EtherCAT commands – Xeryon stages & actuators

EtherCAT commands

Remarks

- Commands and settings used via USB or EtherCAT are mostly identical, however there are some differences.
- The USB commands and settings go through a microcontroller which transfers them to the FPGA. Some of these settings are translated by the microcontroller into different settings on the FPGA.
- The settings sent via EtherCAT go straight to the FPGA and cannot be saved on the controller. They will be lost after a power cycle.
- The settings sent via USB can be saved on the controller and will be the default values in case the setting is not provided via EtherCAT.
- The EtherCAT commands are based on the same functionality as the commands over USB. Where possible we adapt the functionality to be as close as possible to the functionality specified by the MC library.
- An important difference between USB and EtherCAT is that certain commands in EtherCAT take multiple parameters as where the USB commands have only one parameter. DPOS, INDX and SCAN have the whole motion profile included in a single EtherCAT message.

EtherCAT message

The EtherCAT message contains the following registers. These are also described in the XML file.

Register	Width	Data flow	Use
Command register	32 bits	PLC -> controller	4 letter ASCI command
Data register 1	32 bits	PLC -> controller	Main parameter for command
Data register 2	32 bits	PLC -> controller	Velocity
Data register 3	16 bits	PLC -> controller	Acceleration
Data register 4	16 bits	PLC -> controller	Deceleration
Execute register	8 bits	PLC -> controller	Execute command
Actual position	32 bits	Controller -> PLC	Feedback about actual position
Status	24 bits	Controller -> PLC	Feedback about status, errors, mode of operation
Slot position	8 bits	Controller -> PLC	Locate blade on backplane

The registers are also described in the XML file. A more detailed description is in appendix A.

Commands

Equivalent for MC_MoveAbsolute

Command name

DPOS

Description

Move to target position. The stage follows a motion trajectory towards the target defined by speed, acceleration and deceleration parameters. Closed-loop control is used to reach and maintain the new position. The target position is expressed in encoder units. Positive and negative values are allowed.

When the index location is not yet known, the target position will be set with respect to the location at power-up (encoder is zero after power-up). In the TwinCAT implementation, a NO_INDEX error will be produced when the index location is not yet known, and the DPOS command will not be executed.

When the target position is reached the motor is switched off and the 'position reached' status bit is set to 1. The controller remains is closed loop. When a disturbance causes the actuator to go outside the tolerance limits, it will automatically become active again to settle again within the tolerance limits. To prevent this, send a HALT command.

Procedure

- Check if controller is enabled
- Check if index location is already known
- Set execute register to 0
- Set target position in register 1
- Set speed in data register 2
- Set acceleration in data register 3
- Set deceleration in data register 4
- Write 'DPOS' in the command register
- Set execute register to 1
- Check acknowledge bit to see that command has been processed
- Wait for the Position Reached status bit to go high.

Errors

- Controller not enabled: when the controller is not enabled, the controller will not process the DPOS command. No error will be produced by the controller, but the TwinCAT code will do. To recover, send ENBL=1.
- NO_INDEX: When a DPOS command is executed without the index location known, a NO_INDEX error will be generated by the TwinCAT code. This error is not produced at the controller level. To recover: send ENBL=1.
- Follow error: when the actuator cannot stay within the maximum follow error limit set by ELIM, then a follow error will be produced, the follow error status bit will be raised, and the actuator will be stopped. Depending on the BLCK settings further movement will be blocked by the controller until ENBL=1 is sent. The TwinCAT code will also block further movement unless ENBL=1 is sent, regardless of the BLCK settings.
- Position fail: if the timeout (TOU3) for settling at the target position is exceeded, then the actuator will be stopped and a position fail error generated. Depending on the BLCK settings

further movement will be blocked by the controller until ENBL=1 is sent. The TwinCAT code will also block further movement unless ENBL=1 is sent, regardless of the BLCK settings.

- Safety timeout: If the motor is active for a time larger than the safety timeout (TOU2) then the actuator is stopped and a safety timeout error is generated. Depending on the BLCK settings further movement will be blocked by the controller until ENBL=1 is sent. The TwinCAT code will also block further movement unless ENBL=1 is sent, regardless of the BLCK settings.

Equivalent for MC_Jog

Command name

SCAN

Description

Continuously move with fixed speed. The speed is maintained by closed-loop control. The direction is specified in the first parameter. Data register1 = +1 sends the stage towards increasing encoder values, -1 sends the stage towards decreasing encoder values. A zero value stops the movement. The stage stops also when the soft limits (LLIM and HLIM) are reached, however, these soft limits are only functional when the index location is known.

