Tuning guide
H-1000-5246-03-A

RENISHAW
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# Digital servo power amplifier

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# Digital servo power amplifier

# tuning guide

# SPA*2* and SPA*lite*

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## References and associated documents

It is recommended that the following documentation is referenced to when installing the UCC.

## Renishaw documents

Documentation supplied on Renishaw UCC software CD.

| Document number | Title |
|---|---|
| H-1000-5057 | UCC controller programmer's guide |
| H-1000-5058 | UCC Renicis user's guide |
| H-1000-5223 | **UCC*2*** installation guide |
| H-1000-5234 | **SPA*2*** installation guide |
| H-1000-5227 | SPA1 servo tuning guide |

# Contents

# 1 Introduction

The object of this digital servo power amplifier tuning guide is to provide a user-friendly publication to assist in the task of setting up the servo response of the CMM when fitted with either a **SPA2** or **SPA***lite* servo power amplifier. Used in conjunction with Renishaw's "RENICIS" installation / fault finding software, this document should enable a competent technician to set up a CMM either at the assembly plant or on-site.

The Renishaw controller family of products has a powerful range of control elements to assist with tuning (attaining the required performance) the CMM system, including; gain control, lead and lag filters, dynamic integrator, acceleration feedback and velocity feed-forward.

The theories behind optimal tuning of control system are lengthy and complex, so we have tried in this issue to simplify the set-up steps that deal with servo-optimisation. A set of performance indices is available to allow checking of the machine tuning at any time and a report can be generated.

# 2 Digital SPA commissioning sequence

The following section outlines the recommended procedure to commission either the **SPA*2*** or **SPA***lite* digital servo power amplifiers.

This procedure assumes that the system being installed is a new installation and little information is known about the machine's servo system characteristics.

## 2.1 Initial machine ini file creation

Using Renicis create a new machine ini file, the following critical parameters must be correctly specified for the initial installation process.

**NOTE:** Most of the default parameters specified in the machine configuration file can remain as default.

### 2.1.1 Common parameters

**MachineDescription section**

| | |
|---|---|
| Make | This should be the make of machine |
| Model | This should be the model of the machine |

**Miscellaneous section**

| | |
|---|---|
| LogFilePath | This should be a valid file path |

**MachineConfiguration section**

| | |
|---|---|
| ProbeHeadType | Probe head type fitted to the machine |
| XscaleIncrement | Resolution of the X axis scale in mm |
| YscaleIncrement | Resolution of the Y axis scale in mm |
| ZscaleIncrement | Resolution of the Z axis scale in mm |
| Xtravel | Distance of machine X axis travel in mm |
| Ytravel | Distance of machine Y axis travel in mm |
| Ztravel | Distance of machine Z axis travel in mm |

**MoveConfiguration section**

| | |
|---|---|
| * MaximumMoveSpeed | Maximum move speed of the CMM in mm/s |
| MaximumMoveAcceleration | Maximum move acceleration of the CMM in mm/s/s |

* See section 2.1.4 for an explanation of this parameter and its importance.

**TORQUEMODE (if used)**

| | |
|---|---|
| ControlMode | Torque mode is enabled or not |

**MachineIOLogic**

| | |
|---|---|
| AmpifierOK | Logic level active high or low |
| CMMdeclutch | Logic level active high or low |
| ESTOPtripped | Logic level active high or low |
| AirPressureLow | Logic level active high or low |
| ZaxisCrash | Logic level active high or low |
| MotorsEngaged | Logic level active high or low |
| OuterLimitXPositive | Logic level active high or low |
| OuterLimitXNegative | Logic level active high or low |
| OuterLimitYPositive | Logic level active high or low |
| OuterLimitYNegative | Logic level active high or low |
| OuterLimitZPositive | Logic level active high or low |
| OuterLimitZNegative | Logic level active high or low |
| InnerLimitXPositive | Logic level active high or low |
| InnerLimitXNegative | Logic level active high or low |
| InnerLimitYPositive | Logic level active high or low |
| InnerLimitYNegative | Logic level active high or low |
| InnerLimitZPositive | Logic level active high or low |
| InnerLimitZNegative | Logic level active high or low |
| OuterLimitY2Positive | Logic level active high or low |
| OuterLimitY2Negative | Logic level active high or low |
| InnerLimitY2Positive | Logic level active high or low |
| InnerLimitY2Negative | Logic level active high or low |

### 2.1.2 SPA*lite* only

**SPAX**

| | |
|---|---|
| ChannelNumber | = 0 |
| SPAType | = SPAlite |

**SPAY**

| | |
|---|---|
| ChannelNumber | = 1 |
| SPAType | = SPAlite |

**SPAZ**

| | |
|---|---|
| ChannelNumber | = 2 |
| SPAType | = SPAlite |

### 2.1.3 SPA*2* only

**Dual Y section (if fitted)**

| | |
|---|---|
| DualAxisScaleIncrement | Resolution of the dual axis scale in mm |
| WhichAxisDual | Which axis is the dual axis |
| DualDriveEnable | Is the dual drive switched on |
| ScaleInputLocation | UCC input location address |
| DriveOutputLocation | UCC output location address |

**RotaryTable (if fitted)**

| | |
|---|---|
| MeasurementUnits | Units of increment for the rotary table |
| WscaleIncrement | Resolution of the W axis scale |
| WmaximumMoveSpeed | Maximum move speed of the rotary table |
| WmaximumMoveAcceleration | Maximum move acceleration of the rotary table |

**Torque mode (used where motors with no tachimeter or encode feedback are fitted)**

| | |
|---|---|
| Control mode | = 1 if enabling torque mode |
| Feedback gain (X, Y and Z) | = (10 / MaximumMoveSpeed) |

Refer to section 2.5.1.

**SPAX**

| | |
|---|---|
| ChannelNumber | = 0* |
| SPAType | = SPA2 |

**SPAY**

| | |
|---|---|
| ChannelNumber | = 1* |
| SPAType | = SPA2 |

**SPAZ**

| | |
|---|---|
| ChannelNumber | = 2* |
| SPAType | = SPA2 |

**SPAW (if fitted)**

| | |
|---|---|
| ChannelNumber | The SPA2 output channel number* |

**SPADUAL (if fitted)**

| | |
|---|---|
| ChannelNumber | The SPA2 output channel number* |

**SPAConfiguration**

| | |
|---|---|
| SPA2ConfigurationFilePath | A valid file path if a SPA2 configuration file ,otherwise leave blank. |

* The **SPA*2*** channel number is the output channel that the motor is connected to on the **SPA*2***. Typically between 0 and 3, but can be between 0 and 7).

### 2.1.4 Machine and move configuration

This is a very important part of the machine set-up where all the physical and motion properties are defined.

**CAUTION:** Particular care is needed in specifying the *maximum move speed and acceleration* since this defines the velocity gain of the remainder of the CMM servo system (the motors, the tacho-generators (if fitted) and the drive gearing).

The “MaximumMoveSpeed” is a theoretical speed which corresponds to a maximum demand being applied to the servo power amplifier. To control a specified speed, we apply a margin about that speed to effect control. This is set to 20%. This means that the actual maximum move speed is 80% of the “MaximumMoveSpeed” specified in the machine configuration file i.e. if you set “MaximumMoveSpeed” to 500 mm/s the maximum move speed you can request is 400 mm/s.

If *maximum move speed* is altered after the CMM has been commissioned (with no change in the CMM hardware), two problems will become apparent: -

**Problem 1**

All machine speeds will be altered. e.g. if the *maximum move speed* value is halved, this implies that the full 10 V motor command will now produce only half the previous speed. The controller will therefore compensate by sending speed commands to the motors, which are twice the original values to get the same target machine speeds. This will result in much faster moves than intended, with probably “over-speed” and “overdriven” faults being produced.

**NOTE:** The machine speed in a command (move or scan) is limited to only 80% of the maximum move speed to ensure servo control at all times.

**Problem 2**

If the machine’s performance characteristics change then some of the settings will become invalid. The machine will need to be re-tuned.

## 2.2 Renicis sequence

### 2.2.1 Initial steps

1. Start the commissioning process by ensuring the step icon on the toolbar is not indented and then click on the GO icon on the toolbar, as shown in the figure 1 below:


**Figure 1**

2. The Renicis commissioning step list will now be displayed within a window that will open on the desktop, as shown in the figure 2 below:

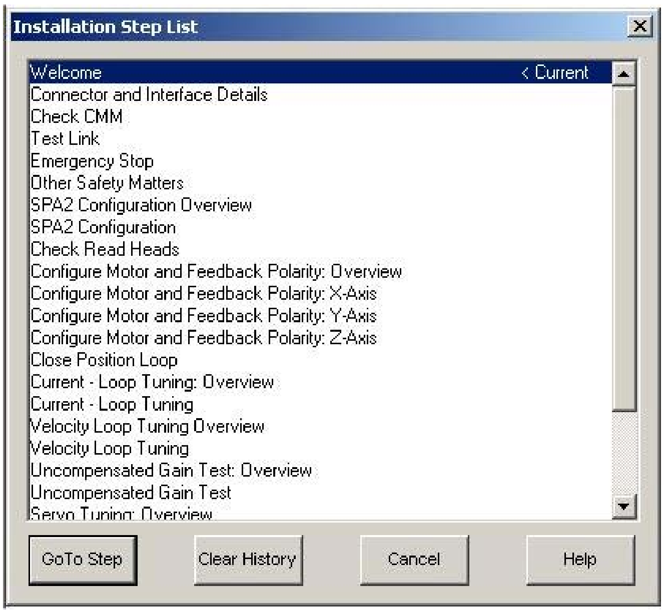



**Figure 2**

3. Highlight the Welcome step within the list and then click on the GoToStep button to start the commissioning process.

4. Proceed through the following Renicis steps following the instructions:
   - Welcome
   - Connector and interface details
   - Test link
   - Emergency stop
   - Other safety matters
   - **SPA2** configuration overview

5. If problems are experienced with any of the above steps, refer to the Renicis user guide (Renishaw part number H-1000-5058) or **UCC2** installation guide (Renishaw part number H-1000-5223).

### 2.2.2 SPA*2* configuration screen

For torque mode configuration please refer to section 2.5.2.

1. At this step, the following window will appear with the X axis screen presented (see figure 3 below):

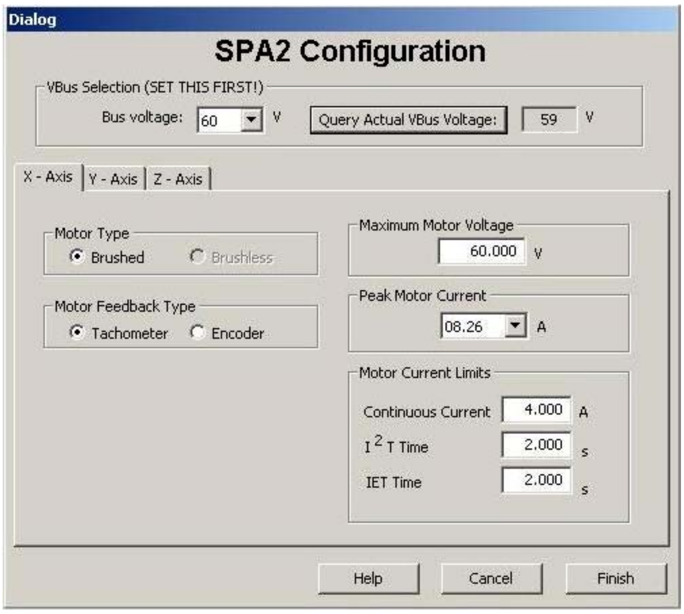



**Figure 3**

2. Under VBus selection the bus voltage should be set to 60 V for a **SPA2** installation and 48 V for a **SPA***lite* installation.

3. Select the correct motor and motor feedback type for the installation.

4. Enter the maximum motor voltage for the motor connected to the axis of the installation. Typically, this is stamped on the body of the motor.

5. Select the nearest peak motor current from the drop down list. Typically, this is stamped on the body of the motor.

6. Enter the continuous motor current specification. Typically, this is about 50% of the peak motor current, but can sometimes be found on the body of the motor.

7. It is recommended that the $I^2T$ and IET time values are left at the default value of 2 s (refer to section 4 for more information).

8. Repeat steps 2 to 6 for the other machine axes.

**NOTE:** It is possible to have different specification motors for different axes.

9. When all axes are complete click ‘Finish’.

### 2.2.3 Check readheads

Continue to 'Check Read Heads' Renicis step and perform the test as instructed on the screen display.

### 2.2.4 Configure motor and feedback polarity

**NOTE:** It is essential that the scale resolution and polarity for all machine axis have been checked and are correct before performing this step (section 2.2.3 'Check readheads')..

The configure motor and feedback polarity steps automatically check and configure the motor and feedback polarity for the installation.

During these steps, an increasing percentage of the machine's maximum current will be applied to each motor in turn with the aim of moving the machine a minimum of 1 mm.

Using the axis scales as reference the motor and feedback polarities are then automatically configured.

The configuration is finally checked by the next Renicis step 'close position loop'.

### 2.2.5 Current – loop tuning

In this section you are tuning the current-loop to ensure that:

a) The amplifier delivers the required current to the motors.

b) High frequencies are not introduced by the response being too sharp.

