Force Control

Slow approach

Operation mode switching

Open-loop current control / Closed-loop force control

Application Note

agito

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Revision History

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Contents

1 Introduction

1.1 Background

In many applications, such as polishing, bending, cutting, clamping, welding, pick-and-place and many more, it is required for the tool to exert a controlled and consistent force on the part. This can be achieved in multiple ways, with mechanical springs, pneumatics and other types of pliant devices.

Arguably, the simplest and most cost-effective solution would be to make do without the mechanics and control the servo stiffness by manipulating the current.

Agito controllers have built-in features that allow the user to control the current/force that the motor exerts.

1.2 Scope

This application note seeks to introduce the gist of how force control can be implemented for standard applications. For the user's convenience, this document will pull in relevant definitions and details from other manuals; this document alone should be sufficient reference for the user to implement force control for the standard application.

However, for the full technicalities, the user should still refer to the relevant manuals.

This application note will take the approach of going through the implementation process of one of the more common applications, pick-and-place.

The steps of the pick-and-place example will be as such,

1. From initial position, move at high speed towards the object.
2. Before reaching the object, decelerate to a lower speed to prepare for contact.
3. Upon contact with the object, switch from Position to Current/Force operation mode.
4. Apply a predefined Current/Force profile on the object.
5. Return to original position.

The application note will also cover some basic information about the hardware setup.

2 Setup

2.1 Equipment and overview

The typical setup topology is presented in the following figure:

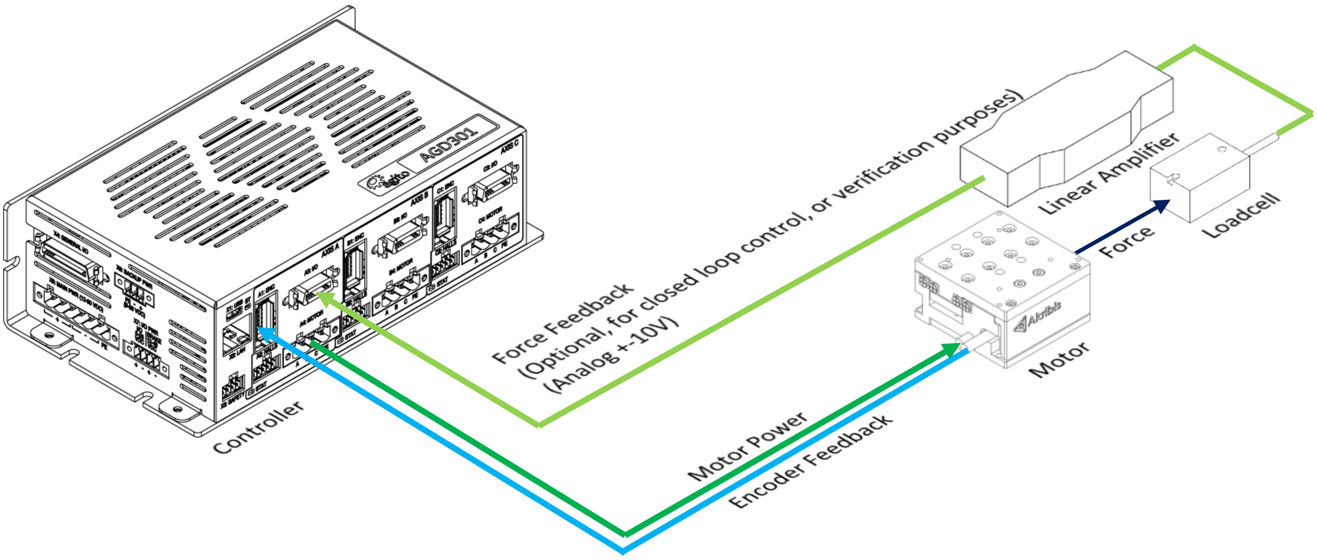


Figure 1. Standard setup topology

The example setup includes:

1. AGD301 motion controller with integrated drive, which generates motion profile and supplies power to the motor (could be any Agito controller or drive).

2. BLDC brushless linear motor with feedback (could be any rotary, linear or DC motor).

3. (Optional) Force sensor (Loadcell with Linear amplifier), to provide ±10V analog feedback to the controller. It is common to use force sensors during the design phase to get some readings for verification, and then remove them in the in the production phase.

2.2 AGD301 Wiring

AGD301: A1 – Encoder Port (Example shows pinout for sincos encoder)

Function	Pin Name	Pin #	Remarks
5V	5V	1	Power for encoder
GND	GND	2	Power return for encoder
SIN+	Encoder_2+	5	Encoder signal input
SIN-	Encoder_2-	6	Encoder signal input
COS+	Encoder_3+	7	Encoder signal input
COS-	Encoder_3-	8	Encoder signal input
Z+	Encoder_4+	9	Encoder signal input
Z-	Encoder_4-	10	Encoder signal input

AGD301: A3 – I/O Port

Function	Pin Name	Pin #	Remarks
Analog Input 1+	Analog_Input_1+	7	±12V, 12-bit resolution
Analog Input 1-	Analog_Input_1-	8	Connect to GND if single-ended

AGD301: A4 – Motor Power

Function	Pin Name	Pin #	Remarks
Motor Phase A	Phase A, M1	1	Motor Power
Motor Phase B	Phase B, M2	2	Motor Power
Motor Phase C	Phase C, M3	3	Motor Power, NC for voice coils
PE	PE	4	Motor PE

Note – Wiring for other controllers

This example uses Agito controller, AGD301 for the example. Wiring information for other controllers or encoder protocols can be found in their respective Product Manuals.

