Force Control

Application Note

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.

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.
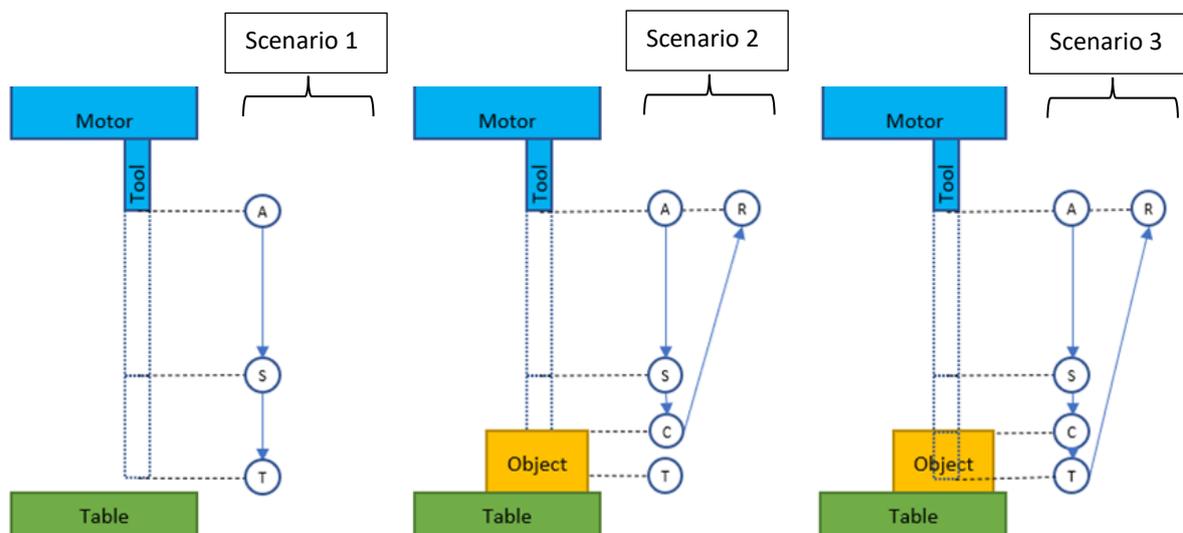
Scenario 1 (When the compressed object is absent or the mode-switching parameters are set improperly)

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 (Most common force control scenario)

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 (When the compressed object deforms excessively)

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 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:
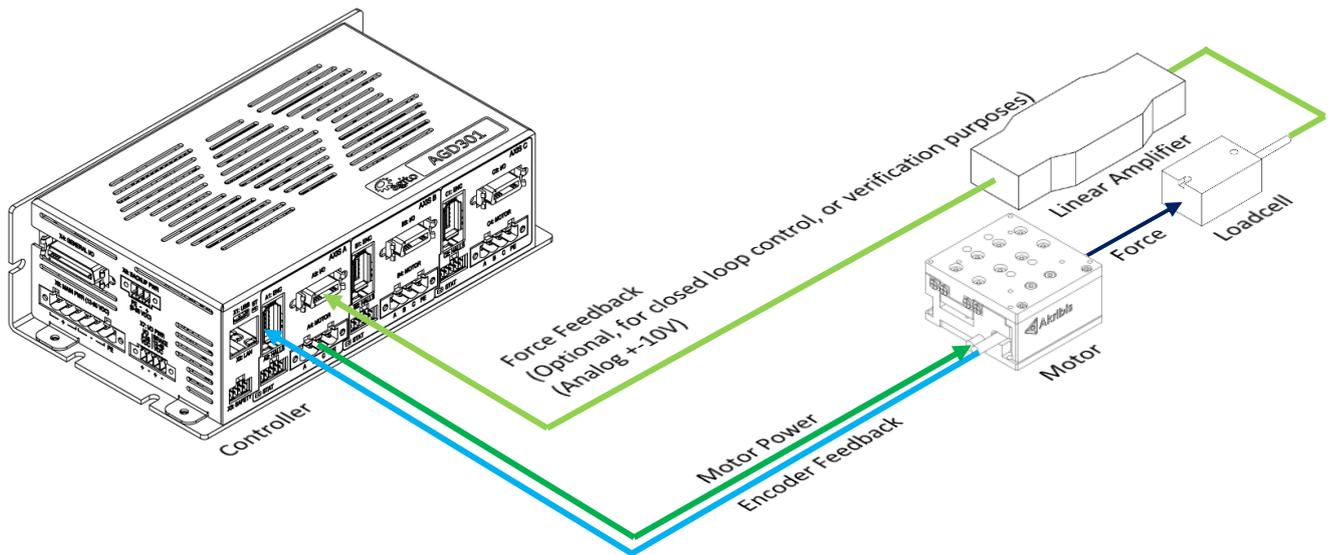
The example setup includes:

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.

Controllers that support force control include AGD301, AGC301, AGD200, AGC300, AGD155, and AGM800 + AGA series.

In closed-loop force control, the motor with a force sensor presses on the object. The force detected by the sensor is amplified by the force sensor amplifier and converted into an analog output signal, which is then fed into the controller's analog input as force feedback to achieve closed-loop force control.

In contrast, open-loop force control removes the force sensor and its amplifier, or connects the force feedback signal only for observation without participating in control. In this mode, the so-called open-loop force control essentially outputs a current value through the current control loop.

2.2 Wiring Example

Let's take AGD301 as an example.

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

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.

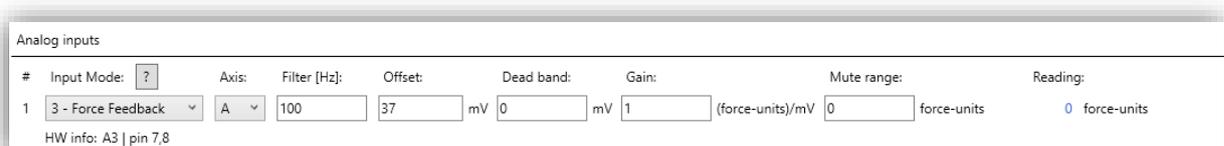Next, the analog input has to be configured to be a force feedback signal in PCSuite.

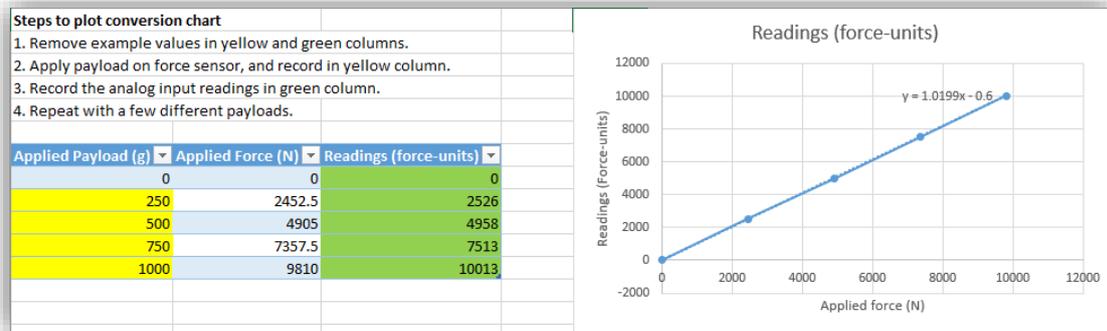In PCSuite, navigate to IO Tab and then the Analog Menu .

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.

Analog inputs									
#	Input Mode: ?	Axis:	Filter [Hz]:	Offset:		Dead band:	Gain:	Mute range:	Reading:
1	3 - Force Feedback	A	100	37	mV	0	mV 1	(force-units)/mV 0	force-units 0	force-units
	HW info: A3	pin 7,8								

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

Readings (force-units)

$y = 1.0199x - 0.6$

Appendices - Force
Control - Force to Fo

3   Interface Introduction

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.

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 vs Closed-Loop

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

Check the ☑ No Force Sensor checkbox if you want to use open-loop force control.

Otherwise, leave the ☐ No Force Sensor 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 Open-Loop Force Control Interface

Ensure that the Current 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 and tune.

3.2.1 Frc. (Curr.) Tune
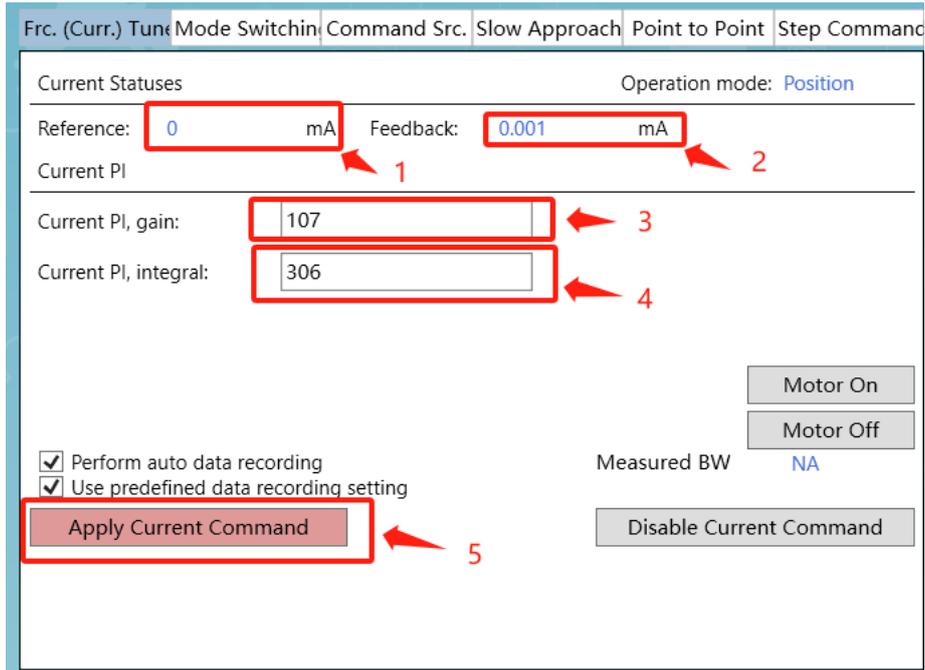
1) **CurrRef:** Current command value, in **mA.**

2) **MotorCurr:** Current feedback value, in **mA.**

3) **CurrGain:** Proportional gain parameter for tuning the current loop.

4) **CurrKi:** Integral gain parameter for tuning the current loop.

5) **Apply Current Command:** When pressed, outputs the current command set in the Step Command interface, used for testing the current loop PI parameters.

3.2.2   Mode Switching
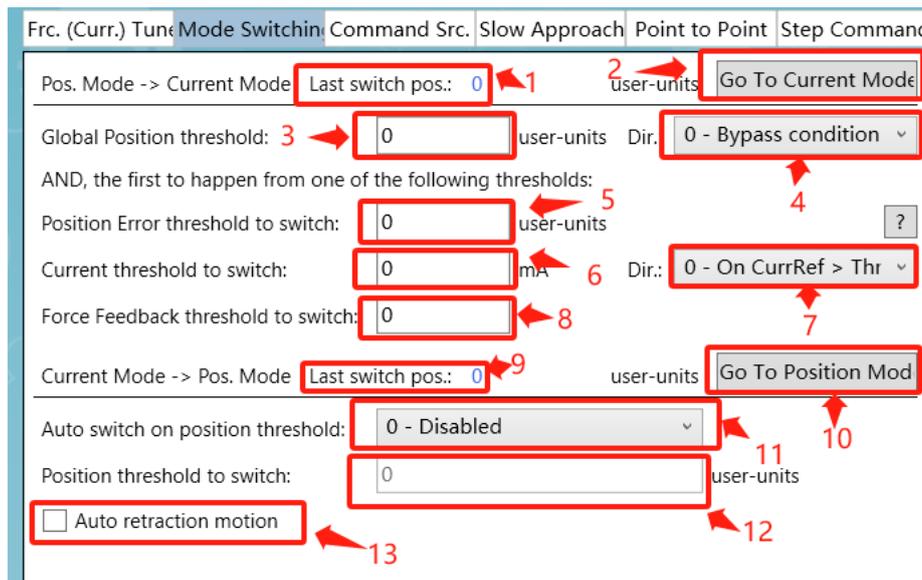
1) **ModeSwitchPos[1]:** Records the feedback position at the last switch from position control mode to force control mode.