At this step the following screen will appear with the X axis active:

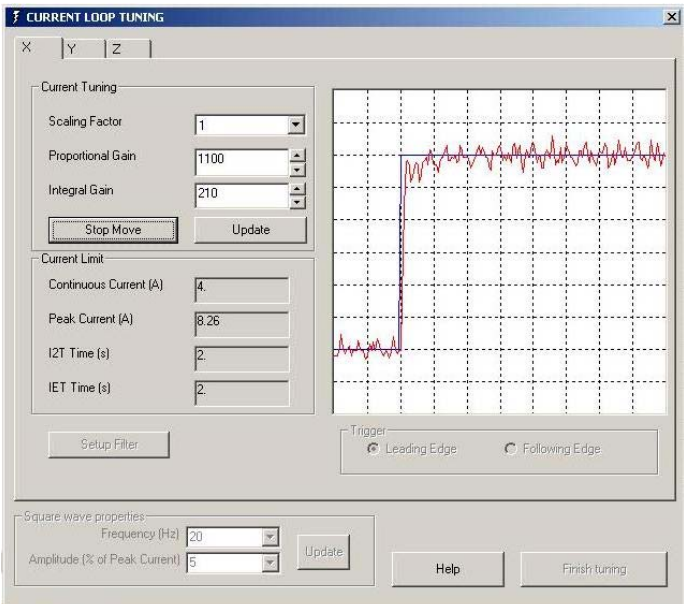



**Figure 4**

1. Start the current loop tuning by clicking on the “Start move” button this will produce a waveform something like that shown in the example on previous page.

2. Experience has shown that at this stage it is best not to tune this response to follow the square wave precisely as shown in figure 4. It is better to achieve a response similar to the example shown in figure 5 below with some initial rounding of the waveform. Adjust the proportional and integral gain until a good response is obtained.

- Changes to the proportional and integral settings can be made using the up/down arrows located to the side of the fields, otherwise the installer can type directly into the input box and then click on the update button for this setting to be applied to the **SPA*2*** system.

- The input boxes have a range from 0 to 32767, if values are required outside of this range then it is possible to apply a multiplication factor to these values using the scaling factor.

- Increasing the scaling factor by one (i.e. 1 to 2 or 2 to 4) in the drop down box will effectively double the value based on the previous scaling factor selection, reducing the scaling factor will effectively half the value based on the previous scaling factor.

- The recommended method to be used during this process is firstly to increase the proportional gain. If this is set too high, instability can be seen on the trace (high frequency oscillation). Next increase the integral gain. This will have the effect of sharpening the response. However, if too much integral gain is applied, an initial overshoot spike will become apparent.

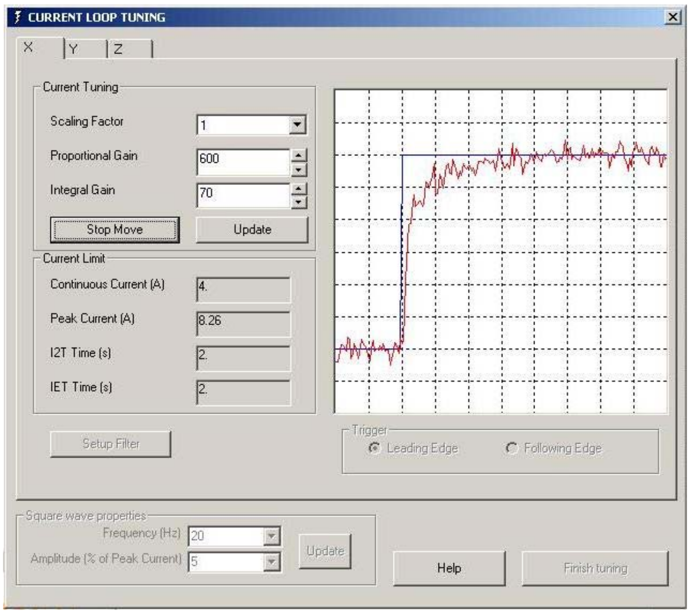



**Figure 5**

3. Press “Stop Move” button and increase the amplitude in the square wave properties to 10%, the machine response trace on the graph should change such that it follows the demand trace closer.

   If overshoot is experienced as shown in figure 6, it will be necessary to re-tune the system to remove this. Experience shows that typically increasing the proportional gain and/or reducing the integral gain will permit the trace to match the demand closer.

**NOTE:** Experience has shown that any overshoot, shown in figure 6, in the current loop tuning will reduce the ability for the system to be optimised for scanning. An over damped response, as shown in figure 7, should be achieved.

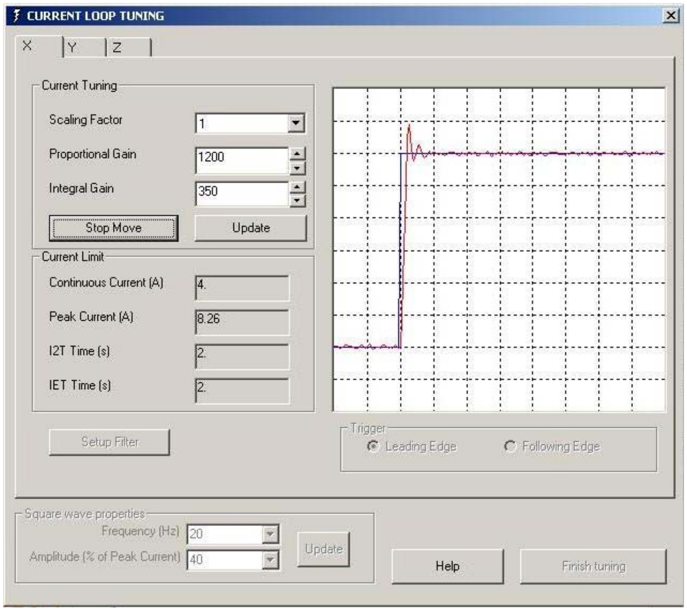



**Figure 6**

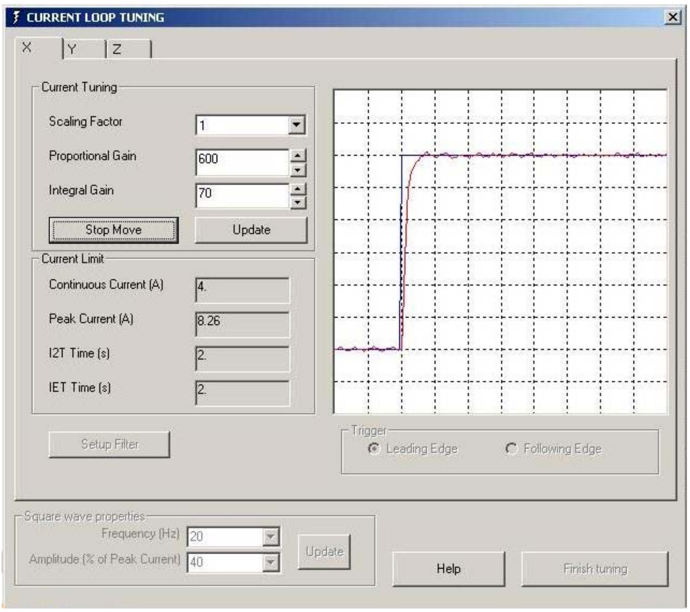



**Figure 7**

4. Repeat step 3, increasing the amplitude of the square wave (recommended steps 20%, 30%, 40%, 50%).

**CAUTION:** As the current loop is exciting the motor on the machine vibrations will become apparent, at the point of when the vibrations just start to introduce axis movement the amplitude of the current should not be increased.

**NOTE:** If there is a requirement for the amplitude to be increased past the 50% level then it is possible that the IET error will cause the test to stop after its defined time period.

5. Click the stop button when complete.

6. Repeat step 1 to 5 for all other machine axis.

7. When all axis have been commissioned then clicking on the finish tuning button will save all the parameters to the servo power amplifier and to the spa configuration file.

**NOTE:** Please refer to sections:

1. 2.2.6 for velocity loop tuning with motor tachometer feedback.
2. 2.2.7 for velocity loop tuning with motor encoder feedback.
3. 2.5.3 for torque mode tuning procedure.

### 2.2.6 Velocity loop tuning with motor tachometer feedback

**NOTE:** If your motors have encoder velocity feedback ignore this section and proceed to section 2.2.7.

This test moves the CMM forwards and backwards by the distance entered.

1. It is recommended that initially the tests are completed on individual axes, the X axis is selected by deselecting the Y and Z axis check boxes.

2. Run the test using the default values to start with by clicking the Go button. Check the operate continuously box to keep the machine moving, otherwise the machine will stop after one cycle.

**NOTE:** If the machine is unstable, it is recommended that the scaling factor is reduced by 1 step until you have stability and can continue with the tests.

Increasing the acceleration value for this test will give a sharper square wave stimulus to the machine.

The test will not change the maximum acceleration value stored in the UCC Configuration File.

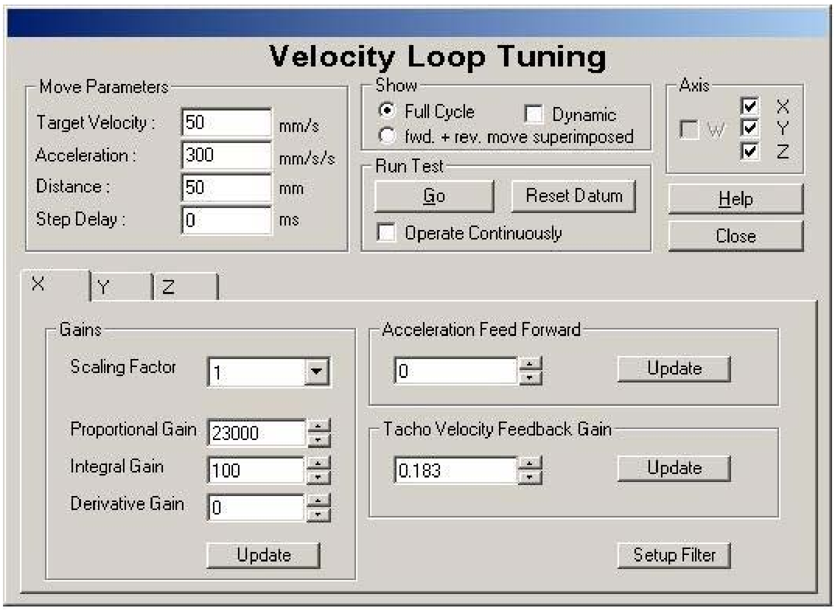



**Figure 8**

**NOTE:** If you use the up/down arrows on this screen the new values are applied immediately. If you type in the new values you have to click on the update button before the new value is applied. If the value is in red type it has not been applied.

If the machine response amplitude does not match the demand you could get the following message:


**Figure 9**

Check the machine is still in the centre of its operating range, move it if necessary, click on the OK button, click on the reset data button, then adjust the gain setting and continue the test by clicking on GO.

3. The initial adjustment is to set the tacho velocity feedback gain, using the up / down arrows or by entering the value and clicking on update, to adjust the values until the amplitude of the plots are matched. Figure 10 shows a graph plot were the tacho velocity feedback gain is set too high.

**NOTE:** Decreasing the value in this box will have the effect of increasing the amplitude of the machine speed.

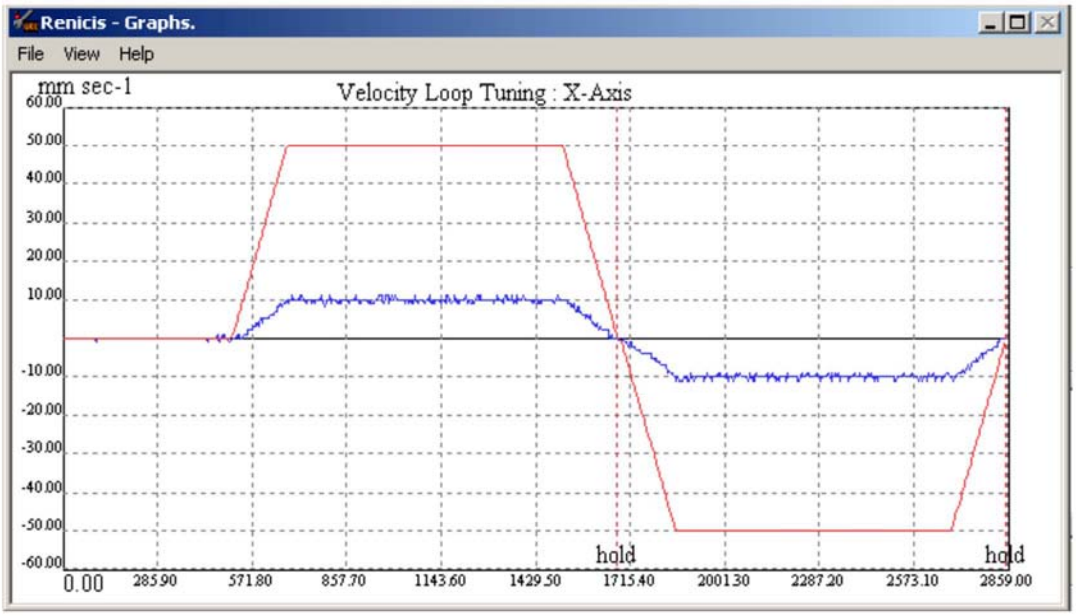



**Figure 10**

If the gain is excessive, when setting the tacho feedback, then the following screen will be displayed during the test.


**Figure 11**

If it appears you will need to click OK, click the Reset Datum button to zero the counters, adjust the gain setting, then click on the Go button to start the test again.

4. The response of the servo system should now be set up for this axis, proceed to section 2.2.8.

### 2.2.7 Velocity loop tuning with motor encoder feedback

**NOTE:** This section covers tuning of motors with encoder feedback. If you have tacho motors then the set up will have been covered in section 2.2.6.

This test moves the CMM forwards and backwards by the distance entered.