SCAN functions also when the index location is not known and produces no warning or error for that situation. As long as the index location is not known, the soft limits do not work, resulting in a risk that the stage stays active while pushing against a hard limit. Therefore it is advised to first perform an INDX command.

The MC library also has a mode parameter not mentioned in the specification document. BSE uses MC_JOGMODE_CONTINOUS (source Scott Sutherland).

The SCAN motion can be stopped by SCAN=0, STOP or HALT.

Procedure

- Check if controller is enabled
- Set execute register to 0
- Set direction in register 1
- Set speed in data register 2
- Set acceleration in data register 3
- Set deceleration in data register 4
- Write 'SCAN' in the command register
- Set execute register to 1
- Check acknowledge bit to see that command has been processed
- Potential checks while moving
    - Status bit 'Motor on' should be high
    - Status bit 'Left end stop' should remain low when moving left.
    - Status bit 'Right end stop' should remain low when moving right.
    - Status bit 'Endstop bit' combines previous two bits, depending on direction.
- Send SCAN=0, STOP or HALT to stop the motion.

Errors

- Controller not enabled
- Follow error
- Safety timeout

See DPOS for more details about these errors.

Command for finding the index

Command name

INDX

Description

Find the index. A direction bit indicates the initial search direction. INDX=0 starts in descending encoder direction, INDX=1 starts in ascending encoder direction.

The controller sets off in the specified direction to search. When the stage reaches a mechanical limit it reverses the search direction. A mechanical limit is detected when the following error exceeds the ILIM parameter.

It has to reverse at a mechanical limit before the actual detection is switched on.

After finding the index, the encoder count is reset to zero and corrected with an offset. At the same time, the 'index found' aka. 'encoder valid' status bit is set to 1. The stage is then positioned at the zero position (after correcting with the offset). The offset is set with the ENCO command.

The speed during the search is set by the ISPD parameter. After detecting the index, the speed is again the value set by SSPD.

The soft limits LLIM and HLIM will become active after the index is found.

In case the INDX command is given when the index location is already known, the stage will go directly to the zero position (equals DPOS=0).

The encoder can be reset (index location lost) using the ENCR command. This resets only the encoder without losing other settings.

The INDA command can alter the index detection method: with INDA=1 you can specify that the index is found automatically when moving over it, e.g. during a SCAN (JOG) command. With that setting, the index will also be detected without first hitting the mechanical end limits. Default INDA=0.

The follow error is temporarily switched off during an index location search.

Procedure

- Check if controller is enabled
- Set execute register to 0
- Set direction in register 1
- Set speed in data register 2
- Set acceleration in data register 3
- Set deceleration in data register 4
- Write 'INDX' in the command register
- Set execute register to 1
- Check acknowledge bit to see that command has been processed
- Wait for the index found status flag to go high
- Wait for the position reached flag to go high to be sure that the actuator has settled at the zero position.

Errors

- Controller not enabled
- Position fail (when finally positioning at the zero position)
- Safety timeout

See DPOS for more details about these errors.

Equivalent for MC_Reset

Command name

RSET

Description

Reset the controller. This has the following effects:

- Any motion is immediately stopped and motor signals go down.
- The controller is brought into the disabled state.
- All settings are replaced by the standard values saved on the controller. These values can be uploaded via USB, followed by the SAVE command.
- Encoder position is set to zero and the location of the index position is lost.
- Communication between the controller and the EtherCAT board is briefly stopped but the EtherCAT board is not reset. Connection to EtherCAT is not lost.
- The reset does not cause a power cycle.

The settings that are to be controlled over EtherCAT should be sent again over EtherCAT after a reset.

Alternatives:

- If you want to reset the encoder, there is a command ENCR that only resets the encoder. All other values remain unchanged.
- If you want to clear error signals, use the ENBL command.

Procedure

- Set execute register to 0
- Write 'RSET' in the command register
- Set execute register to 1
- Wait a second (or less; the microcontroller and FPGA startup time is very short)
- Alternative: check status bit

Equivalent for MC_Power

Command name

ENBL

Description

Enables or disables the controllers motor signals. Send ENBL=1 to enable, ENBL=0 to disable. To recover from an error, send ENBL=1.

When disabled, no motor signals will be generated. These signals will be kept at zero Volt. However, other functions of the controller remain functional. It still receives and processes commands and settings and still gives feedback about position, status, etc.

Equivalent for MC_Halt

Command name

HALT

Description

Stop the actuator without blocking further motion commands. The motor is simply switched of and the friction between the motor and actuator rod causes it to stop and then stay locked into position. No specific motion profile is followed during the stop. The position reached flag is not raised and the actuator is no longer in closed-loop control. This means that there will be no reaction when the actuator is disturbed by external forces and moved away from the position where it came to a halt.

