



Application Note: Loop Tuning

Commissioning of the closed loop position controller

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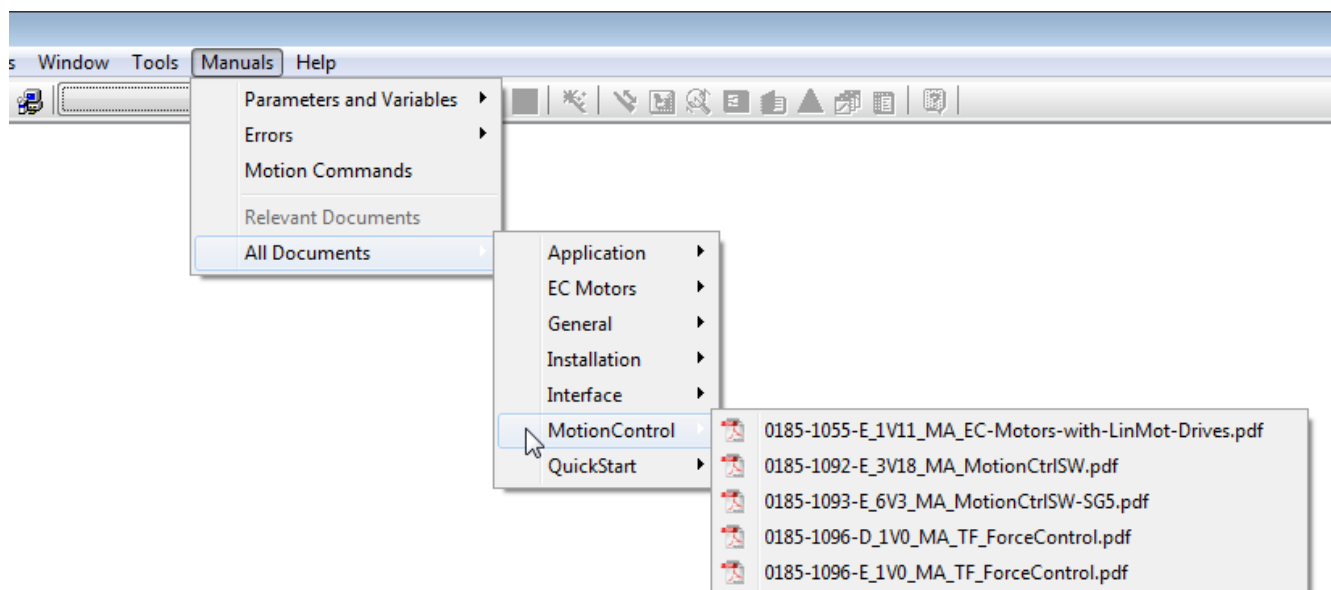
Use of This Document

- Description:** This document is thought as guideline for position control loop tuning
- Drive(s):** A1100, B1100-XX-XX, C11X0-XX, C12X0-XX(-XX), E11X0-XX, E12X0-XX(-XX), E14X0-XX(-XX)
- Classification:**
- Application Note
 - Installation Guide
 - User Manual
 - Documentation
 - LinMot internally

Recommended Documentation

The manuals are included in LinMot-Talk software (*Menu Manuals* → *All Documents* or *Relevant Documents* if logged in to a drive) or can be downloaded from the LinMot e-Catalogue (search by document reference): <http://shop.linmot.com>

User Manual	Document Reference
LinMot-Talk	0185-1059
Motion Control Software	0185-1092 / 0185-1093



1 Commissioning of Closed Loop Position Controller

When commissioning a position controller with closed loop force control, there are some considerations that may be useful especially when accurate positioning is needed. A general rule of thumb for a position controller is that it is possible to achieve 10 times the resolution of the sensor. If the position sensor has a resolution of 50um, the position controller can achieve a control precision of 500um. Figure 1 shows an overview of the control structure for the position control system. In general, the letters “FF” like FF Friction, are abbreviations for “Feed Forward”. This is a general naming for pre-filter parameters. These pre-filters are used in the control technology to compensate fixed and well known disturbances. These disturbances don't need to be treated with the PID controller. The advantage of this pre-filter is a fast response to the disturbance. Pre-filters act directly since this disturbance is separated from the PID loop. This separation allows for easy tuning of the complete system.

LinMot servo controller use the following pre-filter parameters:

- FF Friction: Pre-filter to compensate a fixed known friction of the mechanical system
- FF Damping: Pre-filter for compensation of damping systems, like viscous friction
- FF Acceleration: Force compensation of the load during acceleration phases
- FF Spring Compensation: Pre-filter if springs are used
- FF Constant Force: Pre-filter for fixed load mass, especially used in a vertical orientation

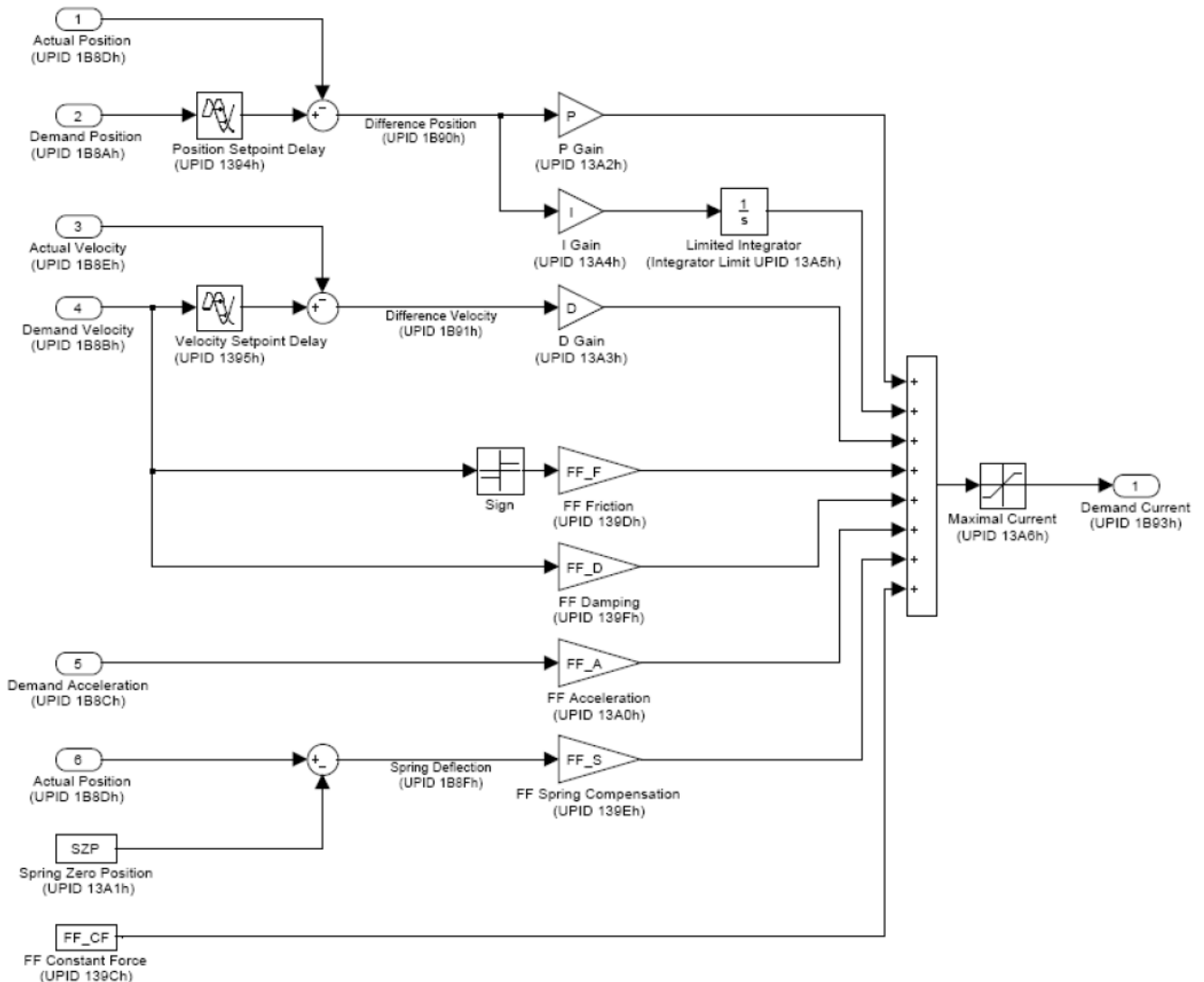


Figure 1: Control Structure of the Position Control System

1.1 Pre-filter Parameters

Figure 1 shows what kind of input values are multiplied together. These pre-filter values will be summed up directly to the controller output current.

