

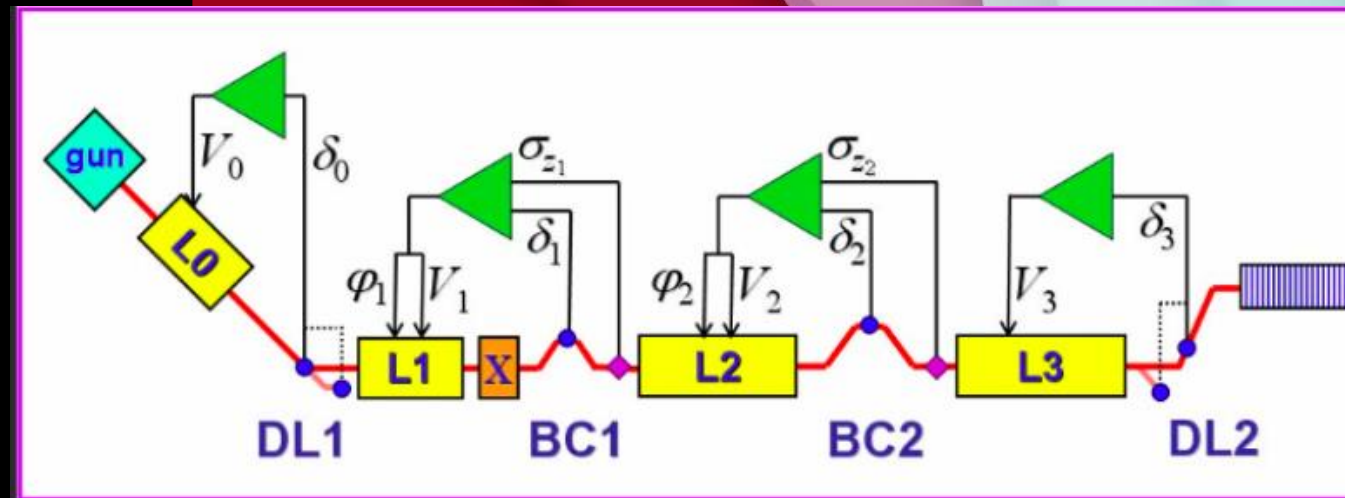
Updating a Script Almost Old Enough to Vote: The Journey of the Fast Feedback System

Chanel O'Dell Canada College CCI,
EED, SLAC

Mentor: Kyle Leleux, EED, SLAC

Overview of Linac

- Beam energy maintenance in 4 locations: DL1, BC1, BC2, and DL2. DL1
- DL2 are simple energy feedback loops.
- L0 and L1 typically use only 1 klystron to control the energy
- L2 and L3 have multiple klystrons available.
- BC1 and BC2 are energy feedback and bunch length to control the RF phase.



How Feedback ReGold Works

Objectives:

- Collect reference orbit
 - Physicists manually input: # of measurements, beamcode, timeout, number average.
- Write ref orbit to feedback PV
- Zeros out orbit