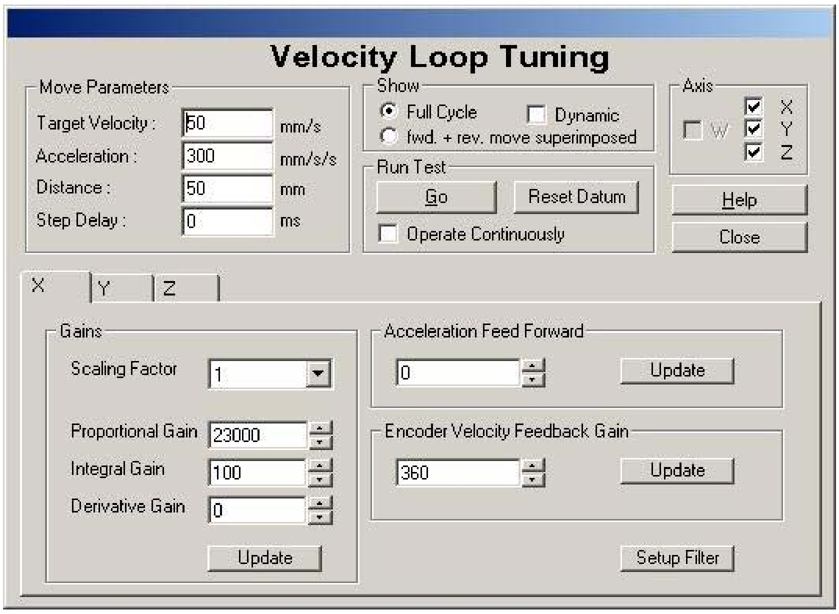



**Figure 12**

**NOTE:** If you use the up/down arrows on this screen, the new values are applied immediately. If you type in the new values you have to click on the update button before the new value is applied. If the value is in red, it has not been applied.

1. It is recommended that initially the tests are completed on individual axes, the X axis is selected by deselecting the Y and Z axis check boxes.

2. Before the test is started the encoder gain for the axis under test should be calculated such that the machine moves close to the specified speed, the formula for calculating this is:

$$\text{Encoder gain} = \frac{32767}{(4 \times \text{Encoder resolution (pulses/mm of axis travel )}) \times \text{Max move speed (mm/s)} \times 0.0001}$$

Enter this value into the “Encoder Velocity Feedback Gain” box. This value need not be accurate, one significant figure is sufficient.

3. When using an encoder as a velocity feedback device, it is normally necessary to include a filter. This is required because the encoder has a finite resolution with step changes and you are differentiating a digital signal into an analogue one. As a default for all encoder based feedback systems a 500 Hz bandwidth low pass filter is applied to the tacho feedback. If it is necessary to modify this setting, please follow the procedure listed below. Normally a 500 Hz bandwidth filter is sufficient but if the encoder is low in resolution, it may be necessary to increase the filtering by reducing the filter bandwidth.

   Click on the "Setup filter" button located the following screen will open:

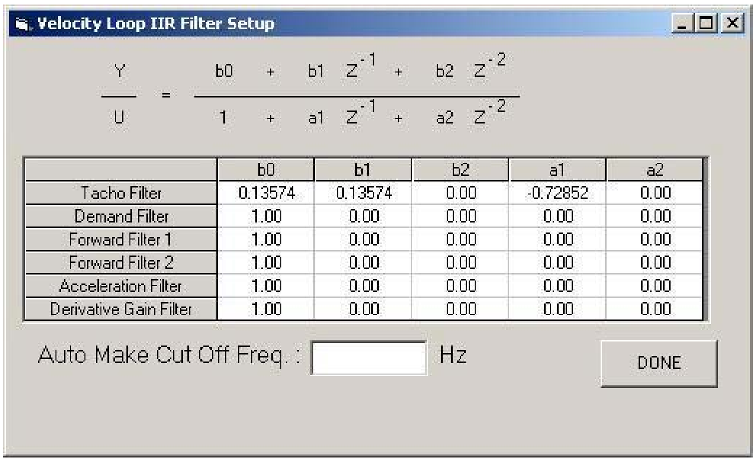



**Figure 13**

Enter a value of between 200 and 500 Hz (default = 500) into the "Auto Make Cut Off Freq" input box.

Right hand mouse click on the tacho filter box to open the filter type option screen and then click on the "make 2nd order BW LP" to make a second order bandwidth low pass filter, as shown below.

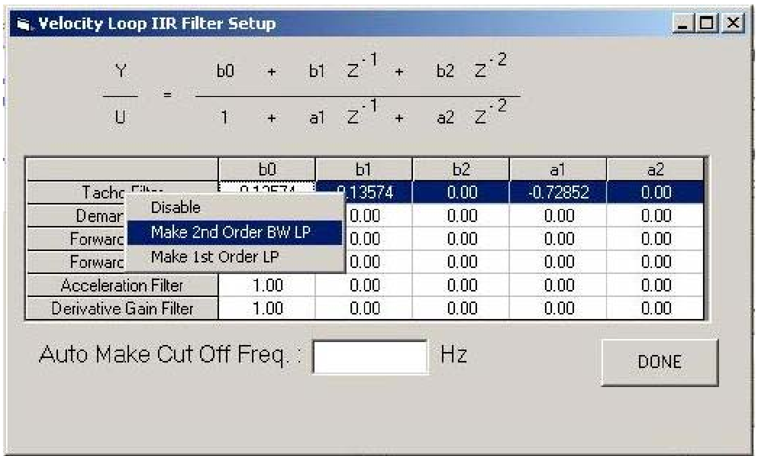



**Figure 14**

Click on the DONE button to close the screen.

For details of where the filters are applied in the current loop please refer to section 5.

4. Start the test, using the default values, by clicking the Go button. Check the operate continuously box to keep the machine moving, otherwise the machine will stop after one cycle.

**NOTE:** If the machine is unstable, it is recommended that the scaling factor is reduced by 1 step until you have stability and can continue with the tests.

Increasing the acceleration value for this test will give a sharper square wave stimulus to the machine. The test will not change the maximum acceleration value stored in the UCCConfiguration File.

5. The initial adjustment is to set the encoder velocity feedback gain, this can be done using the up / down arrows or by entering the value and clicking on update, to adjust the values until the amplitude of the plots are matched. Figure 15 shows a graph plot where the encoder velocity feedback gain is set too low.

**NOTE:** Decreasing the value in this box will have the effect of increasing the amplitude of the machine speed.

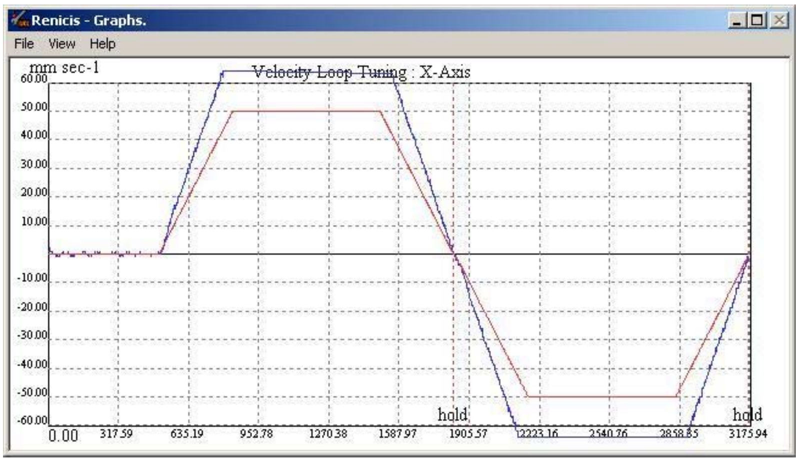



**Figure 15**

If the gain is excessive, when setting the encoder tacho feedback, the following screen will be displayed during the test.


**Figure 16**

Check the machine is still in the centre of its operating range, move it if necessary, click on the OK button, click on the reset data button, then adjust the gain setting and continue the test by clicking on GO.

6. The response of the servo system should now be set up for this axis, proceed to section 2.2.8.

### 2.2.8 Adjustment of scaling factor, proportional, integral and derivative gains

Initially the response displayed may look as shown in figure 17 below:

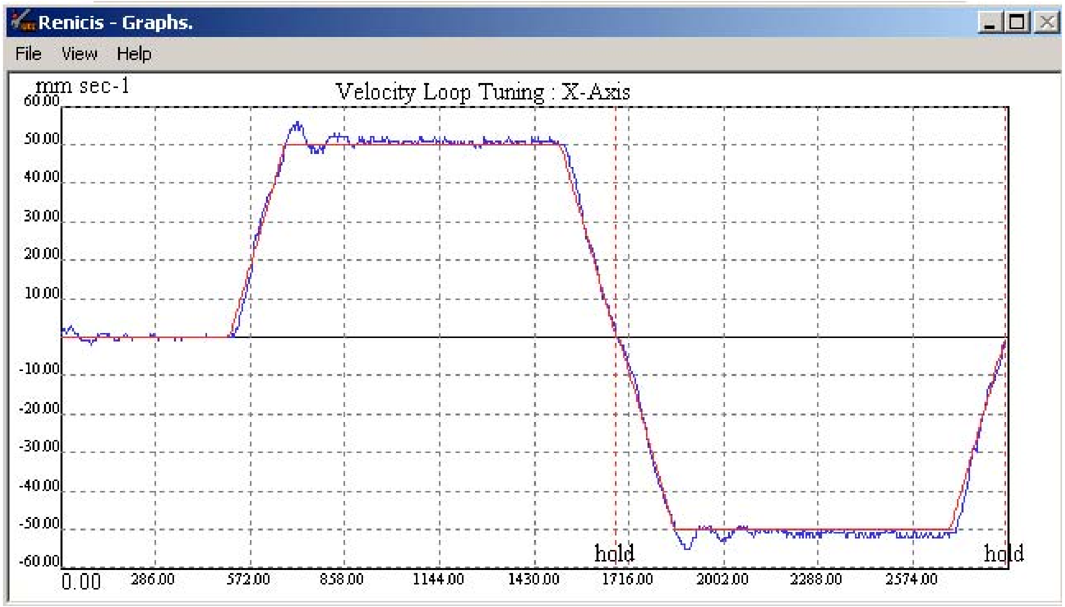



**Figure 17**

The objective is to get the machine response (blue line) as close to the demand (red line) but with no or minimal overshoot. The optimum performance will require some adjustment of the gains and these should be varied to confirm that no further improvements can be obtained.

Changes to the proportional and integral settings can be made using the up/down arrows located to the side of the fields. Otherwise, the installer can type directly into the input box and then click on the update button for this setting to be applied to the **SPA2** system.

The input boxes have a range from 0 to 32767. If values are required outside this range, it is possible to apply a multiplication factor to these values using the scaling factor.

Increasing the scaling factor by one (i.e. 1 to 2 or 2 to 4) in the drop down box will effectively double the value based on the previous scaling factor selection. Reducing the scaling factor will effectively half the value based on the previous scaling factor.

It is recommended to increase proportional gain first to get the fastest rise time possible with minimal overshoot. If this is set too high, instability (high frequency oscillation) will be seen.

Increasing integral gain will have the effect of sharpening up the response. However, if too much is applied an initial overshoot spike will be seen.

The derivative gain is usually not used. However, if used it will have the effect of damping the response and reducing overshoot. This is usually at the expense of a slight delay.

When complete the response should look something like:


**Figure 18**

Experience has shown that, in most cases, optimal system performance is obtained if the values for the integral gain used for the three machine axis are closely matched in value.

When the system has been tuned it is recommended that the machine speed for the velocity loop test is reduced to match the default trigger / scanning speed and the test is repeated to ensure that the system response is still tuned.

**NOTE:** If it is necessary to change the tuning settings for the trigger / scanning speed then it is recommended that these values are used for the installation.

Repeat the velocity loop tuning for the remaining axes using sections 2.2.6 and 2.2.8 for tacho motor systems or 2.2.7 and 2.2.8 for encoder motor systems

## 2.3 Position loop tuning

**NOTE:** To keep the machine response “balanced”, the same tuning parameter values must be used for all axes, with the exception of acceleration feedback.

### 2.3.1 Setting the uncompensated gain

In this section we will be increasing the uncompensated gain $\mathbf{K_P}$ to a safe maximum before switching on any conditioning filters. To do this, it is necessary to run a three axis move.

1. Ensure button is not depressed and operate the button on the RENICIS toolbar. Highlight the “*Uncompensated Gain Test*” step, run the “*Uncompensated Gain Test*” by clicking the “Go to Step” button.

2. Follow the instructions given until the test dialog is displayed, refer to figure 19. Ensure that the default value of 0.2 is indicated, then click on the "Start" button. The machine should move in a forward and reverse cycle in all three axes. The following error present during the move is displayed in graphical format. Examine the graphs produced (refer to figure 20).

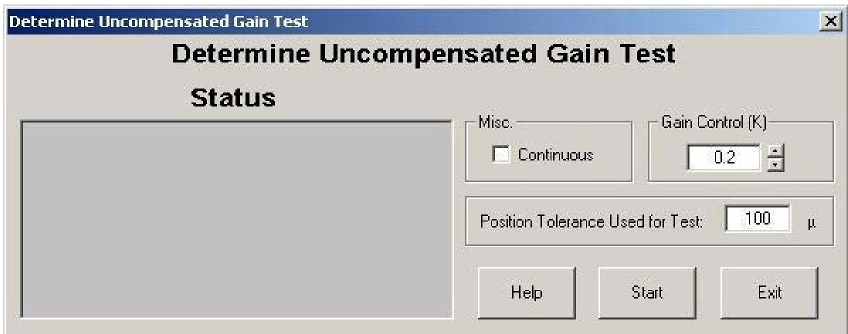



**Figure 19**

3. If the machine runs smoothly and no periodic oscillations are apparent (refer to figure 20). The uncompensated gain can be increased (either directly in the edit box, or by clicking on the upper 'spin' button to the right of the edit box) by approximately 10%, now referred to as $\mathbf{K_{P1}}$, and the test repeated by clicking on the "Start" button again.