The input values of this structure are generated by the set point generator. This will not be explained in detail in this manual.

Let's take a look at the "FF Friction" pre-filter parameter.

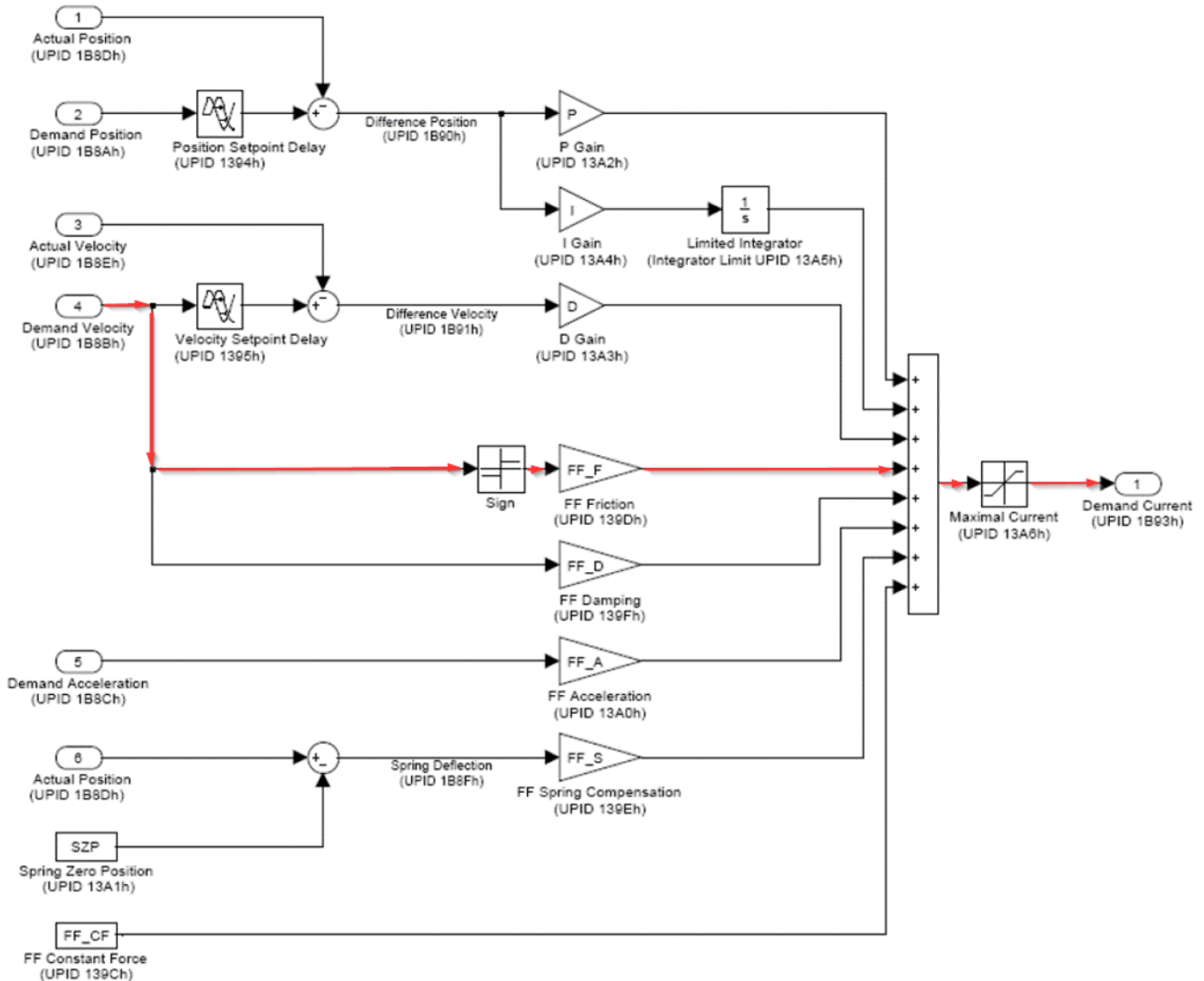


Figure 2 Operational path for FF Friction

In figure 2 you can see the operational path of this parameter. The demand velocity is used with sign to do the calculation. Every change of the sign of demand velocity will generate a direct acting output value.

The pre-filter for viscous friction is calculated with the demand velocity as well. The demand acceleration will be calculated directly with the pre-filter value "FF Acceleration".

The pre-filter value "FF Constant Force" is very important. This parameter is always acting to compensate a constant force. This force can be caused by the load mass in a vertical orientation.

All of these pre-filter values are calculated with the motor wizard of LinMot Talk. The calculations are based on user entries. Therefore, it is very important to enter all confirmed values of the load conditions. If some of these values are not known, please enter zero.

The pre-filters for spring compensation are a bit different. First the difference in spring center and actual position will be calculated, then multiplied by the spring constant for the net force. if you want to handle a spring, all spring dependent values are required!

1.2 Closed Loop Control Parameters

PID stands for proportional (P), integral (I), and differential (D) controller. In this controller all three control structures are combined and can be used as required.

P control is working pure multiplication. First, the difference position is calculated (demand position minus actual position). Then this difference position is multiplied with the *P gain*. A change of the demand position or in actual position will cause a direct change of the calculated controller output. This control method is works fast and direct. However, this type of control always needs a position difference between demand and actual position to deliver an output current. A control system with P control alone cannot reach the demand position.

The I control uses the same difference position as the P controller but, it is “integrating” difference position. Every calculation step the controller makes is added the last difference position value. The adding behavior will be influenced by the *I gain* factor. This “adding” behavior will stop if the difference position is zero. The I control behavior acts slow. Normally the I control will not be used alone and will mostly be used in combination with a P controller. The I gain reduces the position difference to zero. I control structure has an integration limit. This value will limit the effect of summing up the difference position. Without this integration limit you can get a “wind up” effect, which means, if the actual position is blocked and cannot be reached, the value of the I controller increase to a huge value.

The D controller (differential controller) is working with the difference of demand velocity and actual velocity. The D controller acts fast like the P controller. It only delivers an output if a change of the input signals is active. The velocity change during a movement can cause from several external disturbances which produce the signal for the D control.

2 Commissioning of the Position Controller

2.1 Using the Motor Wizard

Steps 4 and 5 are essential for setting the position control loop.

In the upper part of Figures 3 and 5, you can enter known values like load mass, friction, and mounting direction. In the table below you can see the calculated pre-filter values which are calculated by the entered data.

In Figure 3 no entries are made and the operation direction is horizontal. The wizard delivers only a value for the FF acceleration (based on slider mass).

In Figure 4 the mounting direction is entered as +90°. The load weight delivers a gravitational force of the slider. The motor wizard calculates a FF Constant Force value to generate a fixed output current to hold the slider on its position.