Talks to the accelerator through Channel Access

Dictates which BSA is collecting information

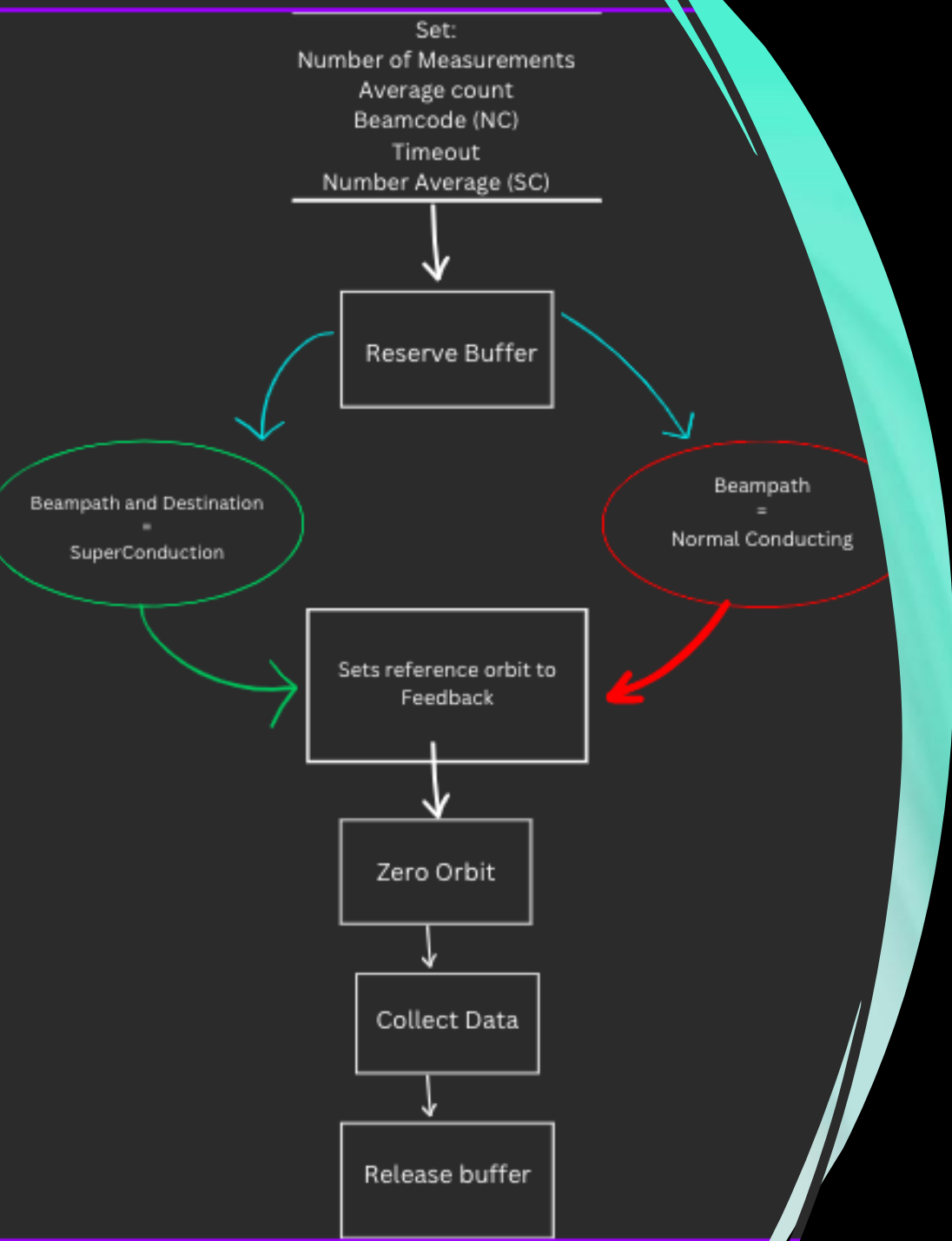
Works with the magnets to keep the beam orbit

Klystrons feed the appropriate amount of energy needed that was set by operators



Feedback ReGold: “Cause I got Issues...”

- Deprecated python package
- Super Conducting was not implemented...Jenkies!
- No way to differentiate between Normal Conducting versus Super Conducting




The Fix

- Depreciated Python package → PyEpics
- Add FACMODE to determine in Normal Conducting or Super Conducting
- Include Beampath PV for Hard X-ray, Soft X-Ray or both.

Testing procedure

- Familiarize with BSA facilities and wrote test scripts.
- Reserved and released buffers for a few beam pulses.
- Compared with signals coming from the accelerator.
- Why? Avoid caputting.