2.3 Force Sensor Configuration (Optional)

Force sensors tend to be expensive; in most applications, current operation mode is sufficient for the motor to apply controlled forces. And force sensor would usually only be used in the verification phase to check for the actual forces during current operation mode. In such cases, it is optional to connect the force sensor to external measurement devices (e.g., oscilloscope) or to the controller to obtain the readings.

In current operation mode, a controlled force can be obtained by driving a proportional current based on the motor's force constant. This output force however, is offset and subjugated to factors such as decreasing motor force constant as temperature increases, change in friction in the guides over time and varying payloads. The user should consider these factors to determine if closed-loop force control is required.

If the application is highly sensitive with many varying environmental factors, then a force sensor might be necessary. The type of force sensor (piezo electric vs. load cell) should also be considered depending on the duration the force is applied. Lastly, a controller with suitable ADC resolution should be selected. In general, Agito controllers have a default 12-bit ADC resolution (±12V). If necessary, there are 16-bit variants available.

This section briefly explains how to connect and setup a force sensor. In this example, a loadcell rated 1Kg, 1mV/V output, 10V excitation voltage, is used; therefore, if a 500g force is exerted on the loadcell, it will output a voltage of 5mV.

For the controller to read the input, the signal has to be amplified to ±10V. To do so, a linear amplifier with bridge sensitivity of 1mV/V is used to scale up the output by a factor of 1,000. The output is finally fed to any analog input on the Agito controller. Refer to AGD301 Wiring - A3.

Next, the analog input has to be configured to be a force feedback signal in PCSuite.

In PCSuite, navigate to IO Tab 

and then the Analog Menu 

.

For the corresponding input used (in this example, input 1), assign the **Input Mode** as "3 - Force Feedback" and a relevant **Axis** (in this example, axis A). Also, adjust the **Offset** such that the **Reading** shows 0 force-units when no force is applied. Note: It is normal for the **Reading** to jitter a few counts.

You may also explore adding a filter and mute range or adjusting the gains to process the signal if necessary. However, it is usually recommended to leave these as the default values shown below.

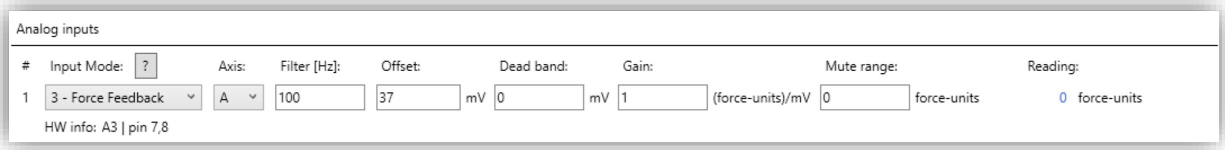
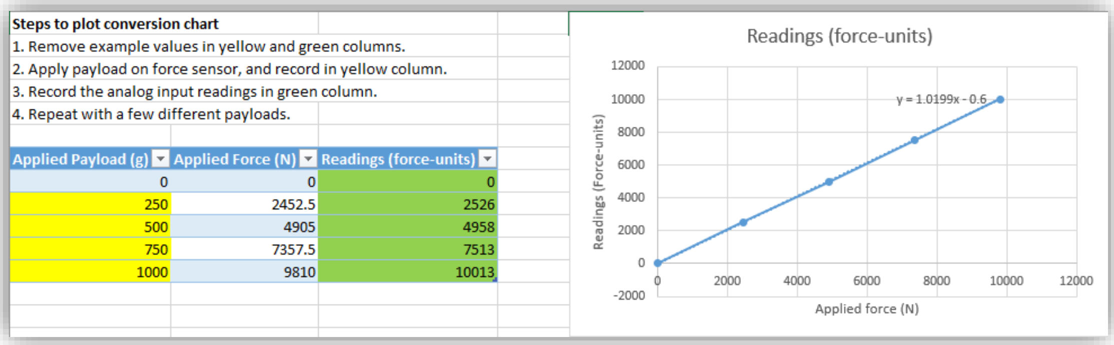


Figure 2. Screen capture of Analog Menu page.

Lastly, calibrate the feedback. Load the force sensor with a known payload (for example 500g) and observe the readings. Adjust the controller's analog input gains or the linear amplifier's bridge sensitivity/gain until you get satisfactory value. If necessary, repeat the test with and few different loads and plot a linear chart of "payload" vs "force units". This chart will be used for conversion between force and force-units.



Steps to plot conversion chart
1. Remove example values in yellow and green columns.
2. Apply payload on force sensor, and record in yellow column.
3. Record the analog input readings in green column.
4. Repeat with a few different payloads.

Applied Payload (g)	Applied Force (N)	Readings (force-units)
0	0	0
250	2452.5	2526
500	4905	4958
750	7357.5	7513
1000	9810	10013

Figure 2. Screen capture of Actual Force to Force-units Excel conversion chart.