   Continue increasing the value of $\mathbf{K_{P1}}$ until one of the axes reaches the brink of instability (refer to figure 21), then reduce the value by approximately 20% to give a stability margin and re-check for stability. If the system is stable and no oscillations are apparent then this value is called the “*Uncompensated Proportional Gain*” $\mathbf{K_{P2}}$ (and is set automatically to be the same for all axes).

**NOTE:** On some systems, and with very low gains, it is possible that timeouts will occur during the move. Should this occur, increase the position tolerance by changing the value in the edit box provided. The new value will take effect at the beginning of the next move, i.e. it will not make any effect whilst the system is moving.

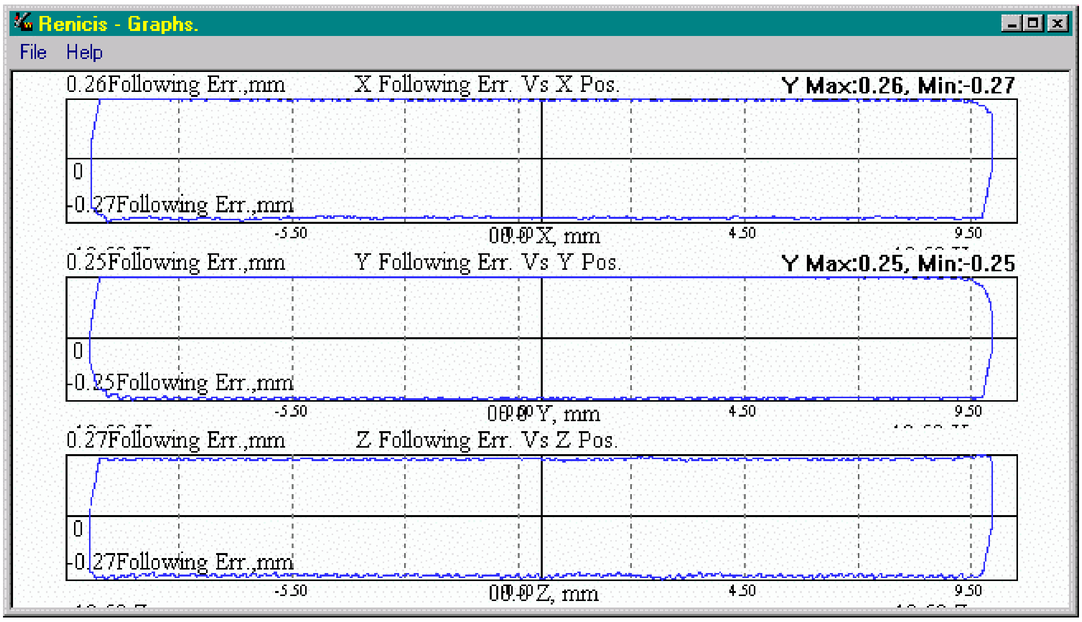



**Figure 20**

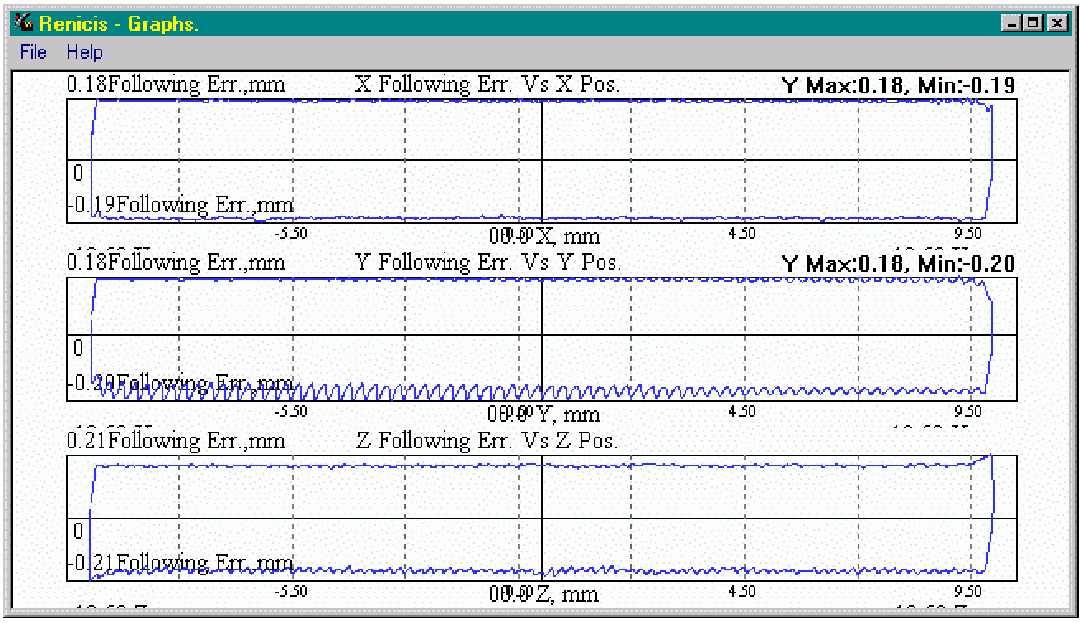



**Figure 21**

If any axes become unstable (Y axis in figure 21), reduce KP1 by 20% and check again, see step 2.

**NOTE:** All axes must have the same $\mathbf{K_{P1}}$. The value of $\mathbf{K_{P2}}$ must be such that ALL axes display stability.

### 2.3.2 Applying acceleration feedback

Acceleration feedback is another level of control that selectively increases the apparent inertia of the machine, allowing the gain to be increased still further before the machine becomes unstable. Machines react in different ways to acceleration feedback so the amount of gain increase can vary between zero and ten times.

**NOTE:** Experience has shown that the use of acceleration feedback is usually not required and therefore not recommended for machines that have an uncompensated gain of ≥ 0.2.

1. The first stage is to increase the proportional uncompensated gain value so that the machine is just unstable using the uncompensated gain step, refer to 2.3.1, record which axes are unstable.

2. It is now necessary to activate the acceleration feedback term ($\mathbf{K_A}$ ) in the axes that are unstable.

   - Enter the machine configuration screen
   - Select the "ServoConfiguration" tab and scroll down to locate the edit boxes for the acceleration feedback terms $\mathbf{K_{A(X)}}$, $\mathbf{K_{A(Y)}}$ and $\mathbf{K_{A(Z)}}$.
   - Set the initial acceleration feedback value ($\mathbf{K_A}$) for the axis that has shown signs of instability to 0.00005. Repeat for each unstable axis (Note: For any stable axes the acceleration feedback value remains set to zero).
   - Check for stability by running the “Uncompensated Gain Test refer to 2.3.1

3. If the machine is stable, increase the uncompensated gain by a further 10 – 20%. If the machine is displaying instability as for the Y axis in figure 21, increase the value of $\mathbf{K_A}$ (refer to step 2) in the unstable axes by a further 0.00005 (to do this follow step 2) and repeat the uncompensated gain test.

   - If the acceleration feedback value is too high the machine will produce an audible singing noise and must be reduced by 10 to 20 % in the unstable axes. Run the “Uncompensated Gain Test refer to 2.3.1 to ensure the machine is stable. If it is not stable repeat this step.

4. Repeat these steps, raising the values of $\mathbf{K_A}$ and $\mathbf{K_{P1}}$ until final values of $\mathbf{K_A}$ and $\mathbf{K_P}$ are found (see figure 22). The final value of $\mathbf{K_P}$ obtained during this process is referred to as $\mathbf{K_{P3}}$.

This will be the new “Uncompensated Gain”.

**NOTE:** It is necessary to increase the amount of acceleration feedback slowly in iterative steps as shown in figure 22, so that the maximum value of $\mathbf{K_P}$ can be found. This is in the peak between gain induced instability line and acceleration induced instability line. The consequence of increasing the acceleration feedback in one large step without increasing the proportional gain on intermediate steps is illustrated in figure 23, note the final value of $\mathbf{K_P}$ is far lower than in that obtained in figure 22.

Once the values for acceleration feedback are determined they must be left unchanged. Their values may be different, but the value of $\mathbf{K_{P3}}$ must be the same for each axis.

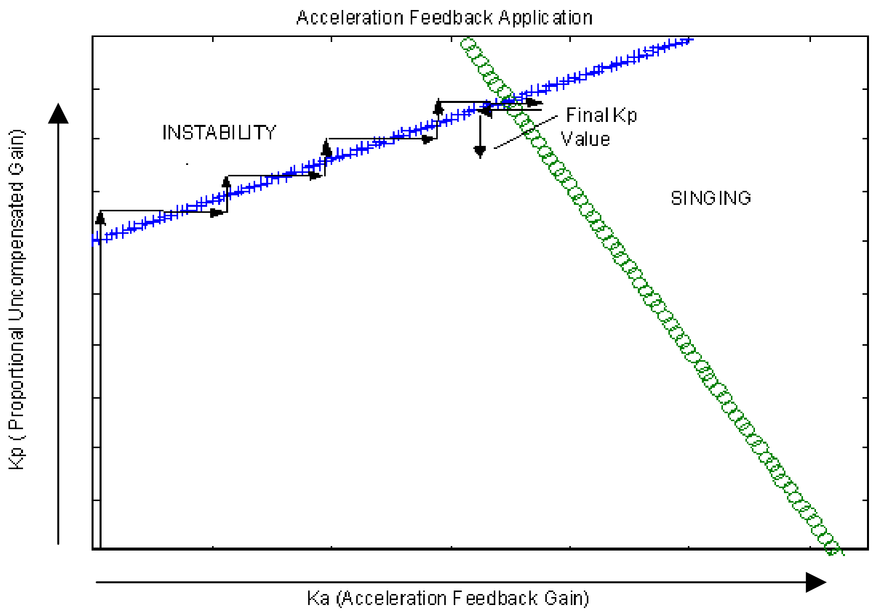



**Figure 22**

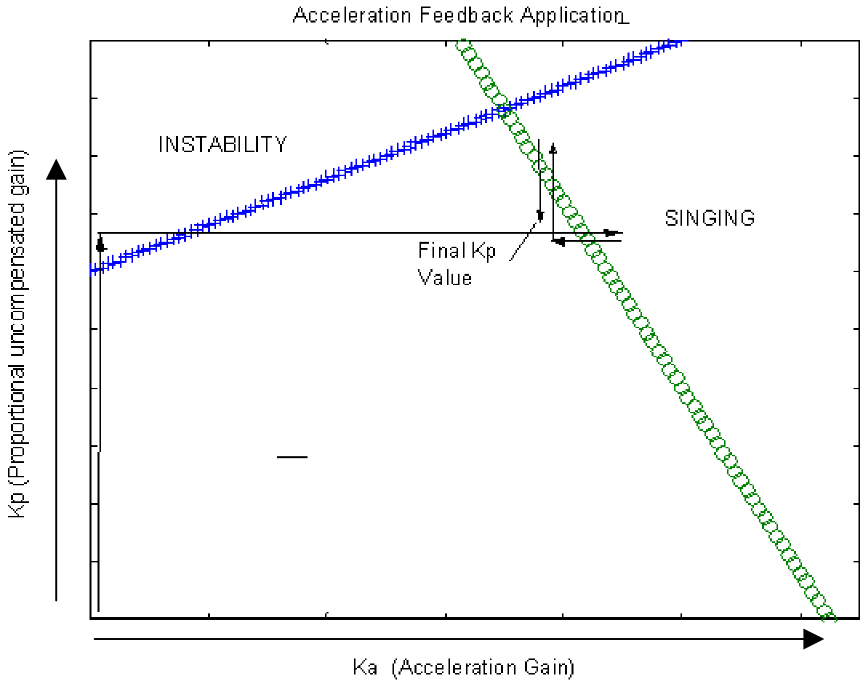



**Figure 23**

---

**NOTE:** At this point, if the positioning is good enough (within specifications), then no further tuning will be necessary.

---

# 2.4 Servo tuning

## 2.4.1 Servo tuning test

The servo tuning test is used to check the steady state error for the installation

Ensure  button is not depressed and operate the 

button on the RENICIS toolbar. Highlight the "*Servo Tuning*" step on the list of steps, run the "*Servo Tuning*" test by clicking the "Go to Step" button.

The dialog box shown in figure 24 will appear:

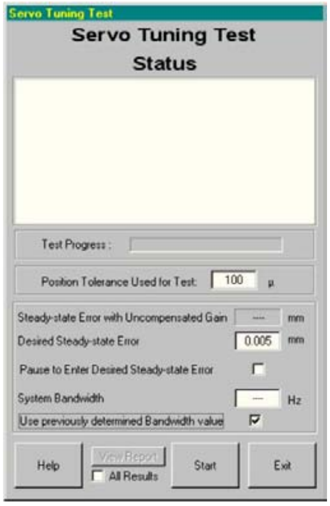



**Figure 24**

If a position tolerance, other than the default 100 microns, was required to prevent timeouts during moves with the uncompensated gain value, enter the same tolerance in edit box provided here. If you know what your desired steady-state error is then also enter that value.

Start the test by clicking on the ‘Start’ button. The test may be aborted at any time after starting. The following dialog picture (figure 25) shows the first move in progress:

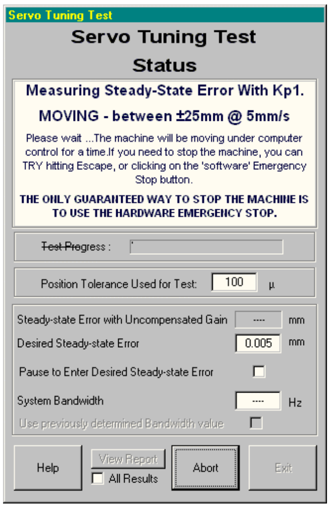



**Figure 25**

At the beginning of this test, four different moves are performed and a worst-case steady-state error value determined and displayed. You may wish to wait until this value is displayed before entering your desired value, in which case, ensure that the 'Pause …' check-box has been checked before clicking on the 'Start' button.