Equivalent for MC_Stop

Command name

STOP

Description

Stops the actuator in the same way as HALT, but blocks further motion commands and raises the emergency stop flag in the status word. Send ENBL=1 or RSET to recover from this error.

There may be confusion when using STOP via the USB interface: there it has the meaning of MC_Halt (simple stop) without blocking effect.

Motion parameters

Parameter	Name	Register size	Range	Meaning
Target position / direction	-	26 bits	+/- 33554431	Target position in case of a DPOS command. Direction (-1,0,1) for INDX or SCAN.
Speed	SSPD	20 bits	0 - 1048575	Set speed. Used as scanning speed (SCAN command) and as target speed towards the next target position (DPOS and STEP). Unit is 1 µm/s. Speed is always positive. Direction is set by the direction bit.
Acceleration	ACCE	16 bits	0-65535	Set acceleration for speed profile. Expressed in m/s2. Default value: 65000
Deceleration	DECE	16 bits	0-65535	Set deceleration for speed profile, when approaching target position. Default value: 65000
Jerk	-	-	-	Not implemented. Not important for systems with low mass.

Parameters speed, acceleration and deceleration apply to all closed loop motion.

List of errors

The errors are part of the status word.

Error	Bit location	Meaning	Applicable ?	Recover from error	How to avoid ?
Thermal protection 1	Status bit # 2	Thermal overload of piezo amplifier 1	Not applicable to XD-custom controller	ENBL or RSET	
Thermal protection 2	Status bit # 3	Thermal overload of piezo amplifier 2	Not applicable to XD-custom controller	ENBL or RSET	
Encoder error	Status bit # 12	Error produced by the encoder	Not applicable to XD-custom controller or XLA actuators	Clean encoder strip / send in for repair	Avoid touching the encoder strip.
Error limit	Status bit # 16	The following error has reached the limit set by ELIM. This can indicate a collision, or the motor not strong enough to produce the acceleration and speed required by the trajectory.	Yes	ENBL or RSET	• Increase ELIM • Switch off by setting ELIM=0 • Adapt motion profile
Safety timeout triggered	Status bit # 18	This defines a safety timeout. When the motor is on for a time longer that the value set by TOU2, then the controller goes in safe mode and the motor signals are switched off. TOU2=0 disables this timeout. Any other value sets the timeout time in seconds. Maximum value: 65535 seconds	Yes	ENBL or RSET	Send a STOP or HALT command
Emergency stop	Status bit # 20	This error is triggered by the STOP command.	Yes	ENBL or RSET	Use HALT instead of STOP.
Position fail	Status bit # 21	The actuator did not settle at the target position within the specified time (TOU3).	Yes	ENBL or RSET	Increase TOU3, PTOL or PTO2.
Left end stop	Status bit # 14	Indicates that the low end stop is passed. When the index location is not yet known, this	Yes	Move away from left end limit	Restrict motion commands within the

		status bit will always remain low.			range of hard and soft limits
Right end stop	Status bit # 15	Indicates that the high end stop is passed. When the index location is not yet known, this status bit will always remain low.	Yes	Move away from right end limit	Restrict motion commands within the range of hard and soft limits
End stop	Status bit # 1	Combination of 'Left end stop' and 'Right end stop', depending on direction. End stop is high when trying to move further into the already reached end limit. End stop is low when trying to move away from an already reached end limit.	Yes	Move away from end limit	Restrict motion commands within the range of hard and soft limits

Busy/ready signals

The busy signals are part of the status word, except for ECAT busy and ECAT done which are generated by the TwinCAT code.

Signal	Bit location	Meaning
Enabled	Status bit # 0	The controller is enabled. No motion signals can be generated while not enabled.
Motor on	Status bit # 5	The piezo motor is on. This means the stage is busy performing a motion trajectory, open loop or closed loop, or trying to settle on the target position. This signal is also displayed on the yellow LED on the controller board.
Searching index	Status bit # 9	The stage is searching the index after an INDX command is given. This status bit may remain high after finding the index as it rather indicates a mode of operation than the actual movement taking place.
Scanning	Status bit # 13	The stage is in scanning mode, moving with constant speed without a specific target position. The stage will stop when it reaches the soft limits (LLIM or HLIM). This status bit may remain high after reaching the soft limits as it rather indicates a mode of operation than the actual movement taking place.
Position reached	Status bit # 10	The stage has reached its target position within the specified tolerance. See PTOL, PTO2 and TOUT to specify the positioning tolerance. See also DLAY and TOU3.
ECAT busy		
ECAT Ack	Status bit # 19	Generated by the controller to indicate that the EtherCAT command has been received and is being processed.
ECAT done		

