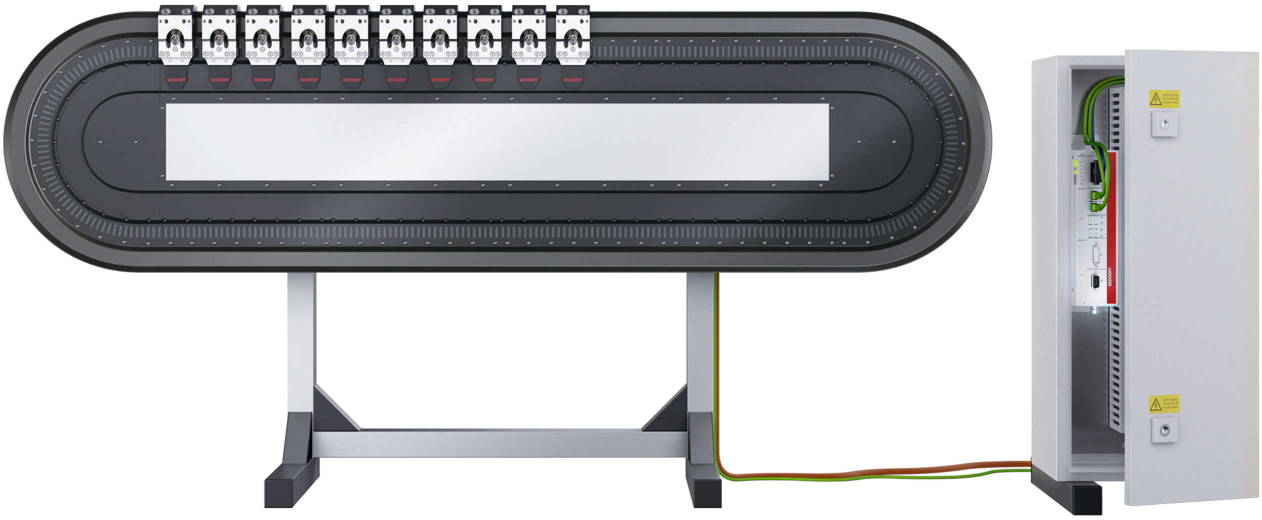

XTS Soft Drive

Extension to the XTS Starter Kit Documentation

Version: 3.1
Date: 2017-03-20

BECKHOFF

Table of content

1 Foreword

1.1 Notes on the documentation

This description is only intended for the use of trained specialists in control and automation engineering who are familiar with the applicable national standards.
It is essential that the documentation and the following notes and explanations are followed when installing and commissioning the components.
It is the duty of the technical personnel to use the documentation published at the respective time of each installation and commissioning.

The responsible staff must ensure that the application or use of the products described satisfy all the requirements for safety, including all the relevant laws, regulations, guidelines and standards.

Disclaimer

The documentation has been prepared with care. The products described are, however, constantly under development.
We reserve the right to revise and change the documentation at any time and without prior announcement.
No claims for the modification of products that have already been supplied may be made on the basis of the data, diagrams and descriptions in this documentation.

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Patent Pending

The EtherCAT Technology is covered, including but not limited to the following patent applications and patents:
EP1590927, EP1789857, DE102004044764, DE102007017835
with corresponding applications or registrations in various other countries.

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EP0851348, US6167425 with corresponding applications or registrations in various other countries.

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1.2 Intended use

The linear eXtended Transport System (XTS) is designed for machines and equipment with the highest demands on dynamics and positioning accuracy. All components of the eXtended Transport System (XTS) are **exclusively** intended to be programmed and commissioned using the TwinCAT automation software from Beckhoff Automation GmbH & Co. KG.

⚠ WARNING

Caution - Risk of injury!

Electronic equipment is not fail-safe. In case of failure of the drive system, the machine manufacturer is responsible for ensuring that the connected components of the eXtended Transport System (XTS) and the machine are brought into a safe state.

⚠ WARNING

Commissioning of the eXtended Transport System (XTS)

The eXtended Transport System (XTS) must be commissioned based on the requirements of the currently valid EU Machinery Directive. Furthermore, the client must ensure that all components installed in the system have a valid serial number.

All components of the eXtended Transport System (XTS) are installed exclusively in electrical systems or machines. They may only be commissioned in connection with components of the eXtended Transport System (XTS) and the previously designed plant. Furthermore, it is essential to take into account all environmental conditions defined in this document before the eXtended Transport System (XTS) is commissioned.

2 Guidelines and Standards

⚠ CAUTION

Danger for persons, the environment or equipment

The components of the XTS are not products within the meaning of the EC Machinery Directive. Operation of the XTS components in machines or systems is only permitted once the machine or system manufacturers has provided evidence of CE conformity of the complete machine or system.

3 Safety

3.1 General safety instructions

3.1.1 Personnel qualification

This description is only intended for trained specialists in control, automation and drive engineering who are familiar with the applicable national standards.

3.1.2 Description of safety symbols

The following safety symbols and associated safety instructions are used in this document. These safety instructions must be read and followed.

⚠ DANGER
Serious risk of injury!
Failure to follow the safety instructions associated with this symbol directly endangers the life and health of persons.

⚠ WARNING
Caution - Risk of injury!
Failure to follow the safety instructions associated with this symbol endangers the life and health of persons.

⚠ CAUTION
Personal injuries!
Failure to follow the safety instructions associated with this symbol can lead to injuries to persons.

NOTE
Damage to the environment or devices!
Failure to follow the safety instructions associated with this symbol can lead to damage to the environment or equipment.

Tip or pointer

This symbol indicates information that contributes to better understanding.

3.2 Special safety instructions

The safety instructions are designed to avert danger and must be followed during installation, commissioning, production, troubleshooting, maintenance and trial or test assemblies. The XTS can operate independently. Installation in a machine or system is not mandatory. During independent commissioning or installation of the XTS in a machine or system, the documentation and safety instructions provided by the machine manufacturer must be read and applied.

⚠ WARNING

Caution - Risk of injury!

The XTS may only be installed by trained and qualified personnel. The qualified personnel must know the national accident prevention regulations and be able to apply them.
When working on the XTS, personal protective equipment (PPE) must be worn. In particular, safety boots must be worn!

⚠ WARNING

Caution - Risk of injury through electric shock!

Bring the electrical environment (XTS, cabinet, etc.) into a safe, de-energized state before installing or working on the XTS.

⚠ DANGER

Acute risk of injury due to improper earthing!

The XTS must be earthed in accordance with the statutory provisions. Non-compliant earthing can cause acute injuries or death by electric shock.

NOTE

Intended use!

The XTS starter kit may only be put into operation under consideration of currently valid EU directives and standards, as well as the EC Machinery Directive in force at the time of commissioning.

NOTE

Destruction of the XTS starter kit!

Ensure adequate ventilation and proper earthing of the cabinet. The permissible ambient conditions are specified in the “Technical data” section. Failure to observe the specified ambient conditions and improper earthing may cause damage to components of the XTS starter kit. Furthermore, EMC problems can arise.

⚠ CAUTION

Risk of burns from hot surfaces!

The XTS issues a warning via TwinCAT if the operating temperature exceeds 65 °C. If the temperature exceeds 75 °C, the system switches off automatically. In the event of an automatic shutdown, the surface temperature of the coils may exceed 105 °C. Acute risk of burns!

Do not touch the components of the XTS during operation and shortly after operation. Wait until all components have cooled sufficiently.

Use a thermometer to check the surface temperature of the components.

In cases that require touching of components directly after operation, use suitable safety gloves to protect from burns. Wear heat-resistant clothing.

Danger from magnetic fields!

The Beckhoff XTS is equipped with permanent magnets at the guide rails and movers. The field strength of the XTS results solely from the magnetic fields of these components. A limit range of < 0.5 mT is reached in energized state at a radius of 150 mm, in non-energized state at a radius of 130 mm. The magnetic field poses a danger to persons and the environment. Observe the regulations for magnetic fields in air transportation (IATA Packing Instruction 902). This applies to already installed magnets. Permanent magnets must be stored in humid conditions. The use of permanent magnets in humid conditions (up to 95% relative humidity) can lead to corrosion and destruction of the permanent magnets.

Danger from magnetic fields!

In particular, the magnetic field poses a danger to:

- Persons with cardiac pacemakers (the magnetic field may cause the pacemaker to switch to test mode and thus cause a cardiac arrest!)
- Persons with magnetically conductive implants
- Magnetic data storage devices
- Chip cards with magnetic strips, and
- Electronic devices
- Also keep in mind that the magnetic fields can influence implanted defibrillators and make external defibrillators inoperable.
- Ensure a safety distance of 500 mm to all magnetic parts. Also, make sure that there is no direct contact with magnetic components near parts that are susceptible to interference.
  The national regulations and guidelines applicable in other countries must be followed! Also note the requirements of BGV B 11 in connection with magnetic fields (BGV B 11 Section 14).

Liability for further transport!

Please note that all components of the XTS starter kit may only be forwarded in the original packaging supplied by Beckhoff. The use of other packaging for further transport would void all liability and warranty claims against Beckhoff Automation GmbH & Co. KG.

3.3 Using in Ex environments

⚠ WARNING

The use of the XTS in potentially explosive atmospheres – Directive 94/9/EC – is not permitted!

4 System Description

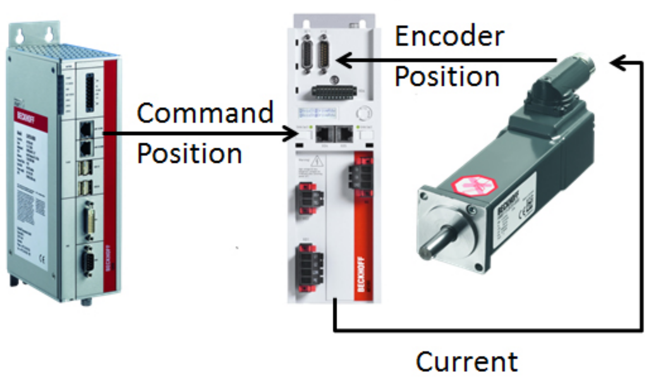
Parameters and are not active on the movers until the TwinCAT configuration is activated and TwinCAT is Restarted in Run Mode.

4.1 The Beckhoff eXtended Transport System (XTS)

XTS combines the advantages of two proven drive principles: rotary and linear systems. The motor has the power electronics and feedback integrated fully integrated. One or more "Mover" – a cable free fully passive mobile carrier module – can be operated with high dynamics independently or coordinated together in a flexible configuration at speeds of up to 4m/s.

4.1.1 Servo Control Technology

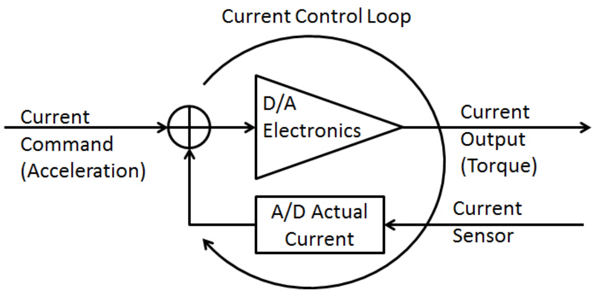
The XTS Soft Drive is equivalent to a Servo Drive/Amplifier but three out of the four core functions are done in the Control PC's software. A typical Servo Drive Configuration has the following setup.

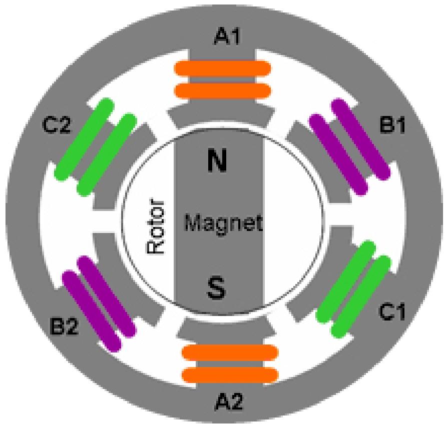


In Standard Servo Control systems, the Controller calculates the motion control profile and provides target positions to the Servo Drive at a fixed rate typically between 2ms and 250us. The Drive contains electronics that can do both the calculations (digital signal processing or DSP) and take the resulting number from those calculations and turn it into a current via pulse width modulation (PWM). The current goes to the motor, flows through coils and this provides a torque. The motor contains an encoder (or other position feedback) that the drive can read and has electronics to turn that back into a number. Thus Digital Servo Control with DSP's and PWM. The drive performs 4 separate but related tasks.