If the desired steady state error is achieved at the end of this test then the following screen will appear (see figure 26). This states that performance will be degraded if the test is continued and filter parameters calculated.

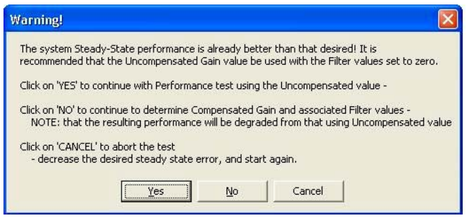



**Figure 26**

If the desired steady state error is not achieved, the system bandwidth is determined by performing a series of sinusoidal moves in each axis to calculate the system gain. The above screen-shot (figure 25) shows that the system bandwidth has not yet been determined.

Once the bandwidth has been determined, the new values for proportional gain and filters are calculated, saved and sent to the controller. The system then performs a full '*Performance Test*'. Once this is complete, the '*View Report*' button will be enabled, allowing the results of the Performance test to be reviewed. With '*All Results*' unchecked, only the worst-case results will be displayed in the report. With '*All Results*' checked, all results will be displayed in the report. From the report viewer, the report may be saved for future viewing.

At the end of this test the option is given to enter the Manual Servo Tuning screen where it is possible to check the machine performance. The Manual Servo Tuning step can also be accessed from the Utilities menu.

### 2.4.2 Servo tuning adjustment

At this stage, when the main tuning process has been completed, small adjustments can be made to optimise the performance for a particular machine. In most cases this will not be necessary and you can proceed to the following section.

The servo tuning objective is to find the controller parameters that meet the performance requirements for a specific application.

Typical requirements are :

- Stability
- High disturbance rejection (reflected through a high proportional gain)
- Steady state error required (precision achievable)
- Very little or no overshoot
- Small rise time and small settling time i.e. quick response.
- Small tunnelling error (specified by user) for trajectory following applications.

The following table shows the effect of a change in the controller parameters. It is a guidance table for the effect of change in proportional gain, lead or lag terms in the system.

The lead and lag terms $Ta_1$ and $Ta_2$ will only be present if the second half of the servo tuning test was performed i.e. the desires steady state error was not achieved using simple gains so a lead / lag filter was applied.

| | **Speed of response** | **Overshoot** | **Stability** | **Precision steady state** |
|---|---|---|---|---|
| **$K_P$** (Higher) | (Higher) Better | (Higher) Worse | (Lower) Worse | (Higher) Better |
| **$K_P$** (Lower) | (Lower) Worse | (Lower) Better | (Higher) Better | (Lower) Worse |
| **$Ta_2$** (Higher) | (Lower) Worse | (Higher) Worse | (Higher) Better | No Effect |
| **$Ta_2$** (Lower) | (Higher) Better | (Lower) Better | (Lower) Worse | No Effect |
| **$Ta_1$** (Higher) | (Higher) Better | (Lower) Better | (Lower) Worse | No Effect |
| **$Ta_1$** (Lower) | (Lower) Worse | (Higher) Worse | (Higher) Better | No Effect |

**$K_P$** is the proportional gain of the controller.

**$Ta_1$** is the time constant corresponding to the zero.

A higher value for **$Ta_1$** means higher lead.

**$Ta_2$** is the time constant corresponding to the pole.

A higher value for **$Ta_2$** means higher lag.

As the table shows, the parameters are inter-dependent making the tuning process far from trivial.

You must be using the manual servo tuning utility if you want to adjust any of these parameters and the test performed if any parameters are changed. This will demonstrate the effectiveness of the change.

If the amount of overshoot is a concern this can be reduced along with the following error by applying velocity feed-forward, as details in the following section.

### 2.4.3 Applying velocity feed-forward

Velocity feed-forward is a tuning parameter that is used to reduce the system following error. It may be needed if the following error is unacceptably high or if the use of filters and dynamic integrator have induced overshoot for short moves with high acceleration. Overshoot is caused by either a lack of stiffness in the servo system or if the servo system is too responsive (tight), so this parameter is used to get the optimum balance between the two.

1. Activate the manual servo tuning test.

2. Select tests 3 and 4 as shown in figure 27 below:

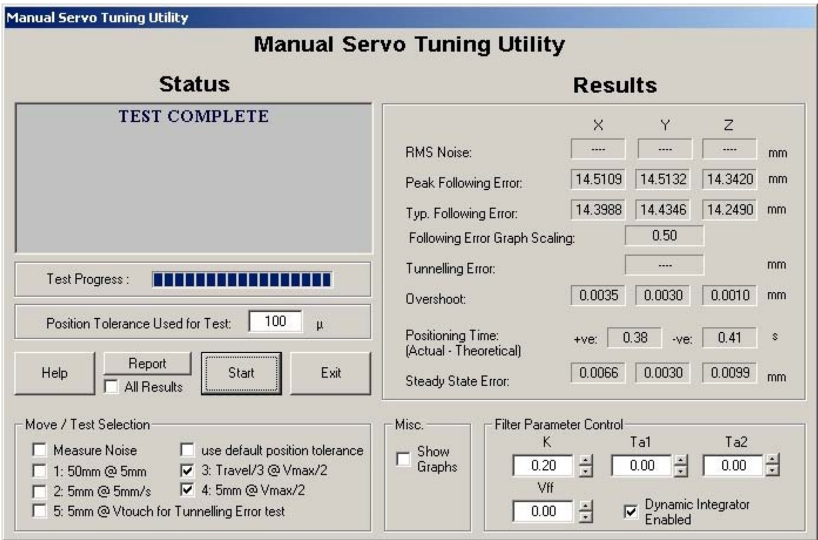



**Figure 27**

3. Click the Start button to run the selected tests initially with no value in the Vff input box. When the test has completed note the values of peak following error and overshoot for all axes. The results shown in figure 27 show a low value for the overshoot but a high following error.

4. Now add Vff, 0.01 is a good starting value and run the test again.

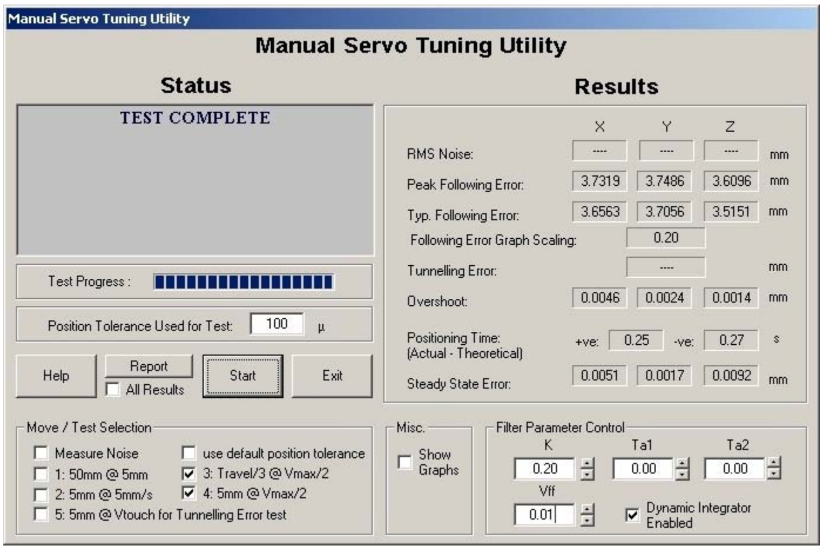



**Figure 28**

You can see the results shown in figure 28 give a much reduced following error and very little change in overshoot.

5. Increasing Vff further will reduce following error, however if too much is applied overshoot will increase to excessive levels and the machine may become unstable whilst performing the point to point moves. Some experimentation in the Vff value will be required. Figure 29 below shows the effect of applying too much Vff. Although the following error has reduced to a low value the amount of overshoot has increased significantly.

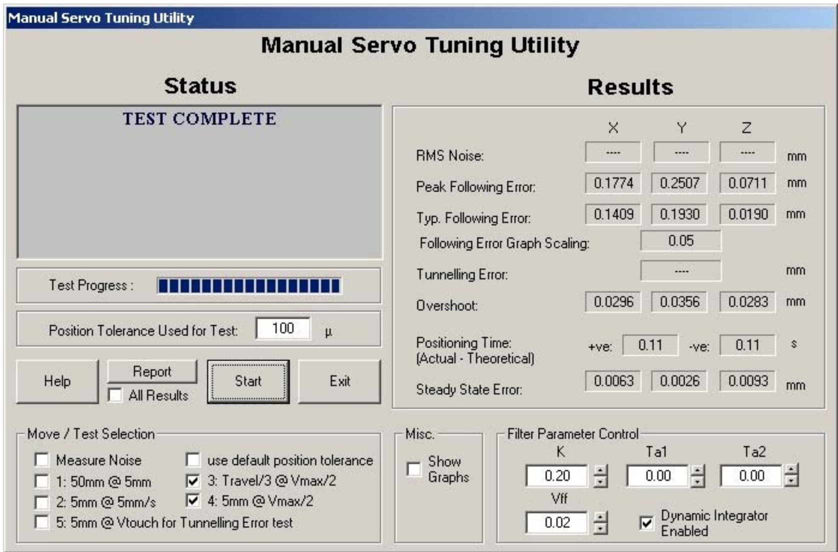



**Figure 29**

### 2.4.4 Scanning tuning procedure

The tuning procedure up to this point has concentrated on getting a well tuned responsive machine that will work well for touch-trigger applications. If it is required to scan on the CMM further tuning optimisation will be required. Tuning for scanning is now incorporated in the **UCC*assist*** utility and is documented in the **UCC*assist*** user's guide (Renishaw part number H-1000-5224).

## 2.5 Torque mode tuning procedure

Torque mode is used where motors with no tachometer or encoder feedback are fitted. In this case, the machine velocity is derived from the scales.

### 2.5.1 Initial steps

In the Torque Mode section of the .ini file

Set Control mode = 1

Set the Feedback gain X,Y and Z to (10 / Maximum Move Speed). For example if the machine maximum move speed was 250 mm/s, the Feedback gain would be set to 0.04.

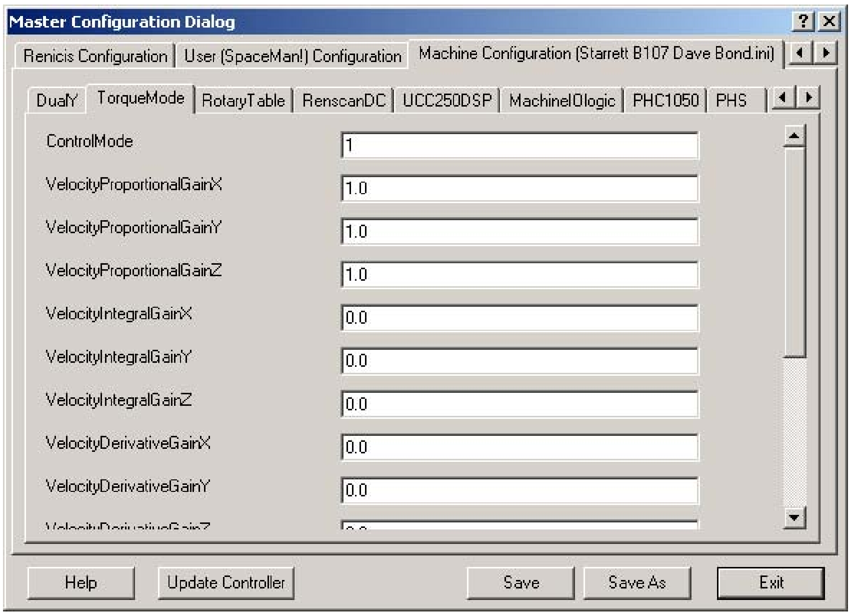



**Figure 30**

Keep all other values as default. Press Save and then Exit.

Follow the installation steps as detailed in section 2.2.1.

### 2.5.2 SPA*2* configuration screen

**NOTE:** In the **SPA*2*** / **SPA***lite* configuration step under motor feedback type it will now say ‘Torque Mode enabled!’

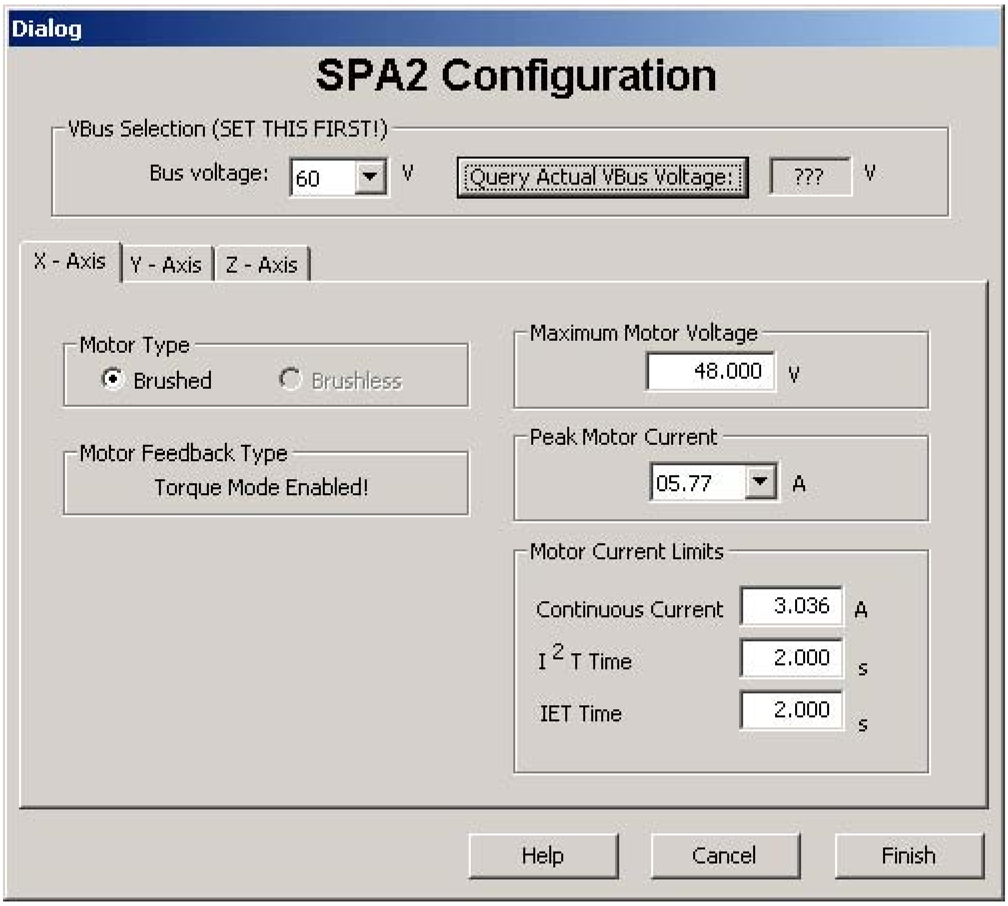



**Figure 31**

Refer to sections 2.2.2 to 2.2.5.