Other status bits

Signal	Bit location	Meaning
Force zero	Status bit #4	Motor signals are suppressed
Motor on	Status bit #5	Motor is on (excitation signals sent to motor)
Closed loop	Status bit #6	The control is in closed loop
Encoder index	Status bit #7	The actuator/stage is exactly on the encoder index location
Encoder valid	Status bit #8	The encoder index location has been detected

List of commands and settings

A: Action
S: Setting

CL: closed loop
OL: open loop

I. Closed-loop motion commands with 4 arguments (complete motion profile)

These commands take 4 arguments

- First argument: depends on the command
  - DPOS: target position
  - INDX: 0 or 1 to indicate direction
  - SCAN: -1, 0, 1 to indicate direction
  - HOME: not used
- Second argument: velocity (same as SSPD)
- Third argument: acceleration (same as ACCE)
- Fourth argument: deceleration (same as DECE)

	Command	Range	Mode	Units	Default value	Explanation
A	INDX	0, 1	CL	-	-	Find the index. A value of 0 or 1 indicates the initial search direction. The controller sets off in the specified direction to search. When the stage reaches a mechanical limit (detected by position error > ILIM) it reverses the search direction. Only after this reverse the index detection is activated. After finding the index, the stage is positioned at the index position.
A	HOME	-	CL	-	-	Go to the home position. This equals DPOS=0
A	DPOS	26 bits	CL	Encoder units	-	Set target position. Closed-loop control is used to reach and maintain the new position. Argument 1: The position is expressed in encoder units. Positive and negative values are allowed within the range of the stage.
A	SCAN	-1,0,1	CL	-	-	Continuously move with fixed speed. The speed is maintained by closed-loop control. A positive number sends the stage towards increasing encoder values, a negative number sends the stage towards decreasing encoder values. A zero value stops the stage.

II. Closed-loop settings for motion profile

The motion profile settings can be set directly through these commands.
These commands take 1 argument.

S	SSPD	20 bits	CL	µm/s	500000	Set speed. Used as scanning speed (SCAN command) and as target speed towards the next target position (DPOS and STEP).
S	ISPD	20 bits	CL	µm/s	5000	Set the speed which is used while searching the index.
S	ACCE	16 bits	CL	mm/s^2	65000	Set acceleration for speed profile.
S	DECE	16 bits	CL	mm/s^2	65000	Set deceleration for speed profile.

III. Open-loop motion

These commands take 1 argument.

	Command	Range	Mode	Units	Default value	Explanation
A	MOVE	-1,0,1	OL	-	-	Continuously move in open loop. Phase and amplitude influence the speed, but speed is not controlled. A positive number sends the stage towards increasing encoder values, a negative number sends the stage towards decreasing encoder values. A zero value stops the stage.
S	PHAS	16 bits	OL	-	16383	Set the phase offset between the excitation signals. Can be used to control the speed in open loop. Input values 0-65535 correspond to a phase shift of 0-360°. Around 16384 the phase corresponds with a MOVE=1 direction, around 49152 (=-16384) it corresponds to a MOVE=-1 direction.
S	AMPL	16 bits	OL	-	65535	Set amplitude for open-loop piezo excitation signals. 65535 equals maximum amplitude (48 V peak-to-peak).

IV. Open- and closed-loop motion

These commands take 0 or 1 argument.

	Command	Range	Mode	Units	Default value	Explanation
A	STOP	-	OL & CL	-	-	Emergency stop: the actuator is stopped and further motion actions are prohibited. Motion actions are enabled again after a reset or enable command.
A	HALT	-	OL & CL	-	-	Stop the stage without disabling further motion commands.
A	CONT	-	OL & CL	-	-	Continue movement after a stop command.