Acquired Knowledge

- Python Language
- Object-oriented programming
- How LCLS and LCLS-II work



Acknowledgements

Special thanks to

- Kyle, Mentor Extraordinaire
- Matt Gibbs, The Great
- Zach & Evren
- The entire EED team
- Hillary, Arturo and Rebecca!
- Stephany and Isabelle: Dream Team

Building a New E-Log

Eamon "Boogie" Mikulec

Biggest Challenges with the Old E-Logs

- Split across the Physics E-Log and the MCC E-Log
- Inaccessible from outside the SLAC network
- Incompatible with mobile devices
- Some pain points with searching
- Timeouts while making an entry

The screenshot displays the SLAC E-LOG MCC interface. At the top, there's a navigation bar with links like 'New Entry', 'Quick Entry', 'Login', 'Jump To Logbook', 'Other Actions', 'Show/Hide Filters', 'Shift Change Mode', and 'E-Log Help'. Below this, there are input fields for 'Date' (Start: 08/13/2023, End: 08/15/2023) and 'Shifts' (Use Start/End). A 'Logbook:' section contains various checkboxes for different areas like ACCEL, PEP, MCC, NLCTA, etc. An 'Options:' section includes dropdowns for 'Area', 'Entry Type', and 'Source', along with 'Sort By' and 'Sort Order' options. A 'Search:' section has input fields for 'Title/text' and 'Username'. A 'Shade entries by area' checkbox is checked. The main content is a table of log entries for 'Swing Shift, Mon, 14-Aug-23' and 'Day Shift, Mon, 14-Aug-23'. The table has columns for 'Flags', 'Time', 'Title', and 'Name'.

Flags	Time	Title	Name
Swing Shift, Mon, 14-Aug-23			
⊕:T	18:00	Will likely need to load a SCORE or reload 6x6 actuators due to problems with the 6x6 that happened on day shift	A_Ausherman LCLS_NC
Day Shift, Mon, 14-Aug-23			
⊕:TA f	10:09	* Re: Score threw a fatal error and crashed--> just happened again trying to save another SCORE. both times the save shows up in the log but it didn't save all regions	S_Khashayar
⊕:T	09:59	NEW BC11 settings until 11-1 and 11-2 are back online	M_DeMario FACET
⊕:T f	09:47	* Re: Fast 6x6 is not actuating	A_Ausherman LCLS_NC
⊕:f	09:37	* Re: Sending beam back to BSYD for now -> back to SXR dump	S_Khashayar LCLS_SC
⊕:F	09:35	Sending beam back to BSYD for now	S_Khashayar LCLS_SC
⊕:T F	09:22	Fast 6x6 is not actuating	A_Ausherman LCLS_NC

Building the New E-Log

- Merge the Physics E-Log and the MCC E-Log into a unified solution
- Build with current industry standards
- Long term support and extendibility
- Fix pain points with the old E-Logs
- Focus on functionality, usability, and visuals

Initial prototype design for the new E-Log

The screenshot displays the initial prototype design for the new E-Log interface. At the top left, the SLAC E-LOG logo is visible. To its right is a search bar with the placeholder text "Search...". Further right is a blue button with a magnifying glass icon and the text "New Entry". Below the search bar, there are two tabs labeled "ACCEL" and "PEP", and a date range selector showing "2021-10-30" to "2021-12-06". The main content area is titled "Fri, 23-Jun-23 (Day Shift)" and contains a list of log entries. Each entry consists of a time stamp "09:02", a description "Controls rebooting a few IOCs, the network row on LCLS home may go white", and the user name "M_Garske". To the right of each entry are two icons: a pencil for editing and a circular arrow for refreshing.