Current/Torque Control: The drive has to ensure the amount of current flowing through the coil matches with the amount of current requested. This is not a “set it and forget it” type of value at different speeds and temperatures the PWM must work differently to provide the same amount of current flow. Constant current flow = constant torque. Also as new current commands are issued the controller must react and provide the requested amount of current as quickly as possible. The control loop is not “continuous” it is done repeatedly at fixed intervals, usually 8000-32000 times per second. The actual current value is sampled, processed and a new command value is issued. The processing can be quite complicated and include things like filtering out specific frequencies. For the drive to have any chance controlling the motor this first loop must work well. If the current/torque/force cannot be controlled accurately nothing else will function.

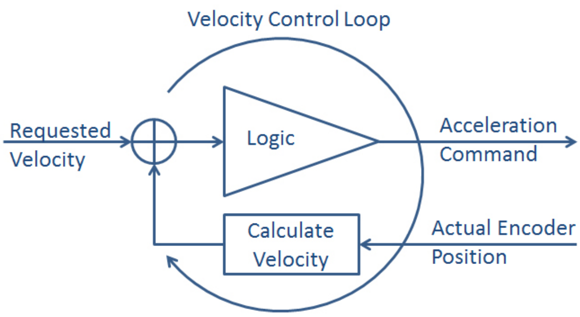
Commutation: The motor has more than one magnet and more than one coil and so the drive must determine how much current each coil should receive and in which direction the current should flow through each coil. To generate a specific torque/force the drive uses the encoder position of the motor to determine how much current each coil should in order to provide the requested force/torque. This is the commutation process. This process is also fairly involved as the commutation process must keep the generated magnetic field ahead of the rotor so that the rotor keeps trying to catch it and creates a torque. With current control and commutation the torque of the motor can be controlled and therefore the acceleration can be controlled. If the goal was to simply control the acceleration of the motor the servo drive design would be complete. However the goal is to control the position of the motor.

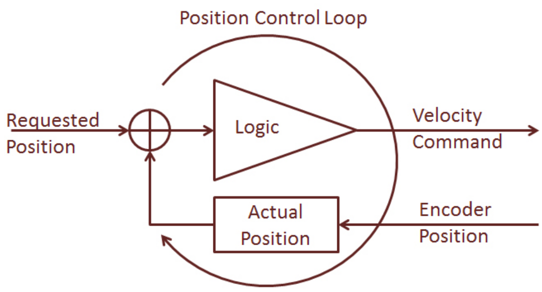




Velocity Control Loop: The third item the drive is responsible for is the velocity control loop, the first integral of acceleration and the first derivative of position. This control loop is generally not calculated as often as this loops needs sends commands to the control loop and operates on the results of the control loop. It takes time for the acceleration to result in a velocity (integration) and the position needs be measured more than once to calculate a velocity (derivative). This loop often runs at cycle times between 250us and 32.25us (4000Hz – 16000Hz). The velocity control loop takes a requested velocity and based on the actual encoder position an actual velocity is calculated and a new acceleration command is generated to speed the motor up or slow it down. For this loop to work properly the current control loop must work properly

The final control loop is the position control loop, this loop typically runs at the slowest update rate 500Hz to 4000Hz.This loop acts on the results of the velocity loop and issues new commands to the velocity loop. This loop takes uses the position as feedback and outputs a new commanded velocity. If the velocity loop doesn’t work the position loop has no chance to control the position. This loop works in exactly the same way as the velocity loop the position is the integral of velocity and velocity is the derivative of position.



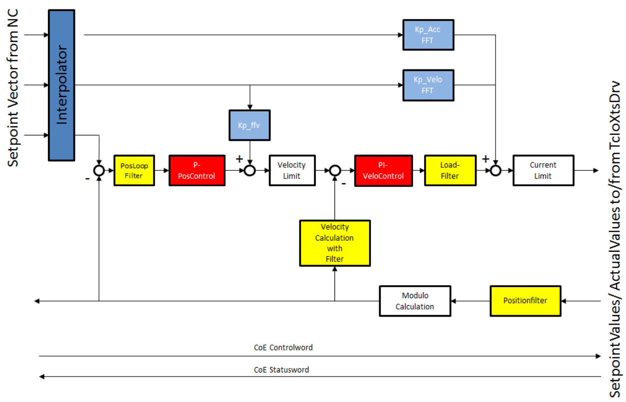


This is an extremely simplified view of what the drives control loops do. Often a drive will be provided with much more information to allow the drive to provide much better control. The Profile Generation (done by the motion controller) will often provide a Velocity and Torque/Force (Feed Forward) values in addition to Position. If it is known the motor must accelerate, a “starting point” acceleration/current will be given to the current control loop. In this way the current loop starts with this amount of current rather than waiting for the current loop to detect that the actual current is less than the requested current and then begin to increase the amount of current that is output. So why include an oversimplified version description of the drive functionality. The reason being that 3 of the 4 tasks a drive would do are now replaced with software. The only function that remains in the XTS Hardware Modules is the Current Control loop. The XTS Module receives a Current Command value for each coil and ensures each coil receives the requested current. All other control is done in the PC in software Based on the position of the mover the XTS Driver and soft drive determine which coils to activate with how much current so that the mover is provided with the requested force/acceleration.

5 Soft Drive

The Soft Drive component is a somewhat generic component; it has not been built solely for the XTS. The soft drive could in fact control any axis that provides an encoder feedback and accepts a current command. For XTS the Soft Drive calculates the current command and gives that current (force) to the XTS driver to commutate. As such some parameters exist that should never be changed. (E.g. Motor coil pitch and feed constant).

5.1 Control Loop

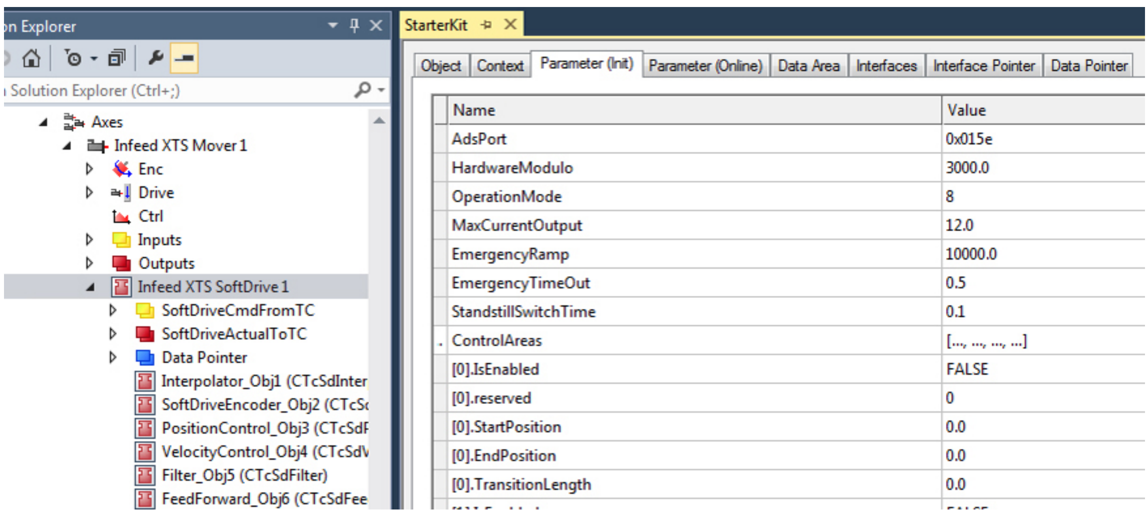


The yellow blocks are filtering blocks and these blocks dictate what signal the soft drive controller will see and operate on. The red blocks are the control loops themselves and operate on the values given by the yellow blocks. The white blocks are limits and fixed constants such that even when the control loop requests more than the maximum values these limits will prevent damage to the components by limiting the commanded velocity or current. The blue blocks are feed forward values. These values dictate how much of a look ahead the system will implement.

The system contains multiple sets (copies) of the same parameters. The use of these multiple sets of parameters can be enabled and the control loops will automatically switch through the various parameter sets according to specific rules. By default 2 sets of parameters are implemented. Moving Parameters that are used while the set point velocity is greater than zero and stand still parameters that are used after the Set Velocity has been zero for 100ms. (The time is adjustable).

A third set and fourth set of parameters become available when “Areas” are implemented. These are generally used for the curves. The system can have 4 sections of track defined as an “Area” of the track. Any time a mover is within any of these “Areas” the Area parameters are used. There is one set of Moving Area Parameters and one set of Area Stand Still Parameters. The Area configuration also includes a Ramp distance. The ramp distance allows for the switch from the normal moving gains to the Area gains to be linearized over a distance. This is done so that the control loop gains do not have a step change, but are ramped in and out. Parameters that have a stopped/standstill setting will indicate this by having _standstill after the parameter name and parameters that have an area setting will have _area after their name.

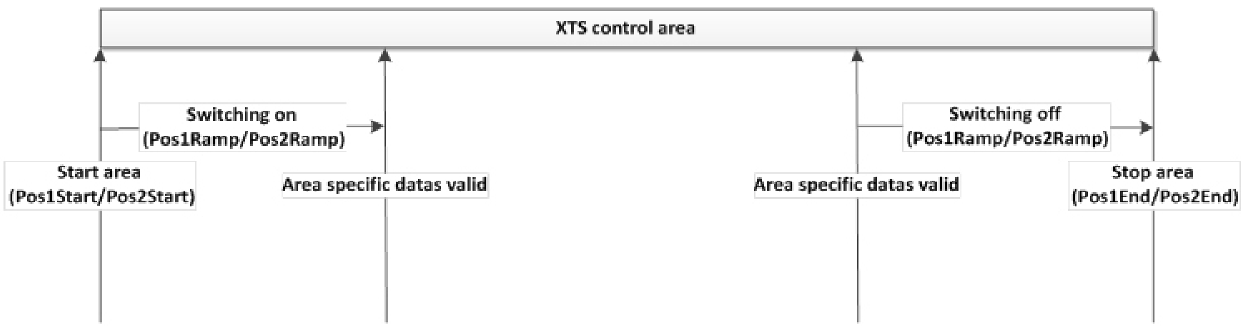
5.2 Drive Components



5.3 Parameters

5.3.1 The Main Soft drive Object contains the following parameters

Parameter	Default value	Unit	Description
ADS Port			This is the ADS Port number of the task that the Soft Drive is linked to; do not change this value by hand.
Hardware Modulo	3000	Mm	The circumference of the track. (E.g. 1m Starter kit has 3000mm circumference. 1.5m starter kit is a 4000mm circumference. This value is automatically entered by the Configurator Tool.
Operation Mode	8		Operation Mode corresponding to CanOpen object 0x6060 for normal operation this must be 8, to allow Velocity Step commands during tuning only this value must be 9.
Max Current Output	12.0	A	Maximum current the mover can use. This value can be lowered but not increased above 12. 12 A corresponds to ~100 N.
Emergency Ramp	10000	mm/s²	Default emergency ramp on fault. Can be changed but ensure it is feasible and will not generate a secondary fault. E.g. Decelerating all movers so fast that the DC bus causes an overvoltage error and all movers coast.
Emergency Time Out	0.5	S	Time after an emergency ramp is engaged after which the soft drive will be disabled. Can be changed if necessary ensure feasibility.
Stand Still Switch Time	0.1	s	Time after Set Velocity is zero before the mover is determined to be at standstill. (Control loops with Standstill parameters enabled will switch to standstill parameters after this time).
Control Areas	1	Array	Determines the number of Control Areas available. A maximum of 4 control areas can be set. When a control area is enabled and a control loop uses area parameters, when the axis is in an area, the area parameter.
[arrayindex] is Enabled	False	True/False	Enable use of Area Parameter Set. Set to True to enable Area Parameters (Control loops must also be enabled to used area parameters)
[arrayindex] reserved	0		Reserved for future use, do not change
[arrayindex] StartPosition Valid values are from 0 to the Hardware Modulo. Negative numbers or values larger than the hardware modulo are ignored	0	mm	Linear Location where the Area starts Note: The hardware positions are determined in accordance with the Soft Drive. Hardware Position. Reversing the counting direction of the mover does not reverse the hardware position
[arrayindex] EndPosition Valid values are from 0 to the Hardware Modulo. Negative numbers or values larger than the hardware modulo are ignored	0	mm	Linear Location where the Area ends Again dependent upon Hardware position.
[arrayindex] Transition Length Valid values are from 0 to half of the defined area. (StartPosition-EndPosition)/2	0	mm	Ramp distance for linearly switching to/from area parameters.



