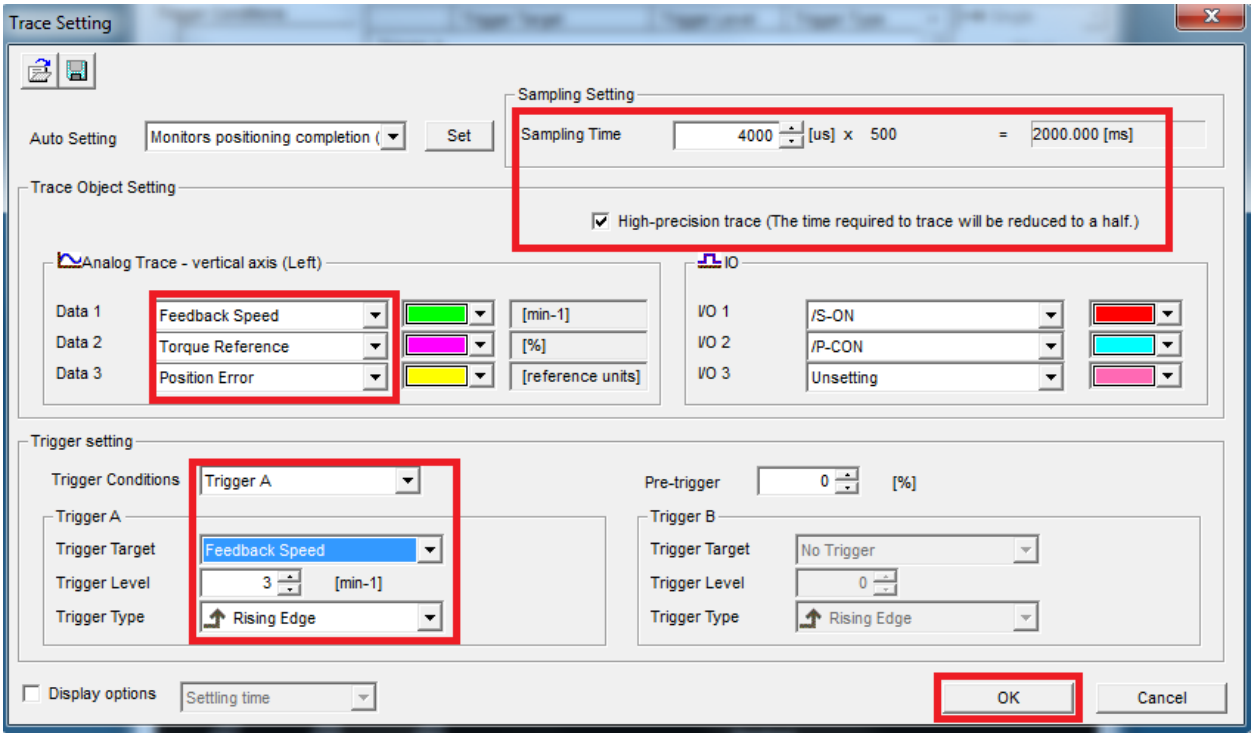

FIGURE 18 TRACE SETTINGS

- The plot may look something like this with some torque ripple.