2) **GoToCurrMode**: Switches the current motion mode to open-loop force control.

3) **CurrPosTh:** Sets a global threshold to determine when to switch to open-loop force control.

   - When **CurrPosThDir = "0 – Bypass condition"**, **CurrPosTh** is ignored.

   - When **CurrPosThDir** = "1 – On PosRef > Threshold" (or "-1 – On PosRef < Threshold"), the position reference must exceed (or be below) the **CurrPosTh** value and at least one of the following thresholds must be met: **position error**, **current**, or **force feedback**, to switch to open-loop force control.

4) **CurrPosThDir:** Used together with **CurrPosTh**, as described above.

5) **CurrPosErrTh:** Sets the position error threshold for automatically switching to open-loop force control.

   - **0** disables this condition.

   - A **positive** value triggers the switch when the position error exceeds the threshold.

   - A **negative** value triggers the switch when the position error is below the threshold.

   Note: If CurrPosThDir is enabled, the CurrPosTh condition must also be met.

6) **CurrCurrTh:** Based on **CurrCurrThDir**, switches to open-loop force control when the current command exceeds (or falls below) the set threshold.
   Note: If CurrPosThDir is enabled, the CurrPosTh condition must also be satisfied.

7) **CurrCurrThDir:** Determines whether the current threshold condition triggers on exceeding or falling below the value.

8) **CurrAInTh:** Sets the analog input force feedback threshold for automatically switching to open-loop force control.

   - 0 disables this condition.

   - Positive value triggers the switch when force feedback exceeds the threshold.

- Negative value triggers the switch when force feedback falls below the threshold.
  Note: If **CurrPosThDir** is enabled, the **CurrPosTh** condition must also be satisfied.

9) **ModeSwitchPos[2]:** Records the feedback position at the last switch from force control mode back to position control mode.

10) **GotoPosMode:** Switches the current motion mode to position control mode.

11) **PosPosFlag:** Determines forced position mode switching in force control:

  - 0: Feature disabled.

  - 1: In force control mode, if position feedback is **below** the **PosPosTh** value, force switch to position control mode.

  - 2: In force control mode, if position feedback is **above** the **PosPosTh** value, force switch to position control mode.

12) **PosPosTh:** Works together with **PosPosFlag** to set the threshold for forced position mode switching.

13) **BeginOnToPos:** When set to 1, enables immediate execution of the predefined position command when switching from force control mode back to position control mode.

Upon triggering, the threshold value of the particular sub-criterion that was triggered will be reset to 0, this is to prevent unintended repeated triggering. The remaining sub-criterion will remain unchanged. Although the controller allows flexibility in defining multiple triggers at the same time, it is recommended to select and just use one.

Note – Arming the 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, although the threshold values seem like it remains unchanged because you don't refresh the page after triggering. Actually, the threshold values have been lost. You would just need to use the [Apply All] 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 [Apply All] button.

3.2.3 Command Src.

This interface is primarily used to configure the command type for open-loop force control, which is determined by the **CurrCmdSrc** parameter shown in the diagram.
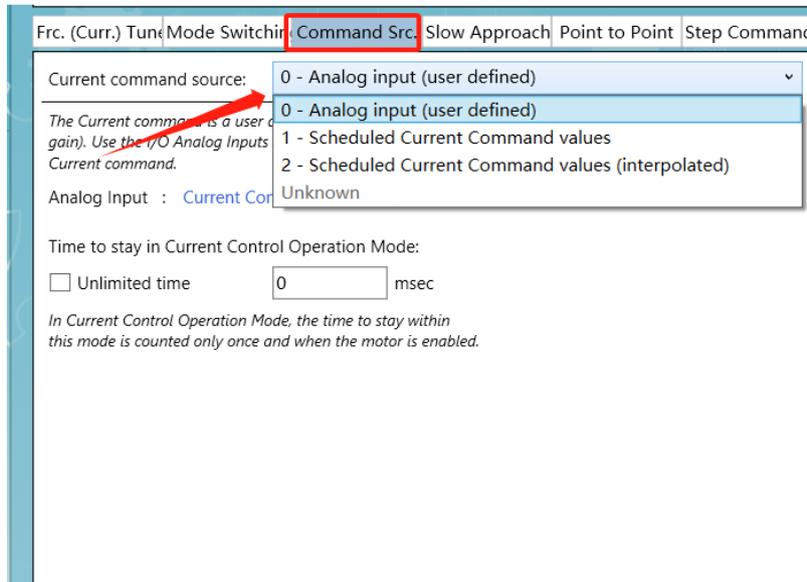
0 – Analog Input (User Defined)

In this mode, the open-loop force control command comes from the analog input signal. You must first set the input signal on the Analog Input interface to "2 – Current Command" mode. After enabling open-loop force control, the motor will follow the Current Command signal to perform open-loop force control.
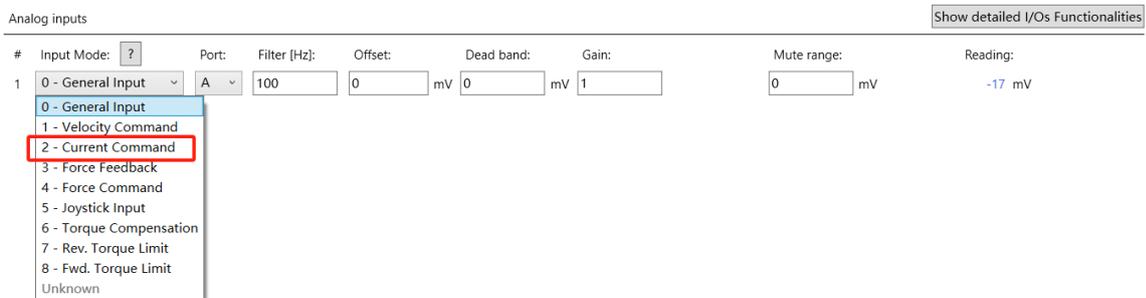
In this mode, you only need to set the duration of force control, which starts counting as soon as the system enters force control mode. The keyword is **CurrCmdHTime[1]**, in milliseconds. Setting the value to **-1** makes the duration indefinite.

1 - Scheduled Current Command Values
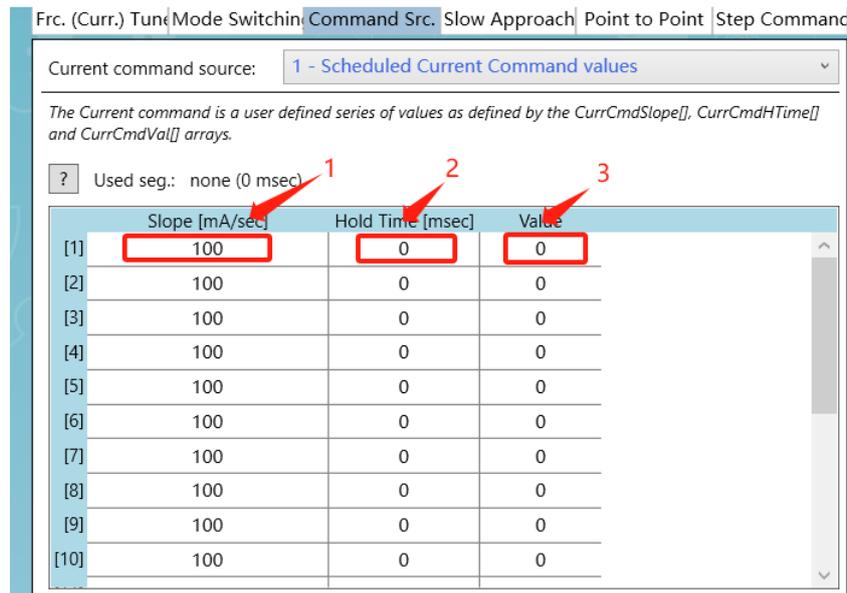
1) **CurrCmdSlope[*]:** The slope of the open-loop force command change for each segment.

2) **CurrCmdHTime[*]:** The duration of the open-loop force command for each segment.

3) **CurrCmdVal[*]:** The target value of the open-loop force command for each segment.

When this mode is selected, entering open-loop force control executes the segments in order from top to bottom according to the table. Each segment is defined by three parameters: **slope**, **duration**, and **target value**. Up to 20 force command segments can be added. Execution continues sequentially until a segment with **HoldTime = 0** is reached. For example, if only the first two segments need to be executed, set **CurrCmdHTime[3] = 0**.

After execution, the system automatically switches back to position mode. You can also set a segment's **HoldTime = -1** to maintain force control mode indefinitely.

Additional Parameters Commands for Open-Loop Force Control:

1) **CurrCmdCntr:** This parameter counts the execution time of each segment during open-loop force control. For example, if three segments of open-loop force commands are used, each with a duration of 500 ms, the **CurrCmdCntr** waveform collected during execution will appear as shown in the diagram.
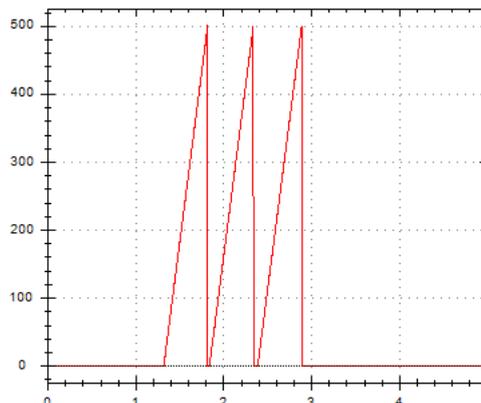
2) **CurrCmdIndex:** This parameter indicates the current segment number being executed during open-loop force control. For example, if three segments of open-loop force commands are used, the **CurrCmdIndex** waveform collected during execution will appear as shown in the diagram.
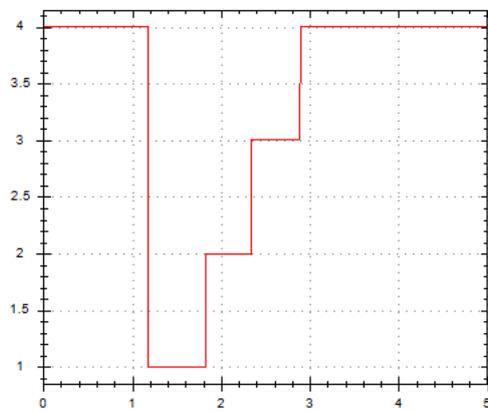
3.2.4   Slow Approach Before Contact

The Slow Approach interface is used to configure the speed transition from high speed to low speed when approaching the object to be pressed, 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.

1) **SpeedChgOn:** Enables or disables the speed switching function.

2) **SpeedChgPos:** Sets the position point at which the speed switch occurs.

3) **SpeedChgDir:** Sets the direction for determining the speed switch at the position point.

   - 0 – Forward: Speed switches when the position increases past **SpeedChgPos**.

   - 1 – Reverse: Speed switches when the position decreases past **SpeedChgPos**.

4) **SpeedChgNew:** Sets the new speed after the switch.

In the figure, 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.

3.2.5   Point to Point

The PTP interface is the same as the standard PTP interface, so its functions will not be repeated here. It is included in the force control interface for user convenience, such as moving the motor close to the contact surface or testing whether the force control thresholds are appropriate.

3.2.6   Step Command for Force (Current) Tuning

This interface is essentially the Step Command interface for current loop tuning, since open-loop force control is equivalent to closed-loop current control.

3.3 Closed-Loop Force Control Interface

Ensure that the 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 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.