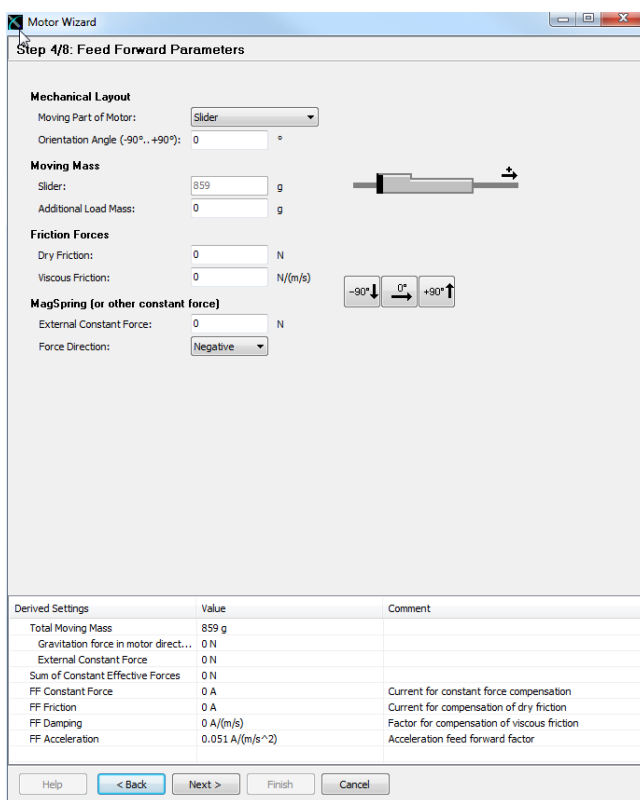


Figure 3: Motor Wizard: Pre-filter Values (horizontal)

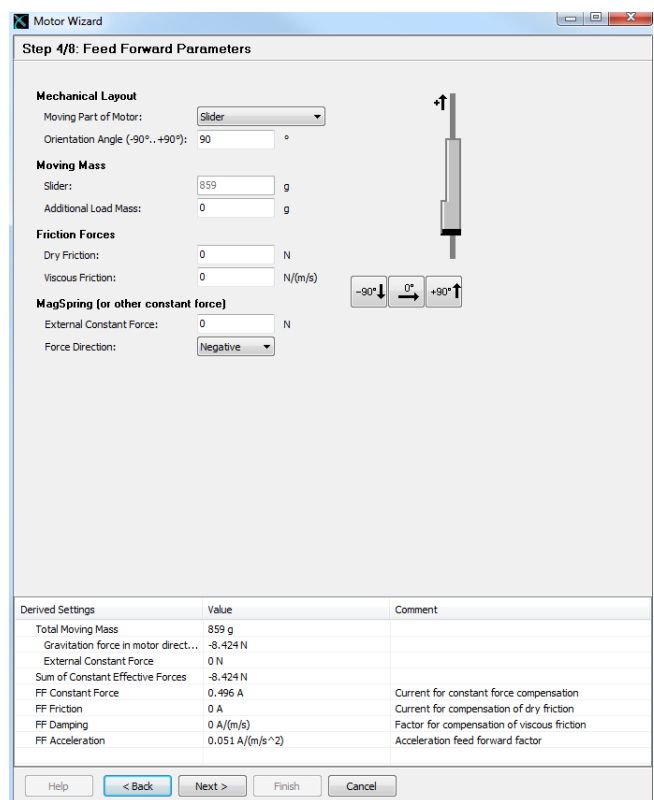


Figure 4: Motor Wizard: Pre-filter Values (vertical)

In step 5 the parameters for the PID controller are set. Here you can directly enter the desired values, or you can choose default parameters for soft or stiff control behavior. These values allow the motor to move. It might be necessary secondary loop tuning depending on the required precision.

The optional Dead Band filter is active by default with a dead band value of 0.02mm. This filter will limit the influence of a position change in the actual position. If the actual position is fluctuating in the range of dead band, the I and D control will not activate preventing strong system reactions (noise reduction).

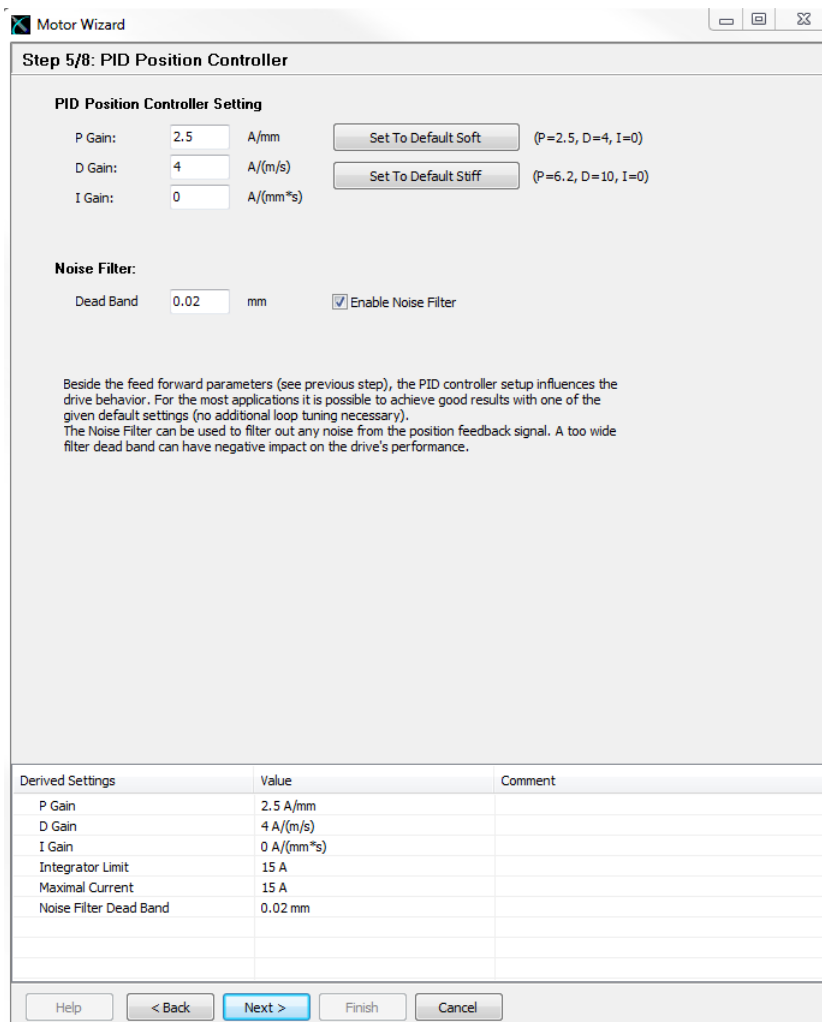


Figure 5: PID Parameters in the Motor Wizard

The final loop tuning for the required precision will be done in the next step by using the parameter tree.



Hint: For normal operation uncheck “Enable Noise Filter”
 If the checkbox “Enable Noise Filter” is checked, the drive will freeze motor current if position deviation reaches the defined “Dead Band” window. This will reduce noise but it may heat up the motor. Motor current is constant as long as motor position deviation is within this “Dead Band”.

2.2 Closed Loop Tuning

An empiric method will be shown for tuning the position control loop in the following chapters. This method delivers good operational results for most cases. The servo axis needs to be completely mounted and the system need to be able to operate in the planned operation range (position, velocity).

2.2.1 Preliminary Steps for Loop Tuning

To see changes in the loop behavior as the control parameters change, the loop needs to be in an operational state with a motion running. This can be achieved very easy and will be shown in the following steps.