S	ENBL	1 bit	OL & CL	-	-	Used to enable/disable controller. Also used to recover from an error. ENBL=1 enables the controller and clears the errors. ENBL=0 disables the controller.
S	RSET	-	OL & CL	-	-	Reset the driver. All piezo signals go to zero and settings are reset to their saved value.
S	BLCK	3 bits	OL & CL	-	0	Determine which errors block further motion commands.
V. Control and tuning parameters (stage commands) These commands take 1 argument.						
	Command	Range	Mode	Units	Default value	Explanation
S	FREQ	20 bits	CL	Hz	173000	Set the frequency of the excitation signals for zone 1.
S	FRQ2	20 bits	OL & CL	Hz	169000	Set the frequency of the excitation signals for zone 2. Also used for scanning.
S	FRAT	24 bits	CL			Interpolation factor for frequency. FRAT = (FREQ-FRQ2)/(ZON2-ZON1)*65536
S	PROP	16 bits	CL	-		Proportional control factor for zone 1. Default: 40.
S	PRO2	16 bits	CL	-		Proportional control factor for zone 2. Default: 10.
S	PRAT	24 bits	CL			Interpolation factor for proportional factor. PRAT = (PROP-PRO2)/(ZON2-ZON1)*65536
S	ZON1	26 bits	CL	Encoder units		Width of zone 1: +/- value around target position. Expressed in encoder units. Default: 100.
S	ZON2	26 bits	CL	Encoder units		Width of zone 2: +/- value around target position. Expressed in encoder units. Default: 1000.
S	CFRQ	20 bits	CL	Hz	100000	Control frequency. Adapt this value to obtain stable closed-loop control. The optimal control frequency depends on the mass or inertia of the load.
S	DUCO	1 bit	CL	-		Amplitude is used in closed loop if set to 1. If set to 0, a fixed amplitude of 50% is used. Default: 1.
S	ELIM	20 bits	CL	Encoder units	0	ELIM (error limit) sets the maximum following error. When the following error exceeds the value set bij ELIM, then the controller goes in safe mode and the motor signals are switched off. Recovery: RSET or ENBL=1 This error may be triggered when trying to move beyond the physical limits of the stage, or by setting a too high speed. Do not forget to first find the index position (INDX command) to avoid that the stage travels beyond the end stops and triggers this error. Default: 10000.
S	ILIM	26 bits	CL	Encoder units	3000	Sets the following-error at which the index search algorithm reverses direction. This influences the time the stage stalls at the end position during an index search.

S	PTOL	16 bits	CL	Encoder units	3	Position tolerance. When the stage is within +/- position tolerance of the desired position, the control is switched off and the 'position reached' flag is raised. Values are expressed in encoder units and should be in the range 0 – 65535. The range is applied symmetrically with respect to positive and negative position errors. E.g. PTOL=2 allows s errors between -2 and +2 encoder units. Default: 2. See also TOUT and PTO2.
S	PTO2	16 bits	CL	Encoder units	5	Second position tolerance, similar to PTOL. Comes into action if first position tolerance PTOL fails within a timeout time TOUT. The default value is 10.
S	TOUT	16 bits	CL	ms	500	Set timeout time. To avoid that the stage keeps vibrating indefinitely around the desired position without 'landing', a timeout time can be set. The timer starts when the stage is near the desired position, within a distance of +/- PTO2. After passing the timeout time, PTO2 becomes the new position tolerance. The time is expressed in milliseconds. The default value is 50 (50 ms). Also check PTOL and PTO2.
S	TOU2	16 bits	CL	s	60	This defines a safety timeout. When the motor is on for a time longer that the value set by TOU2, then the controller goes in safe mode and the motor signals are switched off. Recovery: RSET or ENBL=1 Status bit #18 goes up when this timeout is triggered.ss TOU2=0 disables this timeout. Any other value sets the timeout time in seconds. Maximum value: 65535 seconds
S	TOU3	16 bits	CL	ms	1000	Timeout for settling at target position.
S	DLAY	16 bits	CL	ms	20	Delay between reaching the target position and raising the position reached flag.
S	DTIM	16 bits	CL	ms	0	Deadtime. Minimum time before the motor can be switched on after being switched off.
S	INTF	16 bts	CL	-	5	Integration factor.
VI. Signal shape and conditioning (stage commands) These commands take 1 argument.						
	Command	Range	Mode	Units	Default value	Explanation
A	ZERO	-	OL & CL	-	-	Force the piezo signals to zero volt.