3.3.1 Frc. (Curr.) Tune
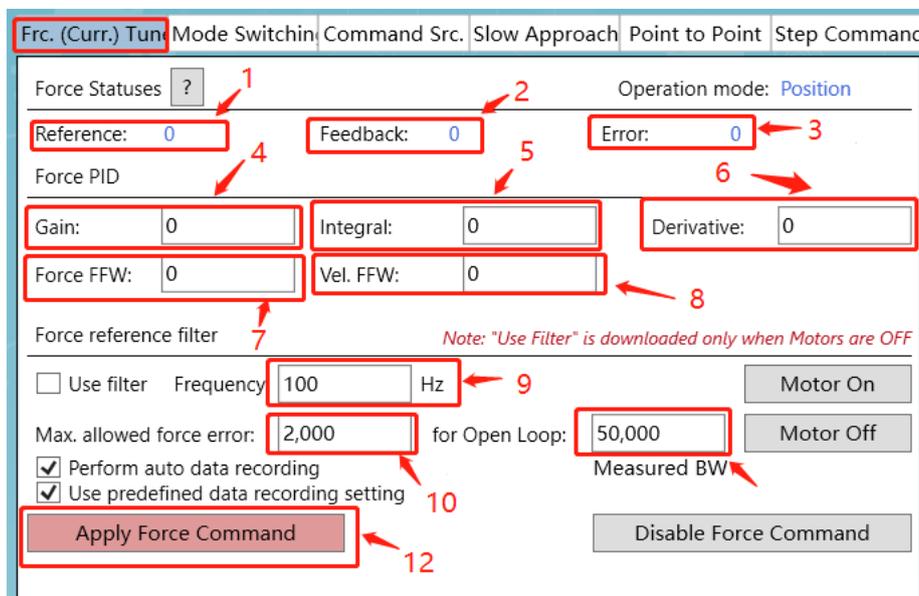
1) **ForceRef**: The command value for closed-loop force control, in **Force-unit**. When not in closed-loop force control mode, this keyword's value always equals the value of the Force keyword, which corresponds to the feedback from the force sensor.

2) **Force:** Feedback value from the force sensor, in **Force-unit**. The force sensor signal must be connected to the analog input port, and the port mode should be set to **Force feedback**.

3) **ForceErr:** Force control error, in **Force-unit**, calculated as Force minus ForceRef. When not in closed-loop force control mode, ForceErr is always **0**.

4) **ForceGain:** Proportional gain parameter for tuning closed-loop force control.

5) **ForceKi:** Integral gain parameter for tuning closed-loop force control.

6) **ForceKd:** Derivative gain parameter for tuning closed-loop force control.

7) **ForceFFW:** Force feedforward parameter for closed-loop force control tuning.

8) **ForceVelFFW:** Velocity feedforward parameter for closed-loop force control tuning.

9) **ForceRefFilt:** Low-pass filter frequency applied to the closed-loop force control command. Whether the filter is enabled is determined by the **ForceRefFOn** keyword.

10) **MaxForceErr:** Maximum allowable error for closed-loop force control. Exceeding this value triggers protective disable. In closed-loop force control, this represents the difference between **ForceRef** and **Force**.

11) **MaxForceErrOL:** Maximum allowable error for open-loop force control. Exceeding this value triggers protective disable. In open-loop force control, this represents the difference between **CurrRef** and **MotorCurr**.

12) **Apply Force Command:** When pressed, outputs the force command set in Step Command, facilitating tuning of the PIV parameters for force control.

3.3.2 Mode Switching

1) **ModeSwitchPos[1]:** This keyword records the feedback position at the last switch from position control mode to force control mode.

2) **GoToForceMode:** Switches the current motion mode to closed-loop force control.

3) **CurrPosTh:** This keyword sets a global threshold to determine when to switch to closed-loop force control.

   - When the **CurrPosThDir** parameter is set to "0 – Bypass condition", **CurrPosTh** has no effect.

   - When **CurrPosThDir** is set to "1 – On PosRef > Threshold" (or "-1 – On PosRef < Threshold"), the position reference must exceed (or be below) the **CurrPosTh** value and at least one of the following conditions must also be met: the position error threshold or the force feedback threshold, in order to switch to closed-loop force control.

4) **CurrPosThDir:** As mentioned previously, used in conjunction with the **CurrPosTh** keyword.

5) **ForcePosErrTh:** Sets the position error threshold for automatically switching to closed-loop force control.

   - A value of **0** disables this switching condition.

   - A **positive** value triggers automatic switch to closed-loop force control when the position error exceeds the set value.

- A **negative** value triggers automatic switch when the position error is below the set value.

*Note: If **CurrPosThDir** is enabled, the **CurrPosTh** condition must also be met to switch to force control mode.*

6) **ForceAInTh:** Sets the analog input force feedback threshold for automatically switching to closed-loop force control.

- A value of **0** disables this condition.

- A **positive** value triggers the switch when the force feedback exceeds the set value.

- A **negative** value triggers the switch when the force feedback is below the set value.

*Note: If **CurrPosThDir** is enabled, the **CurrPosTh** condition must also be satisfied.*

7) **ModeSwitchPos[2]:** Records the feedback position at the last switch from force control mode back to position control mode.

8) **GotoPosMode:** Switches the current motion mode to position control mode.

9) **PosPosFlag:** Determines the position-based forced switch in force control mode:

- 0: Feature disabled.

- 1: In force control mode, if the position feedback is below **PosPosTh**, force switch to position control mode.

- 2: In force control mode, if the position feedback is above **PosPosTh**, force switch to position control mode.

10) **PosPosTh:** Works together with **PosPosFlag** to define the threshold for forced switching.

11) **BeginOnToPos:** When set to 1, enables immediate execution of the predefined position command when switching from force control mode back to position control mode.

Upon triggering, the threshold value of the particular sub-criterion that was triggered will be reset to 0, this is to prevent unintended repeated triggering. The remaining sub-criterion will remain unchanged. Although the controller allows flexibility in defining multiple triggers at the same time, it is recommended to select and just use one.

Note – Arming the 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, although the threshold values seem like it remains unchanged because you don't refresh the page after triggering. Actually, the threshold values have been lost. You would just need to use the Apply All 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 Apply All button.

3.3.3   Command Src.

This interface is primarily used to configure the command type for closed-loop force control, which is determined by the **ForceCmdSrc** parameter shown in the diagram.
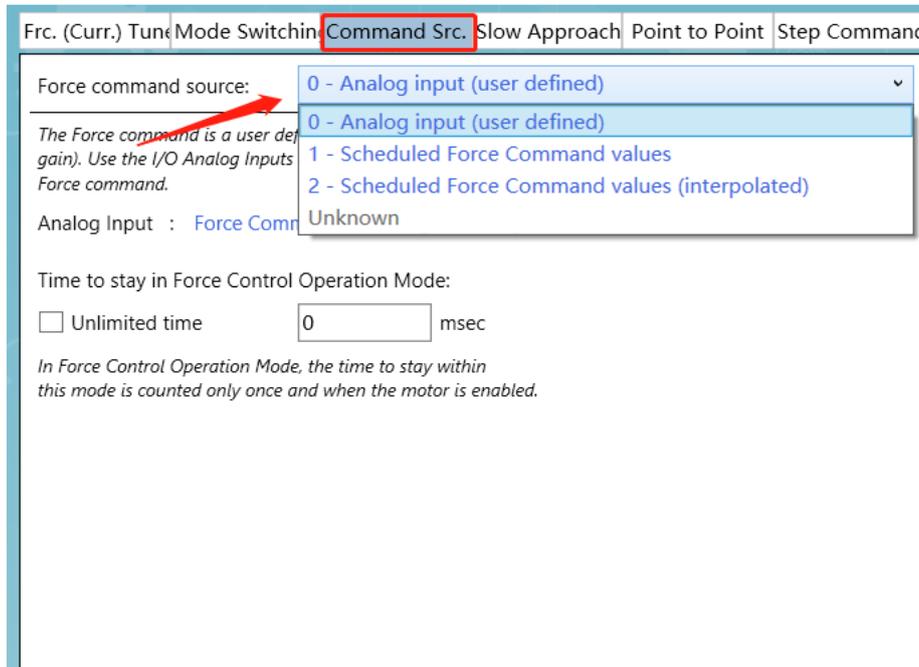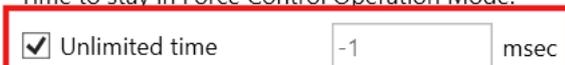

0 – Analog Input (User Defined)

In this mode, the closed-loop force control command comes from the analog input signal. You must first set the input signal on the Analog Input interface to "4 – Force Command" mode. After enabling closed-loop force control, the motor will follow the Force Command signal to perform closed-loop force control.
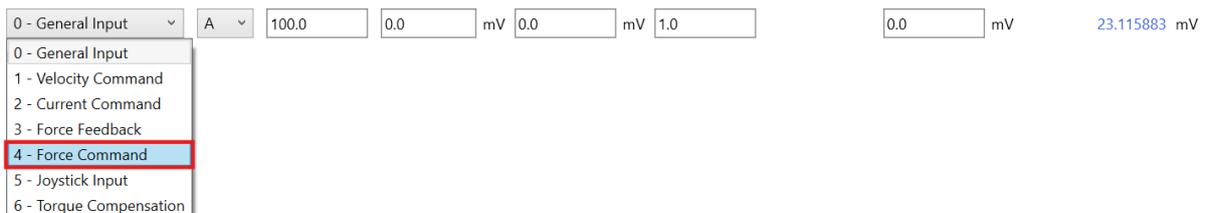
In this mode, you only need to set the duration of force control, which starts counting as soon as the system enters force control mode. The keyword is **ForceCmdHTime[1]**, with units in milliseconds. Setting the value to **-1** makes the duration indefinite.

1 - Scheduled Force Command Values

1) **ForceCmdSlope[*]:** The slope of the closed-loop force command change for each segment.

2) **ForceCmdHTime[*]:** The duration of the closed-loop force command for each segment.

3) **ForceCmdVal[*]:** The target value of the closed-loop force command for each segment.

When this mode is selected, entering closed-loop force control executes the segments in order from top to bottom according to the table. Each segment is defined by three parameters: **slope**, **duration**, and **target value**. Up to 20 force command segments can be added. Execution continues sequentially until a segment with **HoldTime = 0** is reached. For example, if only the first two segments need to be executed, set **ForceCmdHTime[3] = 0**.

After execution, the system automatically switches back to position mode. You can also set a segment's **HoldTime = -1** to maintain force control mode indefinitely.

Additional Parameters Commands for Closed-Loop Force Control:

1) **ForceCmdCntr:** This parameter counts the execution time of each segment during closed-loop force control. For example, if three segments of closed-loop force commands are used, each with a duration of 500 ms, the **ForceCmdCntr** waveform collected during execution will appear as shown in the diagram.
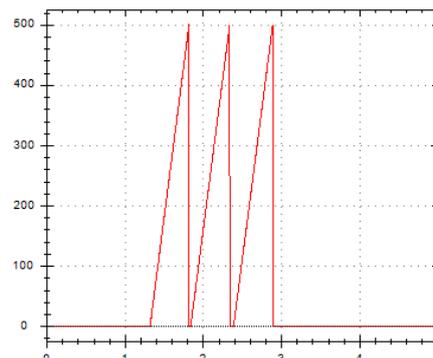
2) **ForceCmdIndex:** This parameter indicates the current segment number being executed during closed-loop force control. For example, if three segments of closed-loop force commands are used, the **ForceCmdIndex** waveform collected during execution will appear as shown in the diagram.
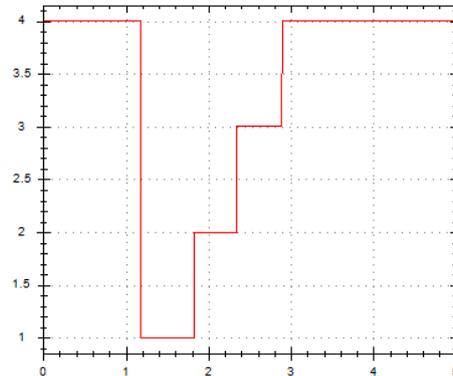
3.3.4   Slow Approach

The Slow Approach interface is used to configure the speed transition from high speed to low speed when approaching the object to be pressed, 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.

1) **SpeedChgOn:** Enables or disables the speed switching function.

2) **SpeedChgPos:** Sets the position point at which the speed switch occurs.

3) **SpeedChgDir:** Sets the direction for determining the speed switch at the position point.

- 0 – Forward: Speed switches when the position increases past **SpeedChgPos**.

- 1 – Reverse: Speed switches when the position decreases past **SpeedChgPos**.

4) **SpeedChgNew:** Sets the new speed after the switch.

In the figure, 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.