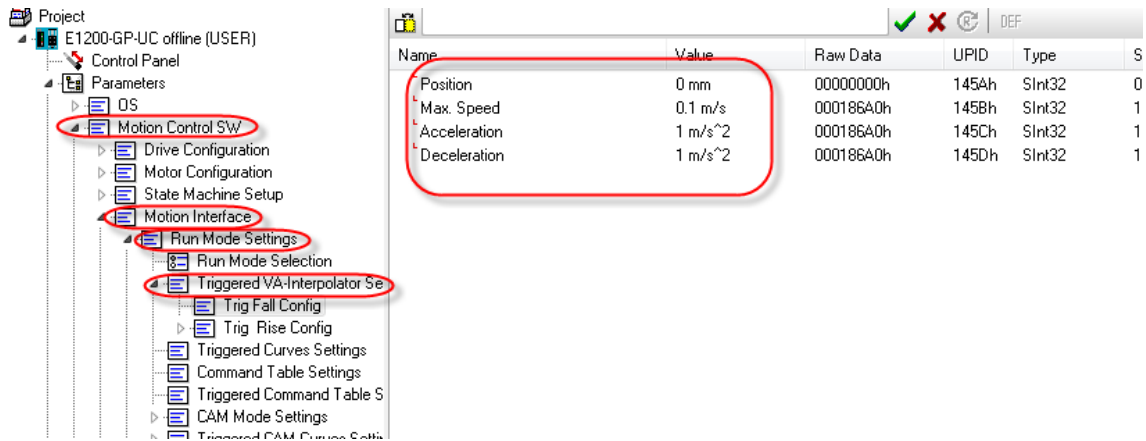


Figure 6: Definition of Target Positions for Test Operation

In the parameter tree open the “Triggered VA Interpolator” and set the values for “Trig Fall Config” and “Trig Rise Config”. These values define two positions of the axis. For example, “Fall Config” for position 0mm, the “Rise Config” for position 100mm (these values depend on your motor’s available stroke!).

Furthermore, you should define the values for maximum velocity, acceleration and deceleration for both positions which will be used in normal operation of the axis.

Then, set the run mode to “VAI 2Pos Continuous”.

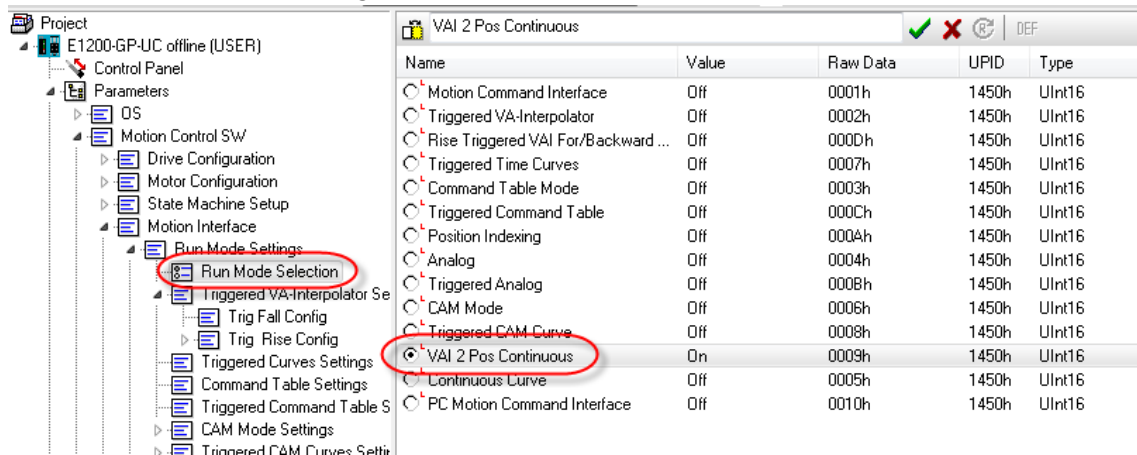


Figure 7: Select the Run Mode “VAI 2 Pos Continuous”

After selecting this mode, the axis will travel continuously between the two defined positions. Motion will start as soon as the axis is switched on and homed (use the control panel to switch on and home).

The built in oscilloscope can be used to evaluate the controller performance. Oscilloscope features and functionality are further described in Appendix I.

Recommended procedure for loop tuning:
Use the above described operation mode where the axis will travel between two points continuously.
Open a second LinMot Talk window with the actual controller.

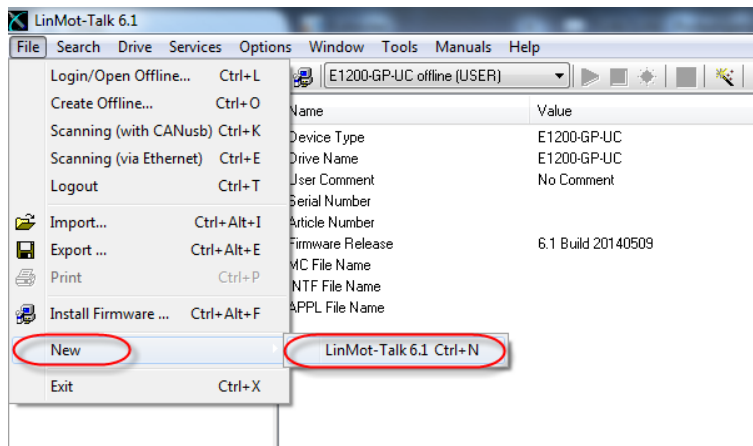


Figure 8: Open a Second LinMot-Talk Window

Now you can see the same drive in two windows.

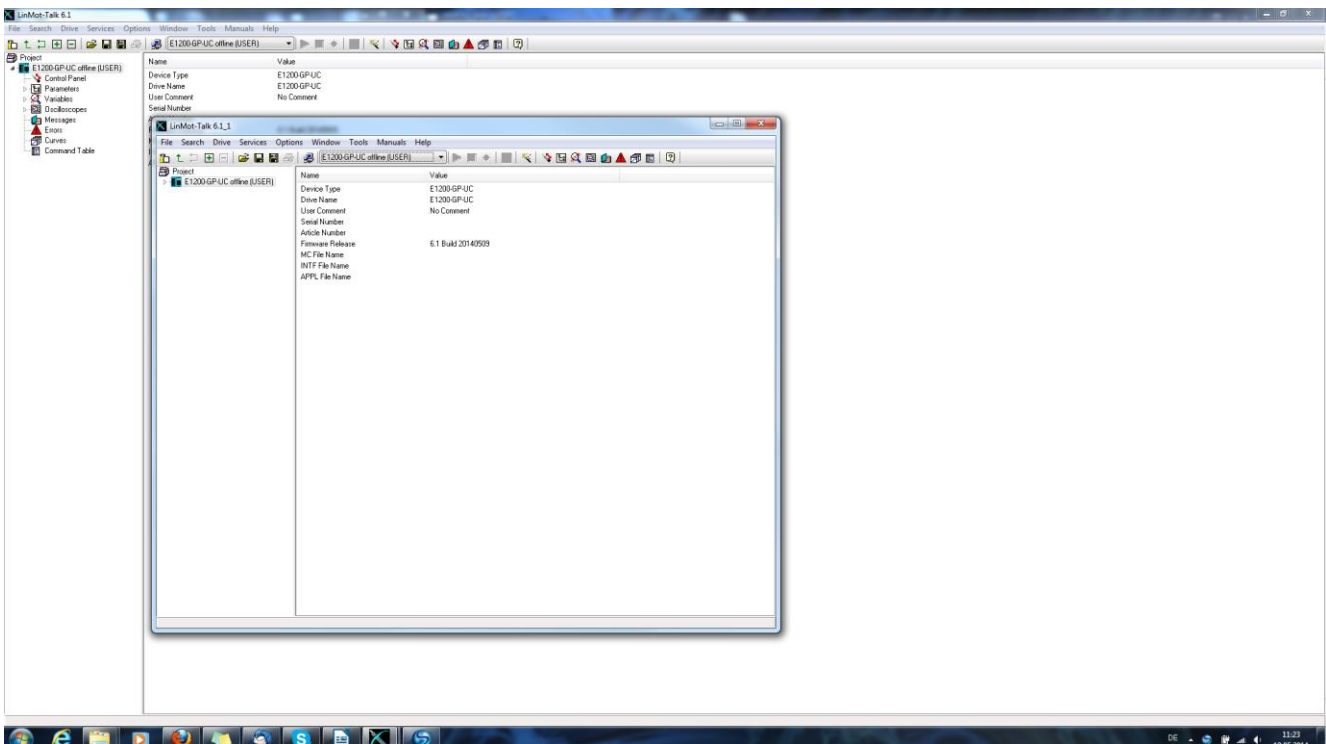


Figure 9: Servo Drive in Two Windows

In one of the windows change the view to the following:

Name	Value	Raw Data	UPID
FF Constant Force	0 A	00000000h	139Ch
FF Friction	0 A	00000000h	139Dh
FF Spring Compensation	0 A/m	0000h	139Eh
FF Damping	0 A/(m/s)	0000h	139Fh
FF Acceleration	0.072 A/(m/s ²)	0048h	13A0h
Spring Zero Position	0 mm	00000000h	13A1h
P Gain	3 A/mm	001Eh	13A2h
D Gain	7 A/(m/s)	0046h	13A3h
D Filter Time	0 us	0000h	13A8h
I Gain	0 A/(mm*s)	0000h	13A4h
Integrator Limit	7.5 A	00001D4Ch	13A5h
Maximal Current	7.5 A	00001D4Ch	13A6h
Noise Deadband Width	0 mm	0000h	13A7h

Figure 10: Position Control Parameters in the Parameter Tree

In the other window, open the oscilloscope (see Appendix I for using the oscilloscope).

Figure 11: Preparing the Oscilloscope Recording

The advantage of having two LinMot-Talk windows is that the control parameters can be modified in one window while the motion can be traced and observed in the second window.

2.2.2 Closed Loop Tuning Using the Empiric Method

First enter the following values into the control parameter set:

- P gain the value 0.25
- D gain the value 2.00
- I gain the value 0.0

These values are entered in the control parameters (the first window). Start the continuous motion!

Increase the value for D gain incrementing by a value of 1. Continue until the motor starts oscillating (strong noise appears). Then take this value and reduce it to 60%. For example, D gain is 10 while oscillation ($10 \cdot 60\% = 6$), so enter 6.

In the next step you do the same step by step operation with the P gain. This time increment by 0.25 until the motor oscillates (noise). Then take this value and reduce it by 80%. For example, P gain is 20 ($20 \cdot 80\% = 16$), so enter 16.

Perform an oscilloscope reading. If the difference position is in the required precision range, then loop tuning is finished.

It is important to monitor the position difference when one of the defined demand positions are reached (short standstill of the motion!). If a higher precision is needed, you need to set up the I gain. Increase here the I gain step by step by a value of 5. Do this until the difference position is in the required range and no overshoot is detected during acceleration or deceleration. Here you need to find a reasonable compromise which is in the required accuracy range. During the I gain tuning perform snap shots with the oscilloscope to check the change in the control behaviour!

2.2.3 Inspection of the Actual Control Quality by Using the Oscilloscope

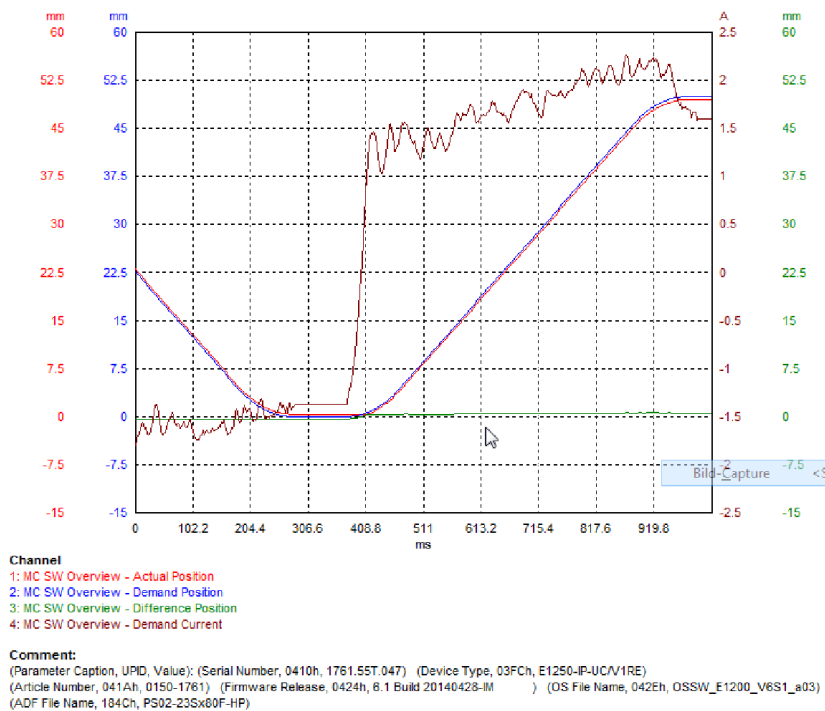


Figure 12: Control Loop with Default Values of the Motor Wizard

In this recording a permanent position lag is present.

Oscilloscope trace after setting the P gain and D gain, I gain = 0:

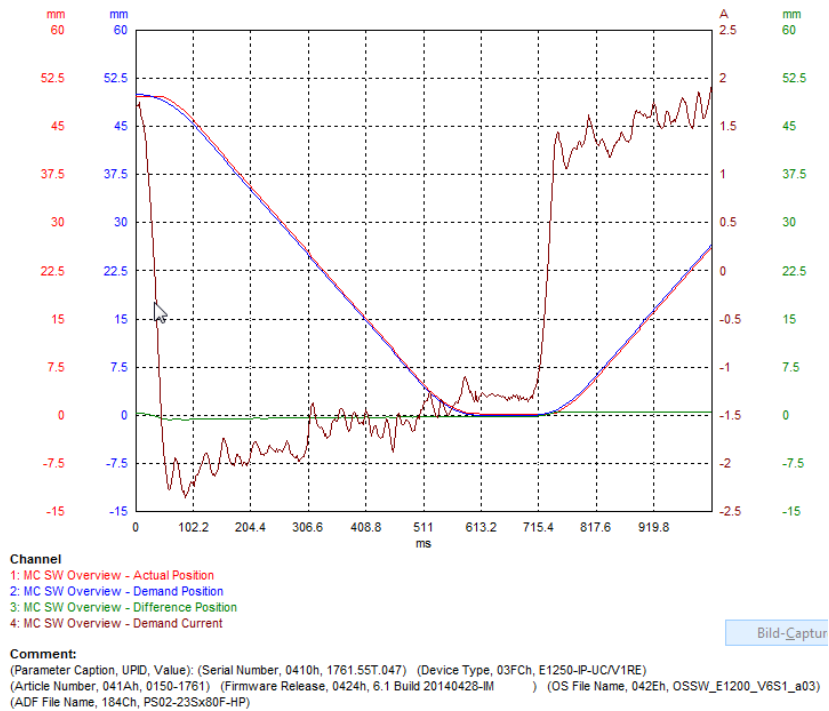


Figure 13: Control Loop After Tuning (P and D gain, I gain = 0)

After the first steps of tuning with D gain and P gain, you get this typical picture of an oscilloscope trace. There is still a small difference position left.