Appendices - Force
Control - Force to F(

3 Current/Force Control

This chapter will be a guide on how to configure the relevant parameters for current/force control using the pick-and-place application as an example. In particular, the behavior of the controller will be configured such that it behaves in the manner described by the three scenarios below.

Scenario 1 depicts the event when there is no object. Scenario 2 depicts event when there is an object. Scenario 3 depicts the event where the object deforms or slips out of position.

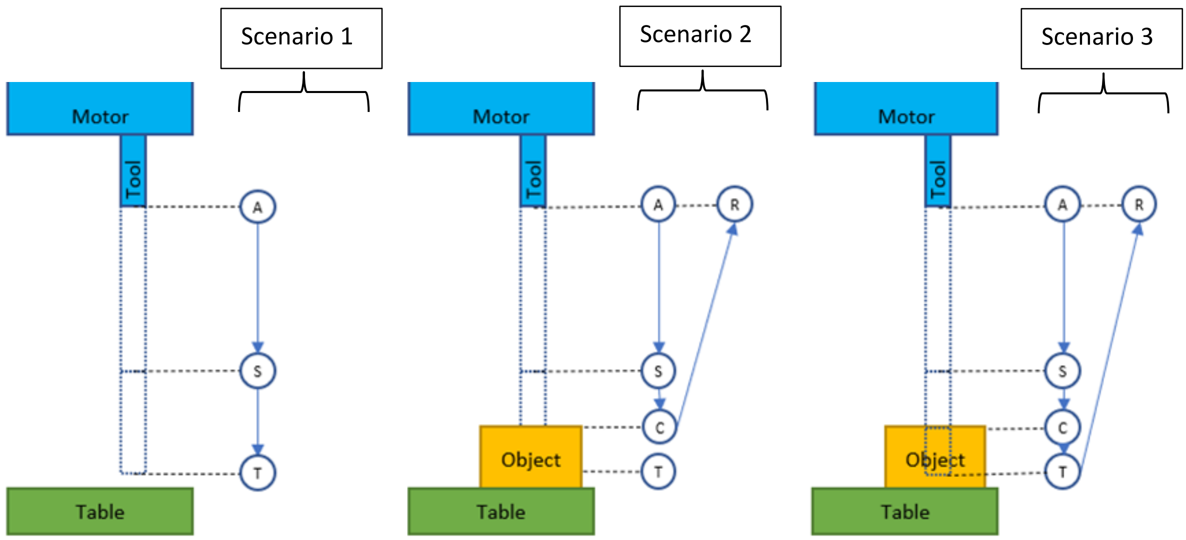


Figure 3. Scenarios for pick and place example.

Scenario 1

1. From initial position A, move at high speed towards the object.
2. Upon passing point S, decelerate to a lower speed to prepare for contact.
3. If there is no object present, or switching thresholds are set to high, normal point-to-point motion will continue and end at the target position T.

Scenario 2

1. From initial position A, move at high speed towards the object.
2. Upon passing point S, decelerate to a lower speed to prepare for contact.
3. Upon contact with the object, switch from Position to Current/Force operation mode.
4. Apply a predefined current or force profile on the object.
5. Return to position R (can be any position).

Scenario 3

1. From initial position A, move at high speed towards the object.
2. Upon passing point S, decelerate to a lower speed to prepare for contact.
3. Upon contact with the object, switch from Position to Current/Force operation mode.
4. Apply a predefined current or force profile on the object.
5. If object deforms and position exceeds point T during current/force operation, switch back to position operation.
6. Return to position R (can be any position).

The configuration will be done via PCSuite. In any feature implementation, it is always recommended to use PCSuite to experiment and tune the feature for optimal performance before implementing/automating the feature via User Program or API.

Launch PCSuite, navigate to 

tab and then 

page.

3.1 Open-Loop Current Control vs Closed-Loop Force Control

As explained earlier, force control can be achieved with open-loop current control or with closed loop force control.

Check the 

checkbox if you want to use open-loop current control.

Otherwise, leave the 

checkbox unchecked if you have a force sensor connected and want to use closed-loop force control.

Note that this is not a parameter of the controller, it is just for Boolean on PCSuite to indicate which set of control parameters to display.

Attention – Do not use force sensor on first try

To avoid damage to the force sensor, it is recommended that the user tests and familiarizes with the feature without the use of a force sensor first. There is a chance that the motor might collide with high impact if the parameters are not configured properly.

3.2 Force (Current) Tuning

Next, ensure that the Current/Force loop is tuned. In the Force (Current) Tuning window, the current gains will be displayed. If not already tuned, navigate to Step Command for Force (Current) Tuning window to Apply Current Command or Apply Force Command and tune.

Attention – Move motor to contact sensor before applying force command

If tuning the Force control loop, make sure that the motor is already in contact with the sensor before applying force command. Otherwise, the motor might accelerate towards the sensor and damage it.

Please refer to the User Manual if more information on tuning is required.