5.3.2 Interpolator Parameters

Parameter	Default value	Description
Interpolator Type	Interpolation_Poly-Nom3	Method of handling determining points between position updates from the NC Process. The system has been optimized for Polynomial operation.

5.3.3 Encoder Parameters

Parameter	Default value	Unit	Description
Velocity Feedback Mode	Observer		Method used to determine position and actual velocity. The system has been optimized for Observer.
Position Feedback Mode	Modulo_Start		How the mover positions are calculated on start.
	Standard: all positions are absolute and all axis with positions less than half the modulo distance start with a negative number. Modulo: The start positions are modulo but movers that are more than half the modulo distance start with a negative number. Modulo_Start: positions are modulo but on start all movers have a positive value. Simulation: the encoder is simulated rather than receiving feedback from the XTS. Simulating a random noise and adding the noise to the real signal. When moving the actual position is following the set point with 1 cycle delay. Modulo Start Invert: The same as modulo start, but all al movers are given a negative value. (Movers that have had their Encoder Count direction and Motor Polarity inverted will start with a positive number)		
Position Low Pass Filter	500	Hz	Low Pass frequency of the Observer model and speed filter. Can be increased if an extremely stiff mover/track system is used. E.g. Steel Track Steel wheels nearly zero mover flex. Never be below 100Hz.
Bandwidth	160	Hz	The bandwidth used for the observer model and speed filter. Adjust this value as necessary to eliminate oscillations. As a rule the more flex the load induces on the mover, the lower the value but it is dependent upon the stiffness of the mover, load, and track. Never set below than 80Hz
Correction Factor	0.5		Load correction factor of the observer model. This is the ratio of the load to the mass of the mover. For an unloaded mover this can be a value of 1. For loads greater than 350g the correction factor should not be less than 0.5
Simulation Offset	10.0	mm	If the simulation encoder is used this is the start position of the mover. Every mover should have a different (realistic) start position.

5.3.4 Position Control Object

Parameter	Default value	Unit	Description
Position Loop Type	P_POSITION_STAND-STILL		**OFF**: Disables the Position Loop control, no commands will be passed onto the velocity loop. **P_POSITION:** enables the loop but only with Kp values. **P_POSITION_STANDSTILL:** Kp is used while in motion, KP_Standstill will be used after the mover is in Standstill (according to Standstill Switch Time Parameter) **P_POSITION_STANDSTILL_AREA:** provides all 3 parameter sets Kp used while moving, Kp_standstill after Standstill is reached, while the mover is in an enabled Control Area, Kp_Area and Kp_Area_Standstill will be used according to the area configuration
Kp	0.03	1/s	Proportional Gain used while not overridden by another parameter. Never Set below 0.0075
Kp_standstill	0.02	1/s	Proportional Gain used when standstill is enabled and the mover has had a command velocity of 0 for longer than SoftDriveStandStill.SwitchTime and the mover is not under area control Never Set below 0.0075
Kp_area	0.015	1/s	Proportional Gain used when the axis is within the Hardware Position range as defined by the Control Area settings and the axis is not at standstill Never Set Below 0.0075
Kp_area_standstill	0.015	1/s	Proportional Gain used when the axis is within the Hardware Position range as defined by the Control Area settings and the axis is at standstill determined the Soft Drive Standstill Switch Time parameter Never Set Below 0.0075
Pos Loop Filter	75	Hz	First Order Filter cut off frequency for the Position loop input
	A lower frequency filter value reduces the response of the position loop increasing the delay between command and action. (Actions less than Cut off Hz are filtered out) but the system will then see less noise in the signal and not respond to this. Increasing the cut off frequency will increase the reaction of the control loop but the system more noise will be let through and the system will respond to this noise. This is very rarely changed		
Pos Loop Filter_area	75	Hz	Same functionality as above. The First Order Filter for the Position loop input when area control is enabled and the mover is in the area defined by SoftDriveControlArea. Again very rarely changed

5.3.5 Velocity Control Object

Parameter	Default value	Unit	Description
Velocity Loop Type	PI_VELOCITY_STANDSTILL		**OFF** Disables the Velocity Loop control **PI_VELOCITY** enables the velocity loop but only with Kp and Tn **PI_VELOCITY_STANDSTILL** enables the velocity loop with Kp and Kp_Standstill, Tn and Tn_Standstill. **P_VELOCITY_STANDSTILL_AREA** provides all 4 parameter sets Kp, Kp_Standstill, Kp_area, and Kp_area_standstill
Kp	0.05	As/rad	Proportional Gain used while no other gain is active. Never set below 0.03. Stiff track systems this can be as high as 0.1
Kp_standstill	0.033	As/rad	Proportional Gain used when standstill is enabled and the mover has had a command velocity of 0 for longer than SoftDriveStandStill.SwitchTime Never set below 0.01
Kp_area	0.025	As/rad	Proportional Gain used when Area control is enabled and when the axis is in the area defined by Control Area Never set below 0.01
Kp_area_standstill	0.025	As/rad	Proportional Gain used when Area control is enabled and when the axis is in the area defined by Control Area and the axis is at standstill. Never set below 0.01
Tn	0.025	S	Integral time constant
	Integral Resetting time or integration time. Integrates the difference between the command value and the actual value over the time specified by this parameter. Shorter times react faster longer times react slower. Never set above 0.1 (100ms)		
Tn_standstill	0.05	S	Integral time constant used when area control is enabled and the axis is at standstill. Never set above 0.1 (100ms)
Tn_area	0.05	S	Integral time constant used when area control is enabled and the axis is in the area defined by the SoftDriveControlArea (shorter faster response, longer slower response) Never set above 0.1 (100ms)
Tn_area_standstill	0.05	S	Integral time constant used when Area control is enabled and when the axis is in the area defined by Control Area and the axis is at standstill. Never set above 0.1 (100ms)
Max Velocity	4200.00	Mm/s	Max Velocity of the mover Do Not Increase this value above 4200mm/s. This can be decreased but the value must be at least 5% larger than the maximum velocity commanded.

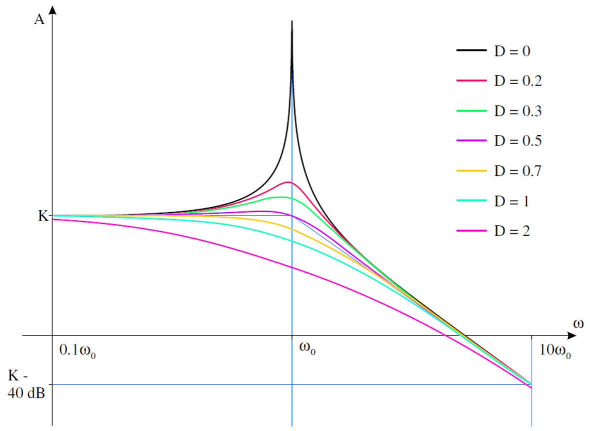
5.3.6 Filter Object

Parameter	Default value	Unit	Description
Type	LOWPASS2		Type of Filter Implemented Use LowPass2 unless the results of the TcTuningAssist indicate otherwise
Reserved	0		Do Not change
Low Pass Frequency	250.0	Hz	The Low Pass cut off Frequency. Adjust as necessary to eliminate oscillations. Higher cut off frequency allows faster reaction, but more signals to pass through. Lower cut off frequency allows fewer signals to pass through but slower reaction. Never set below 100Hz.
Low Pass Damping	0.8		Do Not Change. See the Second Order Low Pass Filter diagram to see how the damping is implemented and that 0.8 is optimal.
High Pass Frequency	0	Hz	Not used with Low pass Filter. Do not Change
High Pass Damping	0		Not Used with Low Pass Filter Do Not Change

Further description of the Filtering Types and parameters:

Filter Type	Description
LOWPASS2	When cut off frequency is reached the output signal is decreasing 40db/decade It is even designated as Spring-Mass-System. This is the default filter of choice for XTS movers.
Other Filter Types	The TcTuningAssist may recommend another filter, if so use the settings the TcTuningAssist has recommended.

Damping Factor



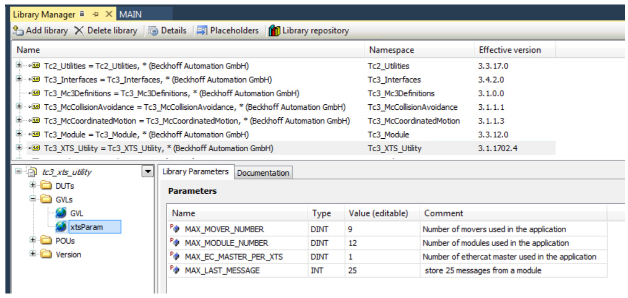
A damping factor of 0.8 provides a reasonable response and is generally sufficient. Damping factors less than 0.5 should not be used.

5.3.7 Feed Forward Object

Parameter	Default value	Unit	Description
Type	FFT_ON		FFT_OFF No acceleration feed forward is used FFT_ON KpAccFFT is used as feed forward MOVE_OPENLOOP: FFT_ON_AREA KpAccFFT used and KpAccFFT_Area used when the mover is in any of the Areas
KpAccFFT	1.0	As²/mm	Acceleration Feed Forward Gain. For large loads this value should be changed to reduce position lag encountered during acceleration and deceleration. Too high and it will create a negative lag distance. A value of 1 corresponds to a mover mass of 350g a value of 2 would be for a mover mass of approx. 700g.
KpAccFFT_area	1.0		Acceleration Feed Forward gain to be used in the curve when Type is set to FFT_ON_AREA.
Open Loop Area Current	3.0	A	Sets the open loop current with the position command for commutation. Changing this value can result in incorrect Commutation.
Area Current Limit	0.0	A	When greater than zero, and Control areas are enabled, when the axis is in a Control Area the axis current will be limited to this value.

5.4 Parameter Access via the PLC

The ease of reading and writing Soft Drive parameters is greatly improved in this version. All parameters are now accessible via the Axis_Ref of the mover. All Soft Drive parameters and diagnostics can be read via this single interface. Secondary values no longer need to be linked to obtain and change the Soft Drive Parameters.

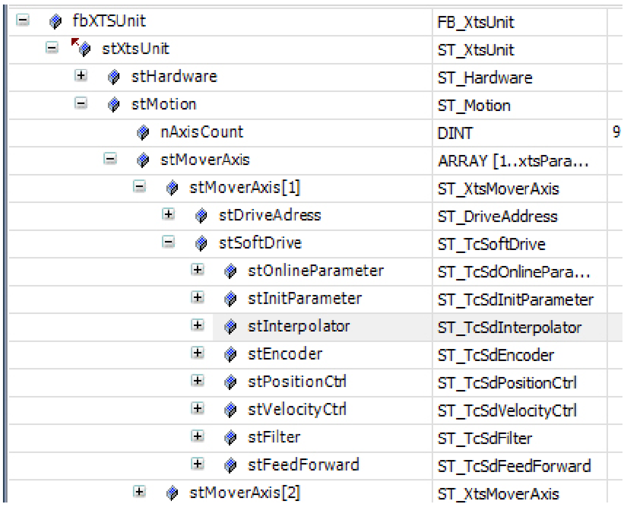


The XTS_Utilities library contains a block FB_XTSUnit. This block will obtain ALL XTS module status and diagnostic information as well as all Soft Drive Mover Parameters. It is also possible to write any value to any Soft Drive Parameter of any mover. To use this block simply add the XTS_Utilities Library, adjust the library's Global Parameters to match the configuration of the XTS.

- **MAX_MOVER_NUMBER** is the number of movers on the XTS
- **MAX_MODULE_NUMBER** is the number of XTS modules installed
- **MAX_EC_MASTER_PER_XTS** is the number of EtherCAT Masters the XTS system has (generally one master per Infeed Module)
- **MAX_LAST_MESSAGE** is used for the Diagnostic Message history.