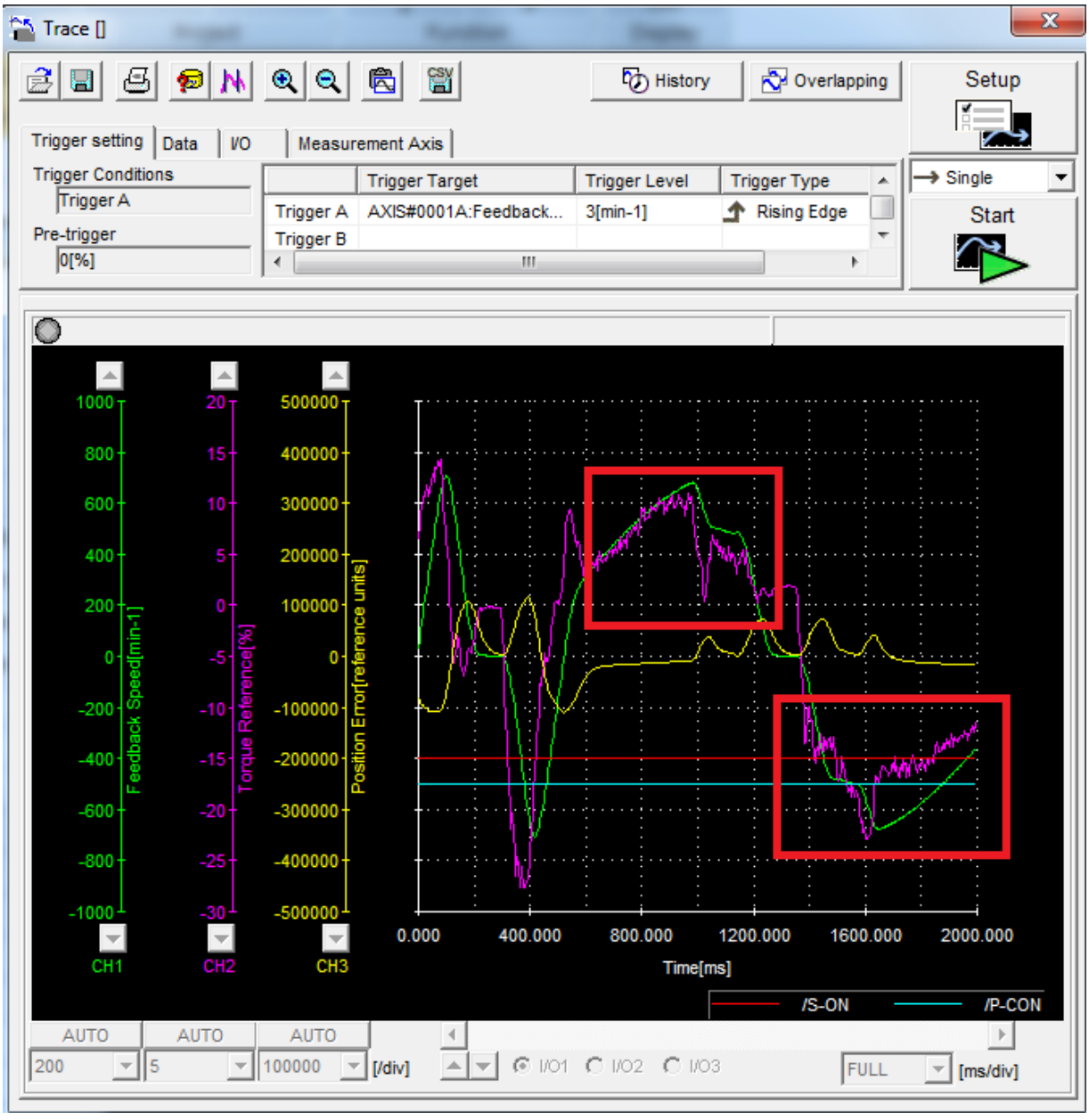

FIGURE 19 FEEDBACK SPEED, TORQUE REFERENCE, POSITION ERROR WITH AUTOTUNE PARAMETERS

- Manually tune parameters in the **Edit Parameters** menu until satisfied with amount of torque ripple and position error. Typically, editing **Pn100, Pn101, and Pn102** will be good enough. Keep in mind that the first priority is minimizing vibration, which may shows up as torque ripples. High speed video of the TCP would also be useful to ensure the payload is not vibrating during moves. **For Sigma5 servopacks, controller parameter 1310 may need to be disabled**. After tuning, the plots should show a smoother torque profile and TCP vibration should be minimized.