3.3.5   Point to Point

The PTP interface is the same as the standard PTP interface, so its functions will not be repeated here. It is included in the force control interface for user convenience, such as moving the motor close to the contact surface or testing whether the force control thresholds are appropriate.

3.3.6   Step Command for Force (Current) Tuning

This interface is similar to the Step Command interface used for tuning the current, velocity, and position loops, but here it provides force commands. By default, the command is a square wave with a frequency of 5 Hz and an amplitude of 100 Force-unit. You can also uncheck Use Predefined Command to freely configure force commands with different frequencies, amplitudes, and waveforms.
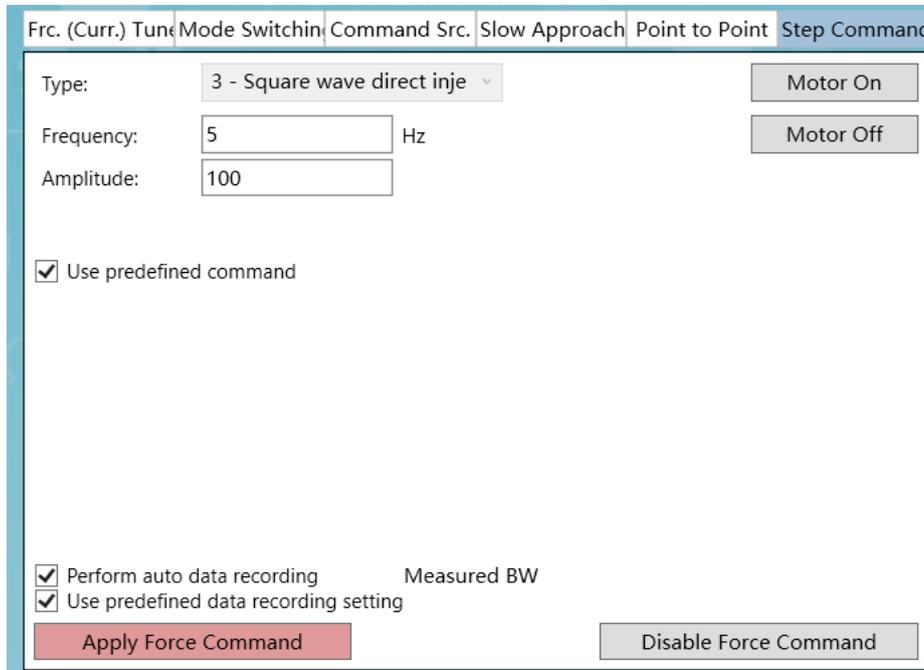
Note: Before executing the command, ensure that the motor is pressing against the object, because clicking **Apply Force Command** *immediately switches to closed-loop force control mode and sends the force command.*

4 Operation

4.1 Open-Loop Force Control Operation Example

Before executing open-loop force control, make sure to **tick** the "No force sensor" option in the upper-right corner of the **Force Control** interface.


4.1.1 Frc. (Curr.) Tune

In the **Frc. (Curr.) Tune** interface, adjust the **PI parameters** for Open-Loop Force Control.

When debugging Open-Loop Force Control using square-wave commands, the motor does not need to contact the compressed object—the debugging can be performed in the air.

Clicking the **Apply Current Command** button sends a current command to the motor. Adjust the current PI parameters so that the current feedback closely follows the current command, while avoiding excessively large parameters that could cause overshoot or oscillation.
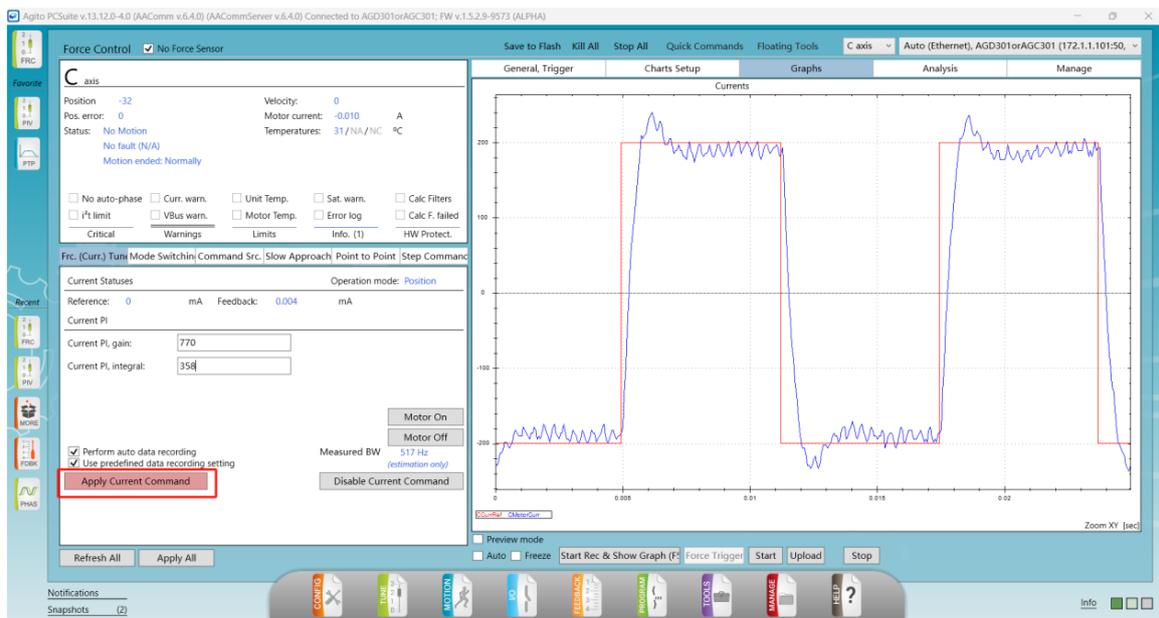
The current tracking achieved through parameter adjustment here determines the following tracking performance during Open-Loop Force Control.

You can also switch to the **Step Command** interface. By unchecking **Use Predefined Command**, you can freely set the type, frequency, and amplitude of the current command.

4.1.2   Mode Switching

Switch to the **Mode Switching** interface and fill in the **transition conditions** from Position Mode to Open-Loop Force Control.

- The first condition is the **position condition**. When the **Dir** on the right is set to **1** or **-1**, the position condition must be met for the system to switch to force control.

- Only when the position condition is met, and **any one** of the three conditions below (**position error, current value,** or **force feedback**) is also met, will the system switch to Open-Loop Force Control.

In the example, the motor contacts the compressed object at **3600 counts**. The position condition in the graph is set to **3500 counts**, with **Dir = 1**. This means the system will evaluate whether to switch to Open-Loop Force Control when the position is **greater than 3500 counts**.

The **current command** is used as the trigger condition. The system switches to Open-Loop Force Control when the current command exceeds **120 mA**. The three conditions—position error, current value, and force feedback—can be set simultaneously; if any one of them is triggered, the system will switch to Open-Loop Force Control.

The **Auto Switch on Position Threshold** function is used for protection. In the example, it is set to switch from Open-Loop Force Control back to Position Mode when the position exceeds 4000 counts.

Tick **Auto Retraction Motion**. The auto retraction motion is enabled. When switching from Open-Loop Force Control back to Position Mode, the system moves to the position 0 at a speed of 20,000 counts/s.
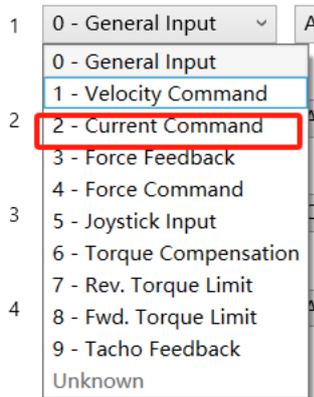
4.1.3   Command Src.

Here, select the source of the open-loop force control command.

0 – Analog input (User defined)

1) When "0 – Analog input (User defined)" is selected, the command comes from the analog input configured in "2 - current command" mode.

2) Set the duration for operating in open-loop force control mode.

If the duration is set to **-1**, the mode will run indefinitely. Otherwise, when the specified time elapses, the system will automatically switch back to position mode.

1 - Scheduled Force Command values

When "1 – Scheduled Force Command values" mode is selected, the commands are executed sequentially from top to bottom according to the table. Each segment is defined by three parameters: **slope**, **duration**, and **target value**. Up to 20 force command segments can be added, and execution continues downward until a segment with **HoldTime = 0** is encountered. (If **HoldTime** is set to **-1**, the segment will execute indefinitely.)

As the figure shown, three open-loop force command segments are set sequentially: 150 mA current held for 500 ms, 170 mA current held for 500 ms and 120 mA current held for 500 ms.

After the commands are completed, the system will automatically switch back to position mode.

Note: *If the Open-Loop Force Control command value is less than the current required to maintain contact, the motor may lose contact with the compressed object after switching to Open-Loop Force Control.*

4.1.4 Slow Approach Before Contact

When switching from position mode to force control mode, to reduce overshoot, motion is typically divided into two segments: a long-distance high-speed movement and a short-distance slow approach toward the object.

The Slow Approach interface is used to set the conditions for the slow approach and the speed value after switching to slow movement.

Slow approach state: Disabled

When armed and when moving in the selected direction and when passing the defined position, the motion speed will automatically change to the new speed value. Upon speed automatic change, this functionality will be disabled and must be re-armed again for the next change.

Slow approach:	Arm
Change speed at:	3,400 user-units
Slow approach direction:	0 - Positive
New speed:	500 user-units/sec

Since 3600 counts is the contact position, slow approach is set to start at 3400 counts, with the post-switch speed set to 500 count/s. Clicking the **Arm** button enables the Slow Approach function. During the next position movement, speeds below 3400 counts use the value set in the PTP interface, and once 3400 count is exceeded, the speed switches to the configured 500 count/s.
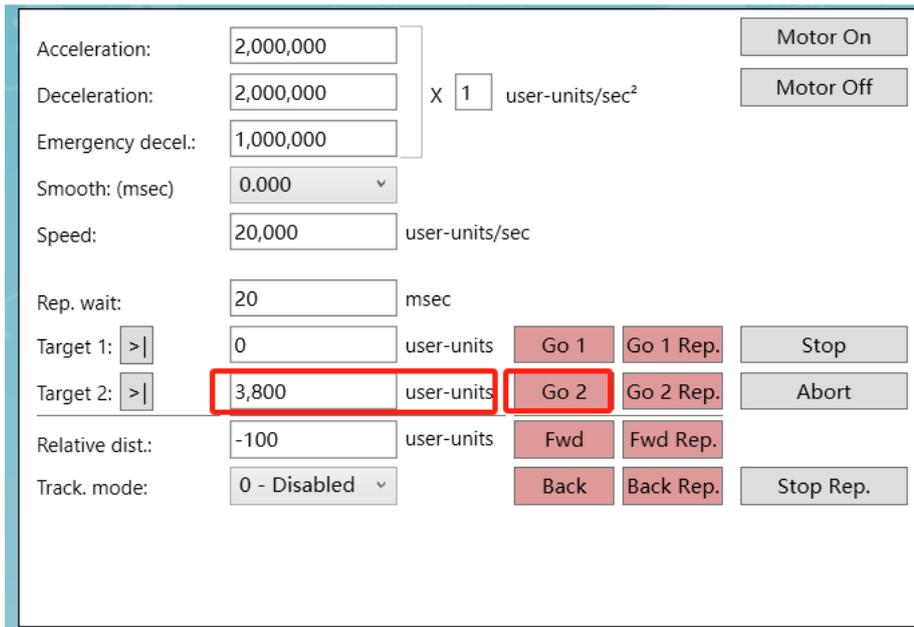
Note: The Slow Approach function only takes effect once after being enabled; to use it again, it must be re-enabled.

4.1.5 Point to Point

After completing these steps above, switch to the **Point to Point** interface for a full open-loop force control test.

Due to contact position with the object is **3600 counts**, so target position in the **Point to Point** interface is set to **3800 counts**, which is beyond the contact point.

Clicking **Go 2** moves the motor toward 3800 counts. Setting a target beyond the contact position ensures that the motor will definitely make contact with the object and that the conditions for switching to open-loop force control will be met.