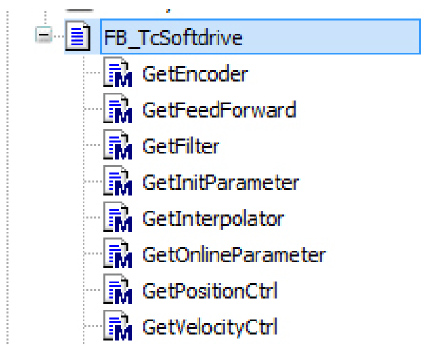
The XTS modules themselves store a maximum of 25 Diagnostic Messages before the oldest messages are overwritten. To gather all the XTS information, simple create an instance of the FB_XTSUnit, and call the block. This block DOES gather a lot of data, expect an execution time of ~ 120-200us this should be called from a slower task. 120us for a 10ms task is 2.5% CPU usage, however at a 1ms update rate, 200us is 25% of the CPU.

All parameters for all modules and drives are automatically updated sequentially, it takes many cycles before all soft drives and all modules are updated. Methods for individual items can be called on demand as well.



The FB_XTSUnit block contains the structure stMotion, stMotion contains the number of movers (axis) and an array with all of the movers information. stMoverAxis [1] contains all the information about the first mover axis.

The structure for each Soft Drive object contains all the parameters for that object. For example the Velocity control loop. There are several helper blocks that the fbXTSUnit calls in order to gather all the appropriate Object ID's so that the method calls work and the values can be read.



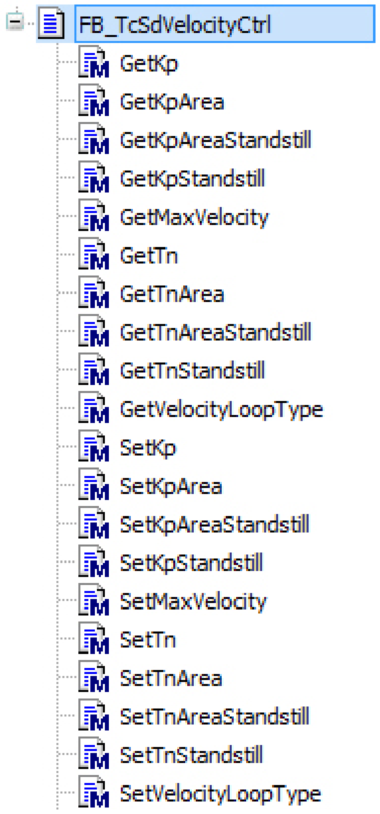
To access an Soft Drive the structure looks like this: fbXTSUnit.fbMotion.fbMoverAxis[Index].fbSoftDrive

fbSoftDrive is an instance of FB_TcSoftdrive which has many methods to get entire parameter lists

This method call

```
velocityParameters := fbXTSUnit.fbMotion.fbMoverAxis[1].fbSoftdrive.GetVelocityCtrl();
```

Will gatheter all velocity parameters and stick them in the velocityParameters structure of type ST_TcSdVelcityCtrl, it is not necessary to know the structure type. If TwinCAT set to autodeclare, it will automatically provide the proper structure type when the line of code is written and the assignment is made.



The FB_TcSoftDrive contains sub blocks, one for each parameter set and these blocks contain methods to read and write individual parameters.

To set the Kp value for the soft drive the following code is called

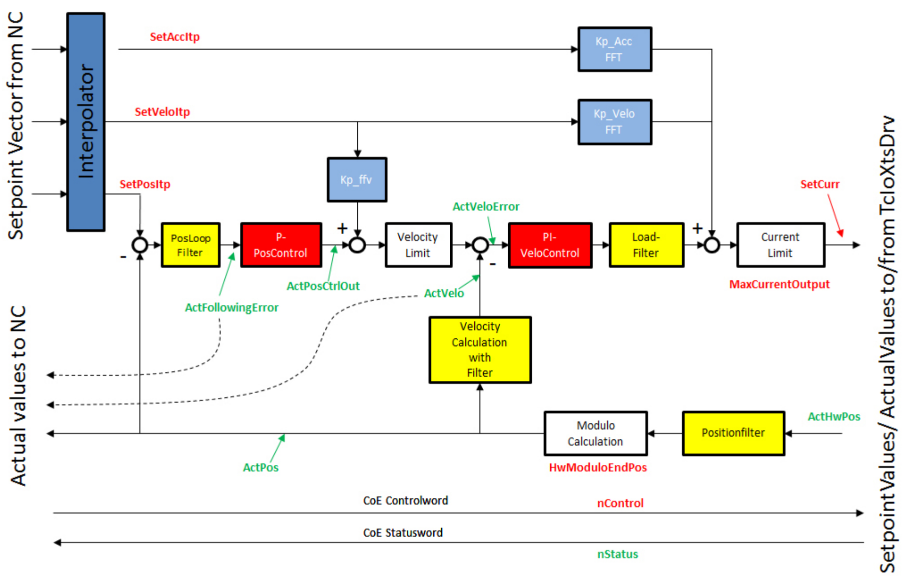
```
SetError := fbXTSUnit.fbMotion.fbMoverAxis[1].fbSoftdrive.fbVelocityCtrl.SetKp(fKP:= newKp);
IF SetError THEN
    errorID := fbXTSUnit.fbMotion.fbMoverAxis[1].fbSoftdrive.fbVelocityCtrl.P_ErrId;
END_IF
```

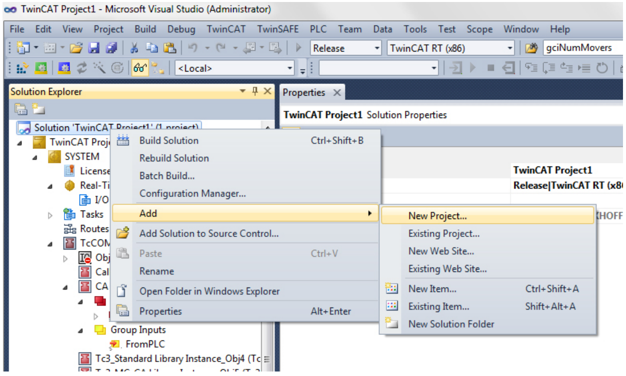
If the call did not function properly (e.g. the Object ID"s have not yet been gathered) the Set Method will return an error and the error ID can be read.

5.5 Tuning

5.5.1 Preparing the Scope for Tuning

The NC axis runs at a 2ms update rate. The Soft Drive runs with a 250us update rate so in order to see what is going on, every value must be viewed, not every 8th value. These parameters need to be scoped from the Soft drive object and not from the NC Axis. The Actual Position, the Set point position, actual velocity and set velocity, the following error, and the set current. In order to tune the drive the following items will need to be scoped:



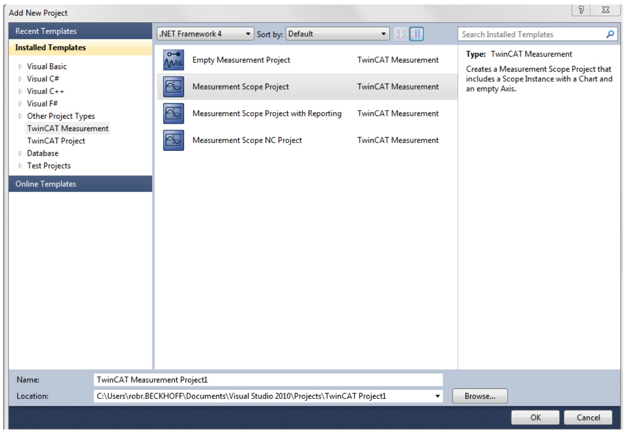


To scope the values add a TwinCAT measurement project to the Solution.

This is done by right clicking on the solution and:

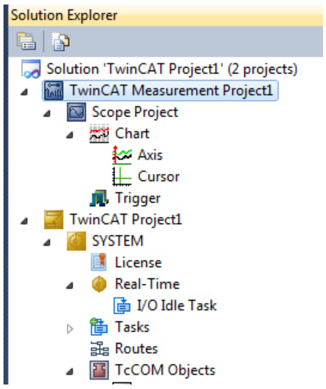
- *Selecting Add → New Project.*

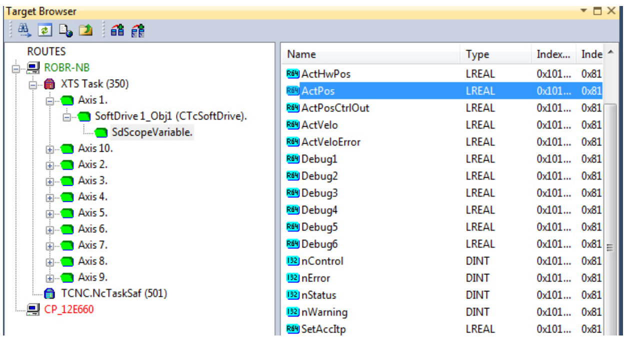
It is often better to open a new instance of TwinCAT/ Visual Studio and build a Measurement Project in a separate solution.



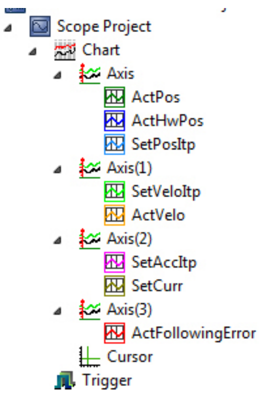
Then select the Template TwinCAT Measurement and a Measurement Scope Project

Now a new Measurement Project will be included solution





To select the appropriate values use the Target Browser (TwinCAT must be in Run Mode). Soft Drive Variables are found under the Axis SoftDrive_Obj (CTcSoftDrive). If the sdScopeVariables are NOT present, check that the XTS Task is correctly configured on Port 350 or higher.



5.5.2 Tuning Procedure

The system as delivered is tuned for an empty mover. Any load added to the mover it will affect how the mover behaves. The mass of the load, the stiffness of the load, and the location of the center of gravity of the load all have a drastic influence on the behavior of the mover. The mover does flex, particularly in the curve. The order in which to tune the control loops is to:

Eliminate resonant frequencies.

- For Beckhoff the TcTuningAssist to provide a Filter Type and Parameter Values.
- If the TcTuningAssist has not been run then adjust following values by hand
- SoftDriveEncoder.Bandwidth
- FilterObject Low Pass Frequency

Disable the Position Control Loop

- a. Disable PositionControl Kp
- b. Disable PositionControl Kp_Standstill
- c. Disable PositionControl Kp_Area
- d. Set Operation Mode to 9

Tune the velocity control loop.

- Adjust Velocity Control Kp
- Adjust Velocity Control Tn
- Adjust Velocity Control Kp_standStill
- djust Velocity Control Kp area
- Adjust Velocity Control Tn_area
- Adjust Velcoity Control Kp_standStill

Re-Enable and tune the Position Control Loop.

- Set Operation Mode back to 8
- Adjust Position Control Loop Kp
- Adjust FeedForward KpAccFFV
- Finalize Position Control Loop Kp
- Adjust Control Loop KpStandstill
- Adjust Position Control Loop Kp_area
- Adjust FeedForward KpAccFFV_area
- Finalize Position Control Loop Kp_area
- Adjust Position Control Loop Kp_standstill_area

If the mover oscillates, uncontrollably it cannot be tuned. Oscillations >200Hz are due to incorrect filter settings. Oscillation must be eliminated in the curves and in the straights. If the velocity loop is not correct then it is simply not possible to accurately tune the position control loop. The current control loop is performed in the motor module and does not need to be tuned nor is it accessible to the user. Prior to tuning the velocity loop all noise and resonant frequencies must be eliminated. Often as soon as a load is added to the mover and the mover is enabled it will begin to oscillate and make a very loud unpleasant noise. Depending on the construction of the load and natural resonant frequencies it may be the case that it is not possible to tune the mover/load combination and the load must be redesigned. See the Project Planning Documentation about for the physics involved with load construction.

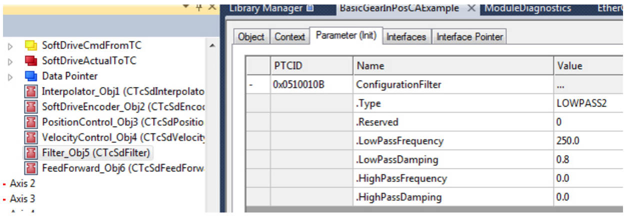
⚠ CAUTION

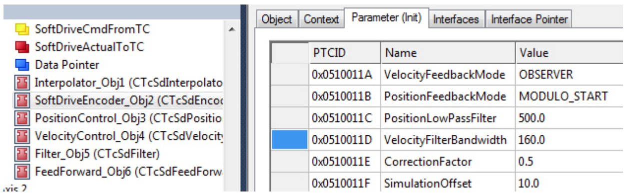
Risk of personal injury!