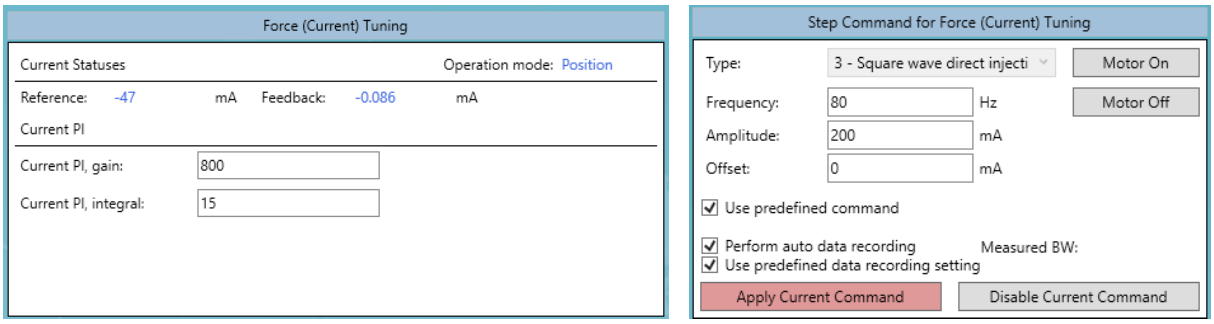


Figure 3. Screen capture of Current Tuning windows.

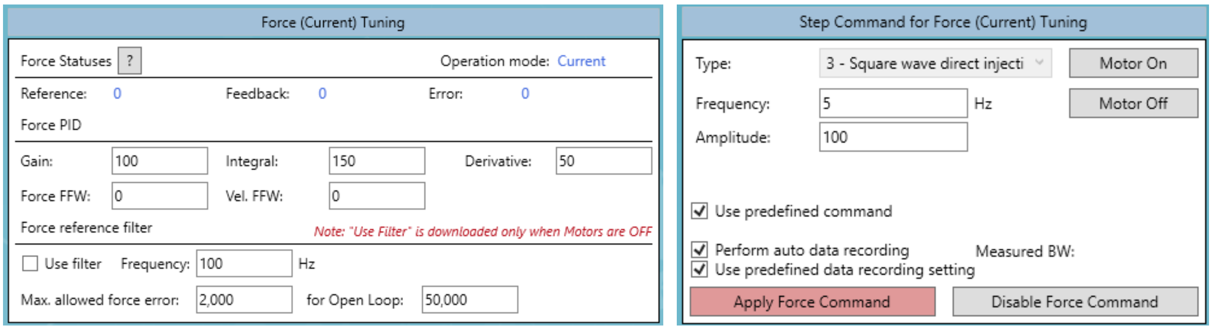


Figure 4. Screen capture of Force Tuning windows.

3.3 Slow Approach

In force control applications, it is common to have the tool move towards the object at a high speed and then slow down when it is approaches, such that it contacts the object at a slow speed therefore reducing the kinetic energy and impulse upon contact. Refer back to point S in the scenario description.

To configure the slow approach, navigate to `Slow Approach Before Contact` window. Set the relevant parameters. See keyword definitions in table 1.

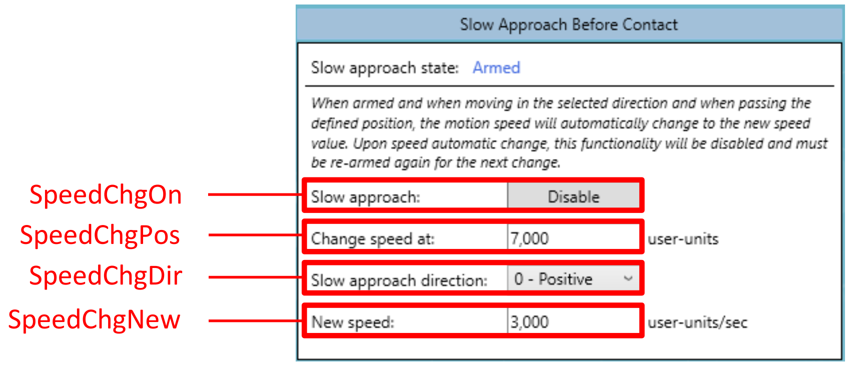


Figure 5. Screen capture of Force Tuning Window.

In Figure 5, the parameters are set such that when the motor moves past the position of 7,000 counts in the positive direction, it will start to decelerate (or possibly accelerate) to the new speed of 3,000 counts/s.

Lastly, click `Arm` to enable the feature, you will see the text turn from Disabled to Armed.

Note – Arming the feature

After the feature is triggered, it will automatically be disabled, this is to prevent accidental usage. The user must 'intentionally' rearm the feature every time he wishes to use it.

Also note that although this feature was developed for force applications, it can be used standalone outside of force applications too.

Slow Approach

<table>
<tr><th>Keyword</th><th>Description</th></tr>
<tr><td>SpeedChgOn</td><td>SpeedChgOn enables or disables the slow approach feature. Upon being triggered, the feature will automatically disable itself; the user has to re-enable the feature to use it again.

<table>
<tr><th>Value</th><th>State</th></tr>
<tr><td>0</td><td>Disabled</td></tr>
<tr><td>1</td><td>Enabled</td></tr>
</table>
</td></tr>
<tr><td>SpeedChgPos</td><td>SpeedChgPos is used in conjunction with SpeedChgDir to define the trigger criteria for speed change to occur. Note that speed change does not necessarily have to occur at this position; for example, if position jumps to</td></tr>
<tr><td>SpeedChgDir</td><td>SpeedChgDir defines the direction of the trigger criteria.