Acceleration:	2,000,000				Motor On	
Deceleration:	2,000,000	X	1	user-units/sec²	Motor Off	
Emergency decel.:	1,000,000					
Smooth: (msec)	0.000 ⌄					
Speed:	20,000	user-units/sec				
Rep. wait:	20	msec				
Target 1: >|	0	user-units	Go 1	Go 1 Rep.	Stop	
Target 2: >|	3,800	user-units	Go 2	Go 2 Rep.	Abort	
Relative dist.:	-100	user-units	Fwd	Fwd Rep.		
Track. mode:	0 - Disabled ⌄		Back	Back Rep.	Stop Rep.	

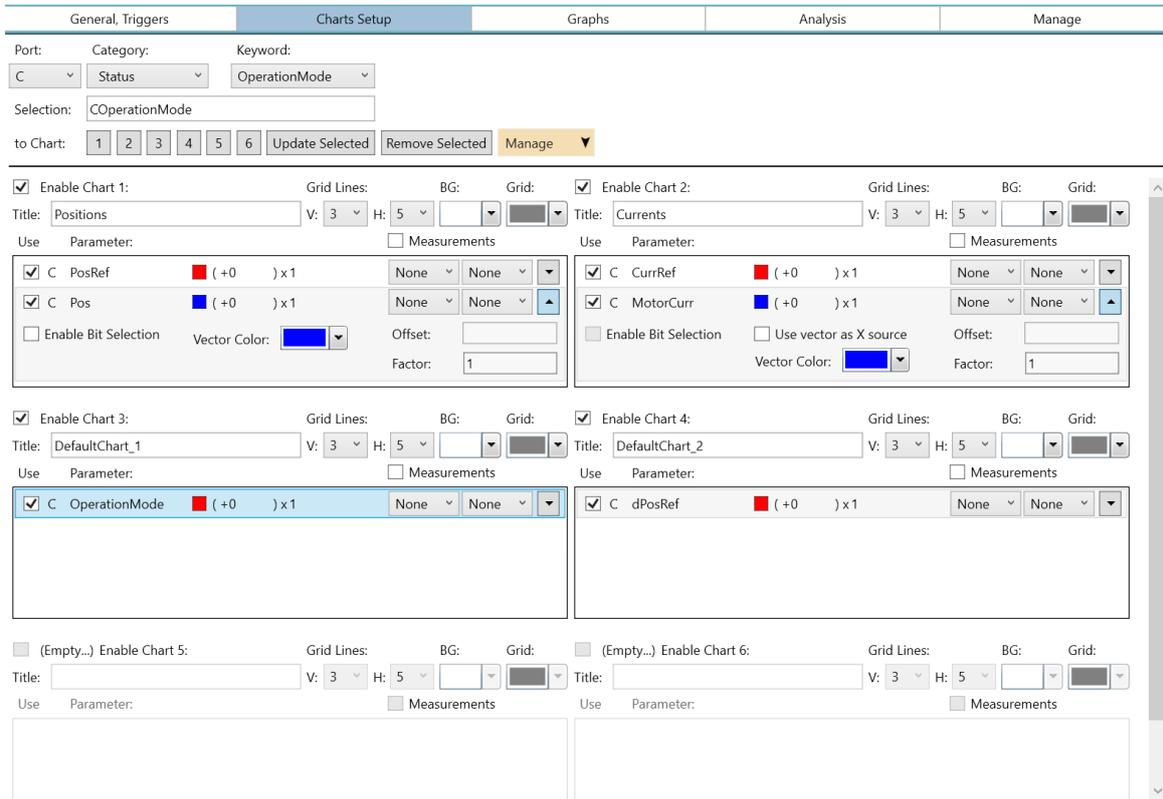## 4.1.6 Execution and Validation

Finally, the last step would be to execute and observe the motion.

1) Setup the chart parameters, trigger conditions and start the recording.

➢ Set the chart parameters as below.

Stay within the **FRC** page, navigate to the Charts Setup window.
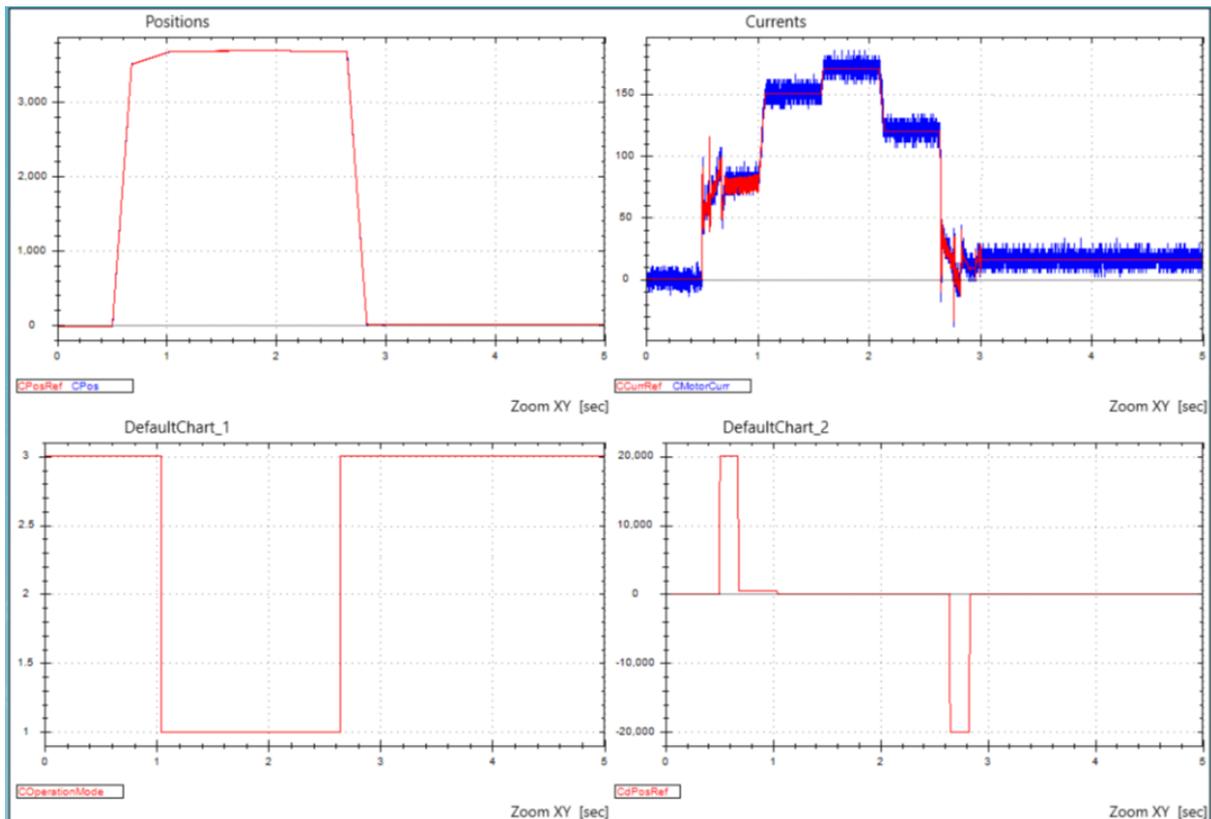

➢ Set the capture trigger condition to **Start Motion**.

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.
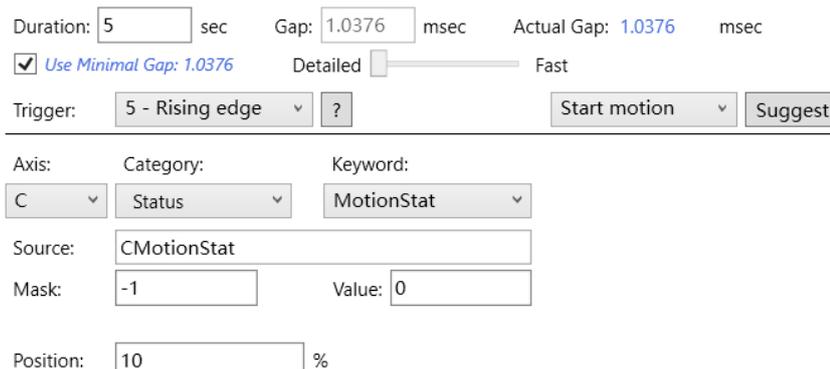
➢ The four captured graphs are **Position**, **Current**, **Operation Mode**, and **Speed** as below.

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.
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.
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.
OperationMode	OperationMode determines what control loops will be activated. The values for OperationMode are: 1 – Current Mode 2 – Velocity Mode 3 – Position Mode 4 – Force Mode

2) The next step will be to execute the motion.

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), 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 1), or when the object is pliant (Scenario 3).
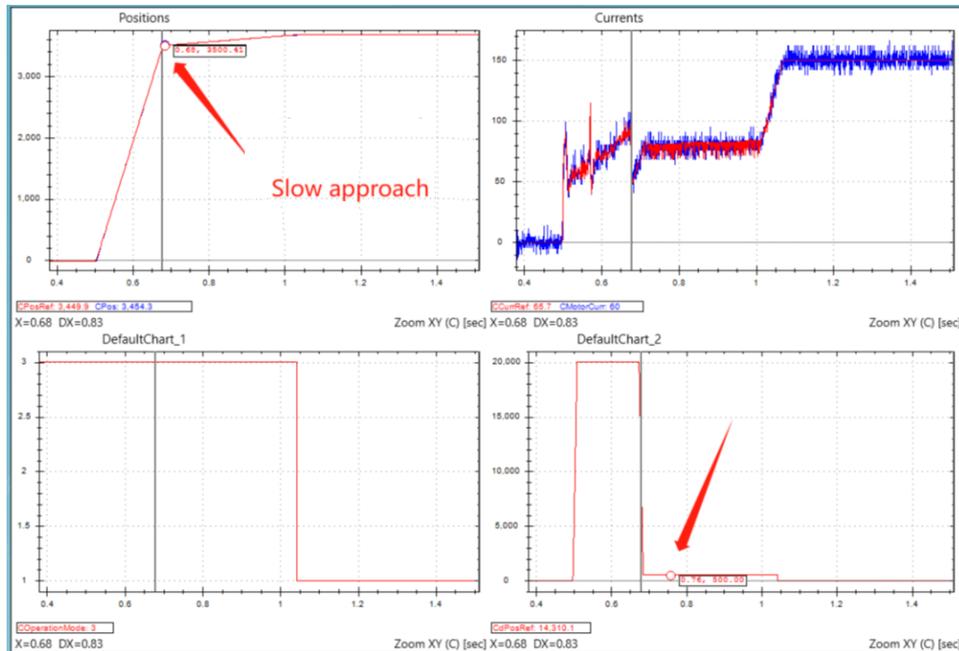
Let's explain the several key points in the entire motion process.

➢ The first part is **Position Mode motion** until contact with the compressed object.

During this process, the **Operation Mode** remains at **3**, which is **Position Mode**.
You can also see, as previously set in **Slow Approach**, that positions below 3500 counts use high-speed movement, while positions above 3500 counts switch to slow speed at 500 counts/s.

➢ The second part is switching to **Open-Loop Force Control** based on the set transition condition.