Tuning of the mover is the adjustment of its ability to move and achieve a target position. The mover can drastically overshoot or undershoot a target position while tuning.

5.5.2.1 Eliminate resonant frequencies

First position the mover to be tuned in a straight section of track. The straight sections are much easier to tune than the curved sections. Eliminate resonance in the straight section, then test for resonance in the curve and adjust the filters as necessary. The TcTuningAssist can greatly help in selecting filters and filter settings for movers that can flex slightly. For very inflexible flex movers (steel wheels, steel rails) very little oscillation occurs and a low pass filter with a filter frequency of > 500Hz can be used.





Start the Scope of the Axis, Enable the Axis and monitor the oscillations. **Depending on the load these Oscillations can be extremely loud > 80dB.** Increase/decrease the filters as necessary until the mover settles nicely without significant oscillations.

First Enabling and moving:

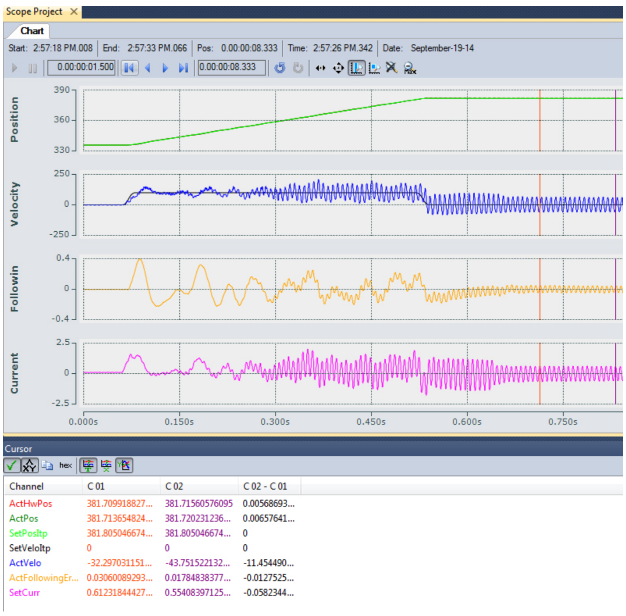
Step 1

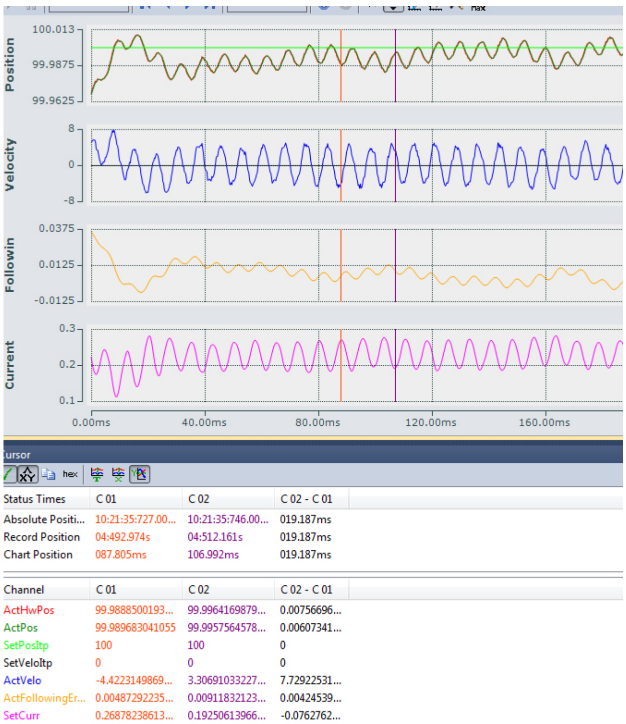
For the filter the main concern is not the operation of the mover while moving it’s the small resonance at a frequency > 100 Hz that continues while the mover is stopped that must be eliminated. Here the oscillation is at 146Hz. It can be seen that 100ms after the set velocity is zero the control loops switch from moving parameters to standstill parameters and while the amplitude of the oscillation slightly decreases the frequency remains the unchanged.

Step 2

Through trial and error it may be possible to eliminate the resonance by setting the filters low or setting the filters high.

This has an oscillation of about 4mm/s





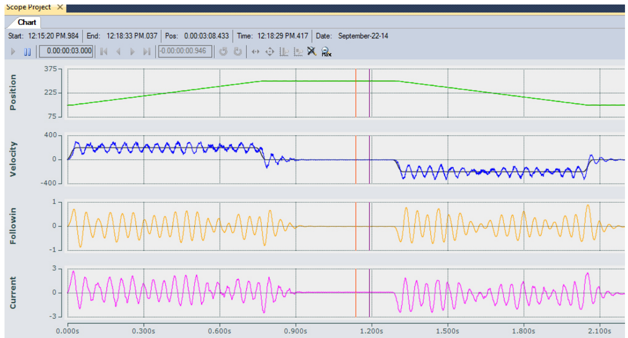
Step 3

The system will now be tested with lower bandwidth to see if it performs better.

Here the velocity ripple is very low 2mm/s when at standstill.

Step 4

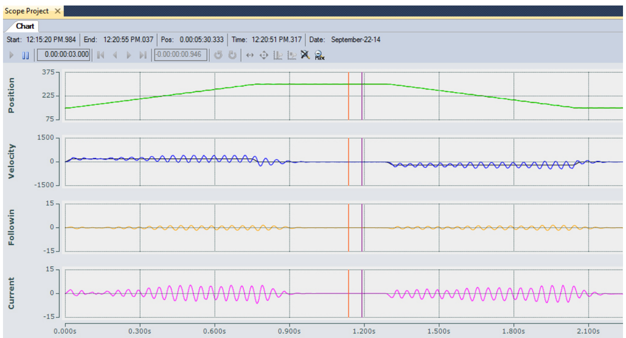
Now it will be attempted to reduce the LowPassFilter Frequency with the original Bandwidth.



Step 5

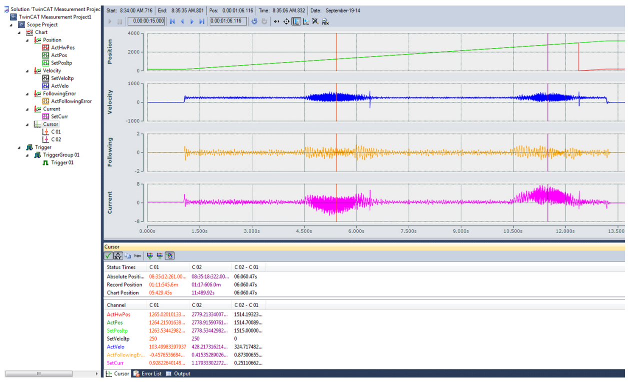
With this configuration there is a lot of oscillation.

It is clear that regardless of the bandwidth, setting the low pass filter lower makes the oscillations in this system worse.



Step 6

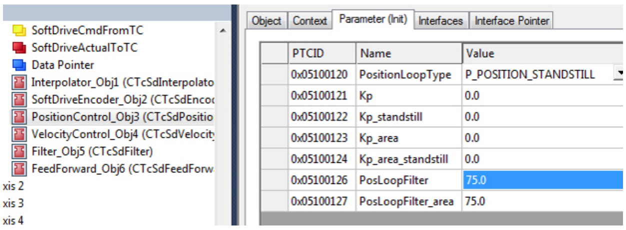
For this system a LowPassFilter setting of 320Hz and bandwidth 250Hz will be selected. This is because while the results are marginally better with a low bandwidth, higher settings are always preferred when possible. A higher bandwidth allows a faster the reaction.



The mover behaves much more poorly than the straight sections. This is to be expected, the physics of motion change when rotating vs travelling in a straight line. The important part is that there are no high frequency oscillations in the curves, if the mover oscillates in the curves, the filters must be re-adjusted so that the mover does not oscillate in the curve.

The use of the TcTuningAssist can determine the filter settings much more precisely than trial and error.

5.5.2.2 Disabling the Position Control Loop



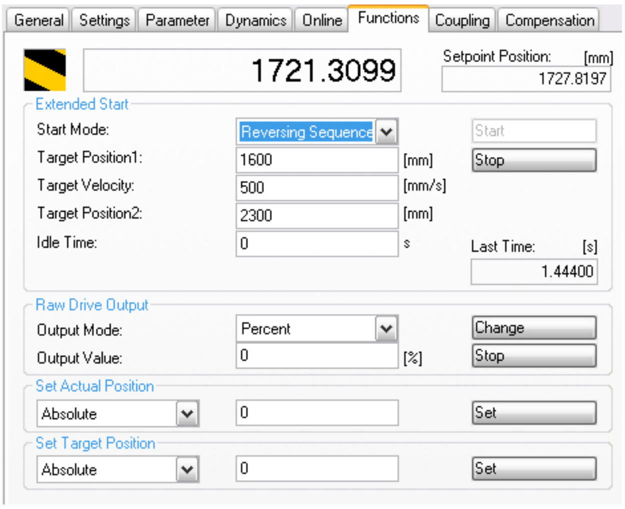
With the filters set either by using the TcTuningAssist or by hand, the tuning can now truly be started.

For the Position Control loop, set all Kp values to 0 and perform and Download. Set the operation mode of the mover to Operation Mode 9. (Velocity) Do not simply select Position Control Loop Type OFF. Removing the control loop completely will also eliminate the velocity feed forward and no velocity values will be issued to the velocity loop and the axis will not move.

5.5.2.3 Tuning the Velocity Control Loop

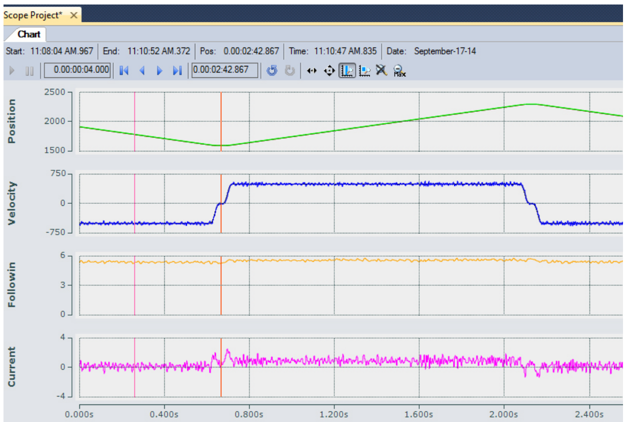
Step 1

Once the oscillations of the system are removed and the position control loop disabled, the velocity loop can be tuned. The goal of tuning the velocity loop is to get the mover to respond as quickly and accurately as possible to new velocity commands. The Velocity Command should change as quickly as possible. To that end, the dynamics on the mover should be set very high and a reversing sequence employed moving the mover back and forth. If a reversing sequence command is to be used the Jerk, Acceleration, and Deceleration should be set impossibly high.



Step 2

The above command results in the following graph.



This accel and decel values are a bit low. To see how the system behaves the system must be asked to do something it cannot do. The Jerk and Accel and Decel should be set very, very high >100,000 for accel and >400,000,000 for Jerk. The best option is to use the Velo Step Sequence if possible. The velocity step sequence simply issues a command velocity with an instantaneous acceleration. This is particularly helpful when attempting to tune the velocity loop. However the velocity step command does not have a target position, simply a driving time. As such care must be taken that the mover being tuned does not crash into something.

Important!

While standard motor tuning techniques can and should be used for the XTS, it must be noted that the velocity ripple of an XTS mover is much higher than a standard rotary motor.

Step 3

Here the a velo step sequence is implanted with a 0.75 second driving time

This reversing sequence has acceleration/deceleration and jerk parameters high enough to perform a tuning of velocity loop but a Velo Step Sequence is always preferred as it has an Impulse Acceleration.

Important!