<table>
<tr><th>Value</th><th>Criteria</th></tr>
<tr><td>0</td><td>Positive, trigger when PosRef > SpeedChgPos</td></tr>
<tr><td>1</td><td>Negative, trigger when PosRef < SpeedChgPos</td></tr>
</table>
</td></tr>
<tr><td>SpeedChgNew</td><td>SpeedChgNew defines the new value to assign to speed once speed change conditions are triggered.</td></tr>
</table>

Table 1. Slow Approach Parameters.

3.4 Mode Switching

Navigate to Mode Switching window; the trigger parameters to switch from position to force/current mode are configured in this window.

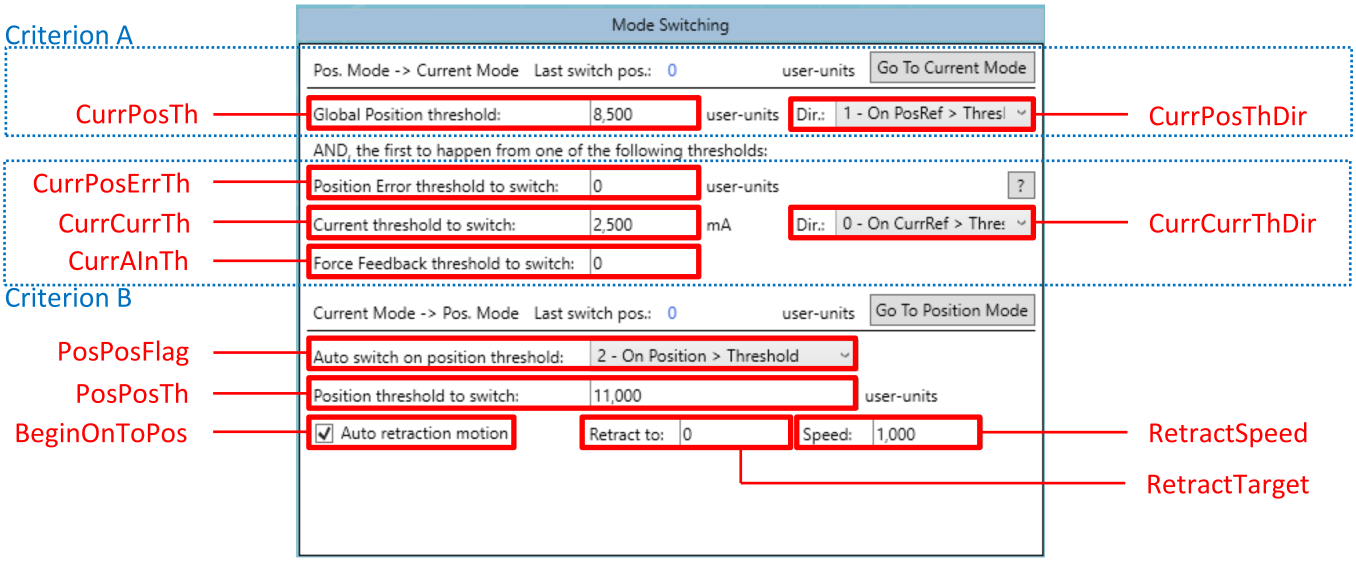


Figure 4. Screen capture of Mode Switching window (No Force Sensor).