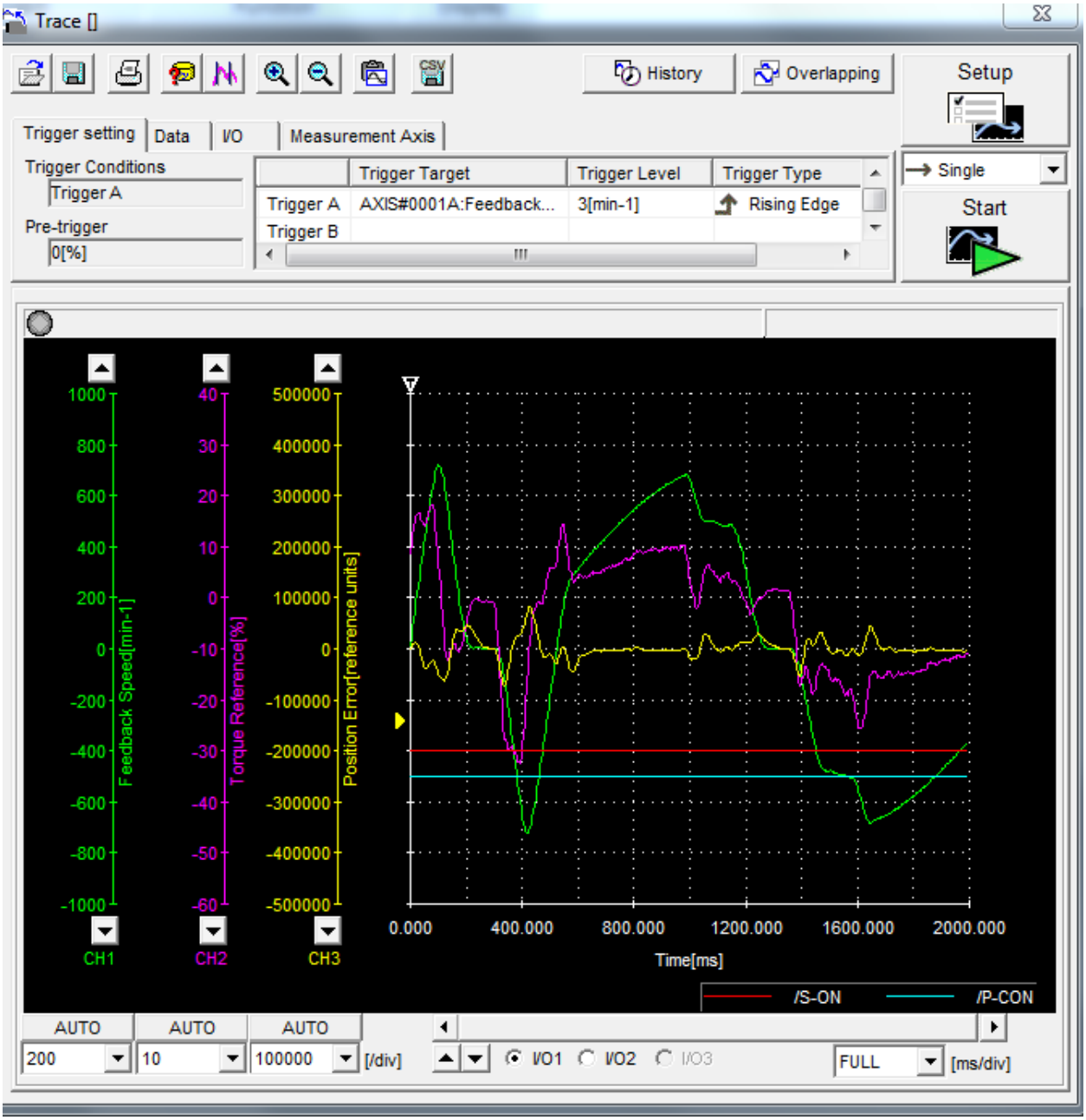

FIGURE 20 FEEDBACK SPEED, TORQUE REFERENCE, POSITION ERROR AFTER MANUAL TUNING

- Stop the move routine, save the parameters, and copy the parameters over to the other two arm axes.

- Power cycle controller and servopacks.
- Run sample path again and check SigmaWin+ on all arm axes to make sure that the tuning is still satisfactory.
- If it is satisfactory, run the same sample path at higher speed. Check SigmaWin+ again. If tuning is not satisfactory at high speed, do manual tuning of parameters again while running at high speed. For pick and place applications, position error values that correspond to less than 0.5 degrees on the arm is typically good enough depending on accuracy required by application.
- Sample plot of an arm axis when running the sample path at high speed. 7000mm/sec velocity, 120000mm/sec^2 acceleration after manual tuning. In this data set, the max position error after converting to arm angle is about 0.45 degrees. (around 800000 units max position error, 24bit encoder for Sigma7 motor, 38.5 gear ratio)

Title: Custom Delta Robot Motor Tuning

Product(s): MP3200iec-RBT, MP3300iec-RBT, MotionWorks IEC	**Doc. No.** AN.MP3300iec.02