The Velo Step Sequence should be used whenever possible

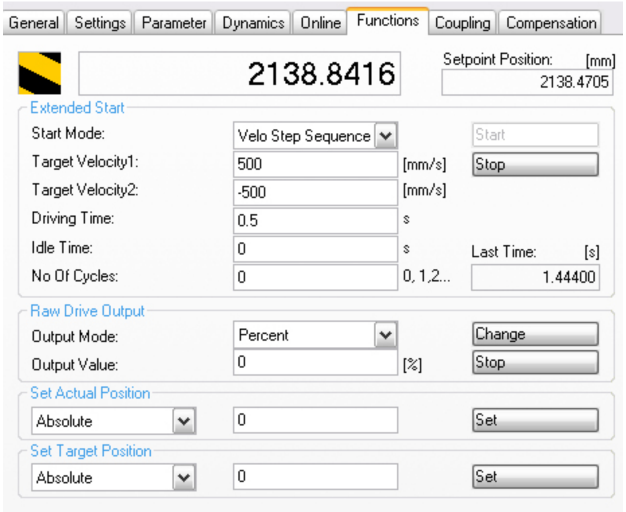
⚠ CAUTION

Risk of personal injury!

When using the Velo Step Sequence. The mover is given a commanded velocity for a given time. There is no position control, as such care must be taken that there is nothing for the mover to crash into.

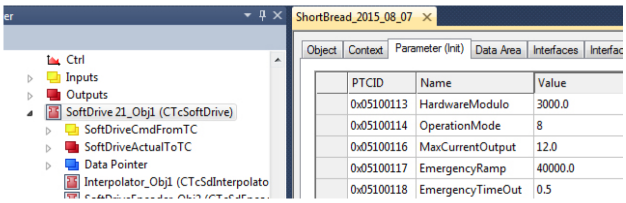
Velo Step Sequence command

Step 4



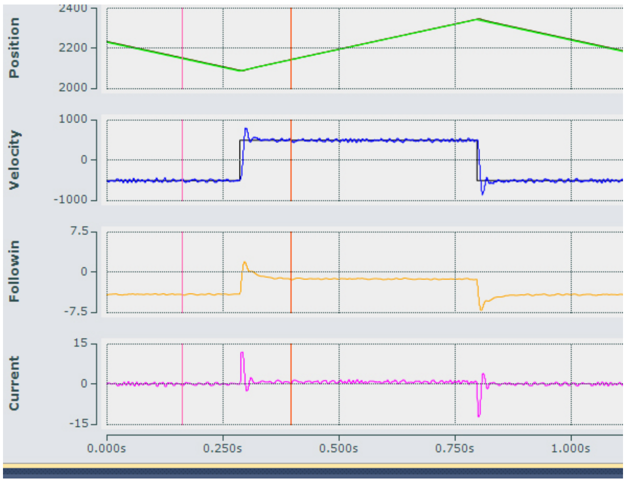
Step 5

When using the Velo Step Sequence the Operation Mode of the Axis also has to be changed from Operation Mode 8 (Cyclic Synchronous Position Mode) to Operation Mode 9 (Cyclic Synchronous Velocity Mode)



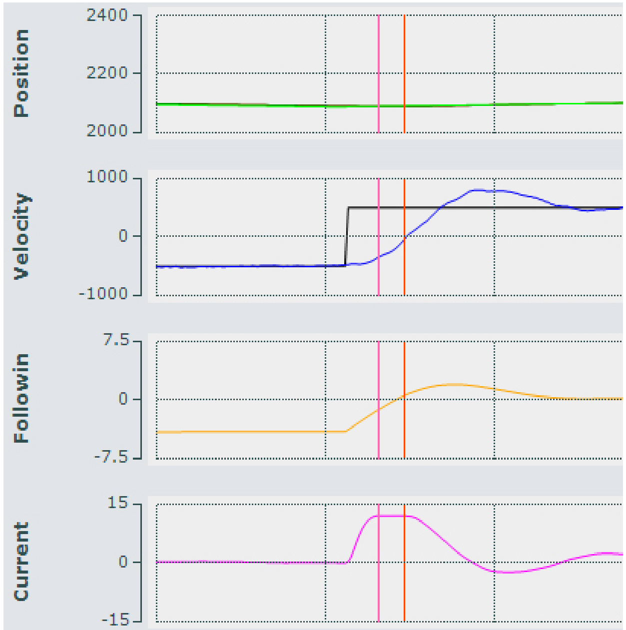
Step 6

With the previous velocity step sequence command the axis will drive forward at 500mm/s for 0.5 seconds and then reverse at -500mm/s for 0.5 seconds.



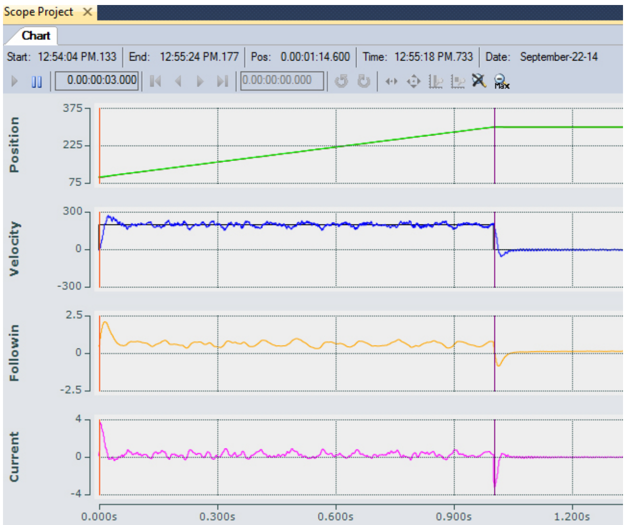
Step 7

With this configuration it is much easier to tune the Velocity control loop. Using standard motor control tuning practices the velocity should have an over shoot of approximately 10% without reaching current saturation. In the above example we see that the current is being saturated and a lower velocity command must be used.



Step 8

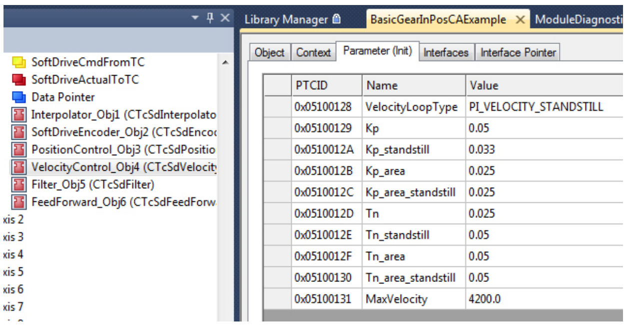
Adjusting the command to a command value of +/-200mm/s gives a usable value with the below graph



Step 9

The +/-200mm/s command reaches a peak current of less than 4A and the peak velocity is 257mm/s, 25% % overshoot. This can be minimized somewhat but the velocity ripple of an XTS system is generally quite large.

The parameters to be adjusted are the Kp Parameters and the Tn Parameters.

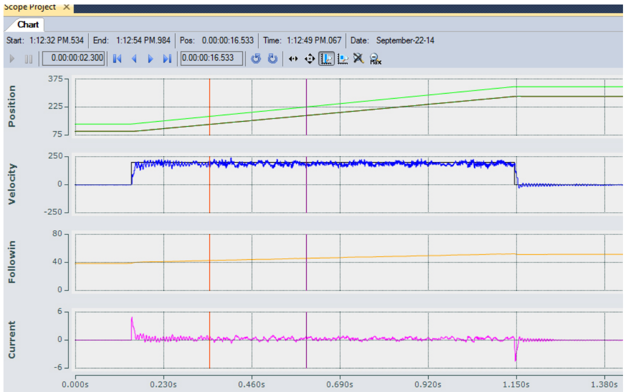


5.5.2.4 Tuning the Velocity Kp Value

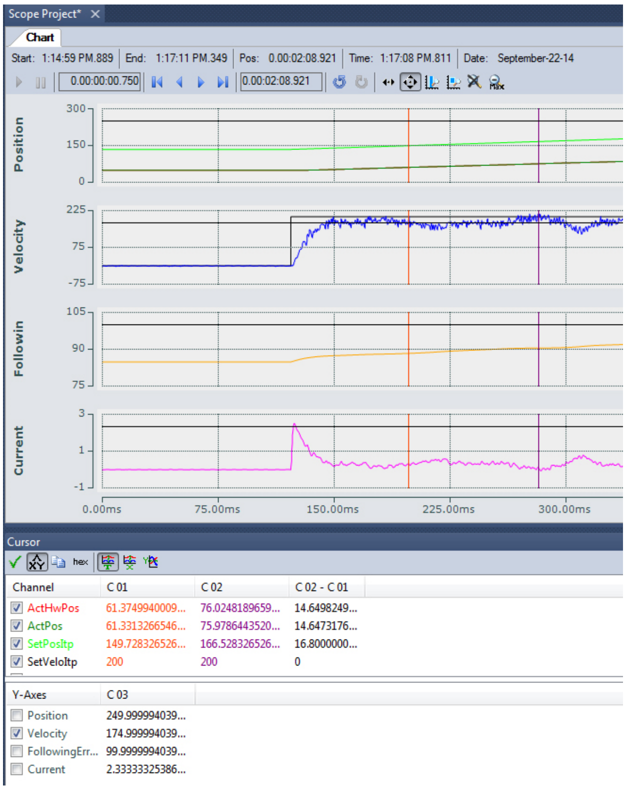
First set Tn to 0

With Tn Set to zero the mover is no longer looking at the error over time and the velocity will be a little low. Kp can now be initially adjusted so that it brings the velocity to 80-90% of the commanded velocity. Kp should never be set below 0.025.

In this picture you see that the value of Kp is too high.



Kp set to reach ~90% of the commanded velocity



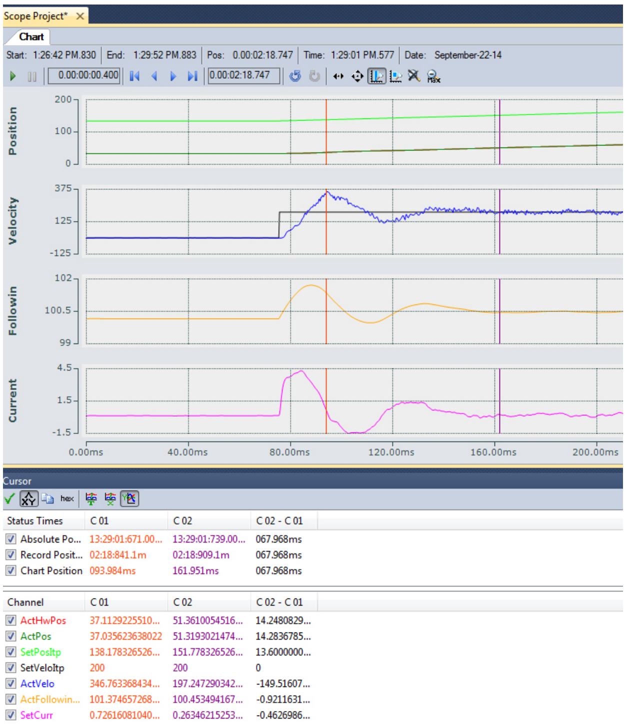
In this case a Kp of 0.45 has been selected

5.5.2.5 Adjusting Tn for the Velocity Control Loop

To make up the last bit of difference between Command Velocity and Actual Velocity an integral is necessary. Kp is simply a multiplication factor between actual velocity and set velocity. This integrates the difference between the actual velocity and set velocity over time. A long integral time constant (Tn) will cause the error will be integrated over a longer time resulting in a slower softer response. Reducing the Tn will give the system a faster harder response. The target is to have the velocity overshoot by about 10% and settle quickly.