Oscilloscope reading after tuning P gain, D gain, and I gain:

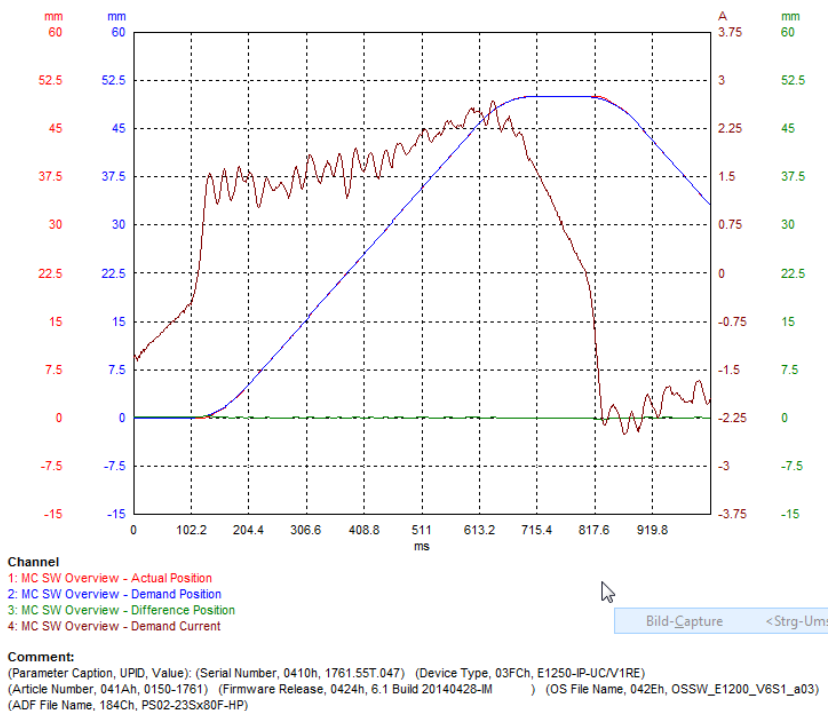


Figure 14: Control Loop After Tuning (P, D, and I gain)

Now, the position difference is nearly zero and fluctuates only in a small range. The fluctuations are caused mainly from the position measuring system/mechanical influences.

Check the demand current in the oscilloscope reading. This demand current should not reach the current limits of the motor or stay at the motor's max current limit for much time. If this happens, the position controller is set to maximum gain and the system cannot provide more energy to hold the position control stable.

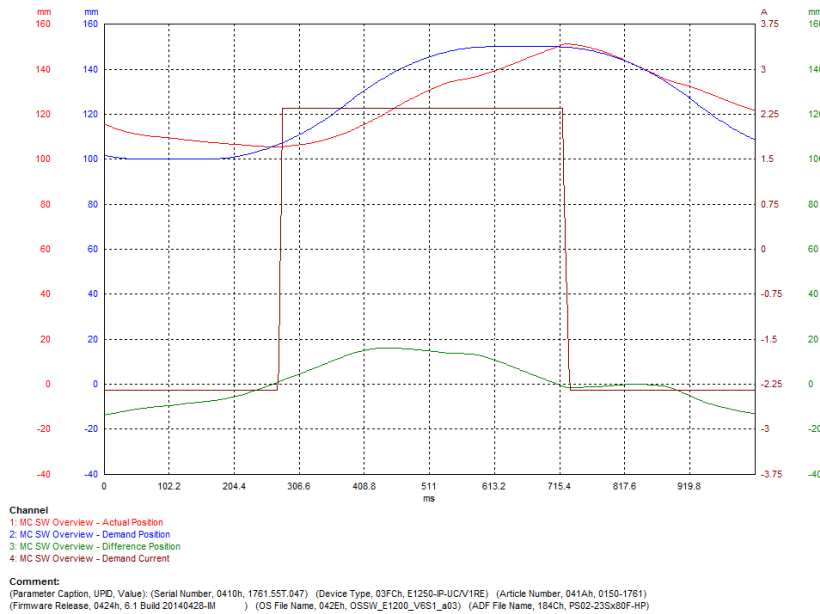


Figure 15: Position Control with Current Limit

In this trace, the current limit of the motor was set to a low value. You can see the current hits the set limit (straight line in parallel to X axis, 2.25A). The position control loop is not working as it should. The motor system gets a position lag error. Mechanical overloads can create a similar situation where the motor is operating at its current limit.

In figure 16 you can see a trace with critical areas in the demand current circled in red. Such pictures often appear in real applications. This can occur if the moving masses, velocities, or accelerations are greater than defined in the motor sizing

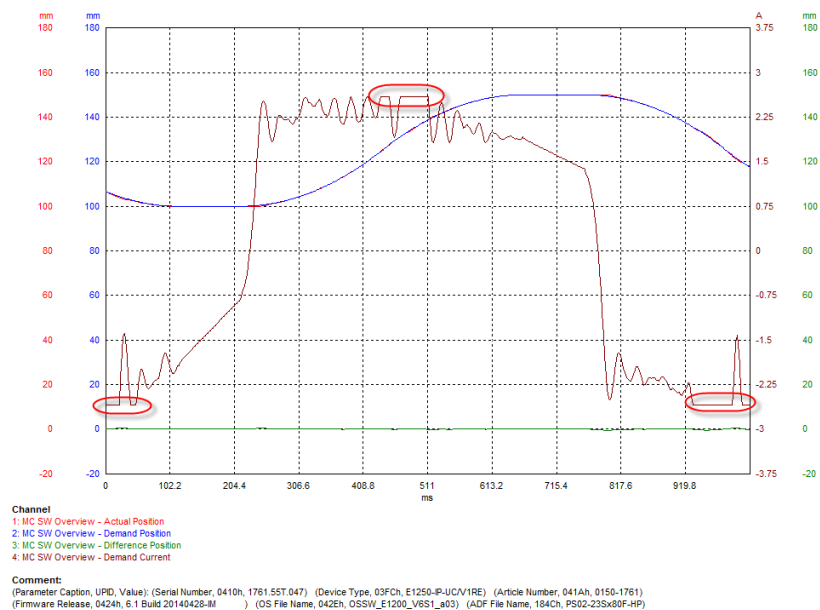


Figure 16: Position Controller with Load/Dynamic Limits

This situation is still able to run but, the position controller has limited dynamics. Depending on the operational conditions (Load, Set points) and the system aging it can cause in occasional positioning problems.



Note: The current can be limited by user!

In some applications like pressing, the current can be limited by the PLC. Especially, if the system is running and you want to make changes to the system. Check the current limit before doing a loop tuning. The maximum allowed motor current should be set in the current limit (Maximal Current) of the used position control parameter set (Set a or B) .

The maximum allowed motor current is defined by motor data sheet and can be found here:

Name	Value	Raw Data	UPID	Type
Maximal Current	7.5 A	00001D4Ch	119Eh	SInt32
Maximal Motor Supply Voltage	92 V	000023F0h	11A7h	UInt32
Phase Resistance	4.4 Ohm	01B8h	119Fh	UInt16
Phase Resistance Definition Temp	20 °C	00C8h	120Bh	SInt16
Phase Inductance	0.6 mH	0006h	11A0h	UInt16
Force Constant	9.68 N/A	03C8h	11A1h	UInt16
Zero Position (ZP)	375 mm	00393870h	11A2h	SInt32
Shortened Stroke (SS)	720 mm	006DDD00h	11A3h	SInt32
Maximal Stroke	780 mm	007704C0h	11A4h	SInt32
Edge Force Constant	6.05 N/A	025Dh	11A5h	UInt16
Extension Cable Resistance	0 Ohm	0000h	11A6h	UInt16

Figure 17: Location of the Maximum Allowed Motor Current

2.3 Special Operation Modes of the Servo Drive and Their Influences on the Position Controller

If the servo drive is used in “Streaming Mode” the set point generator cyclically receives new set points. These new set points are linked directly to the position controller. For a better understanding look into the controller structure in Figure 18.