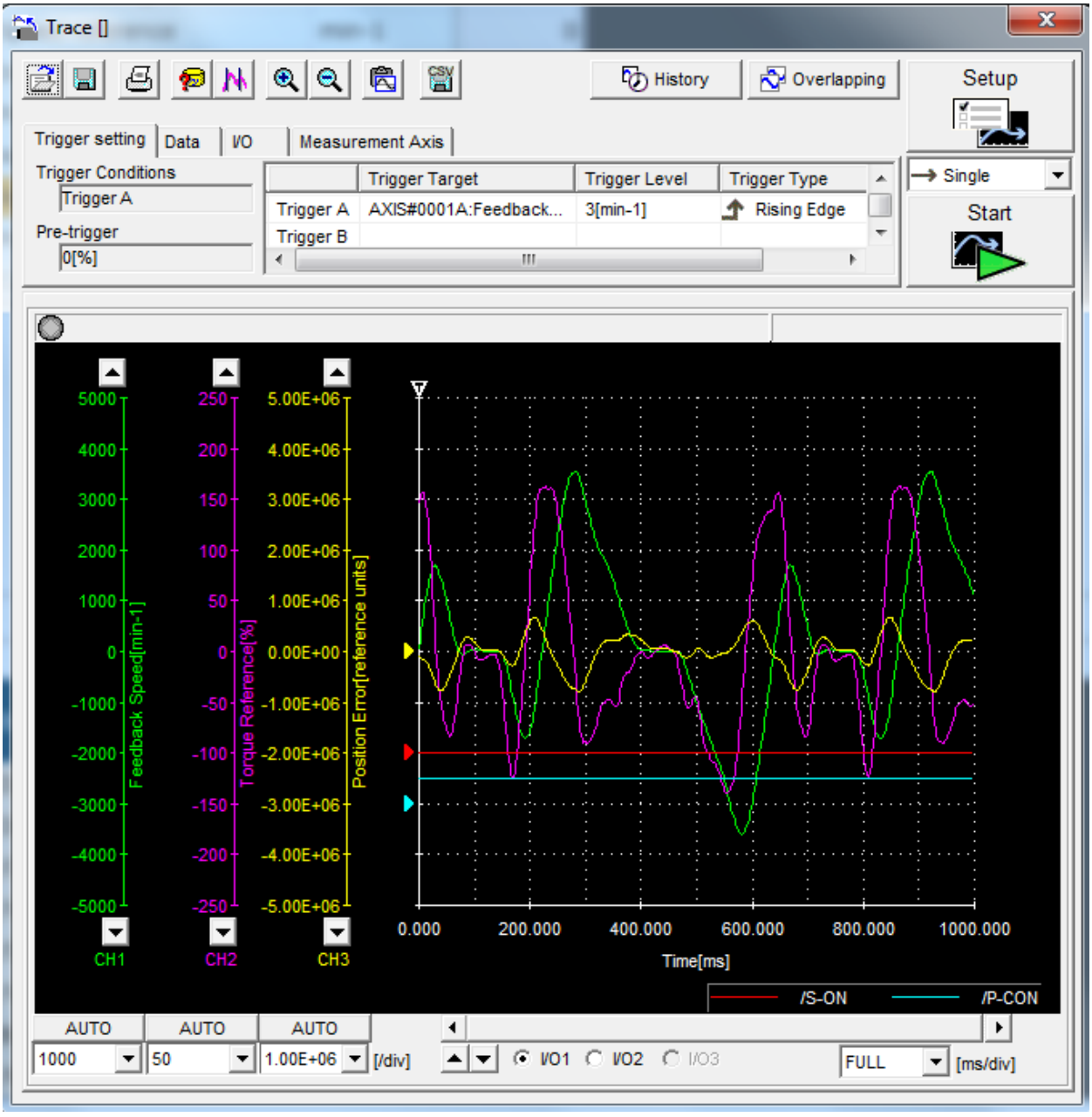

FIGURE 21 FEEDBACK SPEED, TORQUE REFERENCE, POSITION ERROR AT HIGH SPEED

☐ Additional Performance Improvements: Torque Passthrough

Torque Passthrough is a kinematic parameter that is used to estimate torque feedforward for the delta mechanism. It may help with lowering vibration and position error.

It is calculated as:

$$\text{Torque}(\%\text{Rated}) = \text{TorquePassthrough} * \text{MotorAcceleration}\ (\text{rad/sec\^2}).$$

The full expanded calculation to solve for Torque Passthrough is follows:

$$\text{Passthrough} = \text{RotorInertia}(\text{kg} - \text{m\^2}) * \text{InertiaRatio}\ (* 100\%) * \text{GearRatio} * \text{PI}/180 * 100/\text{RatedTorque}(\text{N} - \text{m})$$

- Calculate an initial value of **Torque Passthrough**
- Enable **Torque Passthrough** in Hardware Configuration for the delta group used. In the **Set Kinematics** tab of Hardware Configuration, scroll down to the S L U **Torque Passthrough** parameters. Use the calculated value as a starting point. Click OK when done.