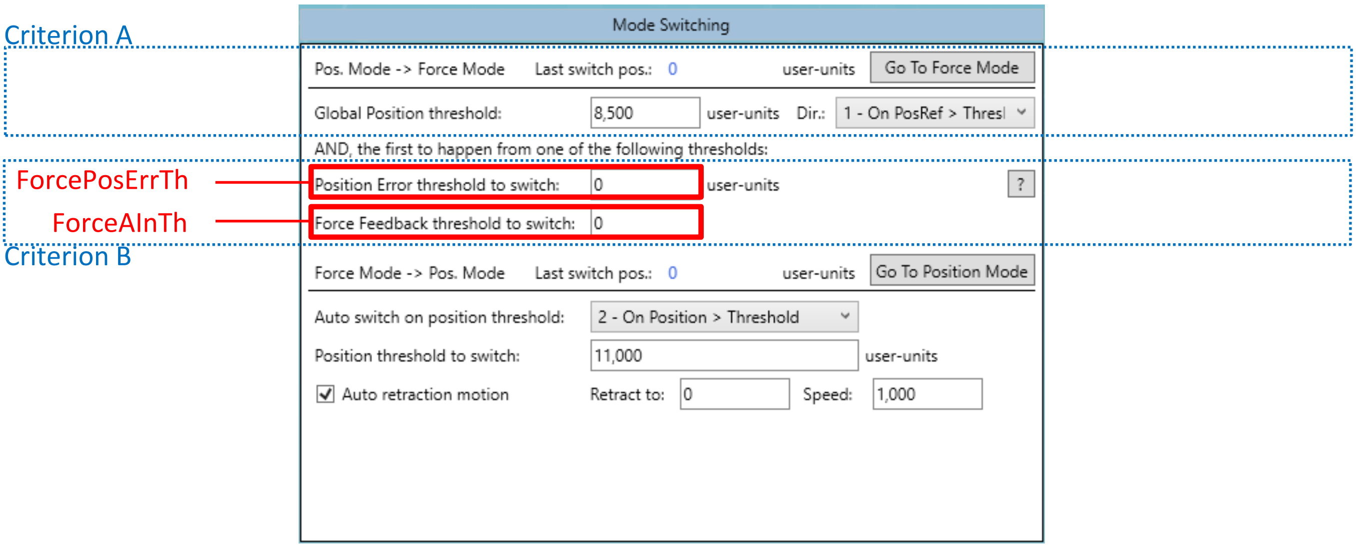


Figure 4. Screen capture of Mode Switching window (With Force Sensor).

Two main criterions have to be fulfilled for switching to occur; in this document we will refer to them as Criterion A and Criterion B.

Criterion A is a position criterion which allows for mode switching to occur only when the motor is out of a certain position range. This prevents unintended switching during the acceleration and deceleration phases of the motion profile which tend to have higher currents and higher position errors. Such unintended, early switching may cause the motor to accelerate (in current/force mode) over a distance and cause damage to the system or part. See relevant keywords below.

<table>
<tr><th>Keyword</th><th>Description</th></tr>
<tr><td>CurrPosTh</td><td>CurrPosTh defines a position threshold value that PosRef must be greater (or smaller) than, as one of the criteria for switching to Current/Force Mode to occur.

Set this value to a position slightly before your contact point. For example, if the starting position is at 0 counts and the contact position is between 9,000 to 10,000 counts, this value can be set to 8,500 counts.</td></tr>
<tr><td>CurrPosThDir</td><td>CurrPosThDir defines if the criteria of CurrPosTh is positive, negative or bypassed when set to the following values.

<table>
<tr><th>Value</th><th>Criteria</th></tr>
<tr><td>-1</td><td>PosRef < CurrPosThDir</td></tr>
<tr><td>0</td><td>Bypass</td></tr>
<tr><td>1</td><td>PosRef > CurrPosThDir</td></tr>
</table>

Set this value to 1 if moving in a positive direction towards the contact point. E.g., Starting point is at 0 counts and contact point is at 10,000 counts.
Or set the value to -1 if the contact point is in the negative direction. E.g., Starting point is at 20,000 counts and contact point is at 10,000 counts.</td></tr>
</table>

Criterion B is composed of sub-criterions (three sub-criterions **[B1**, **B2**, **B3]** for current operation mode and two **[B1**, **B2]** for force operation mode).

Criterion B is fulfilled as long as any single one of the sub-criterions, B1 <u>or</u> B2 <u>or</u> B3 is fulfilled.

Sub-criterion B1: The first sub-criterion checks for position error, if the position error grows bigger than the threshold value, then criterion A is fulfilled. See relevant keywords below.

Keyword	Description
CurrPosErrTh/ ForcePosErrTh	CurrPosErrTh/ForcePosErrTh defines a threshold value for going into Current/Force Operation Mode if position error is greater than the threshold. If the threshold value set is 0, then this trigger is not used.

Sub-criterion B2: The second sub-criterion checks for analog input, if the analog input grows larger (or smaller) than the threshold value, then criterion A is fulfilled. See relevant keywords below.

Keyword	Description
CurrAInTh/ ForceAInTh	CurrAInTh/ForceAInTh defines a threshold value for going into Force/Current Operation Mode if analog input is greater (less than, if threshold value is negative) than the threshold. If the threshold value set is 0, then this trigger is not used.

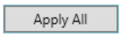
Sub-criterion B3: The third sub-criterion is only applicable for current operation mode and checks for current reference, if current reference is greater than (or less than) the threshold value, then criterion A is fulfilled. See relevant keywords below.

<table>
<tr><th>Keyword</th><th>Description</th></tr>
<tr><td>CurrCurrTh</td><td>CurrCurrTh defines a threshold value for going into Current Operation Mode if the motor current is greater (or lesser) than the threshold. If the threshold value set is 0, then this trigger is not used.</td></tr>
<tr><td>CurrCurrThDir</td><td>CurrCurrThDir defines if the criteria of CurrCurrTh is positive or negative when set to the following values.
<table>
<tr><th>Value</th><th>Criteria</th></tr>
<tr><td>0</td><td>CurrRef > CurrCurrTh</td></tr>
<tr><td>1</td><td>CurrRef < CurrCurrTh</td></tr>
</table>
</td></tr>
</table>

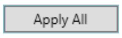
When both **Criterion A <u>and</u> Criterion B** are fulfilled, operation mode switching will be triggered. **Upon triggering, the threshold value of the particular sub-criterion B that was triggered will be reset to 0, this is to prevent unintended repeated triggering**. The remaining sub criterions will remain unchanged. Although the controller allows flexibility in defining multiple triggers (sub-criterions of B) at the same time, it is recommended to select and just use one.

Note – Arming the feature

Just like the Slow Approach feature, when Mode Switching is triggered, it will automatically be disabled (threshold value will be reset to 0) to prevent accidental usage. The user must 'intentionally' rearm the feature (by reapplying the threshold value) every time he wishes to use it.