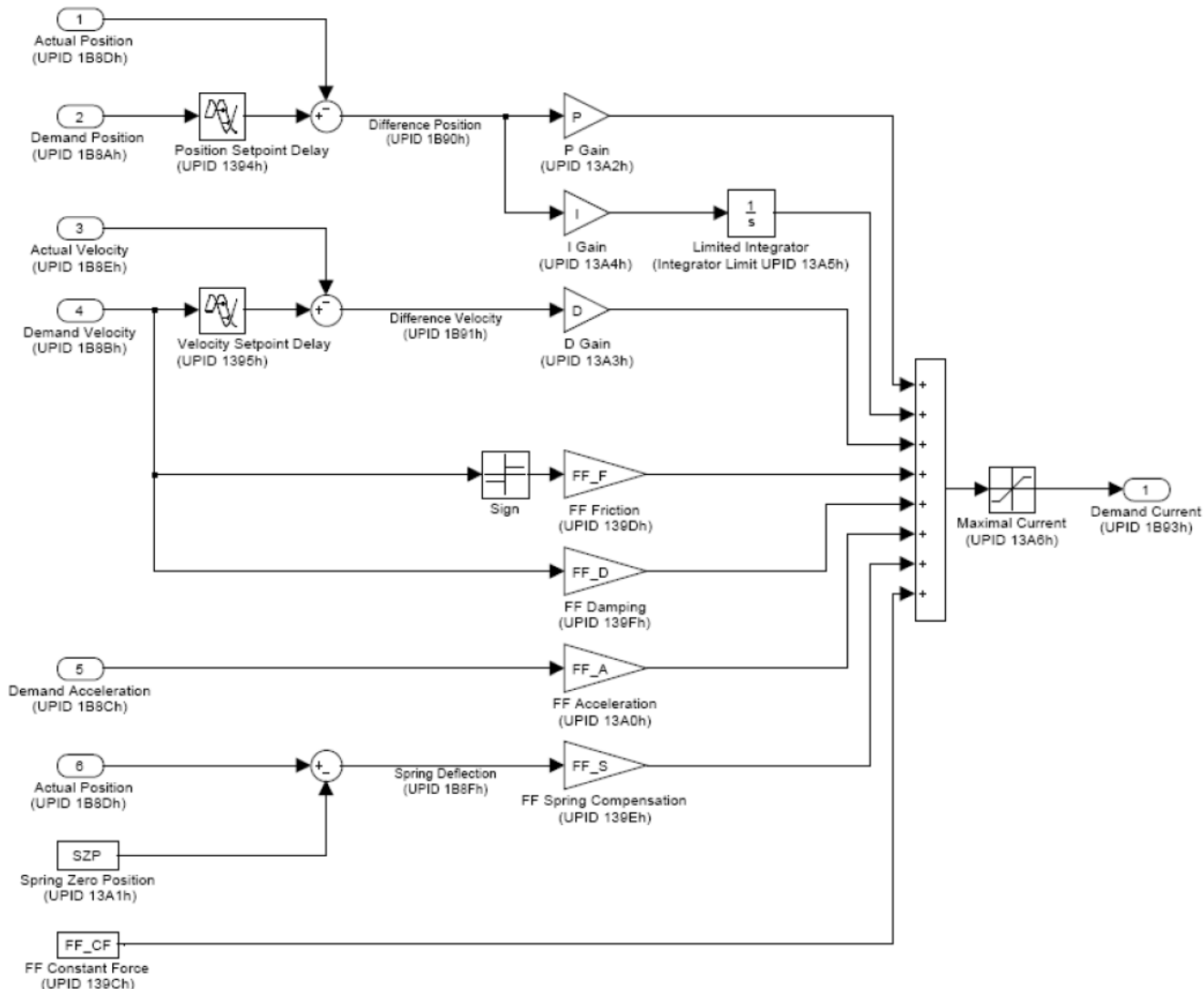


Figure 18: Control Structure of the Position Control System

If the set point generator delivers a new “Demand Velocity” and/or “Demand Acceleration”, the pre filter parameters react directly with a change of the motor current. This can cause an unstable positioning with oscillations (strong noise). In the worst case the whole system is oscillating, independent of changing the tuning parameters P, D, and I. When this operational mode is used, it is recommended to set all of the motor wizard pre-filter data values to zero. Only the pre-filter “FF Constant Force” should be left as configured by the motor wizard.

i Note: Reduce the pre-filter values if position streaming mode or drive profiles (SoE, DS402, FSP_DRIVE ...) are used and disturbance during motion occurs!
Set all pre-filter values to zero, only the „FF Constant Force“ value can be left on the configured value to prevent unexpected oscillations and positioning problems.

The same behavior will occur if the drive is used in „Analog Mode“. In this mode, an analog input is used to set the demand position (0...10V). This mode needs to be configured. In this configuration you can define the minimum change in the demand position value, before this new set point will be evaluated by the set point generator. If this minimum change is small, the reaction of the position controller gets harder, if the pre filter values are still active!

The screenshot shows the configuration interface for a LinMot drive. On the left, a tree view displays the configuration hierarchy. The 'Analog Mode Settings' folder is expanded and highlighted with a red circle. Below it, the 'Position Setpoint Configuration' folder is also highlighted with a red circle. On the right, a table displays the parameters for the '0 mm' position. The 'Evaluation Position Deviation' parameter is highlighted with a red circle.

Name	Value	Raw Data	UPID	Type	Scale	Offset
0V/-10V Position	0 mm	00000000h	14D2h	SInt32	0.0001 mm	0 mm
10V Position	50 mm	0007A120h	14D3h	SInt32	0.0001 mm	0 mm
Update Period Time	2	0002h	14D7h	UInt16	1	0
Evaluation Position Deviation	0 mm	00000000h	14D4h	UInt32	0.0001 mm	0 mm

Figure 19: Analog Position Deviation Settings

Appendix I

All LinMot servo drives provide a built in oscilloscope. The oscilloscope can be used for many different purposes. In this case, the general use for tuning the position controller is shown.

You have to be connected to the drive when using the oscilloscope. You can open the oscilloscope in the parameter tree by finding the entry “Oscilloscopes”.

When you click this entry, you can find an entry in the window on the right side named “Default”. If you double click this entry the oscilloscope view appears. If you right click on “Default”, a pop up window appears. This gives you options and allows oscilloscopes to be duplicated, renamed, and more. These features are useful to create several views with useful naming. This would be used if the first view is the starting behavior before tuning. A duplicate can be created to show the tuning process and the final results. This allows the different settings to easily be compared.

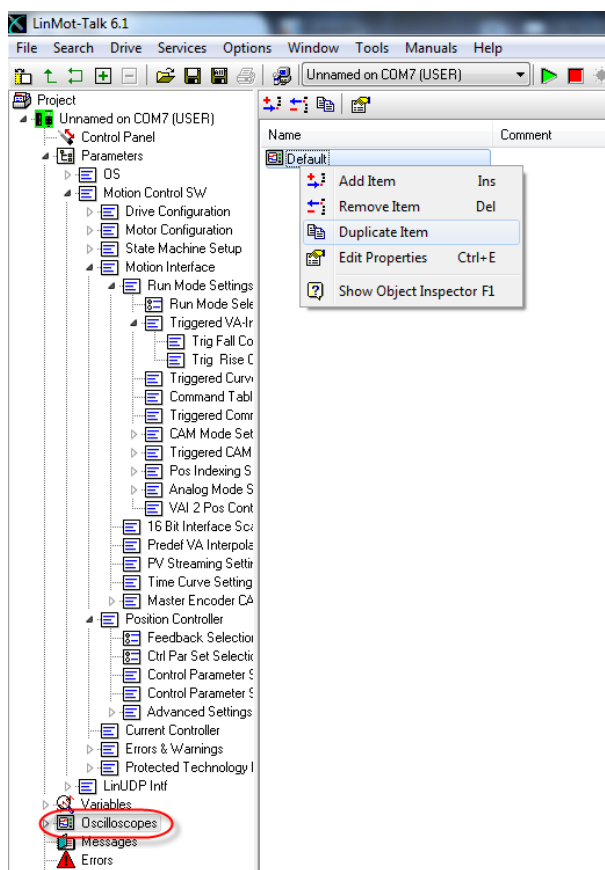


Figure 1: Oscilloscope Location and Right Click (more options)



Hint: The oscilloscopes can be exported with the drive settings

If you want to document your tuning procedure, you can store all oscilloscope readings by using „Export Configuration“. This export file can be opened offline with LinMot Talk and can be examined.