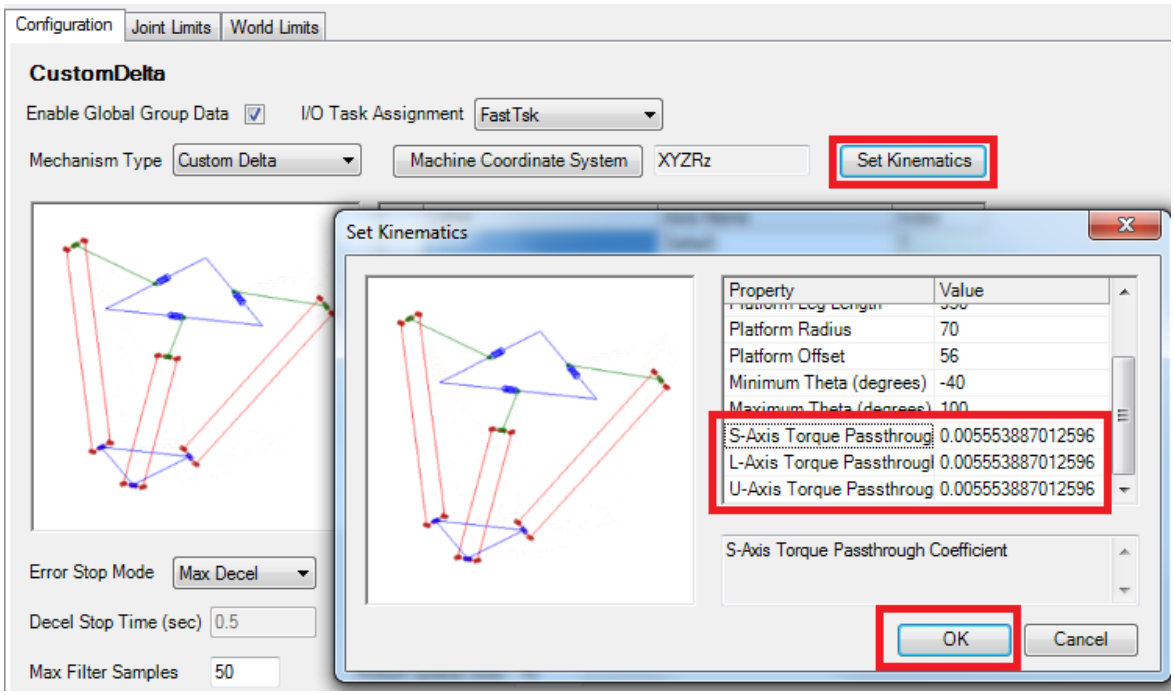

FIGURE 22 TORQUE PASSTHROUGH IN THE SET KINEMATICS WINDOW

- Save configuration and power cycle controller and SERVOPACKs.
- Run a sample path at a slow speed. The same path from manual tuning was used.
- Use the **Trace** function in **SigmaWin+** to plot **Torque FeedForward**, **Torque Reference**, and **Position Error**. Check if **Torque FeedForward** and **Torque Reference** have a high discrepancy and if **Position Error** is getting better. In the sample plot, it is shown that the **Torque FeedForward** is much lower than **Torque Reference**, but the **Position Error** has decreased.

Title: Custom Delta Robot Motor Tuning

Product(s): MP3200iec-RBT, MP3300iec-RBT, MotionWorks IEC	**Doc. No.** AN.MP3300iec.02