S	MAMP	16 bits	OL & CL	-	65000	Set maximum amplitude. The piezo excitation signals are limited to the corresponding voltages. MAMP=65535 sets them to the maximum voltage of 48 V. The relation is linear.
S	MIMP	16 bits	CL	-	5000	Set minimum amplitude for the piezo excitation signals. See MAMP for values.
S	SLOP	9 bits	CL	-	312	Slope for amplitude control: SLOP = (MAMP – MIMP)/192
S	SOFS	16 bits	CL	-	-14968	Offset for amplitude slope: SOFS = MIMP – 64*SLOP
S	PHAC	16 bit	OL & CL	-	0	Phase correction. Corrects an imbalance in the motor. Such imbalance may cause a rattling or scratching noise when the stage moves at low speed. Practical values are in the range of a few 1000, positive or negative.
S	FILP	8 bits	OL & CL	-	1	Filter speed for phase of piezo excitation signals.
S	FILA	8 bits	OL & CL	-	1	Filter speed for amplitude of piezo excitation signals.
S	4PHS	1	OL & CL	-	-	4PHS = 1 selects 4 phase piezo-excitation (XLA3). 4PHS=0 selects 2 phase piezo-excitation (XLA1).
VII. Encoder & directional settings These commands take 1 argument.						
	Command	Range	Mode	Units	Default value	Explanation
S	ENCD	1 bit	OL & CL	-	0	Set the encoder direction. Set the counting direction with respect to the A/B signals or sin/cos signals of the encoder. Flip this bit to swap left and right, or clockwise and counter-clockwise.
S	ENCO	32 bits	OL & CL	Encoder units	0	Sets the encoder offset: distance between the index position and the desired zero position. In encoder units.
S	ACTD	1 bit	OL & CL	-	1	Set the actuation direction. If not set correctly, the stage will move away from the desired position.
S	PATH	1 bit	CL	-	0	For rotation stages only. Selects whether the stage will follow the shortest path (PATH=1) to the target position or follow a linear approach, respecting high to low or low to high (PATH=0). Default: 1 for rotation stages, 0 for linear stages
S	LLIM	26 bits	OL & CL	Encoder units	-95000	Set low-side soft end stop.
S	HLIM	26 bits	OL & CL	Encoder units	95000	Set high-side soft end stop.

S	PLIM	0, 1	OL & CL	-	0	Switch on detection of physical end stops. PLIM=1: physical end stops. PLIM=0: soft end stop
S	INDA	0, 1	OL & CL	-	0	Automatic detection of index without INDX command.
S	ENCT	0-3	OL & CL	-	1	Encoder termination. 1 for XLA-312.
S	ENCM	26 bits	OL & CL	Encoder units	1000000000	Maximum encoder value (for rotational stages)
S	ENCR	1 bit	CL	-	0	Reset the encoder by sending "ENCR=1", then "ENCR=0"
VIII. Test These commands take 1 argument.						
	Command	Range	Mode			Explanation
A	TEST	0-1	-	-	0	Test LED indicators. TEST=1 switches all indicators on. TEST=0 brings them back to their function. Used to test communication and functioning of LED indicators.

Explanation of the control parameters

Control parameters have to be set according to the type of stage, load and customer-specific motion requirement. These parameters are pre-set by Xeryon upon delivery of the stage and controller. Nevertheless, it may be required that the user modifies these parameters when conditions change.

The most important control parameters are: excitation frequency (FREQ), proportional factor (PROP), integration factor (INTF), control frequency (CFRQ) and positioning tolerance (PTOL).

Excitation frequency

The first parameter to set is the excitation frequency. This should correspond to the resonant frequency of the piezomotor driving the stage. Resonant frequencies differ slightly among piezomotors and therefore this parameter is tuned for each individual stage. Values close to the resonant frequency generate the highest force and speed, but setting it a few kHz above the resonant frequency often leads to a more relaxed control with better 'landing' characteristics. By using different frequencies for scanning and fine-positioning, the piezomotor can be tuned to work optimally in different scanning and positioning conditions.

Proportional factor

The proportional control factors are a second set of parameters that are used to tune the stage for a specific situation. Higher proportional factors let the controller react stronger and reduce positioning errors, but can also lead to instability or noisy operation when chosen too high. Lower proportional factors, on the other hand, will results in a more sluggish motion response with more overshoot.

Integration factor

The integration factor causes static errors to be controlled away, and is essential in obtaining good positioning accuracy. However, too much integration leads to unstable behaviour.

Control frequency

The control frequency is important when the load on the stage (mass) is significantly increased.

Zones

To optimise closed-loop control for both speed and accuracy, two zones are defined each with a different excitation frequency and proportional factor for both scanning and fine-positioning applications. The zones are defined symmetrically around the target position, with zone 1 being the area closest to the target and zone 2 the widest. The zones are set with the commands ZON1 and ZON2. Corresponding to these zones, there are also 2 excitation frequencies and 2 proportional factors. In between the zones the values for excitation frequency and proportional factor are interpolated:

- Positioning error < ZON1: FREQ & PROP
- Positioning error > ZON2: FRQ2 & PRO2
- ZON1 < positioning error < ZON2: interpolated values

	Zone 1 (close to target)	Zone 2 (far from target)
Set zone width	ZON1	ZON2
Set excitation frequency	FREQ	FRQ2
Set proportional factor	PROP	PRO2

Typically, in zone 1 (closest to the target position), the excitation frequency and proportional factor are both chosen higher. This gives a better ‘landing’ on the target position. For zone 2 (further away from the target position) the excitation frequency is chosen lower to increase speed. At the same time the proportional factor for zone 2 typically has to be chosen lower to avoid instability. Be aware that outside a certain frequency range, the motor will have very limited force (frequency too high) or feature unstable behaviour (frequency too low). A typical frequency difference between FREQ and FRQ2 is between 1 and 3 kHz for an XSU-1 motor and between 0.5 and 2 kHz for an XSU-3 motor. The proportional factors in zone 1 (PROP) are typically 2-3 times the value of the proportional factors in zone 2.