Step 1

With Tn set too low we see the response is very hard, the target velocity is reached within 30ms but the velocity continues to increase overshooting the target velocity of 200mm/s by 75% and reaches a maximum of 350mm/s



Step 2

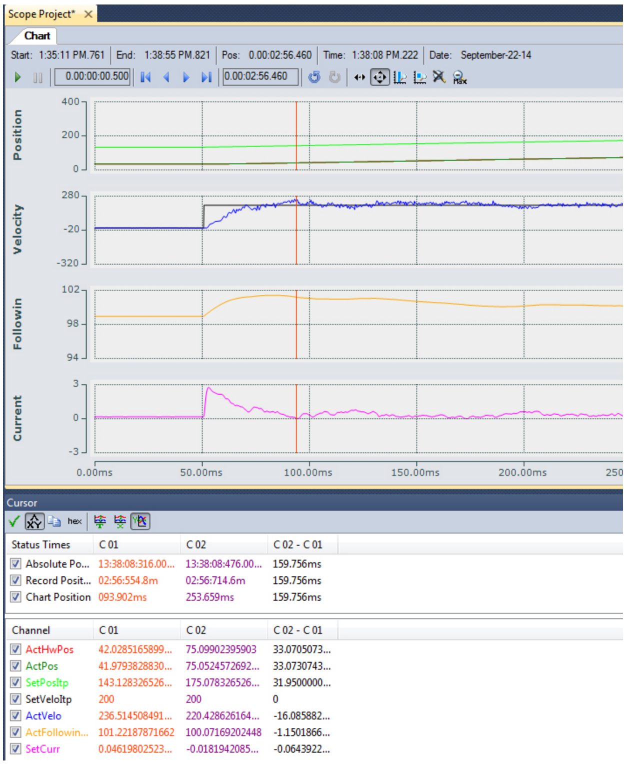
Next Step, increase Tn

With Tn too high, the mover reaches the commanded velocity but it takes over 50ms to get and there is still a definite oscillation above and below the commanded velocity even after 100ms

Step 3

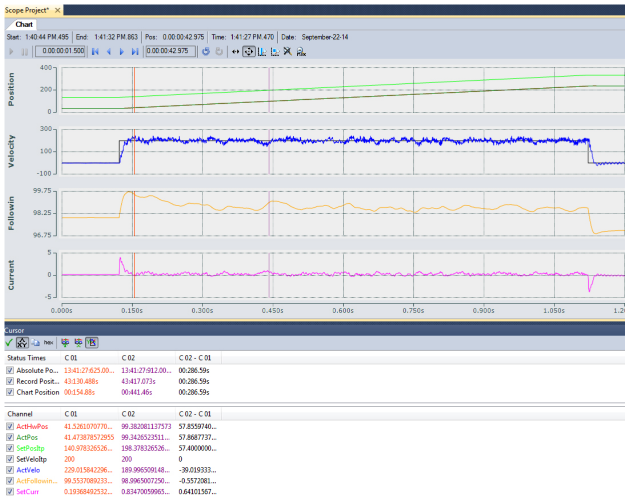
Correctly selecting the Tn Results in a proper response

The overshoot is slightly higher than 10% but the requested velocity is initially reached within 40ms and holds a constant velocity.



Step 4

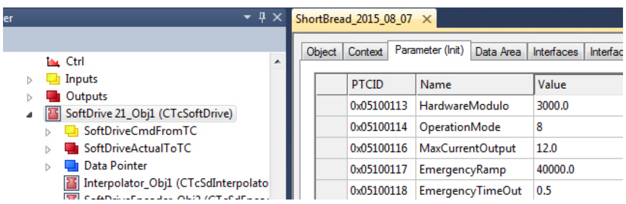
Kp can now be increased or decreased slightly to give us a final velocity tuning



With the velocity loop tuned the Position control loop can now be tuned.

Important!

Return the Operation Mode to Operation Mode 8 prior to continuing.



The Operation mode of the axis must be set back to Mode 8 to allow Position Control

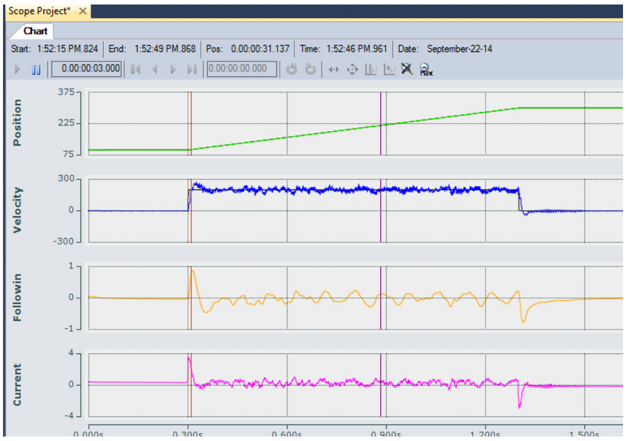
5.5.2.6 Tuning the Position Control Loop

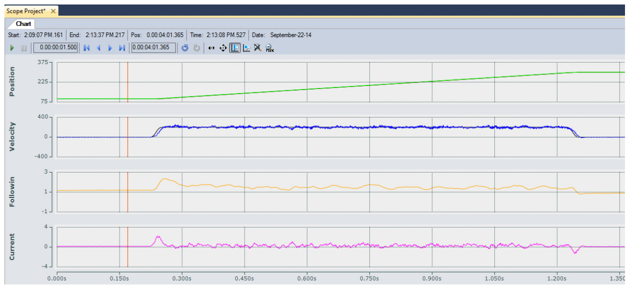
Step 1

With the velocity loop tuned, the position control loop can now be adjusted. If the velocity loop is not well tuned, it is impossible to tune the position control loop. To tune the Position Control Loop the Reversing sequence command is necessary. The Velo Step Sequence is only concerned with velocity. To tune the position loop it is important to select parameters which are actually achievable. Commanding an acceleration which is not possible will result in a very large lag distance at the beginning and there is no point in trying to tune for a move which cannot be physically performed.

Step 2

With a realistic move command it can now be seen that the axis could follow this move. What is achievable will depend on the mass mounted on the mover.





5.5.2.6.1 Setting Initial Position Control Values

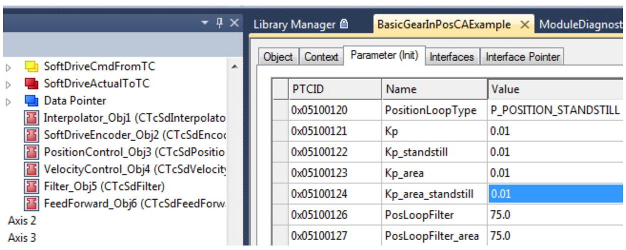
Step 1

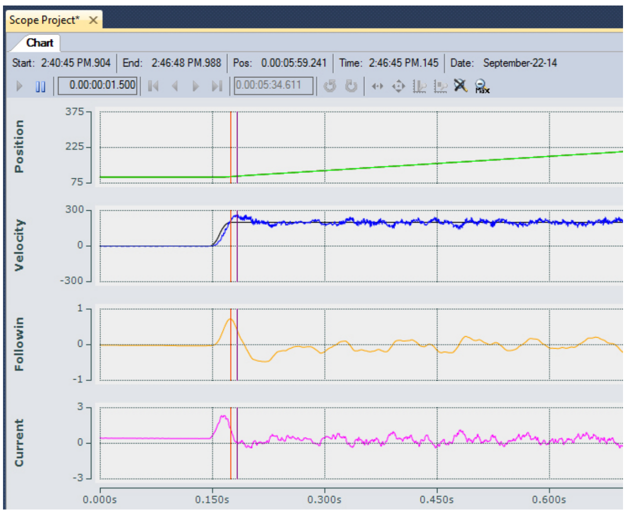
With this reversing sequence selected, the positon control loop can now be tuned and initial values can be written into the Position Control Kp Standstill and Kp values.

With the Control Loop parameters enabled with low values: Kp= 0.01 Kp_Standstill = 0.01

Step 2

The mover used in this example has a mass of approximately 650g and as such it builds up a significant lag during the acceleration and deceleration phases. The slope of the velocity actual velocity matches the commanded velocity however is just slightly late. The mover can achieve the requested acceleration however it should start earlier. This can be overcome with some acceleration feed forward. This is set in the Feed Forward object.





5.5.2.6.2 Setting the KpAccFFT Value

Step 1

Object | Context | Parameter (Init) | Interfaces | Interface Pointer

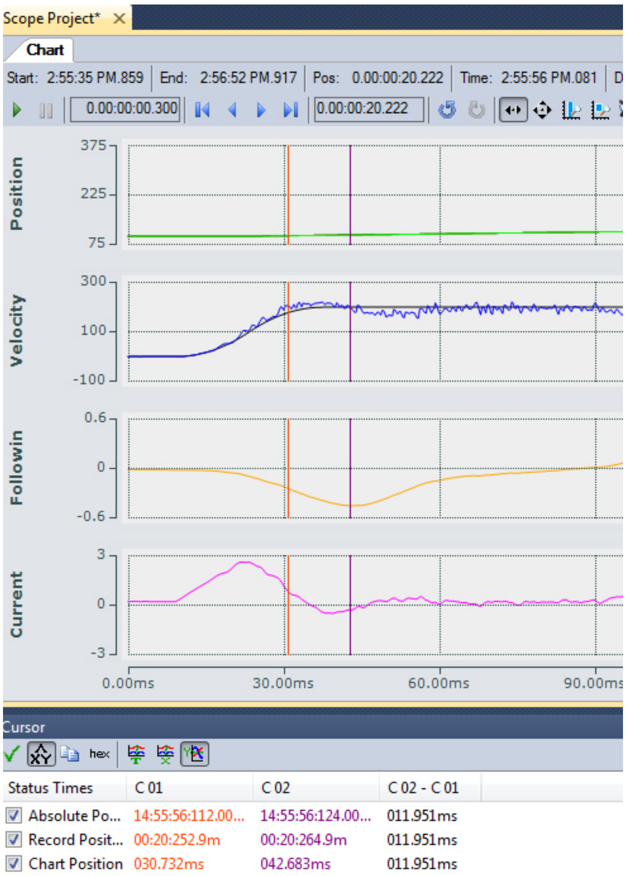
Name	Value
FeedforwardType	FFT_ON
KpAccFFT	1.0
KpAccFFT_area	1.0
OpenLoopMoveCurrent	3.0
AreaCurrentLimit	0.0

If the **KpAccFFT** is to low then the mover is not given enough initial current to accelerate fast enough and the mover lags behind its set position. If the **KpAccFFT** is too high, too much extra current is applied resulting in a faster acceleration than the commanded acceleration.

Step 2

Initial adjustment of the **KpAccFFT**

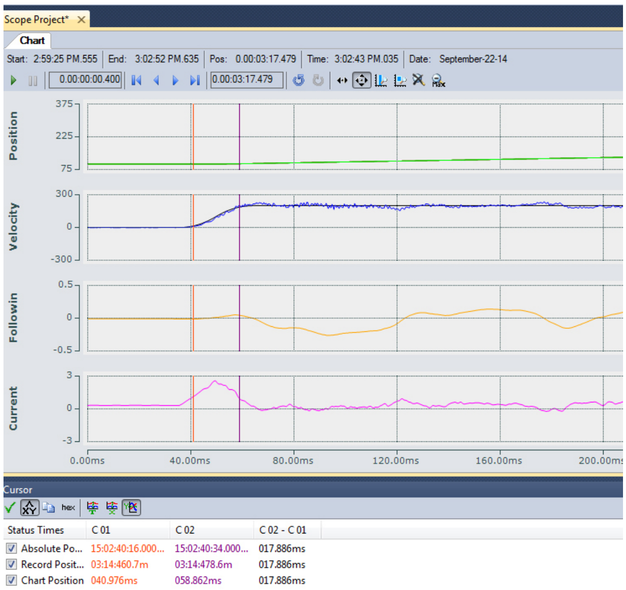
If **KpAccFFT** is too high the mover will accelerate faster than expected and the mover will be ahead of its commanded position. Here we see the following error is negative the mover is moving too fast. This may not seem to be a bad thing however it will be repeated on the stopping side, resulting in the mover stopping before the target position is reached and then having to accelerate once again to come into position, this results in a long settling time.



Step 3

KpAccFFT should be adjusted so that the mover has nearly zero (but not negative) lag during the acceleration phase.

With **KpAccFFT** set correctly there is very little lag built up during the acceleration/deceleration phases. Depending on the mover/track it may be that the mover decelerates faster than it accelerates. In that case **KpAccFFT** may need to be set in such a way that there is some lag during acceleration, but the mover decelerates properly without stopping prior to reaching the target position.



5.5.2.6.3 Adjusting final Kp and Kp_standstill

Step 1

The Kp moving and Kp standstill can now be adjusted so that the Following error is as small as possible throughout the move.