In the graph, at the end of the slow-speed motion, the current value increases upon contact with the compressed object, reaching the set transition threshold of **120 mA**. The Operation Mode changes from **3** to **1**, meaning it switches to **Open-Loop Force Control**.
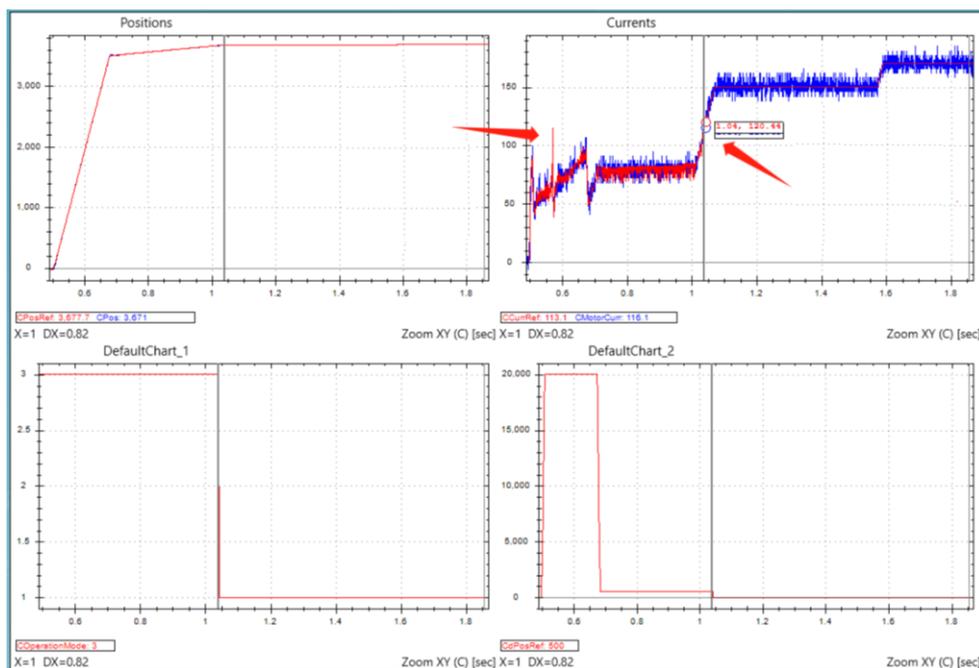
*It is important to note that during the entire approach in Position Mode, because the **Global Position Threshold** function is enabled, even if the current exceeds 120 mA during high-speed motion below 3500 counts, the system will **not** switch to Open Loop Force Control. This condition prevents unintended switching during high-speed position movements.*

Global Position threshold:	3,500	user-units	Dir.:	-1 - On PosRef < Thr ⌄

- ➢ The third part is the execution of **Open-Loop Force Control** commands.

In this example, the **1-Scheduled Force Command Values** mode is used, with three consecutive commands of **150 mA**, **170 mA**, and **120 mA**. From the graph, you can see that after switching to Open-Loop Force Control, the three commands are executed in sequence.
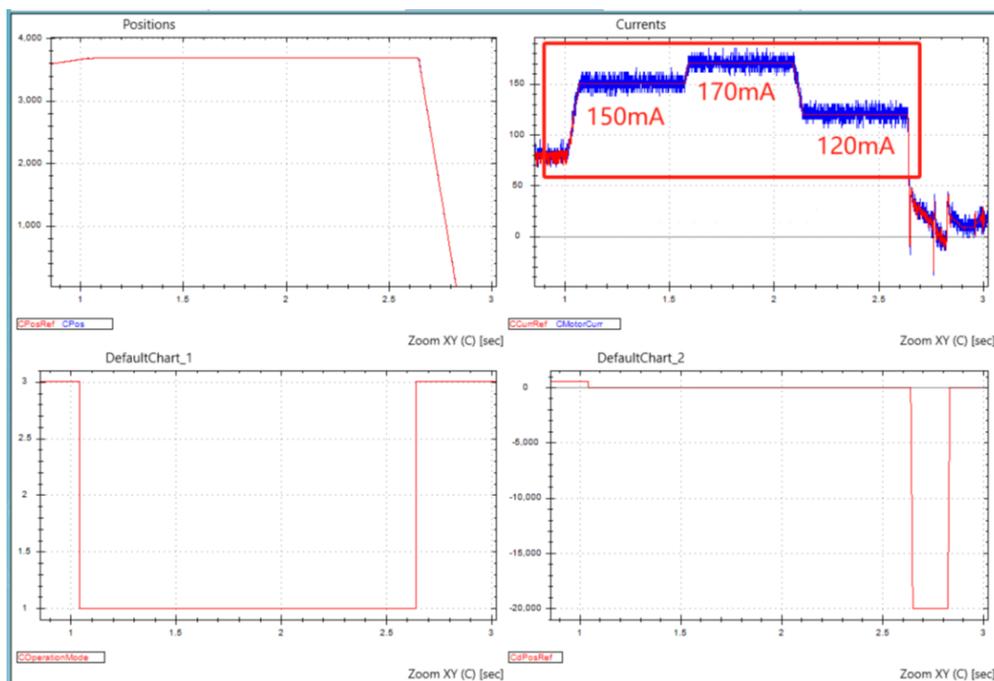
- ➢ The fourth part is after completing the Open-Loop Force Control commands.

☑ Auto retraction motion	Retract to:	0	Speed:	20,000

In the example, after the 120 mA current command finishes, the Operation Mode switches back to **3**, which is Position Mode. According to the **Auto Retraction Motion** settings in the example, when switching from Open-Loop Force Control back to Position Mode, the system moves to position **0** at a speed of **20,000 counts/s**.
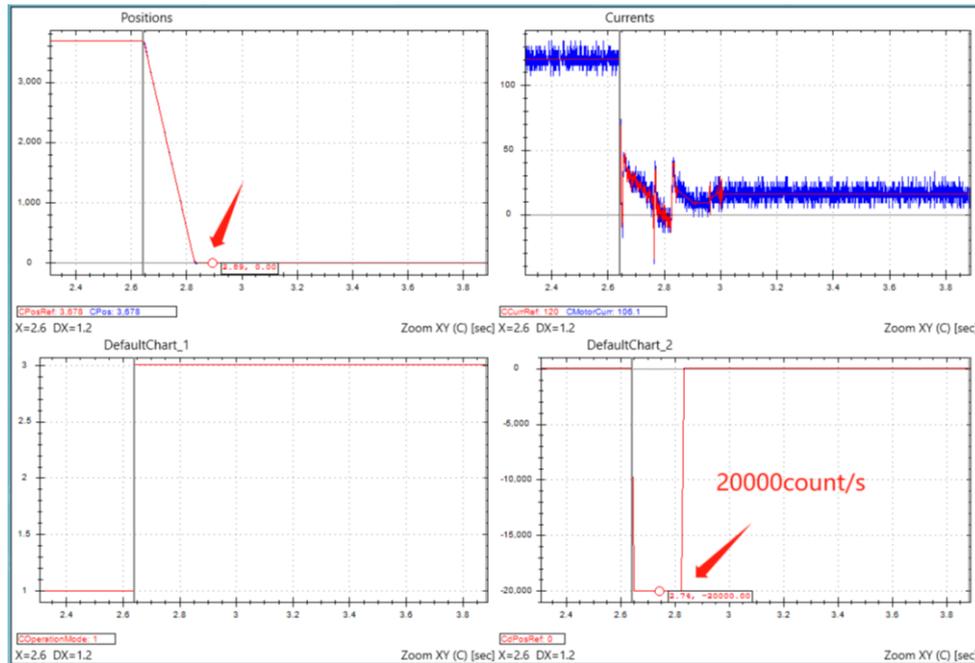
After returning to position **0**, a typical Open-Loop Force Control motion is completed.

By adjusting the force control **PI parameters** and repeating the force control process multiple times, you can verify whether the desired results are achieved.

One important point to note is that after completing a Open-Loop Force Control motion, the conditions for switching to Open-Loop Force Control automatically change to **Bypass**. Both **Auto Retraction Motion** and **Slow Approach** are also set to **disabled** after execution. If the interface still shows them as enabled, it may be due to the interface not refreshing. Clicking **Refresh All** in the lower-left corner will display the current status from the controller.

4.2 Closed-Loop Force Control Operation Example

Before executing closed-loop force control, make sure to **uncheck** the "No force sensor" option in the upper-right corner of the **Force Control** interface.
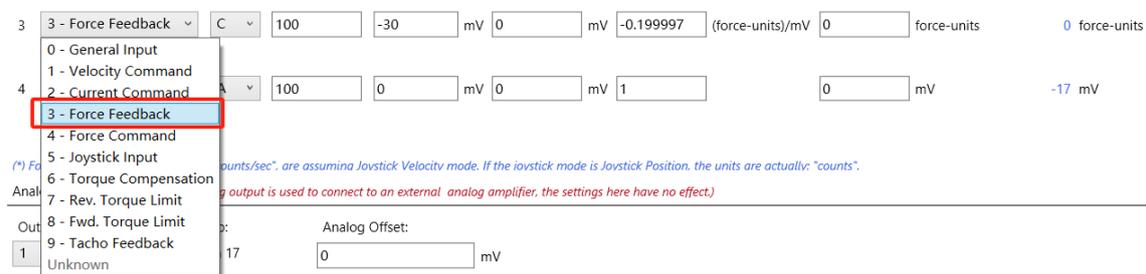

4.2.1   Configure the Input for Force Sensor Feedback

The optional force sensor amplifier must provide an analog signal output.

1)   Connect the analog feedback signal to any analog input port of the Agito controller.

In the Analog I/O interface, set the analog input channel for the force feedback signal to Input Mode = "3 - Force Feedback".

*Note: The axis number of the force feedback signal must match the motor axis number. For example, if the motor is connected to the **C axis**, setting the force feedback signal to the **A axis** will not work properly.*

2)   Check whether the force feedback signal is being correctly read by observing the analog input readings through the force sensor.

When the motor is in a suspended state and the force sensor is not pressing against any object, the measured force should ideally be 0. However, due to mechanical interference and analog signal deviations, the analog input reading may not be exactly zero in this condition. In such cases, you need to set the **AInOffset** value in the analog input interface to apply an offset, ensuring that the displayed analog input value is adjusted to 0 mV.

You can also use weights or similar tools to calibrate the proportional relationship between the analog output of the force sensor amplifier and the actual force. The obtained ratio can then be entered into the **AInGain** parameter, allowing the analog input force feedback value to be displayed in units of force.

In the example, the proportional relationship between the force sensor amplifier's analog output and the actual force is **5 mV/g**. By setting **AInGain = 0.2 (force-units)/mV**, the unit represented by *force-units* becomes grams. As a result, the analog input force feedback value will be displayed in grams.

Note: The polarity of the force feedback analog input must match the motor's motion direction. That is, if the downward pressing direction of the motor is defined as positive, the controller should also receive a positive analog input from the force sensor when it is pressed. Otherwise, you need to invert the sign of AInGain.

4.2.2   Frc. (Curr.) Tune

In this interface, you can configure the PID parameters for closed-loop force control.
It should be noted that the **Gain** and **Derivative** parameters in the force control PID loop are multiplied by a large internal scaling factor in the algorithm. Therefore, it is normal for these parameters to be set to relatively large values—on the order of thousands or even tens of thousands.

This interface also allows you to configure filtering for the closed-loop force command and set the maximum allowable force error. In addition, it provides real-time monitoring of the current force command value, force feedback value, and force error value.

*Note: Do **not** use the "Apply Force Command" button to tune the closed-loop force control parameters. This function involves certain risks and is not suitable for debugging purposes.*

1) Auto Force Tuning

   ➢ Set **Force Command Source** to "1 – Scheduled Current Command Values".

   ➢ Hold Time = **-1** (Unlimited time)

➤ Switch to **Force** Operation Mode, then "Motor On".

Note: Before "Motor On", please make sure the motor can motion normally after auto-phasing, current tuning and PIV tuning.

➤ Navigate to Identification interface, tick "Additive injection", choose "Force Plant" and "Begin Identification"

> ➢ After obtaining the stable result graph, click "Go to Auto-Tune".

> ➢ Then it will automatically switch to the **Design** interface. Click "Run Auto Tune" and "Write to Controller".

> ➢ Switch back to the **Force Control** interface, and you will see the parameters obtained from Auto Tune displayed here.

> ➢ Apply the Force Command to verify the feasibility of the parameters.

2) Manual Tuning

navigate to Step Command for Force (Current) Tuning window to Apply Force Command and tune.

Plese refer to *Step Command for Force (Current) Tuning*.

⚠ **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.

4.2.3   Mode Switching

In this interface, you can set the transition conditions for switching from position mode to closed-loop force control mode.

1) Position Mode -> Fore Mode

When the Dir value on the right is set to "1 – On PosRef > Threshold" or "-1 – On PosRef < Threshold", this position condition becomes a mandatory requirement for automatically switching to force control mode. The system will switch to closed-loop force control mode when the position condition is met and at least one of the two conditions below (position error or force feedback value) is also met.

In this example, the contact position between the motor and the pressed object is 3600 counts. The position condition is set to 3500 counts, and Dir is set to "1 – On PosRef > Threshold", meaning that the system will start evaluating whether to switch to closed-loop force control mode when the position exceeds 3500 counts.