### 2.5.3 Velocity Loop tuning

This is a new step for torque mode.

Select the X axis only by unchecking the Y and Z  axis boxes:

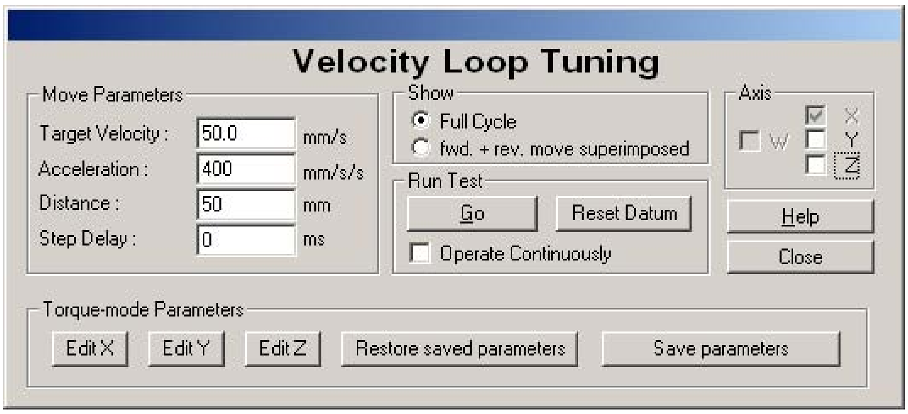



**Figure 32**

Run the test by pressing the ‘Go’ button. You may get a plot something like the following:

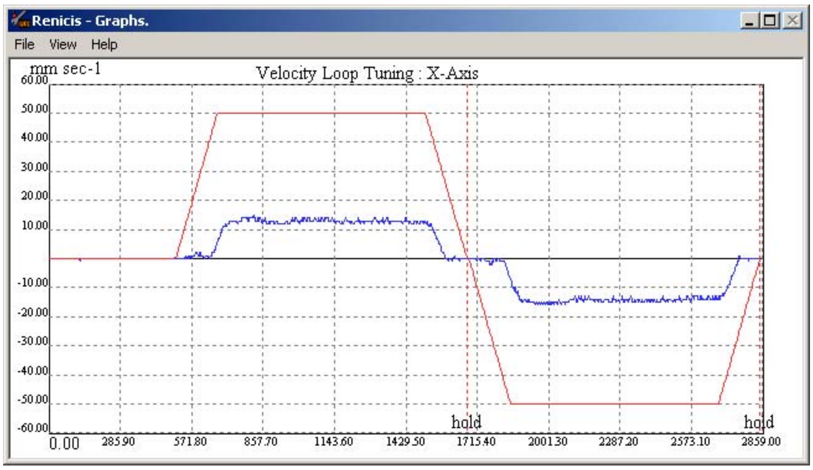



**Figure 33**

Pressing ‘Edit X’ under Torque-mode parameters shows the following dialogue box:

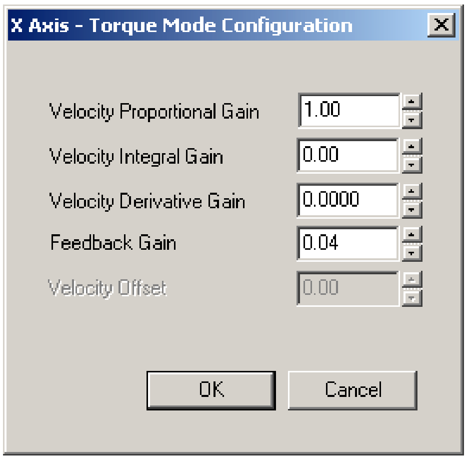



**Figure 34**

Now increase the Velocity Proportional gain (try doubling it from 1 to 2 to start with). Press ‘Close’ and press the ‘Go’ button to run the test again.

Increasing Velocity Proportional Gain should move the waveform closer to the demanded velocity. If stable increase Velocity Proportional gain further.

**NOTE**: You will need to stop the test if operating in continuous mode before editing the parameters (they cannot be edited and take effect whilst the machine is moving).

If the Velocity Proportional gain is set too high, instability will be seen.

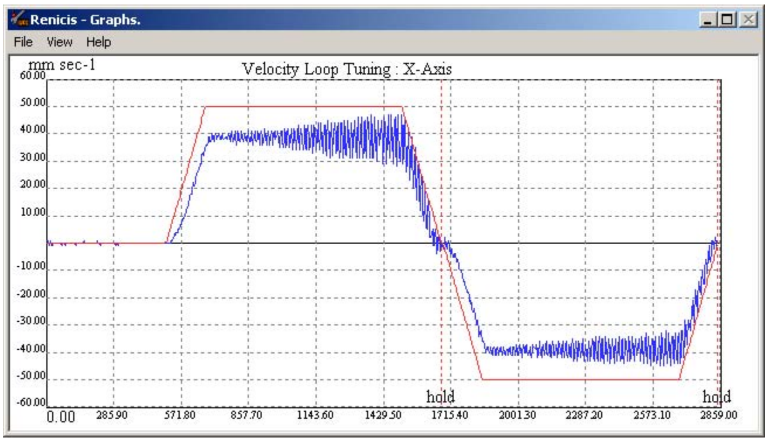



**Figure 35**

If this is the case reduce the Velocity Proportional gain until stability is achieved.

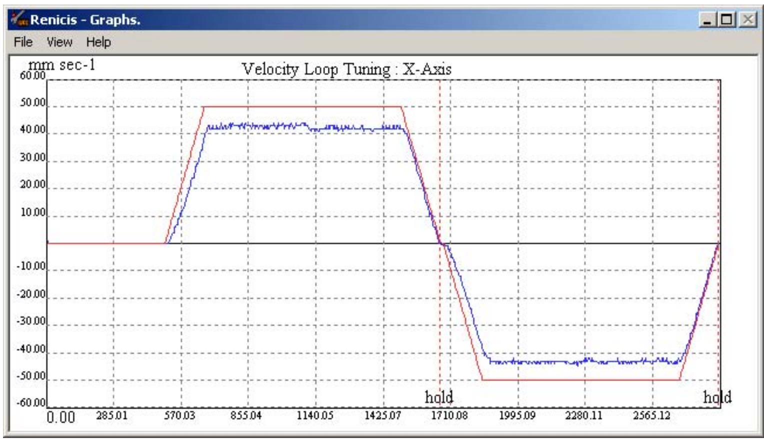



**Figure 36**

Next gradually increase the Velocity Integral Gain which should bring the waveform up to the demanded value.

Some experimentation will be required here, as it will depend on machine characteristics. The value can be between 1 and 1000 so increase in gradual steps.

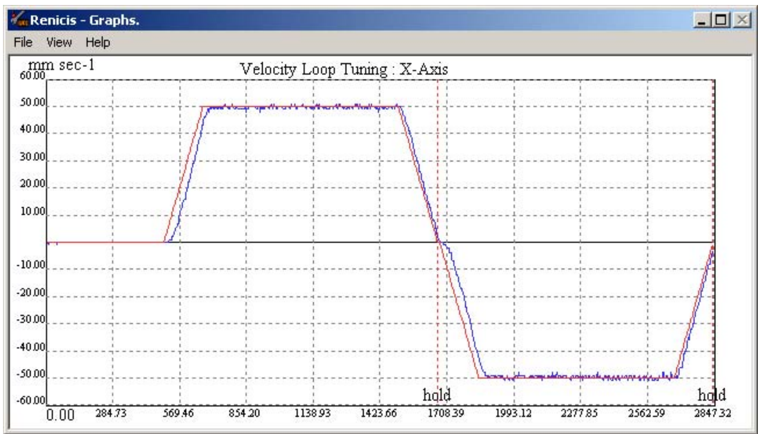



**Figure 37**

Repeat above steps for the Y and Z axes. When satisfied with the responses press the ‘Save parameters’ box and then ‘Close’

### 2.5.4 Position loop tuning

Select the X axis only by unchecking the Y and Z axis boxes

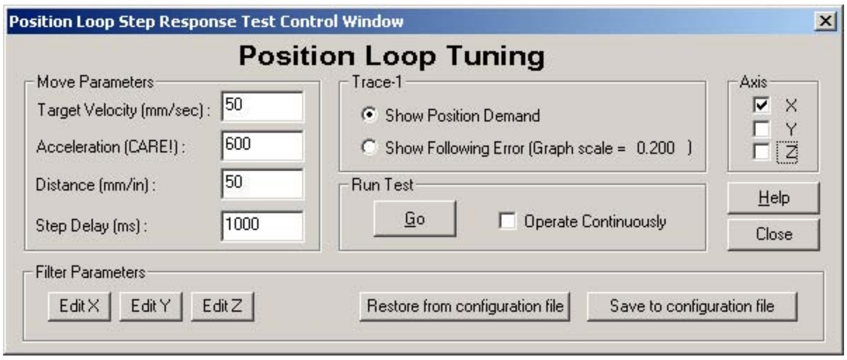



**Figure 38**

Select 'Show Position Demand'.

Run the test by pressing the 'Go' button. You may get a plot something like the following:

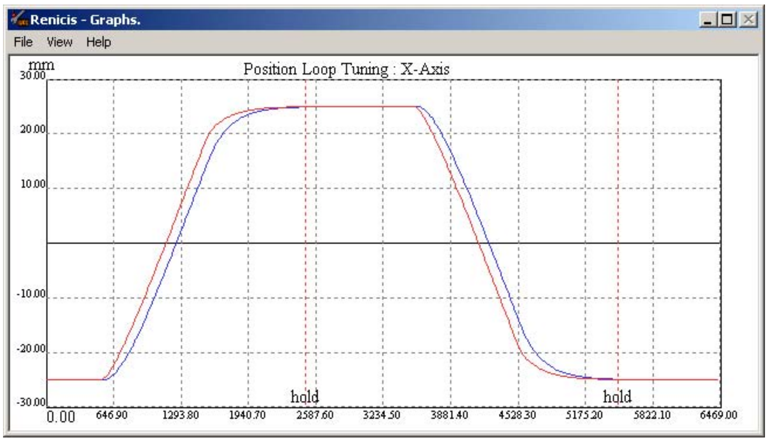



**Figure 39**

Pressing 'Edit X' under Filter Parameters shows the following dialogue box

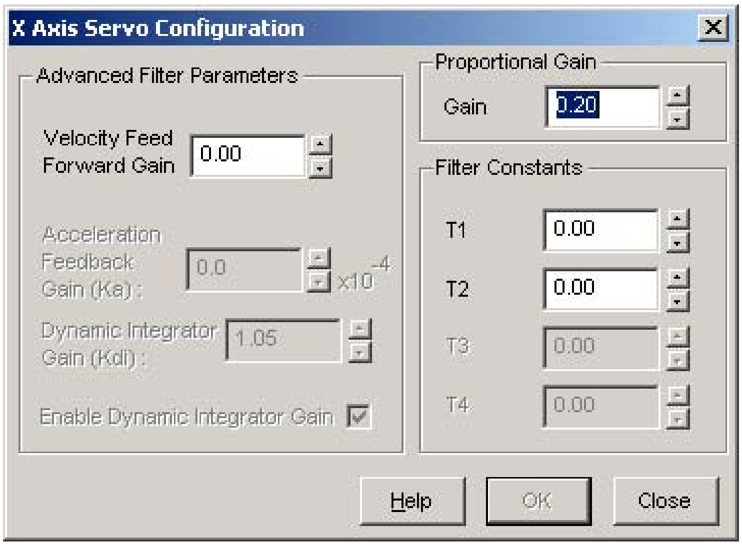



**Figure 40**

Increase Gain to sharpen up the response without introducing instability:

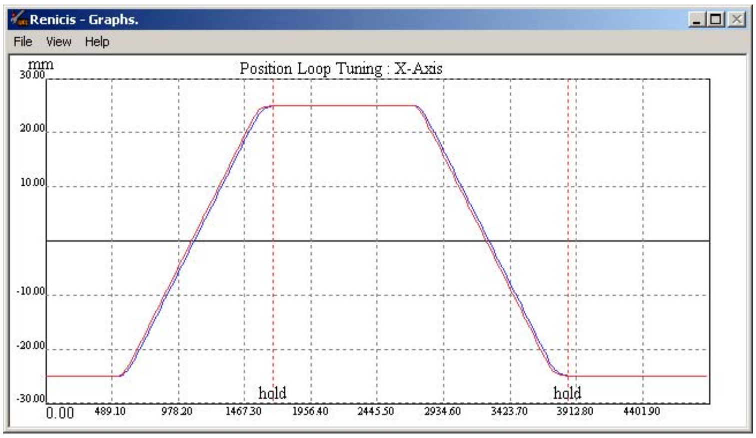



**Figure 41**

Repeat for the Y and Z axis, experience has shown that the gains for each axis should be about the same value.