When the stage does not want to land on the target position, despite optimising frequency and proportional factor for zone 1, try to increase the positioning tolerances PTOL and PTO2. See the instruction set for more information.

During scanning motion, the controller only uses the parameters of zone 2 (FRQ2 and PRO2).

Tuning the control parameters

The control parameters have to be set according to the type of stage and load. Each individual stage is tested by Xeryon and the parameters are pre-set for the load specified by the client. When no load is specified, them the parameters are pre-set for zero payload.

Nevertheless, it may be required that the user modifies these parameters when conditions change.

Step 1

Before tuning the control parameters, switch off timeouts and positioning errors.

- Follow error: ELIM=0
- Timeout for motor being on: TOU2=0
- Timeout for settling at target position: TOU3=0

Specify the zones. Good values to start with:

- ZON1=100
- ZON2=1000

Put position tolerance at reasonable values

- PTOL=3
- PTOL=5

Step 2: FRQ2

Start first with tuning the excitation frequency for the scanning motion (FRQ2). Make the stage or actuator move in open loop (MOVE command) and check what frequency produces the highest speed or highest force. In general, lowering FRQ2 will increase speed and force until suddenly below a certain frequency the performance quickly deteriorates or the stage stops moving altogether.

Step 3: PRO2

Switch to closed loop to find the optimal control parameters. Use the SCAN command to move with a constant speed. SCAN uses excitation frequency FRQ2, found in step 1. Increase the proportional parameter PRO2 to improve response and reduce positioning error. Increase until the actuator or stage starts to show unstable behaviour such as vibrations and noisy operation. Then reduce the proportional factor by at least 1/3.

When no stable closed-loop operation can be established, try with a slightly higher FRQ2.

Step 4: FREQ, PROP and INTF

Start with copying the value of FRQ2 to FREQ and PRO2 to PROP. Use the DPOS command to check the positioning performance, especially the settling of the actuator or stage on the target position. When the stage has difficulty settling, increase FREQ to make it less nervous. Also increase PROP to make it position quicker and more accurate. Also check whether increasing the integration factor improves positioning time and accuracy. Too much integration will result in unstable behaviour. The integration factor should always be larger than zero.

Following rules apply

- FREQ > FRQ2
- PROP > PRO2
- INTF > 0

Step 5: CFRQ

When the mass moved by the actuator is 100 gram or larger, it may be beneficial or even necessary to change the control frequency (CFRQ). In case the stage oscillates despite following the above steps, you may need to decrease CFRQ. The table below gives indicative numbers. However, finding the optimal control frequency is usually obtained by trial-and-error.

Mass (g)	CFRQ (Hz)
0	100000
100	60000
250	30000
500	10000
1000	5000

After changing the CFRQ parameter, the proportional parameters (PROP and PRO2) should also be adapted. A first good practice is to halve the values of PROP and PRO2.

Changing the motion profile

The motion profile can be changed by altering the target speed, acceleration and deceleration.

- SSPD is used to set the speed the stage will move from point to point or during a scan movement. The speed is specified in µm/s. The specified speed is not always attained in case of short distances or slow acceleration and deceleration.
- ACCE defines the acceleration of the stage to the speed set by SSPD. The acceleration is specified in mm/s^2, with a theoretical maximum of 65535 (about 65 m/s^2).
- DECE defines the deceleration of the stage upon reaching its target. The deceleration is specified in mm/s^2, with a theoretical maximum of 65535 (about 65 m/s^2). The value is always positive.

LEDs

On controller board

- Green LED: Power on for controller board
- Yellow LED: Motor is on
- Red LED: Controller disabled or in error
    - Disabled
    - Follow error
    - Safety timeout
    - Position fail
    - Emergency stop

The LEDs on the controller board can also be lit by sending the command TEST=1.