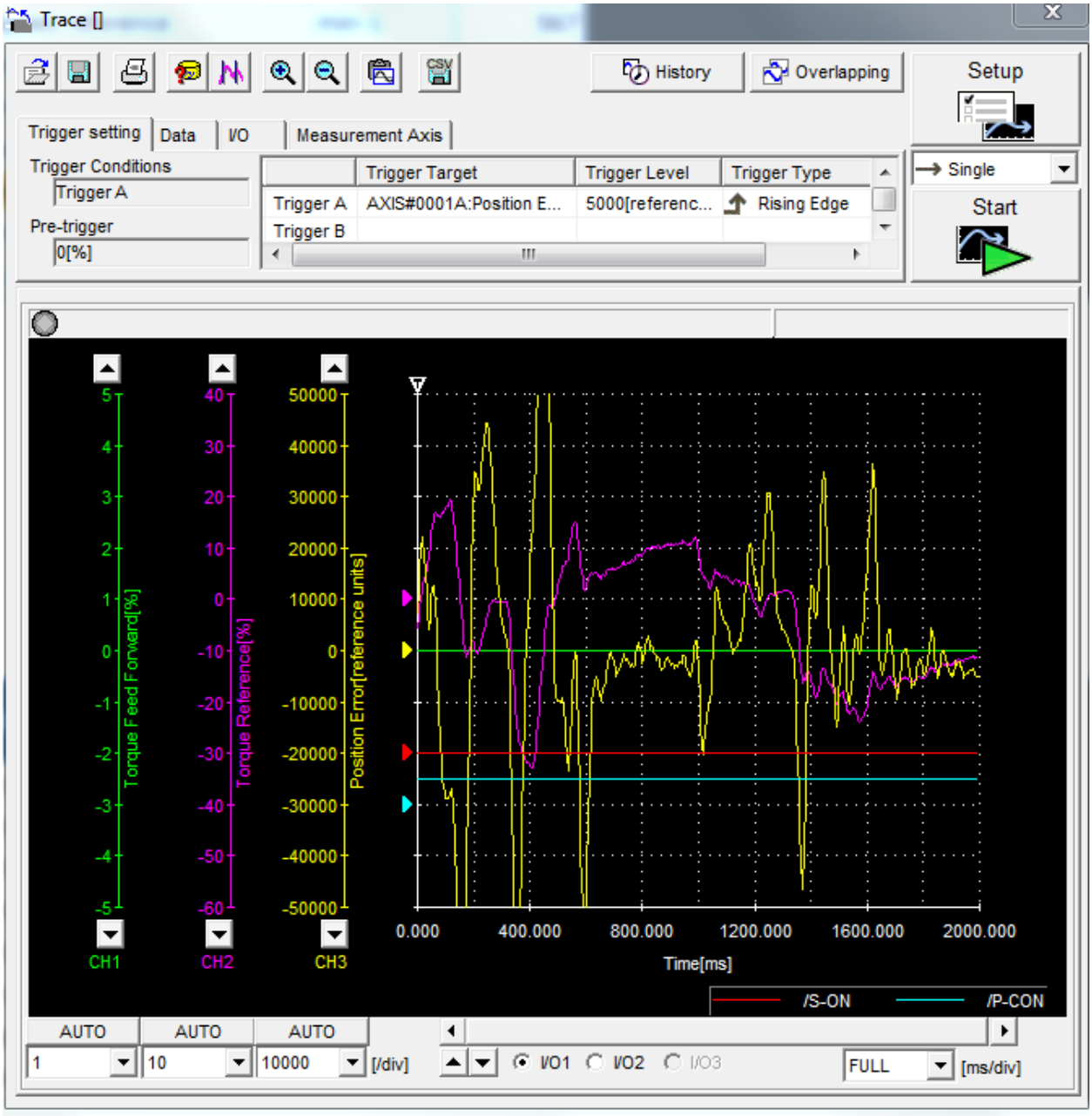

FIGURE 23 LOW SPEED WITHOUT TORQUE PASSTHROUGH

Title: Custom Delta Robot Motor Tuning

Product(s): MP3200iec-RBT, MP3300iec-RBT, MotionWorks IEC	**Doc. No.** AN.MP3300iec.02