Run the test again moving in all 3 axis.

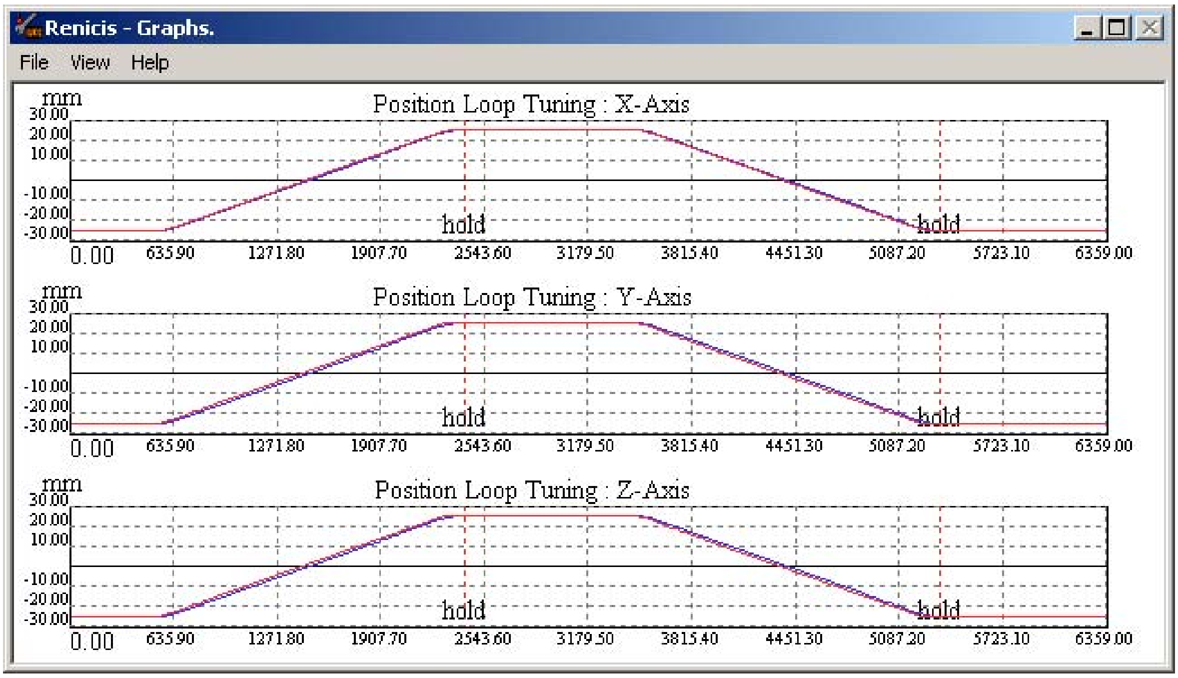



**Figure 42**

The response for each axis should be similar. If they are not adjust the axis gains for individual axes accordingly.

As a final check select 'Show Following Error Graph' and run in all 3 axes.

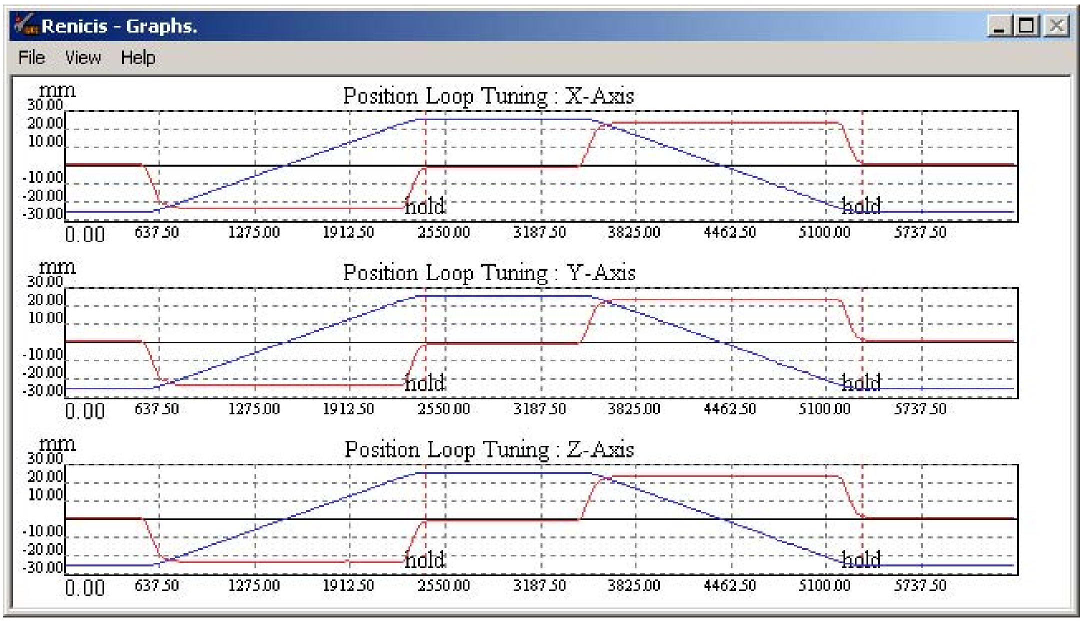



**Figure 43**

Although the scale of this graph is not meaningful, the amplitude of the red line (following error) should be about the same for each axis. If they are not, again adjust the gains accordingly so the following errors are matched.

# 3 Rotary table tuning procedure

## 3.1 Overview

To activate the tuning procedure within Renicis for the rotary table, it is necessary to have a fourth axis daughtercard installed and configured in the **SPA2**. The machine's configuration file must also indicate that a rotary table is installed in the system.

When the rotary table is installed and configured, options within the motor configuration, current loop and velocity loop tuning screens will be included.

An additional step will be included in the Renicis step list, this is the position loop tuning screen for the rotary table. As shown in figure 30.

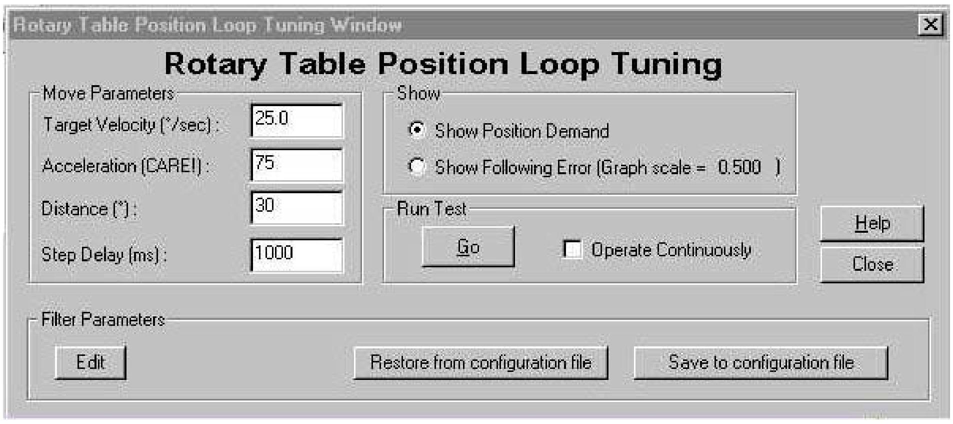



**Figure 44**

### 3.1.1 Initial settings

The initial values recommended for the rotary table tuning that have been obtained from experience are listed below:

| | | |
|---|---|---|
| **Target velocity** | (deg/sec) | 25 |
| **Acceleration** | (deg/sec/sec) | 75 |
| **Distance** | (degrees) | 50 |
| **Step delay** | (ms) | 1000 |

**NOTE:** When tuning the X, Y, and Z axes it is important that the tuning parameters are the same for each axis, this is not the case for the 'W' rotary axis.

# 3.2 Tuning

## 3.2.1 Velocity loop tuning

Select the W check box, this will only be active (enabled) when a rotary table is both detected and enabled.

**NOTE:** It is not possible to perform a move in all four axes simultaneously. Selecting the 'W' axis will automatically disable the other axes.

Initially run test using the default values by clicking the Go button.

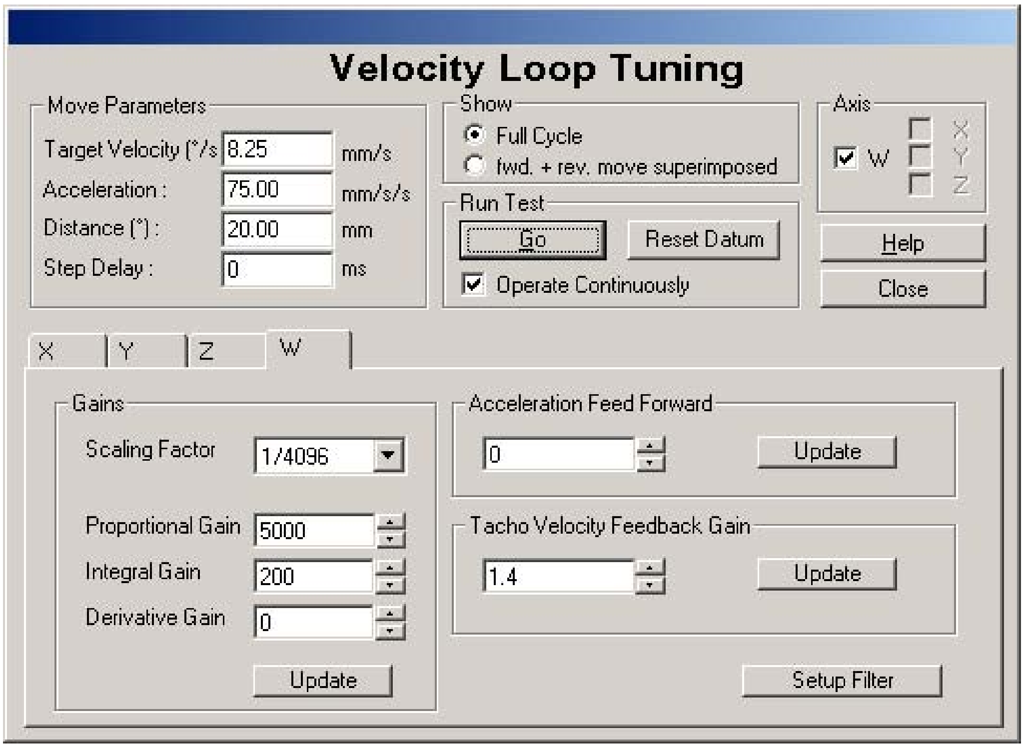



**Figure 45**

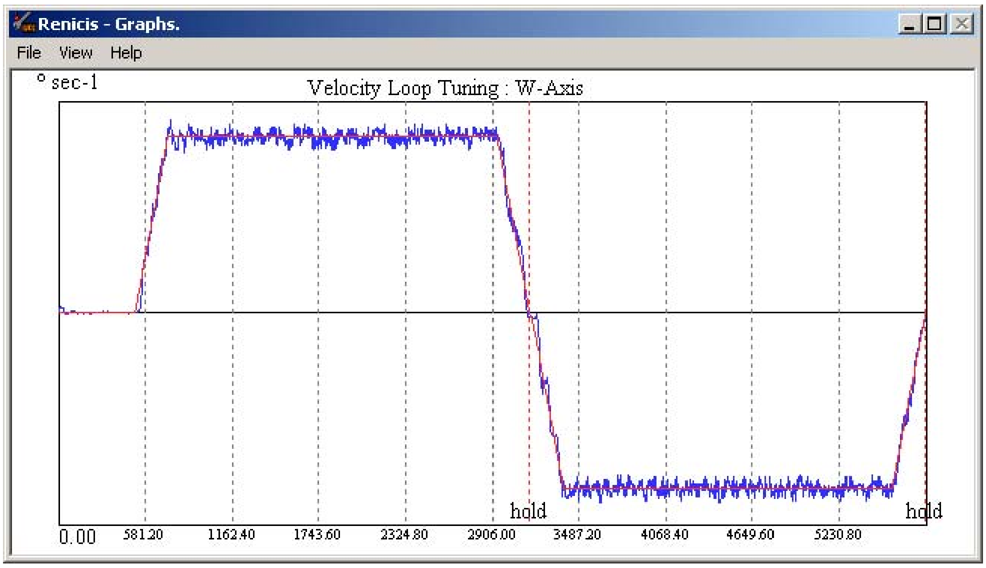



**Figure 46**

You may notice that the machine response amplitude does not match the demand.

If this is the case, adjust the tacho velocity feedback gain until the plots are matched. If you use the up/down arrows the new values are applied immediately. If a value is typed in directly this will appear in red and the update button will need to be clicked to download it to the controller.

**NOTE:** Decreasing the value in this box will have the effect of increasing the amplitude of the rotary table speed.

As with setting up the axis velocity loop steps with **SPA2**, adjust scaling factor, proportional, integral and derivative gain to achieve optimum performance.

### 3.2.2 Position loop tuning

Initially run with the default values.