On EtherCAT board

- Green LED: Power on for EtherCAT board
- Yellow LED: EtherCAT run LED which indicates EtherCAT state
    - Off: “Init” state
    - Blinking sporadically: “Safe-Operational” state
    - Blinking uniformly: “Pre-Operational” state
    - Continuously on: “Operational” state

Settings list for uploading

Legend:

Settings that should not be changed. These are set as default in EEPROM, thus also no need to send.
Setting to be set according to actuator type
Encoder related settings
Most important tuning parameters
Amplitude related parameters
Open-loop settings
Settings for timeouts, errors and flags
Parameters defining motion profile

Setting	XLA3-short	XLA3-long	XLA1	Meaning
ENCT	1	1	1	Encoder termination
PLIM	0	0	0	Physical limits
ENCM	1000000000	1000000000	1000000000	Maximum encoder value
PATH	0	0	0	Shortest path for rotational stage
ACTD	1	1	1	Actuator direction
SLIM	100000	100000	100000	Error saturation limit
4PHS	**1**	**1**	**0**	Motor with 4 phases (or 2)
LLIM	**-45000**	**-95000**	**-39000**	Lower soft end stop
HLIM	**45000**	**95000**	**39000**	Higher soft end stop
ENCD	0	0	0	Encoder direction
ENCO	0	0	0	Encoder offset
INDA	0	0	0	Automatic detection of encoder index
ISPD	5000	5000	5000	Speed during index search
ILIM	3000	3000	3000	Error limit for triggering direction reversal during index search
FILE	0	0	0	Encoder filter
ZON1	100	100	100	Control zone 1: final positioning
ZON2	1000	1000	1000	Control zone 2: fast motion
FREQ	**87000**	**87000**	**173000**	Excitation frequency for final positioning
FRQ2	**85000**	**85000**	**169000**	Excitation frequency for fast motion
FRAT	**145635**	**145635**	**291271**	Interpolation factor for frequency
PROP	40	40	40	Proportional factor for final positioning
PRO2	10	10	10	Proportional factor for fast motion
PRAT	2184	2184	2184	Interpolation factor for proportional factor
INTF	5	5	5	Integration factor
CFRQ	100000	100000	100000	Control frequency
DUCO	1	1	1	Duty control
PTOL	3	3	3	Primary positioning tolerance
PTO2	5	5	5	Secondary positioning tolerance
PHAC	0	0	0	Phase compensation
MIMP	5000	5000	5000	Minimum amplitude
MAMP	65535	65535	65535	Maximum amplitude
SLOP	312	312	312	Slope for amplitude interpolation

SOFS	-14968	-14968	-14968	Offset for amplitude interpolation
FILA	1	1	1	Amplitude filter
FILP	1	1	1	Phase filter
AMPL	65535	65535	65535	Amplitude for open-loop motion
PHAS	16383	16383	16383	Phase for open-loop motion
TOUT	500	500	500	Timeout time for positioning tolerance
TOU2	60	60	60	Timeout time for actuator on
TOU3	1000	1000	1000	Timeout time for settling at target position
ELIM	0	0	0	Max. follow error
BLCK	0	0	0	Blocking errors
DLAY	20	20	20	Delay for position reached flag
DTIM	0	0	0	Deadtime
SSPD	500000	500000	500000	Target speed
ACCE	65535	65535	65535	Acceleration
DECE	65535	65535	65535	Deceleration

Remark:

FRAT, PRAT, SLOP and SOFS have to be calculated based on other settings. The 3-axis demo program contains code to calculate these parameters automatically.

Appendix A: detailed description of communication interface

This interface is described by XeryonDrive.xml

PLC → Drive	Bit length		Datatype	Meaning
Position				
Command	32 bits		STRING	
Target position	32 bits		DINT	
Speed	32 bits		UDINT	
Acceleration	16 bits		UINT	
Deceleration	16 bits		UINT	
Execute	8 bits		BYTE	
-	24 bits		-	Padding
Drive → PLC	**Bit length**		**Datatype**	**Meaning**
Status				
Actual position	32 bits		DINT	
Amplifiers enabled	1 bit	#0	BOOL	
End stop	1 bit	#1	BOOL	
Thermal protection 1	1 bit	#2	BOOL	
Thermal protection 2	1 bit	#3	BOOL	
Force zero	1 bit	#4	BOOL	
Motor on	1 bit	#5	BOOL	
Closed loop	1 bit	#6	BOOL	
Encoder index	1 bit	#7	BOOL	
Encoder valid	1 bit	#8	BOOL	
Searching index	1 bit	#9	BOOL	
Position reached	1 bit	#10	BOOL	
Error compensation	1 bit	#11	BOOL	
Encoder error	1 bit	#12	BOOL	
Scanning	1 bit	#13	BOOL	
Left end stop	1 bit	#14	BOOL	
Right end stop	1 bit	#15	BOOL	
Error limit	1 bit	#16	BOOL	
Searching optimal frequency	1 bit	#17	BOOL	
Safety timetout	1 bit	#18	BOOL	
Execute ack	1 bit	#19	BOOL	
Emergency stop	1 bit	#20	BOOL	
Position fail	1 bit	#21	BOOL	
-	2 bits		-	Padding
Slot	8 bits		BYTE	