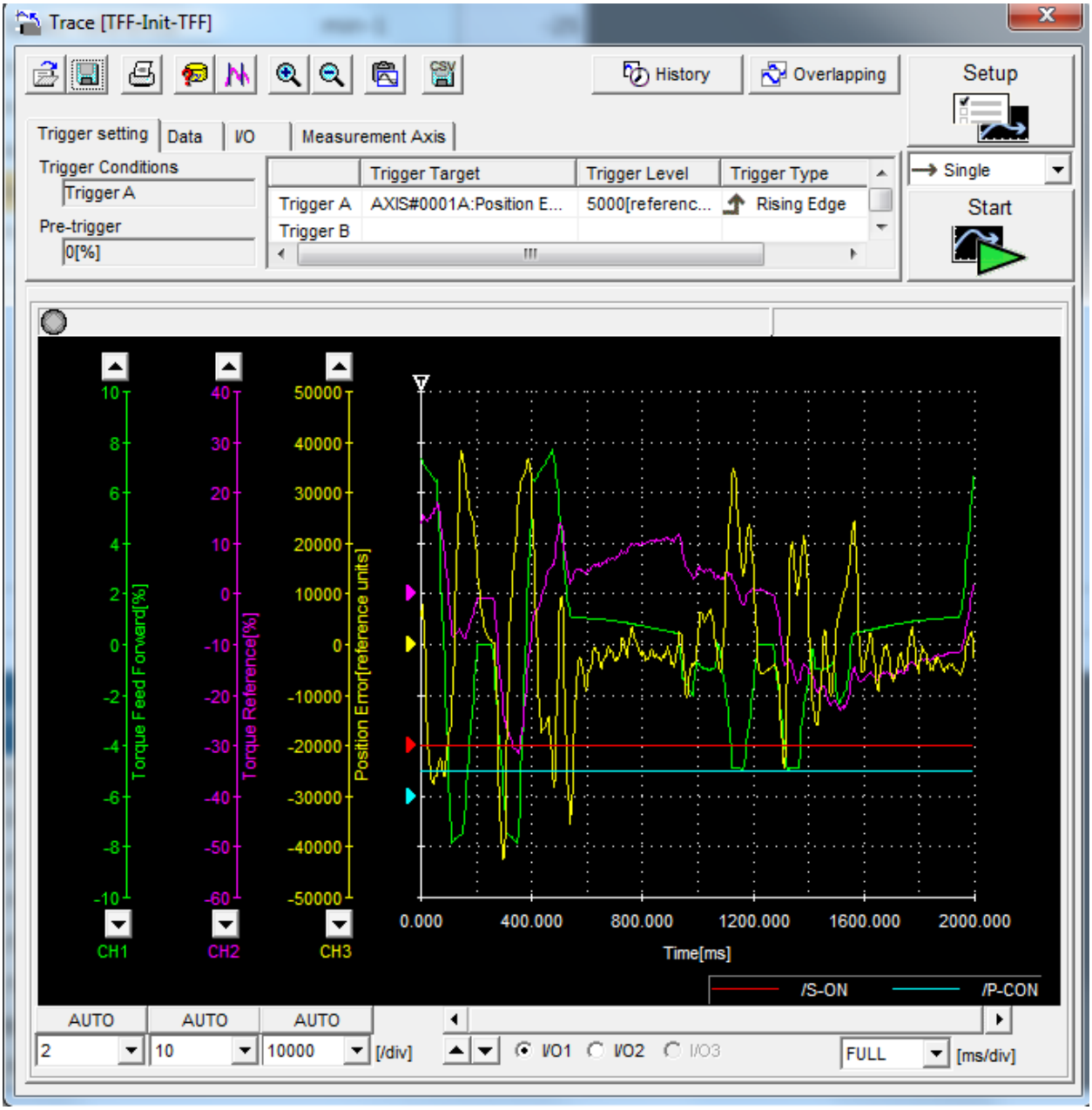

FIGURE 24 TORQUE PASSTHROUGH ENABLED WITH CALCULATED INITIAL VALUE

- Since **Torque Feedforward** is much lower than **Torque Reference**, try increasing the **Torque Passthrough** parameter again in Hardware Configuration.
- After increasing **Torque Passthrough** parameter, there was decrease in **Position Error**. **Torque FeedForward** and **Torque Reference** will not match perfectly. It is typically better to have **Torque FeedForward** be lower in magnitude than **Torque Reference**.

Title: Custom Delta Robot Motor Tuning	
Product(s): MP3200iec-RBT, MP3300iec-RBT, MotionWorks IEC	**Doc. No.** AN.MP3300iec.02

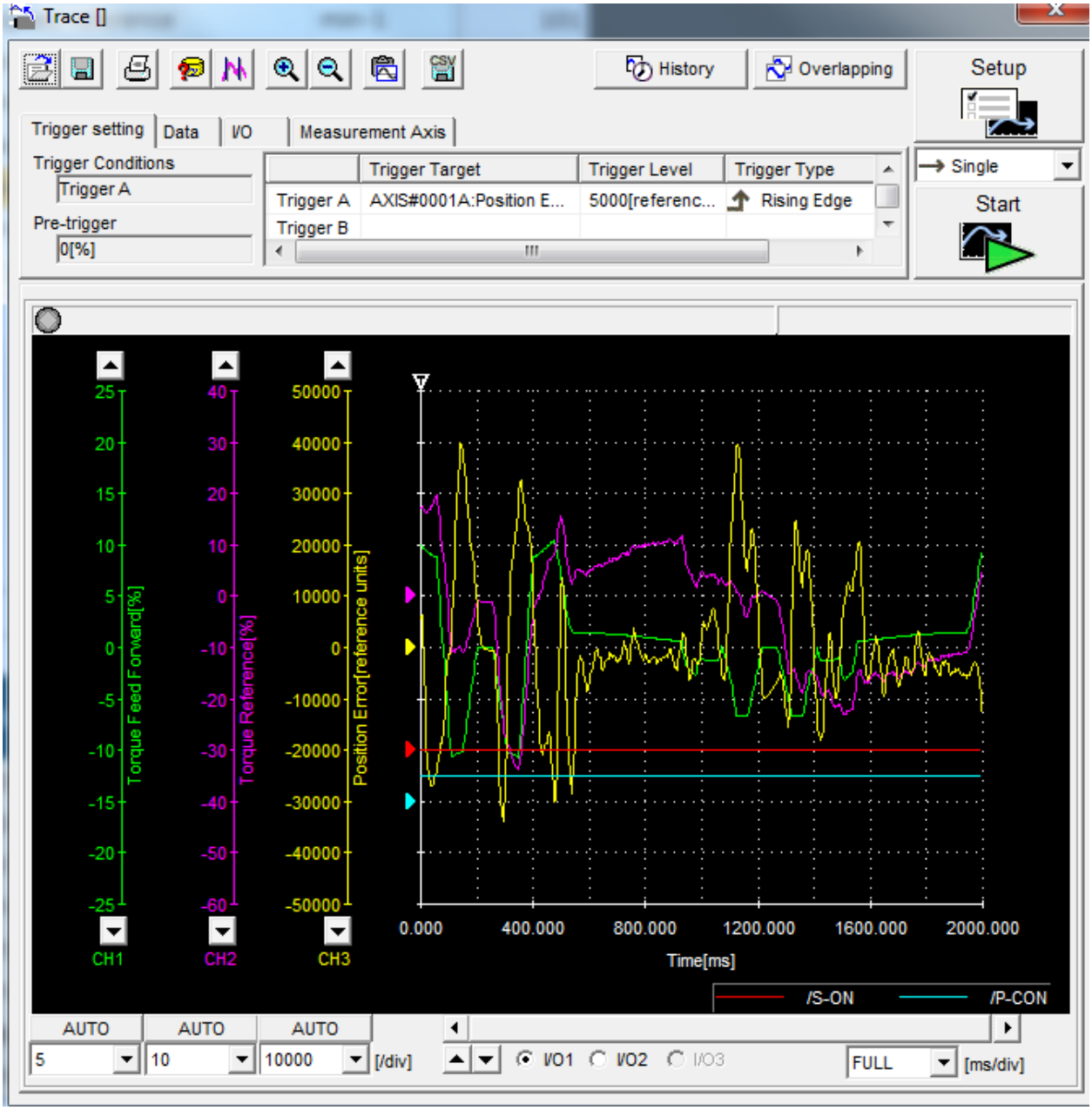

FIGURE 25 INCREASED TORQUE PASSTHROUGH PARAMETER

Run sample path at high speed, and plot **Torque FeedForward**, **Torque Reference**, and **Position Error**, then compare to the previous plot before **Torque Passthrough** was enabled. From the following plot, it shows that when **Torque Passthrough** was enabled, **Position Error** has dropped significantly, from a maximum of 800,000 (after manual tuning) units to 500,000 units.