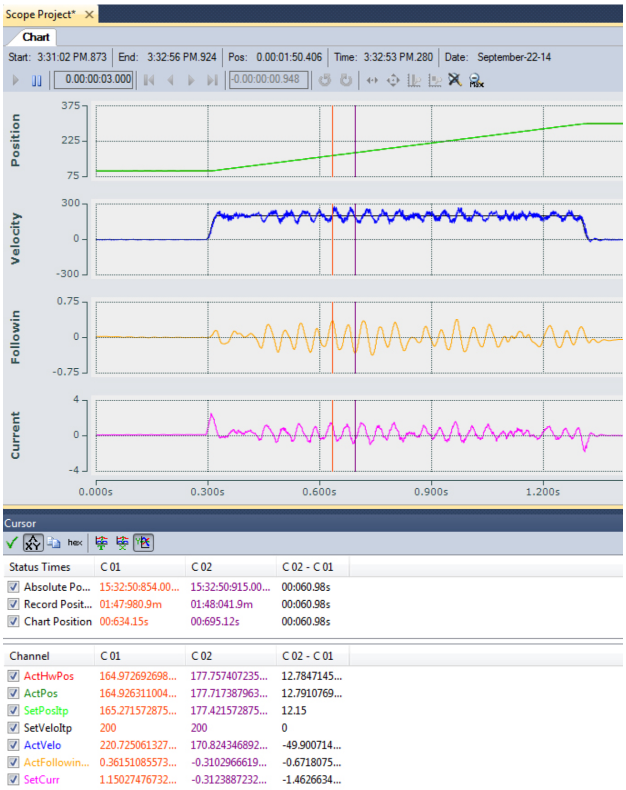
Adjusting the Position Control Loop Kp too high will result in a system that attempt to react too strongly.

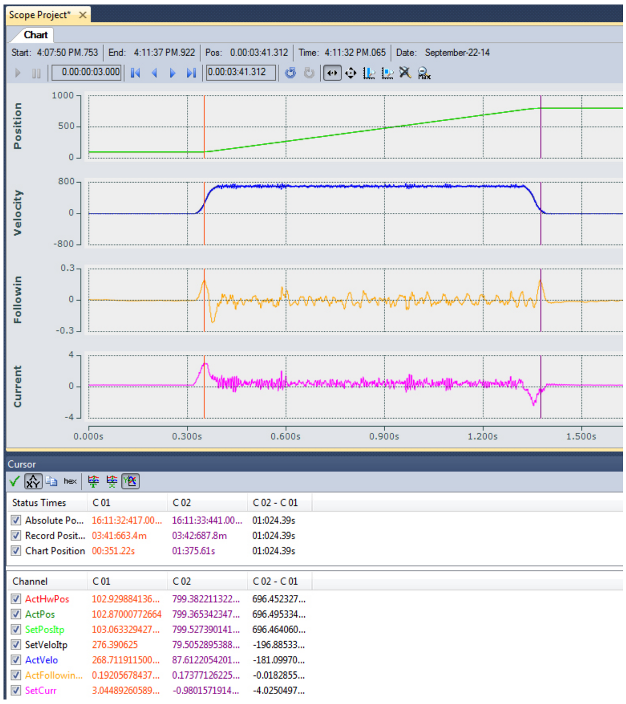
Step 2

Well-Tuned System:

On acceleration and deceleration a maximum of 0.19mm lag distance is reached. This system is quite well tuned on the straight sections. Kp is required in order to attain and hold position the position control loop Kp should never be below 0.01 or position control can never be attained.

Position Control Kp_standstill and Velocity Control Kp_standstill are critical in having the mover hold position. The mover must be able to hold position even when disturbed by an external force. Velocity Control Kp_standstill should never be less than 0.02 and Kp_standstill should never be lower than 0.01.





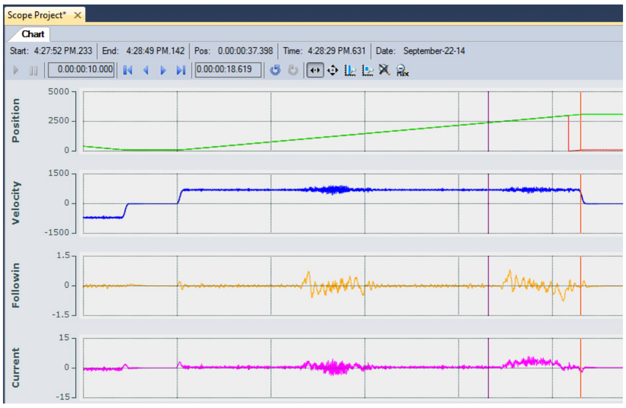
If the mover requires tuning values outside the recommended settings, the mover will not be able to attain and hold position and the mechanical construction of the tooling mounted to the mover should be re-designed. Pay particular attention to Project Planning guide which describes the physics and effects of various loads on the mover.

5.5.2.7 Tuning in the Curve

With the straight section tuned, the curves can be given separate tuning parameters if necessary. Here an entire loop of the track is run; it is very evident which sections of track correspond to the curves.

Step 1

This system is a vertical system as such the load must be lifted and lowered through the curve. Also the center of gravity on this system is about 2cm from the magnets. This has a very large effect for how the system travels through the curve.



Step 2

To enable the Tuning parameters for the curve first the Control Areas must be defined. This system has 2 curves one starting at 1000mm to 1500mm and one from 2500mm to 3000mm

0x05100119	ControlAreas	[..., ...]	2 (Array Elements)
	[0].IsEnabled	TRUE	
	[0].reserved	0	
	[0].StartPosition	1000.0	
	[0].EndPosition	1500.0	
	[0].TransitionLength	30.0	
	[1].IsEnabled	TRUE	
	[1].reserved	0	
	[1].StartPosition	2500.0	
	[1].EndPosition	3000.0	
	[1].TransitionLength	30.0	

Step 3

Then the Position Control Loop needs to be set to P_POSITION_STANDSTILL_AREA

The values in Kp_area, Kp_area_standstill and PosLoopFilter_area are now active when the axis is in a defined and enabled Control Area

ject | Context | Parameter (Init) | Interfaces | Interface Pointer

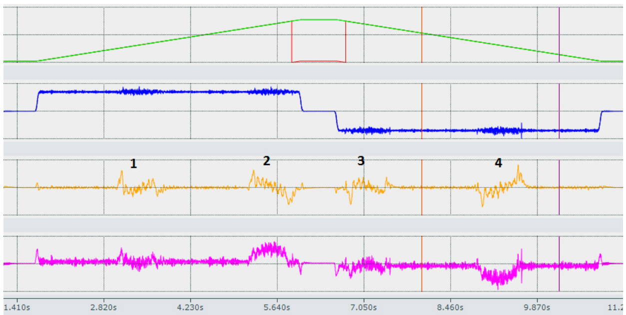
PTCID	Name	Value
0x05100128	VelocityLoopType	PI_VELOCITY_STANDSTILL_AREA
0x05100129	Kp	0.05
0x0510012A	Kp_standstill	0.033
0x0510012B	Kp_area	0.025
0x0510012C	Kp_area_standstill	0.025
0x0510012D	Tn	0.025
0x0510012E	Tn_standstill	0.05
0x0510012F	Tn_area	0.05
0x05100130	Tn_area_standstill	0.05
0x05100131	MaxVelocity	4200.0

Step 4

This allows the Kp_area and PosLoopFilter_area parameters to be used.

The velocity Loop must be set to PI_VELOCITY_STANDSTILL_AREA

With the Area parameters enabled, Kp_area and Tn_area, Kp_area_standstill and Tn_area_standstill are now active when the axis is within a defined and enabled Control Area.



Depending on the location of the center of gravity on the mover and the orientation of the XTS It is much more difficult to tune the system in the curves and it simply will not behave as well as when in the straight sections.

Section 1 is entering the curve and lowering the mover. Section 2 entering the curve and lifting the mover. The motion is then reversed and 3 is running through the same curve as section 2 only backwards and lowering the mover, and section 4 is running through the curve lifting the mover. As the mover is lifted more current is applied as the mover rounds the corner less current is required and the mover overtakes its target positions.

The same sequence for tuning the straight section can be used to tune the curves. Once the area is defined:

Disable the Position Control Loop:

- Position Control Kp_area
- Position Control Kp_area_standstill

Tune the velocity control loop (in this case Velo Step Sequence may not be possible):

- Velocity Control Kp_area
- Velocity Control Tn_area
- Velocity Control Kp_area_standstill
- Velocity Control Tn_area_standstill

Enable and tune the Position Control Loop:

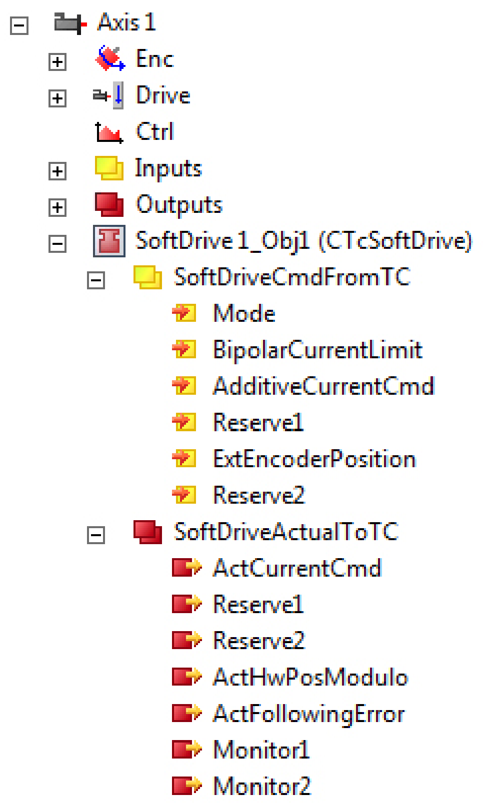
- Position Control Loop Kp Area

The mechanics of what is mounted to the mover will dictate how well it can be tuned. The ideal location for the center of gravity is centered directly between the magnets of the mover as this is where the force is applied. Adding a counter weight will increase the mass but can also drastically reduce the oscillations of the mover, particularly in the curve. Also adding a rubber buffer or a tuned mass damping system can drastically reduce mechanical oscillations. It can be that stiffer is not better. When a system is properly tuned it should follow the move very closely, different systems and different loads will have different results. However when properly fitted with tooling and load the mover should be able to follow the command with a lag distance of <1mm during acceleration and <+/-0.25mm at speed. Stopping should settle within +/-0.01mm within less than 100ms.

If no settings can be found that prevent oscillations, or give the desired settling time and response, the construction of the load must be re-designed OR a new mover type could be used. (50mm 12 roller mover or 70mm mid-range mover) Refer to the project planning guide for load design.

5.6 Soft Drive Cyclic I/O Variables

The soft drive contains parameters that can be cyclically updated from any other TwinCAT cyclic process; these values are typically linked to the PLC.



The feedback Values (Soft Drive Actual To TC) are available and simply need to be linked. Reserve 1, Reserve 2, Monitor 1 and Monitor 2 are for future use. The Actual Current Command, Actual HwPosModulo and ActFollowingErrror are available every 250us XTS cycle and can be linked to track the actual values. (Do not use these values for Scoping and Tuning, use the SdSoftDriveScope values.

For the input parameters into the Soft Drive

Mode: switch the use of the other command values and the Soft Drive operation mode

- Bit 0..7 (0x00FF): set the SoftDrive operation mode (CSP, CSV, CST, CSTA)
- Bit 8 is set (0x0100): the additional BipolarCurrentLimit is used
- Bit 9 is set (0x0200): the ExtEncoderPosition is used as position feedback
- Bit 10 is set (0x0400): the AdditiveCurrentCmd is used as additional current command or in operation mode CST & CSTA the value is used as current command (current orforce control mode)

BipolarCurrentLimit: set an additional cyclic bipolar current limit in milli Amps.

AdditiveCurrentCmd: set an additional cyclic feedforward current in per mill of the rated motor current or set the used current command in OPMODE CST or CSTA.

ExtEncoderPosition: use an position from another encoder (or mover) as position feedback for control loop and commutation the scaling and offset could be set by the parameter „SoftDriveExternalEncoder“ this parameter should only be used after consultation with Beckhoff Automation as dead times and other factors must be determined.

Take care when enabling and adjusting these values enabling a mode takes place immediately (250us) same for restrictions on the current. Switching from a restriction of 5N to unrestricted (100N) will happen immediately and the mover will jump. Ramping the values up or down may be necessary.

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