The oscilloscope functionality is generally identical on all LinMot drives. The amount of channels which can be recorded at same time or the total recording length differs on the different drive series. The preconfigured channels are suitable during the position controller tuning and can be used directly.

Open an oscilloscope by performing a double click in the parameter tree on the entry oscilloscope (for example Oscilloscope → Default). In the oscilloscope view, click the tools symbol in the symbol gallery. The “Oscilloscope Settings” window appears.

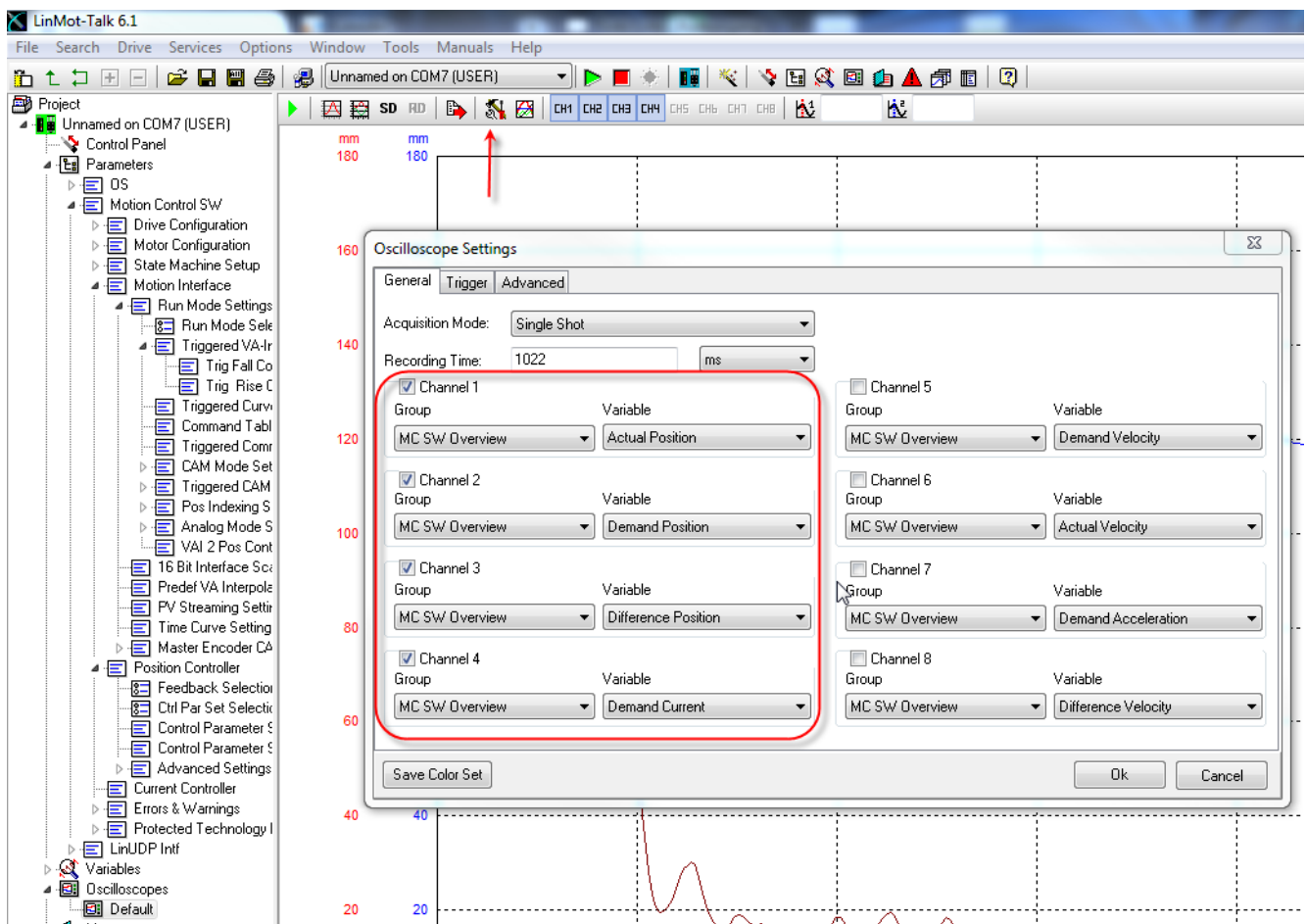


Figure 2: Default Configured Channels

The tab „General“ provides the main options for the recording settings. Here you can choose the required channels and you can set the recording time. Use the acquisition mode “single shot” for position control loop tuning.

If you close this window with the “OK” button, you can start the recording by pressing the green arrow.

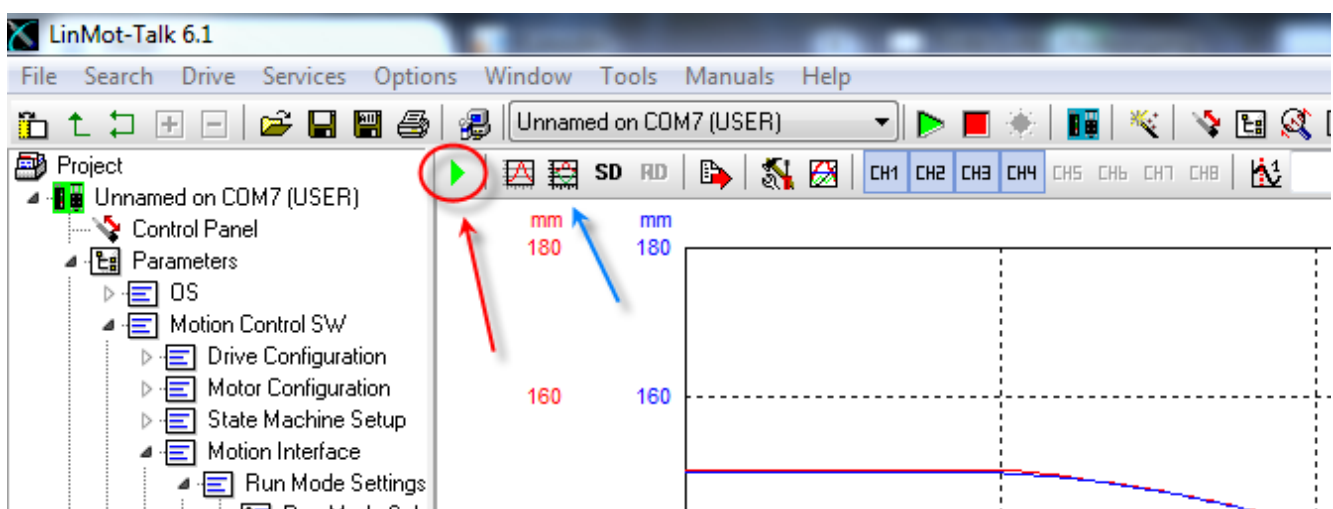


Figure 3: General Use: Start a Trace / Auto Scale Recorded Data

After the recording, you can perform an auto scale by pressing the symbol “Fit View” (blue arrow).



Figure 4: Oscilloscope with Two Movable Cursors

The oscilloscope has two cursors that can be used for measuring. Next to the cursor on/off buttons you can find the measured time of the X-axis. While moving the cursor line you can read out the time and the curve value. The corresponding value is printed below in the legend. If both cursors are used, the system delivers automatically the difference data of the both channels. Directly to the right of both cursors is a Min/Max button. This will show a new window with the minimum and maximum values for each channel.

Single channels can be hidden in the view (Ch1...Chx) to improve the clarity of the data.

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