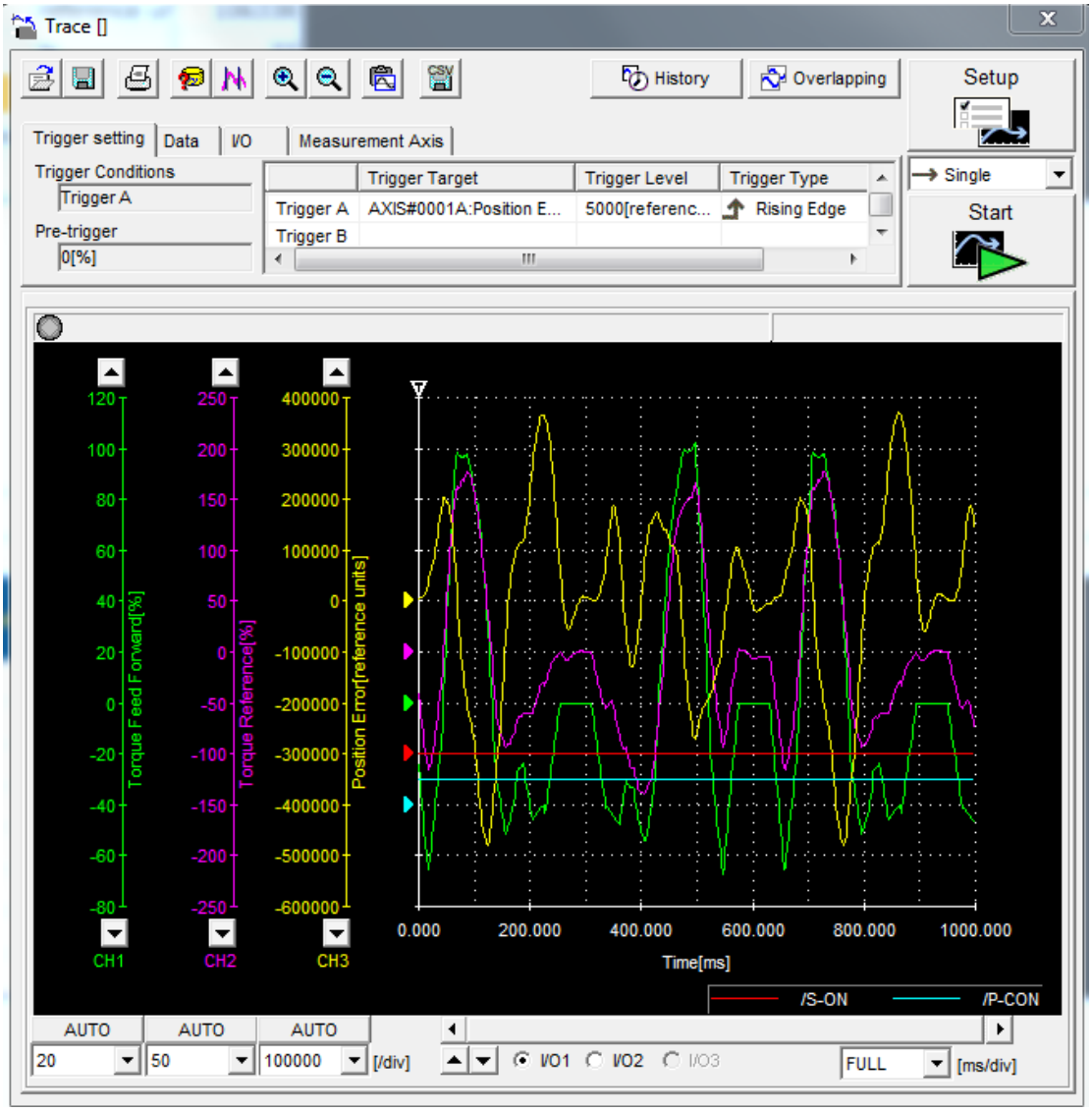

FIGURE 26 EFFECT OF TORQUE PASSTHROUGH AT HIGH SPEED

- Plot **Torque FeedForward**, **Torque Reference**, and **Position error** of the other two arm axes to confirm that this is a good setting. Modify **Torque Passthrough** until satisfied.