In PCSuite, if the user is always at the FRC page, then he would just need to use the 

button to reapply the threshold values, to rearm the feature.

However, if the user navigates to another page and/or returns to FRC page after Mode Switching was triggered, the threshold values will be lost (set to zero upon trigger). In this case, the user will have to re-enter the particular threshold value and then apply the changes with the 

button.

3.5 Command Source

The next step would be to configure the current/force profile, navigate to the Command Source window. In the relevant table, assign the current/force profile. Alternatively, the command source can also be configured to come from an analog input, but the example will not be using that method.

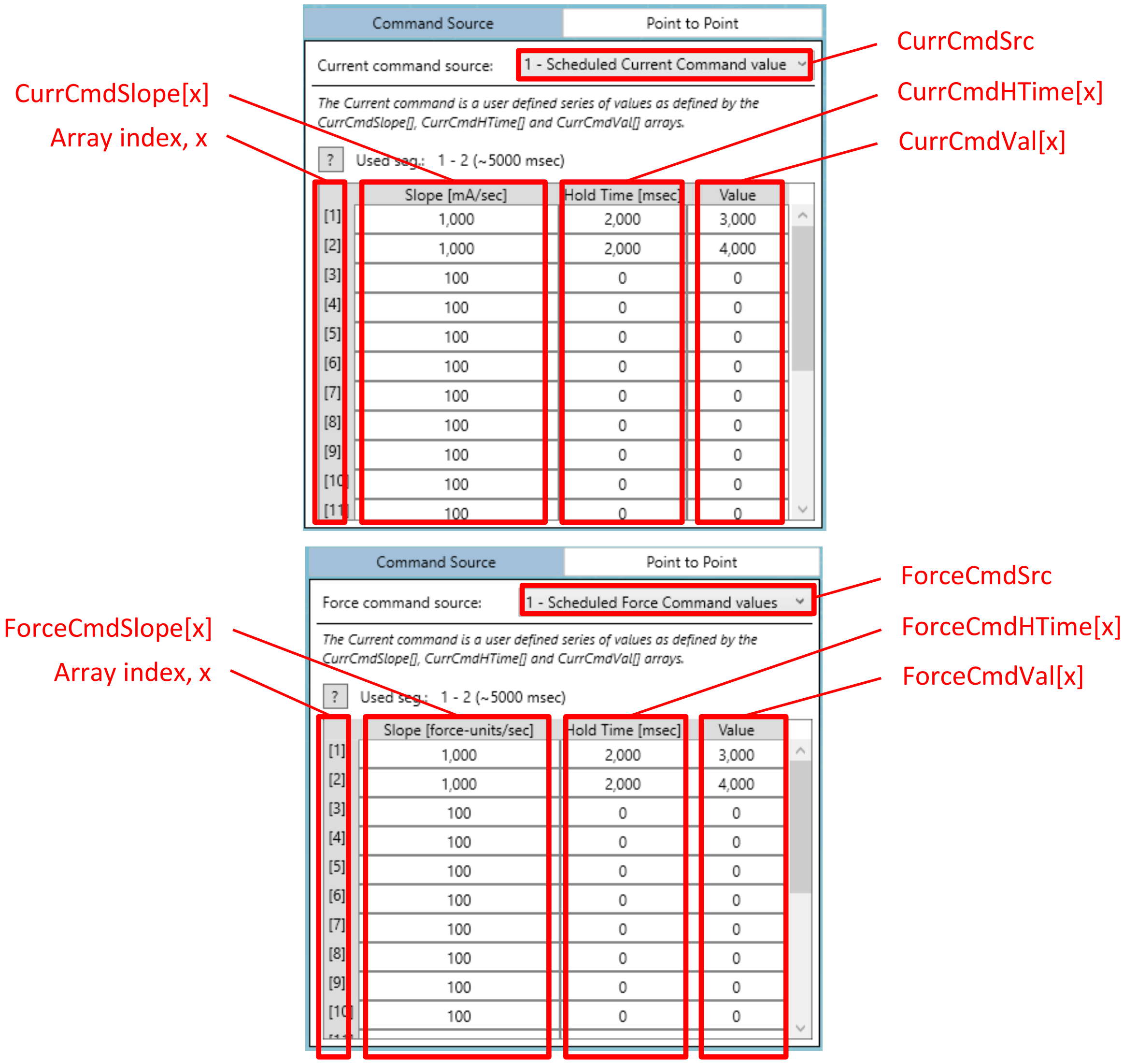


Figure 4. Screen capture of Command Source windows.

In the example above, the profile is configured to have two steps. Upon the trigger to switch operation modes, the controller will increase/decrease the force/current command to 3,000units at a rate of 1,000units/s. Then, the current/force command will then be held at this level for 2,000ms. After which, the controller will increase the current/force command to 4,000mA at a rate of 1,000units/s and held at this level for another 2,000ms. Units will be in mA or force-units depending on the mode you selected.