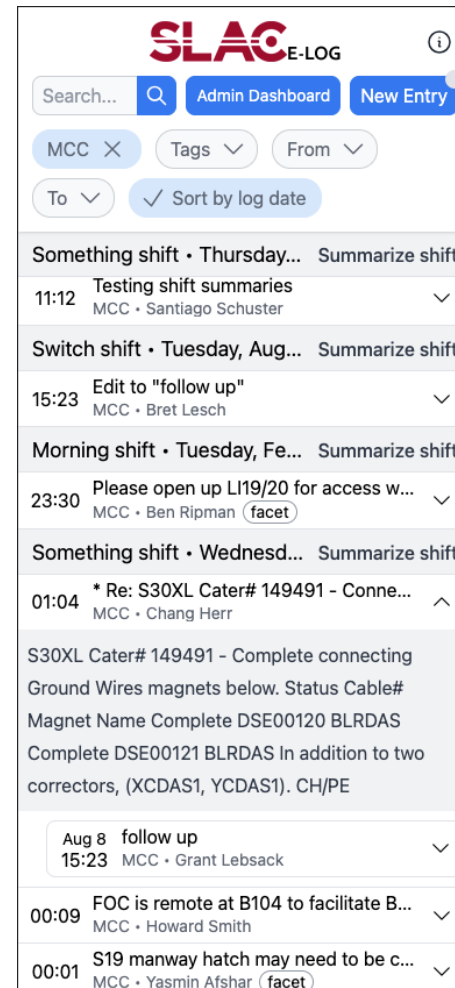
The New E-Log!

- Built with React and Tailwind
- Performant
 - Can handle thousands of entries loaded on the page
 - Whole app is less than 250kB
- Accessible outside SLAC network
- Works on mobile
- Advanced search capabilities
- Infinite scroll grouped by date and shift
- Tags!

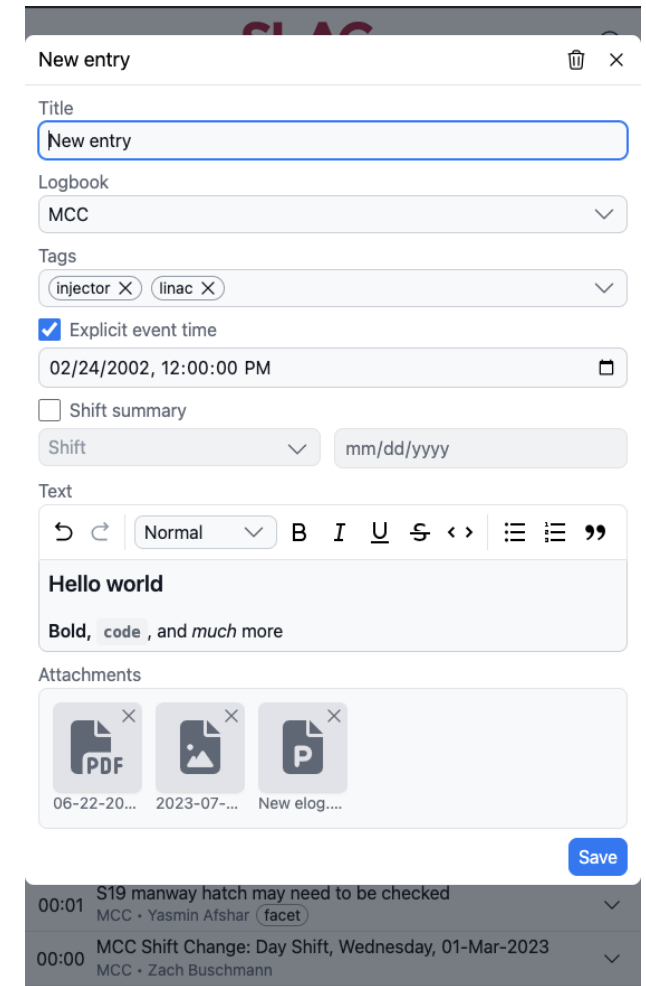
The screenshot displays the SLAC E-Log application interface. At the top, there is a search bar and navigation buttons for 'Admin Dashboard' and 'New Entry'. Below this, a filter bar shows 'MCC and 1 other', 'Tags', and date filters for 'February 7, 2002' and 'August 18, 2023'. The main content area is a list of log entries, each with a timestamp, location/shift, and a brief description. A search dropdown is open over the list, showing terms like 'facet', 'linac', 'lcls-sc-linac', 'lcls-nc-linac', and 'injector'. The entry for '06:31 C. Bianchini requires MPS clear to HXR/SXR for timing tests...' is selected, and its details are shown on the right. The details include the logged by person (Zach Buschmann), the logged at time (Feb 27, 2023, 06:31:36), the event occurrence time (Feb 27, 2023, 06:31:37), the shift (Morning shift), and tags (lcls-sc-linac). Below the details, there is a text description: 'According to K. Leleux, only MP03 (central node 3) is required to broadcast triggers, and it looks green on the expert screen, however we are still limited to "Beam Off" on the Global MPS display. Still investigating...'. Two screenshots are included: 'Figure 1' shows a control room display with various status indicators, and 'Figure 2' shows a close-up of the 'SC MPS Central Node Expert - SIOC SYSD MP03' screen, which has a grid of status lights and text. At the bottom right, there are 'Supersede' and 'Follow up' buttons.