The force feedback value is used as another switching condition. When the feedback value from the force sensor also exceeds 5 force-units (i.e., 5 grams of force), the system switches to closed-loop force control mode.

Note: Both position error and force feedback value conditions can be configured simultaneously — the controller will enter closed-loop force control mode as soon as either of these two conditions is met.

2) Force Mode -> Position Mode

The Auto Switch on Position Threshold function is used for protection. In the example, it is set so that when the position exceeds 4000 counts, the system switches from closed-loop force control mode back to position mode.

Auto switch on position threshold:	2 - On Position > Threshold	
Position threshold to switch:	4,000	user-units

When you tick the "Auto Retraction Motion" function. After switching from closed-loop force control mode back to position mode, the motor will move to absolute position 0 at a speed of 20,000 counts/s.

✓ Auto retraction motion	Retract to: 0	Speed: 20,000

4.2.4   Command Src.

Here, select the source of the closed-loop force control command.

0 – Analog input (User defined)

1) When "0 – Analog input (User defined)" is selected, the command comes from the analog input configured in "4 - force command" mode.

2	4 - Force Command	A

- 0 - General Input
- 1 - Velocity Command
- 2 - Current Command
- 3 - Force Feedback
- 4 - Force Command
- 5 - Joystick Input
- 6 - Torque Compensation
- 7 - Rev. Torque Limit

2) Set the duration for operating in closed-loop force control mode.

If the duration is set to **-1**, the mode will run indefinitely. Otherwise, when the specified time elapses, the system will automatically switch back to position mode.

1 - Scheduled Force Command values

When "1 – Scheduled Force Command values" mode is selected, the commands are executed sequentially from top to bottom according to the table. Each segment is defined by three parameters: **slope**, **duration**, and **target value**. Up to 20 force command segments can be added, and execution continues downward until a segment with **HoldTime = 0** is encountered. (If **HoldTime** is set to **-1**, the segment will execute indefinitely.)

As the figure shown, three closed-loop force command segments are set sequentially: 150 g force held for 500 ms, 170 g force held for 500 ms, and 120 g force held for 500 ms.

After the commands are completed, the system will automatically switch back to position mode.

4.2.5 Slow Approach Before Contact

When switching from position mode to force control mode, to reduce overshoot, motion is typically divided into two segments: a long-distance high-speed movement and a short-distance slow approach toward the object.

The Slow Approach interface is used to set the conditions for the slow approach and the speed value after switching to slow movement.

Since 3600 counts is the contact position, slow approach is set to start at 3400 counts, with the post-switch speed set to 500 count/s. Clicking the **Arm** button enables the Slow Approach function. During the next position movement, speeds below 3400 counts use the value set in the PTP interface, and once 3400 count is exceeded, the speed switches to the configured 500 count/s.

Note: The Slow Approach function only takes effect once after being enabled; to use it again, it must be re-enabled.

4.2.6 Point to Point

After completing these steps above, switch to the **Point to Point** interface for a full closed-loop force control test.

Due to contact position with the object is **3600 counts**, so target position in the **Point to Point** interface is set to **3800 counts**, which is beyond the contact point.

Clicking **Go 2** moves the motor toward 3800 counts. Setting a target beyond the contact position ensures that the motor will definitely make contact with the object and that the conditions for switching to closed-loop force control will be met.

4.2.7   Execution and Validation

Finally, the last step would be to execute and observe the motion.

1)   Setup the chart parameters, trigger conditions and start the recording.

➢   Set the chart parameters as below.

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.
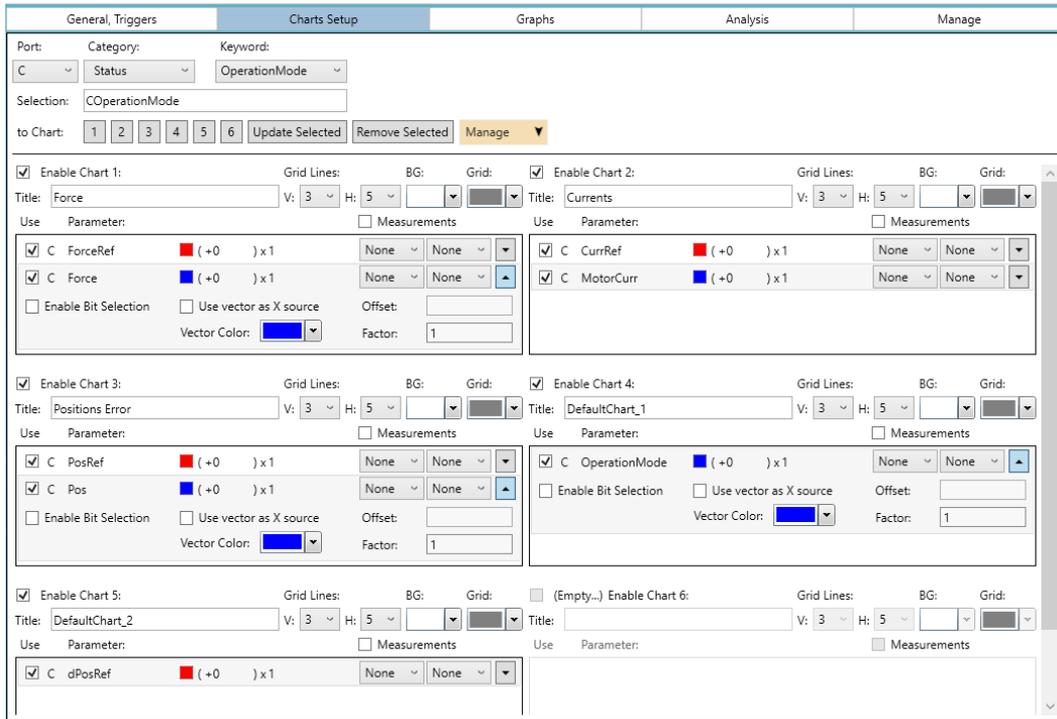
➢   Set the capture trigger condition to **Start Motion**.

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 five captured graphs are **Force**, **Current**, **Position**, **Operation Mode**, and **Speed** as below.
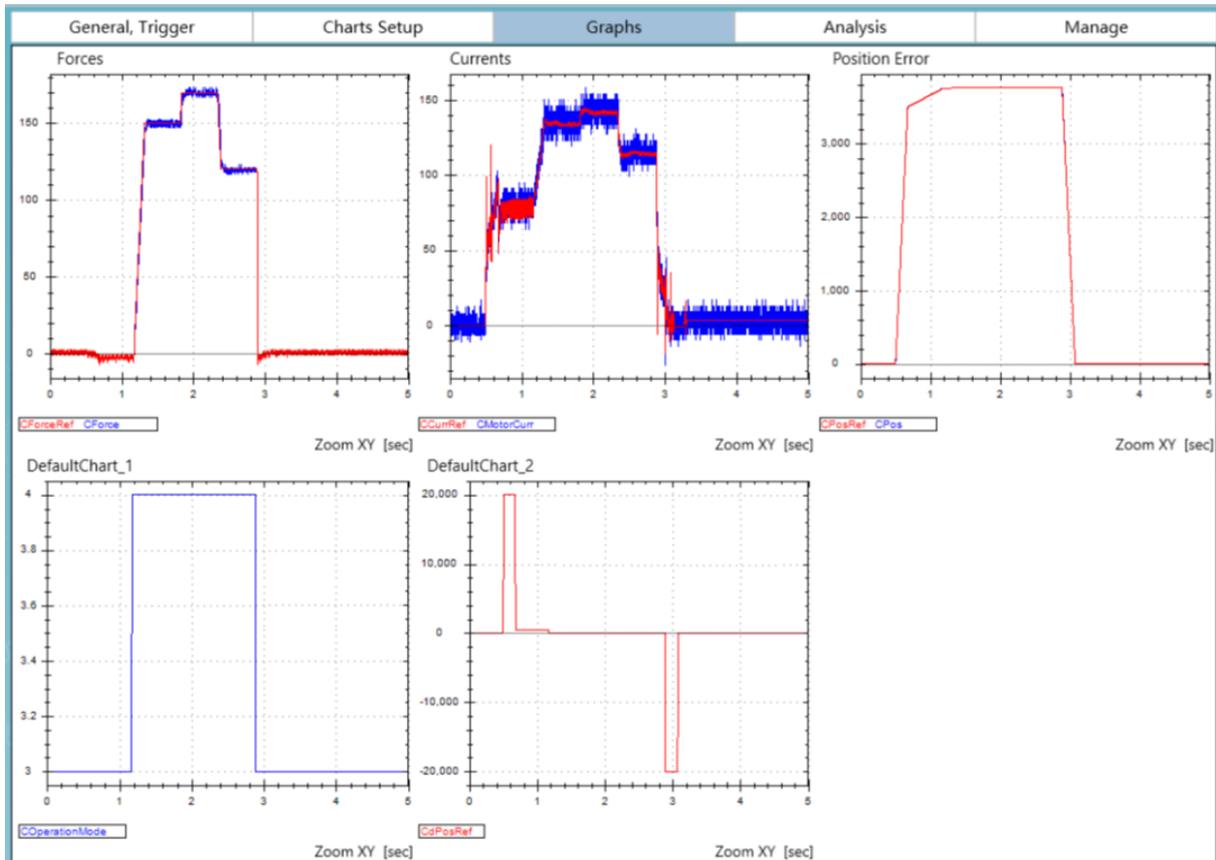
Keyword	Description
AInPort	AInPort is a read only array that contains the processed and original reading of the analog input port. The first half of the array holds the readings after they were filtered and after offset, dead band and gain were applied. The second half of the array holds the original values of the input.
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.
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.
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.

Keyword	Description
OperationMode	OperationMode determines what control loops will be activated. The values for OperationMode are: 1 – Current Mode 2 – Velocity Mode 3 – Position Mode 4 – Force Mode
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.

2) The next step will be to execute the motion.

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), 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 1), or when the object is pliant (Scenario 3).
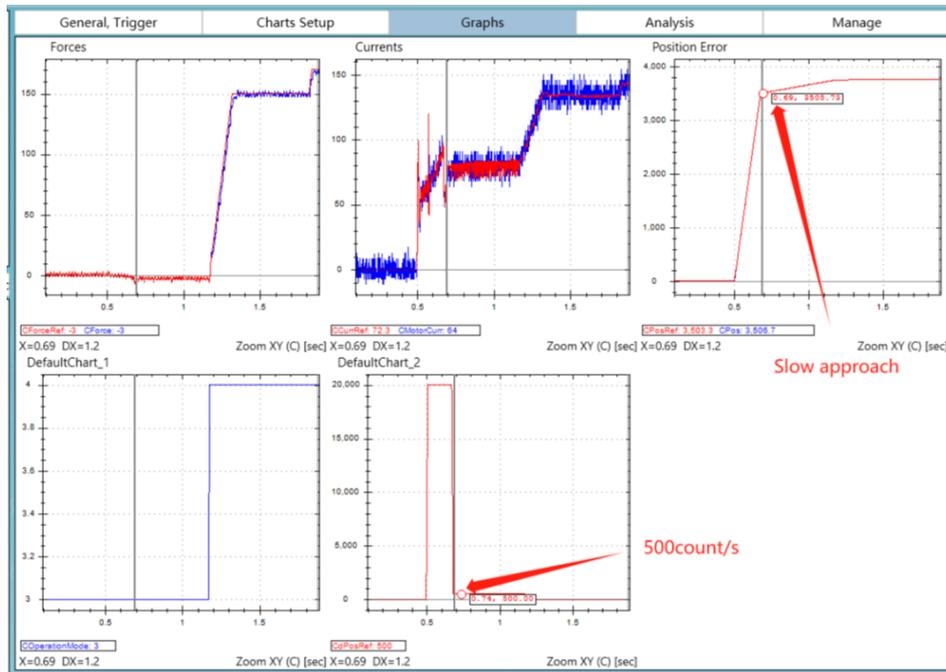
Let's explain the several key points in the entire motion process.

➢ The first part is **Position Mode motion** until contact with the compressed object.