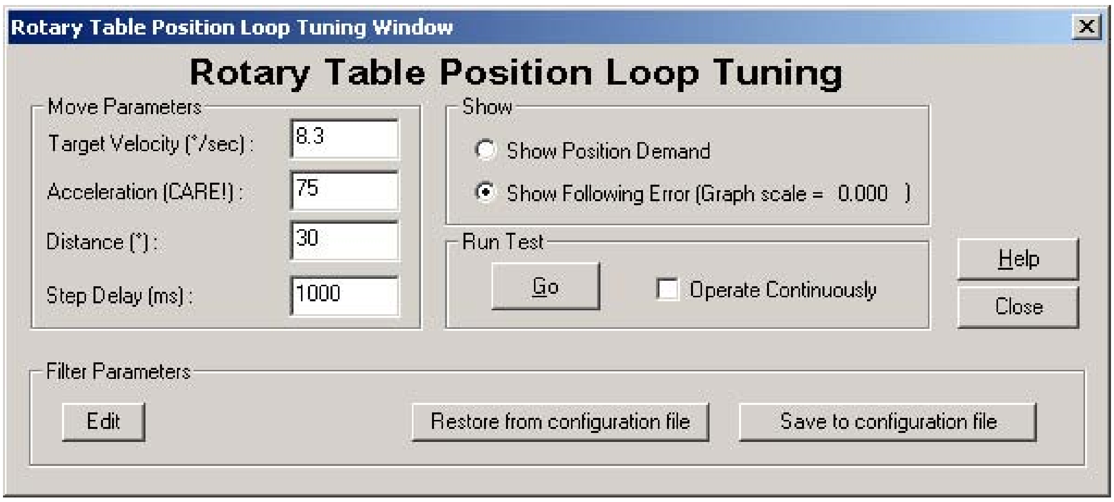



**Figure 47**

By clicking the 'Edit' button you can change the proportional gain. The default value of 1 for W proportional gain should be suitable in most cases. A graph of position demand similar to the one shown should be seen. It is unlikely that this value of proportional gain will need change unless instability is experienced.

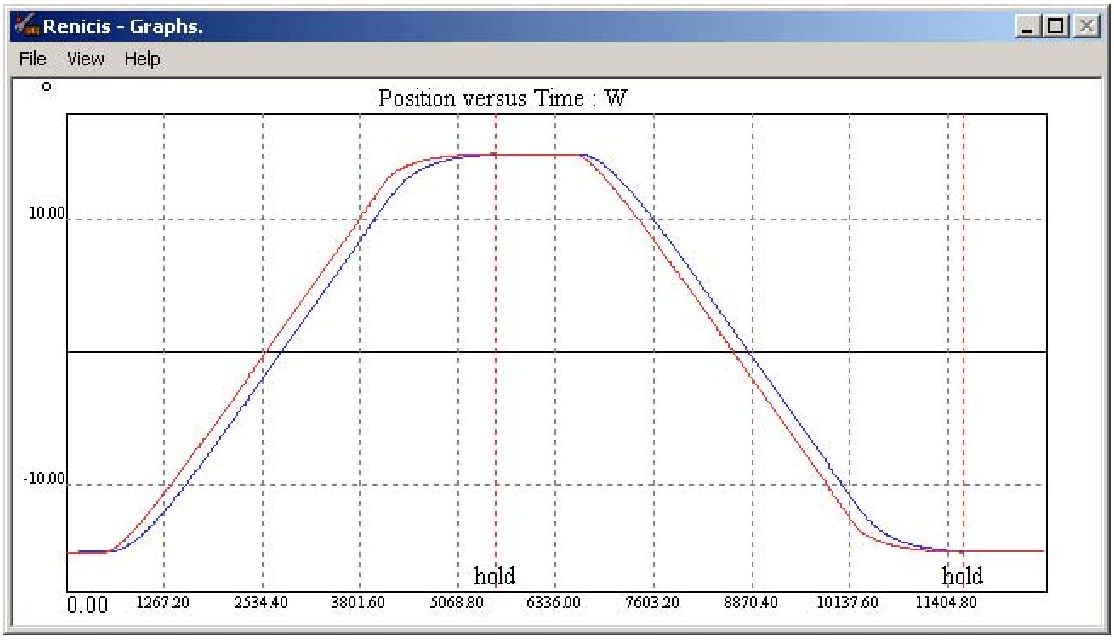



**Figure 48**

In most cases the rotary table is used to rotate the inspection part to another angle and measurement does not occur while it is moving. In these cases the lag between demand and position is not important. If the rotary table is used as part of a multi-axis scan routine with measurement being taken during rotary table motion then the following error will need to be minimised.

# 4 Definitions

## 4.1 Uncompensated gain

The maximum stable gain (with a safety margin) that can be used to compensate the position error without the use of the lead and lag filters.

## 4.2 Acceleration feedback

A high proportional gain is desirable for a high disturbance rejection and better precision (smaller steady state error).

To allow a higher proportional gain, feedback from the acceleration acts as an electronic inertia which pushes the upper limit for the proportional gain.

Furthermore, this does not interfere with any other control that may be added later (filters, etc). Thus you will be able to start at the point where you first have to tune the gain, only this time your upper limit is higher.

## 4.3 Dynamic integrator

To be able to increase the proportional gain, an acceleration dependent, rate-varying lag that prevents windup is used.

One might expect that a higher gain and lag term would induce a high overshoot, but the dynamic integrator peels off the effect of integration (lag) as the target is approached. When the target is hit, the effect of integration (which would have induced the overshoot) is eliminated. Once stationary again, the effect of the integrator is re-applied. Consequently, it is possible to have **very** high gains leading to a high precision and high disturbance rejection.

To summarise, the integration is applied when needed and cancelled (gradually) when it is not needed (and becomes undesirable).

## 4.4 Velocity feed-forward

Velocity feed-forward helps reduce the following error and increase the responsiveness of the system, consequently reducing overshoot due to delay.

It is particularly useful for short moves used with a relatively high acceleration.

This can be seen as a gain on the error that is proportional to the velocity profile which is high at constant speed and gradually increases during acceleration and decreases during deceleration.

Too much gain on velocity feed-forward will result in a higher overshoot for the system’s response.

## 4.5 $I^2t$ Time

The amount of time for which peak motor current is allowed to flow. If this is exceeded a fault indication is software generated to protect against motor over heating. Continuous current, or anything less, will be allowed to flow for unlimited time without fault.

## 4.6 IET Time

This is the current error time limit and will occur if there is a break in the loop after the DSP (e.g. no motor power or motor not connected) or if the current servo is badly tuned. This is a software generated fault that protects against excessive servo error in the current loop.

## 4.7 Overshoot (per axis)

The overshoot will be computed in absolute terms i.e.

***Overshoot = max value of read position – Steady State Position.***

## 4.8 Following error (per axis, already existing)

Following Error (t) = Read position (t) – Demand position (t)

***Typical Following Error = Following Error (mid_time) averaged over 10 readings.***

## 4.9 Steady state error (per axis)

Steady State Error = absolute value (mean of last 10 points of read position – Target position).

**NOTE:** This includes the RMS noise.

## 4.10 Settling time (per axis)

The settling time is the time difference between the theoretical time to get to HOLD and the time measured to get to HOLD.

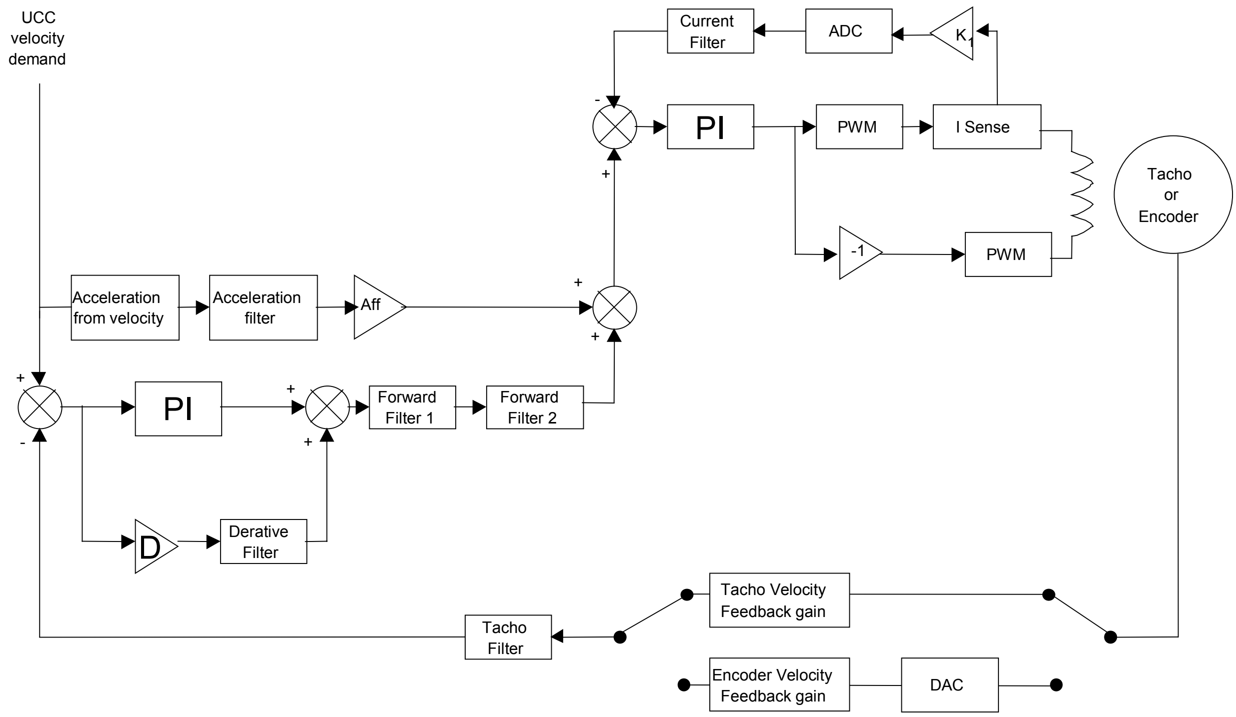
## 4.11 Tunnelling error (for the 3D move)

The tunnelling error is the maximum distance between the two curves (real and demand) and is the distance between the point read (measured) and its projection on the demand vector.

**NOTE:** The distance between two points in space is the modulus of the vector formed by these two points (direction is not relevant here).

# 5 Appendices

## 5.1 Current and velocity loop filters




The **SPA*2*** and **SPA***lite* offer six different conditioning filters within the servo control loop. During the Renicis commissioning sequence access to these filters are given at the appropriate step in the process.

Renicis can calculate either a low pass or a butterworth filter and apply it to the appropriate location.

With the exception of the tacho filter, which is set up in section 2.2.7, these filters are rarely needed and their application is not covered in this tuning guide. Please contact Renishaw if further inormation is required.

### 5.1.1 Current filter

The current loop filter can permit the reduction of noise on the servo power amplifiers current loop.

The recommended range for this filter is between 800 Hz and 2 KHz

### 5.1.2 Acceleration filter

The acceleration filter is only applied to the servo control system if acceleration feedforward is used, this can reduce the noise generated by the acceleration feedforward calculation.

The recommended range for this filter is between 250 Hz and 750 Hz.

### 5.1.3 Forward filter 1 and Forward filter 2

Either of these filters can be applied in the servo control system to apply either a low pass or butterworth filter.

By using both of these filters it is possible to calculate and apply more complex filters such as a lead / lag filter or a notch filter. However to apply these it is necessary to calculate the required values for the filter components external to the Renicis application and apply them through the Renicis velocity loop filter screen.

The recommended range for either a low pass or Butterworth filter is between 250 Hz and 750 Hz.

### 5.1.4 Derative filter

The derative filter is only applied to the servo control system if a derative component is used in the servo loop, this can reduce the noise generated by the derative calculation.

The recommended range for this filter is between 250 Hz and 750 Hz.

### 5.1.5 Tacho filter

The tacho filter should only be applied to tacho feedback within the servo control system if digital signals are used for the speed control (encoder or scales), If encoders are used in the servo loop a default filter of 500 Hz is applied to the system.

The recommended range for this filter is between 250 Hz and 750 Hz.

## 5.2 Glossary of terms

| | | |
|---|---|---|
| $f_B$ | = | The frequency corresponding to the –3dB point |
| $K_A$ | = | Acceleration feedback gain |
| $K_{A(X)}$ | = | Acceleration feedback gain for the “X” axis |
| $K_{A(Y)}$ | = | Acceleration feedback gain for the “Y” axis |
| $K_{A(Z)}$ | = | Acceleration feedback gain for the “Z” axis |
| | | |
| $K_{di}$ | = | Dynamic integrator gain |
| $K_{di(X)}$ | = | Dynamic integrator gain for the “X” axis |
| $K_{di(Y)}$ | = | Dynamic integrator gain for the “Y” axis |
| $K_{di(Z)}$ | = | Dynamic integrator gain for the “Z” axis |
| | | |
| $K_P$ | = | Proportional gain (V/mm of error) |
| $K_{P1}$ | = | Initial value of $K_P$ used at the start of the tuning process |
| $K_{P2}$ | = | Uncompensated gain – final value of $K_P$ obtained before applying the acceleration feedback or dynamic integrator terms |
| $K_{P3}$ | = | Final value of $K_P$ obtained after acceleration feedback but before applying the dynamic integrator term |
| $K_{P4}$ | = | Final value of $K_P$ necessary to produce the required positioning accuracy with the dynamic integrator applied |
| | | |
| $K_V$ | = | Velocity gain (mm/s/V)<br>This value will have been used when setting the servo power amplifier sensitivity control |
| | | |
| $P_E$ | = | Positioning accuracy before the dynamic integrator |
| | | |
| $P_R$ | = | Required positioning accuracy |
| | | |
| $T_{a1}$ | = | “Lead” filter constant |
| | | |
| $T_{a2}$ | = | “Lag” filter constant |
| | | |
| $K_{vffx}$ | = | X axis Velocity Feed-forward gain |
| $K_{vffy}$ | = | Y axis Velocity Feed-forward gain |
| $K_{vffz}$ | = | Z axis Velocity Feed-forward gain |

# 6 Revision history

## 6.1 What’s new in release 01-A

1. First issue.

## 6.2 What’s new in release 02-A

1. Update to include section 3.1.

## 6.3 What’s new in release 03-A

1. Change of document name from **SPA*2*** tuning guide.
2. Update to include **SPA***lite* information.
3. Clarification of installation tuning process.
4. Addition of torque mode tuning procedure (section 2.5).

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