The New E-Log!

- Rich body text
 - Custom WYSIWYG editor
 - Extensible storage format allowing for custom embeddings
- Image previews (full size is downloadable)
- Shift summaries
- Draft storage (If you wrote it, it's saved)
- Admin dashboard



The screenshot shows the SLAC E-LOG interface. At the top, there's a search bar and buttons for 'Admin Dashboard' and 'New Entry'. Below that are filters for 'MCC', 'Tags', and 'From'. A 'Sort by log date' button is also visible. The main content area displays a list of log entries, each with a timestamp, a title, and the author's name. The entries are grouped by shift type and date. For example, one entry is 'Something shift • Thursday...' with a timestamp of 11:12 and the title 'Testing shift summaries' by Santiago Schuster. Another entry is 'Switch shift • Tuesday, Aug...' with a timestamp of 15:23 and the title 'Edit to "follow up"' by Bret Lesch. The interface is clean and modern, with a white background and blue accents.



The screenshot shows the 'New entry' form in the SLAC E-LOG interface. The form has a white background and a blue border. It includes a 'Title' field with the text 'New entry'. Below that is a 'Logbook' dropdown menu set to 'MCC'. There are 'Tags' fields with 'injector' and 'linac' selected. A checkbox for 'Explicit event time' is checked, and the date and time are set to '02/24/2002, 12:00:00 PM'. There is also a 'Shift summary' checkbox which is unchecked. The 'Text' field contains the text 'Hello world' and a rich text editor toolbar with options for bold, italic, underline, link, and list. Below the text field is an 'Attachments' section with three icons for PDF, image, and document. At the bottom right, there is a blue 'Save' button. The interface is clean and modern, with a white background and blue accents.

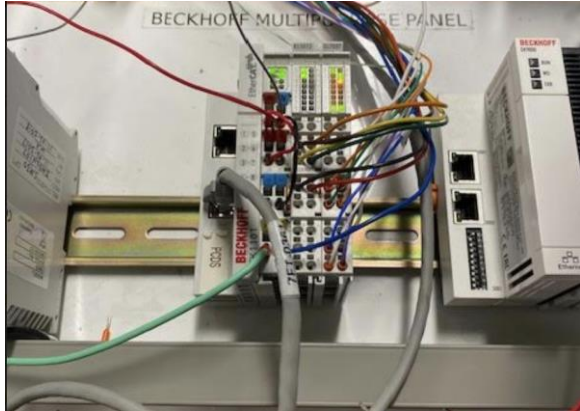
So, let's check it out

Demo time :)