<table>
<tr><th>Keyword</th><th>Description</th></tr>
<tr><td>CurrCmdSrc/
ForceCmdSrc</td><td>CurrCmdSrc/ForceCmdSrc defines the command source.
<table>
<tr><th>Value</th><th>Source</th></tr>
<tr><td>0</td><td>Analog Input
(In addition to setting this keyword to 0, it is also required to set the analog input to Force Command in IO page)</td></tr>
<tr><td>1</td><td>Scheduled by table of values</td></tr>
</table>
</td></tr>
<tr><td>CurrCmdVal[x]/
ForceCmdVal[x]</td><td>CurrCmdVal[x]/ForceCmdVal[x] defines the current/force command value for step x.</td></tr>
<tr><td>CurrCmdSlope[x]/
ForceCmdSlope[x]</td><td>From the previous step to step x, there ‘will’ be a difference in the current/force command. Instead of a step jump, the controller will gradually increase/decrease the current/force command at the rate defined in CurrCmdSlope[x]/ForceCmdSlope[x], in mA/sec or force-unit/sec.</td></tr>
<tr><td>CurrCmdHTime[x]/
ForceCmdHTime[x]</td><td>After increasing/decreasing the current/force reference to the command value, the controller will hold the reference at the commanded value for the period of time defined in CurrCmdHTime[]/ForceCmdHTime[].</td></tr>
</table>

3.6 Execution and Validation

Finally, the last step would be to execute and observe the motion. Setup the chart parameters, trigger conditions and start the recording.

Stay within the FRC page, navigate to the Charts Setup window. If unsure which parameters to check for, use the ones listed below as a starting point. Optionally, record "AInPort[1]" or the relevant input if you have a force sensor connected.

Keyword	Description
CurrRef	CurrRef returns the current reference generated by the internal control loops in mA.
MotorCurr	MotorCurr is the total current to the motor (all phases combined). The value is reported in mA.

Keyword	Description
PosRef	PosRef returns the position reference generated by the internal profiler in user units (UsrUnits). The value of PosRef is fed to the position control loop.
Pos	Pos reports the main encoder position reading in user units (UsrUnits). If UsrUnits = 1 then Pos is in encoder counts. The value of Pos is 0 upon reset.
ModeSwitchPos[1]	Holds the Pos value at the last on-the-fly switch from POSITION to CURRENT (or FORCE) Operation Mode.
ModeSwitchPos[2]	Holds the Pos value at the last on-the-fly switch from CURRENT (or FORCE) Operation Mode back to POSITION Operation Mode. Both get the value of 0 at power on or after reset. Not saved to Flash, read-only, user-units.

Keyword	Description
PosErr	PosErr returns the value of the position error in user units (UsrUnits). The position error is the difference between the position command (PosRef) and the actual position. If the value of PosErr exceeds the maximum allowed position error as defined in MaxPosErr the motor is disabled.

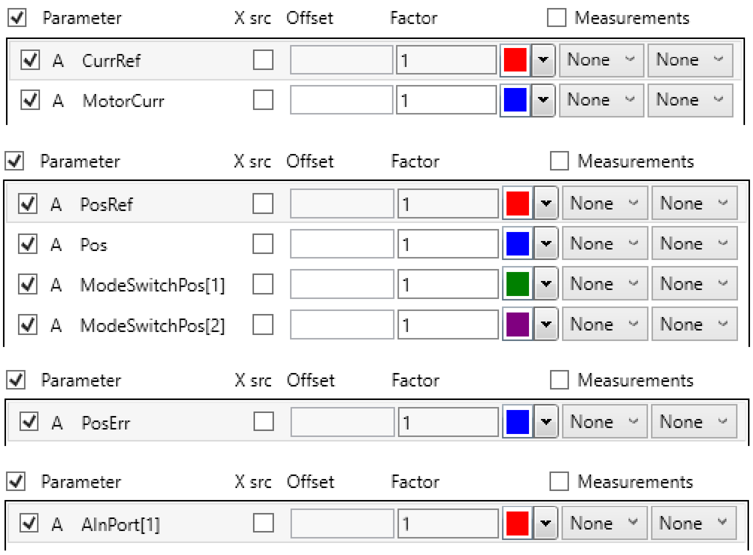


Figure 4. Partial screen capture of Chart Setup window.

Navigate to General, Trigger window. Allocate a reasonable duration to cover the whole motion profile. Select Start motion in the dropdown box and click Suggest to configure the recording to begin upon start of motion. Click on Start Rec & Show Graph (F5) to start waiting on the trigger for the recording.

The next step will be to execute the motion. **Once again, it is highly recommended that the user does not mount the force sensor on the first try.** It is recommended that the user plays around with the feature in open-loop current control to understand the feature before mounting the force sensor.

Stay within the FRC page, and navigate to the Point to Point window. Motor On and set Target 1 to position of point A (initial position), use the Go 1 button to move to Target 1. Next, double check that the Slow Approach and Mode Switch features are armed.

Finally, set Target 2 to position of point T (target position, see scenario chapter), use the Go 2 button to move to Target 2. Upon issuing the command, the force control feature should have triggered if the threshold values were set correctly.

Observe the profiles of the parameters and adjust the threshold values accordingly to be more robust. Also, repeat the tests to check for scenarios where the object is absent (Scenario C), or when the object is pliant (Scenario B).

***Insert sample graphs of recording here.**