During this process, the **Operation Mode** remains at **3**, which is **Position Mode**.
You can also see, as previously set in **Slow Approach**, that positions below 3500 counts use high-speed movement, while positions above 3500 counts switch to slow speed at 500 counts/s.

➢ The second part is switching to **Closed-Loop Force Control** based on the set transition condition.

In the graph, at the end of the slow-speed motion, the force feedback value increases upon contact with the compressed object, reaching the set transition threshold of **5 g**. The Operation Mode changes from **3** to **4**, meaning it switches to **Closed-Loop Force Control**.
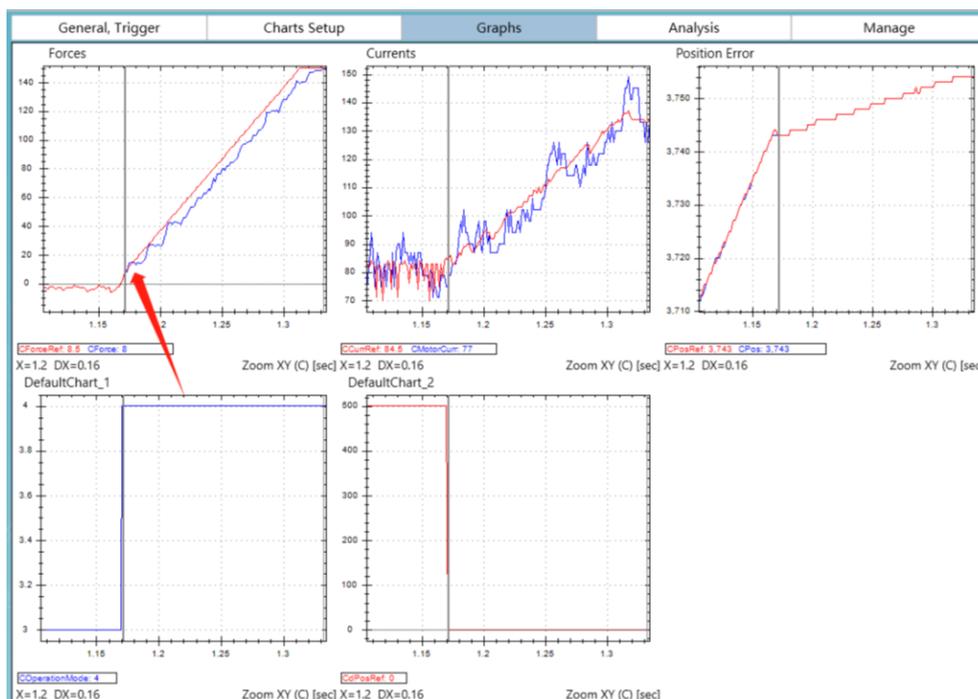
*It is important to note that during the entire approach in Position Mode, because the **Global Position Threshold** function is enabled, even if the force feedback exceeds 5 g during high-speed motion below 3500 counts, the system will **not** switch to Closed-Loop Force Control. This condition prevents unintended switching during high-speed position movements.*

Global Position threshold: 3,500 user-units Dir.: -1 - On PosRef < Thi ∨

➢ The third part is the execution of **Closed-Loop Force Control** commands.

In this example, the **1-Scheduled Force Command Values** mode is used, with three consecutive commands of **150 g**, **170 g**, and **120 g**. From the graph, you can see that after switching to Closed-Loop Force Control, the three commands are executed in sequence.
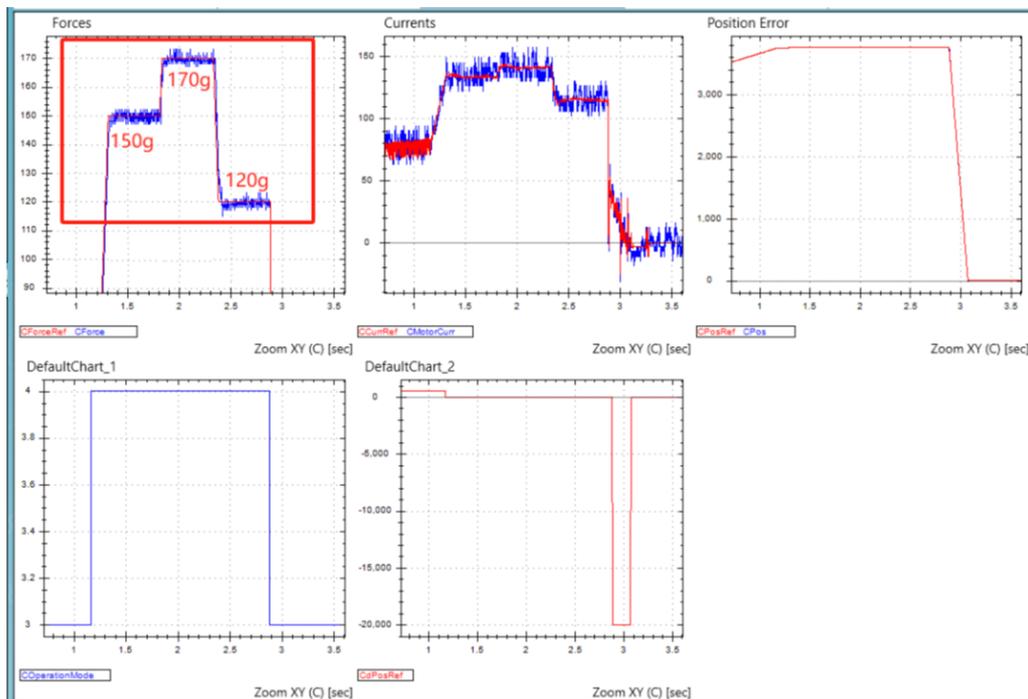
➢ The fourth part is after completing the Closed-Loop Force Control commands.

☑ Auto retraction motion   Retract to: 0   Speed: 20,000

In the example, after the 120 g force command finishes, the Operation Mode switches back to **3**, which is Position Mode. According to the **Auto Retraction Motion** settings in the example, when switching from Closed-Loop Force Control back to Position Mode, the system moves to position **0** at a speed of **20,000 counts/s**.
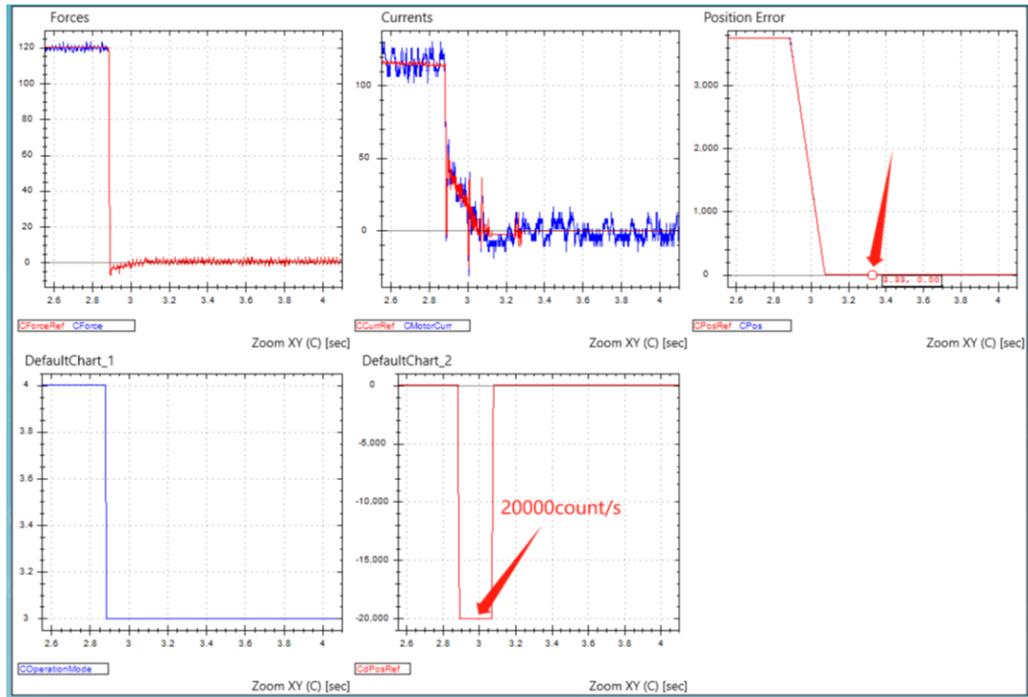
After returning to position **0**, a typical Closed-Loop Force Control motion is completed.

By adjusting the force control **PID parameters** and repeating the force control process multiple times, you can verify whether the desired results are achieved.

One important point to note is that after completing a Closed-Loop Force Control motion, the conditions for switching to Closed-Loop Force Control automatically change to **Bypass**. Both **Auto Retraction Motion** and **Slow Approach** are also set to **disabled** after execution. If the interface still shows them as enabled, it may be due to the interface not refreshing. Clicking **Refresh All** in the lower-left corner will display the current status from the controller.

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 force control to understand the feature before mounting the force sensor.*

5   PCSuite IDE+

5.1 Open-Loop Force Control IDE+ Example

main([10,30],[5,20],[800,1000],[50,100],[50,100],[50,100])

// Switch to Position Mode

     CGoToPosMode

     while (COperationMode == 1)

          CGoToPosMode

          CWaitTime, 500

     end

     CMotionMode = 1

     CRelTrgt = 0

     CAbsTrgt = 3800

     CSpeed = 20000

     CAccel = 2000000

     CDecel = 2000000

     CJerk = 0

     CMotorOn = 1

// Slow Approach Setting

     CSpeedChgNew = 500

     CSpeedChgPos = 3400

     CSpeedChgDir = 0

     CSpeedChgOn = 1

     CBegin

// Mode Switching: Position Mode -> Current Mode

     CCurrPosTh = 3500

     CCurrPosThDir = 1

     CCurrCurrTh = 120

     CCurrCurrThDir = 0

// Command Source Type: Scheduled Current Command Values

     CCurrCmdSrc = 1

// Current Tune Parameters Setting

     CCurrGain = 770

CCurrKi = 358

// Scheduled Current Command Setting

CCurrCmdVal[1] = 150

CCurrCmdHTime[1] = 500

CCurrCmdSlope[1] = 1000

CCurrCmdVal[2] = 170

CCurrCmdHTime[2] = 500

CCurrCmdSlope[2] = 1000

CCurrCmdVal[3] = 120

CCurrCmdHTime[3] = 500

CCurrCmdSlope[3] = 1000

CCurrCmdHTime[4] = 0

// Auto Retraction Motion

CBeginOnToPos = 1

CRetractTarget = 0

CRetractSpeed = 20000

endofmain

5.2 Closed-Loop Force Control IDE+ Example

```
main([10,30],[5,20],[800,1000],[50,100],[50,100],[50,100])
// Switch to Position Mode
        CGoToPosMode
        while (COperationMode == 4)
                CGoToPosMode
                CWaitTime, 500
        end


        CMotionMode = 1
        CRelTrgt = 0
        CAbsTrgt = 3800
        CSpeed = 20000
        CAccel = 2000000
        CDecel = 2000000
        CJerk = 0


        CMotorOn = 1


// Slow Approach Setting
        CSpeedChgNew = 500
        CSpeedChgPos = 3400
        CSpeedChgDir = 0
        CSpeedChgOn = 1
        CBegin


// Mode Switching: Position Mode -> Force Mode
        CCurrPosTh = 3500
        CCurrPosThDir = 1
        CForceAInTh = 5


// Command Source Type: Scheduled Force Command Values
        CForceCmdSrc = 1


// Force Tune Parameters Setting
        CForceGain = 50000
        CForceKi = 5
        CForceKd = 0
        CForceFFW = 0
```

```
        CForceVelFFW = 0


// Scheduled Force Command Setting
        CForceCmdVal[1] = 150
        CForceCmdHTime[1] = 500
        CForceCmdSlope[1] = 1000


        CForceCmdVal[2] = 170
        CForceCmdHTime[2] = 500
        CForceCmdSlope[2] = 1000


        CForceCmdVal[3] = 120
        CForceCmdHTime[3] = 500
        CForceCmdSlope[3] = 1000


        CForceCmdHTime[4] = 0


// Auto Retraction Motion
        CBeginOnToPos = 1
        CRetractTarget = 0
        CRetractSpeed = 20000


endofmain
```