Stepper Motor Test Stand with LVDT Feedback using Beckhoff Drives

OVERVIEW



Collimation System

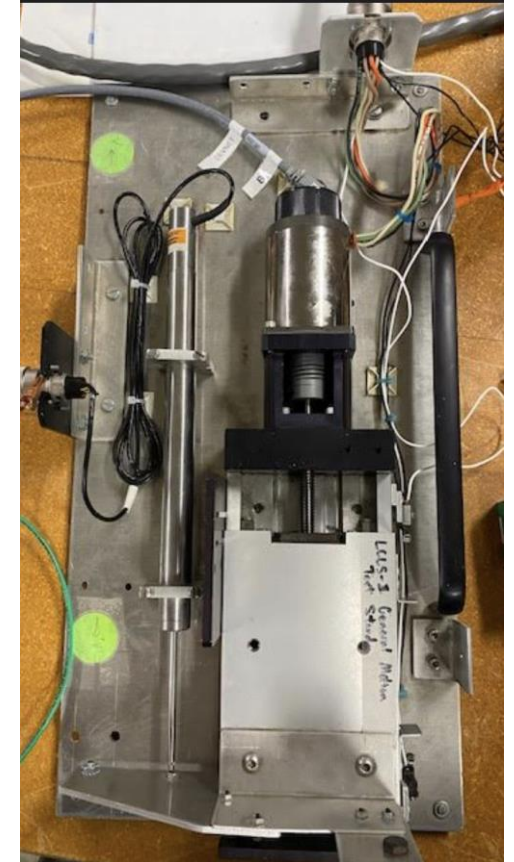
Beckhoff Devices

LVDT and Stepper Motor

EtherCAT communication and TwinCAT

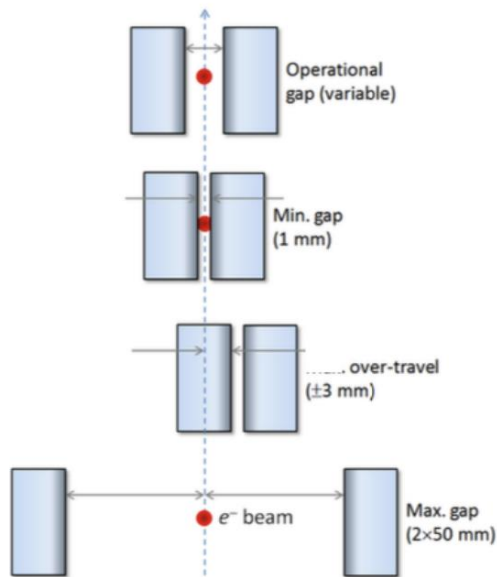
PLC Program and HMI

CX5020



Collimation System

Purpose of Halo Collimation System

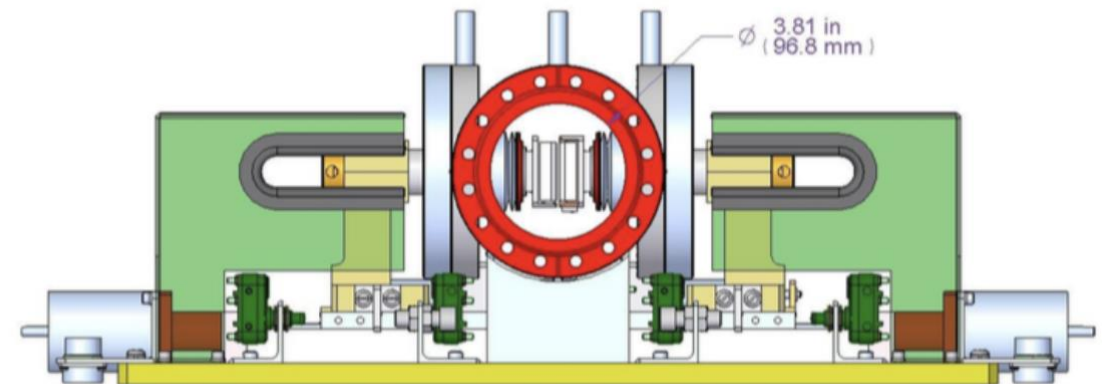


The overall goal of the HALO collimation system in LCLS-II is to eliminate undesirable electrons in order to avoid excessive radiation due to beam loss in sensitive area of the accelerator and those with delicate equipment (such as the undulators). The undesirable electrons exist at either the wrong energy, time, or transverse position and angle

[3]

Collimator Construction

The collimators are composed of two tungsten jaws that can be moved in either the horizontal or vertical directions depending on the orientation of the individual collimator. This movement is what the stepper motor/LVDT test stand aims to control.



LVDT



LVDT Ratings

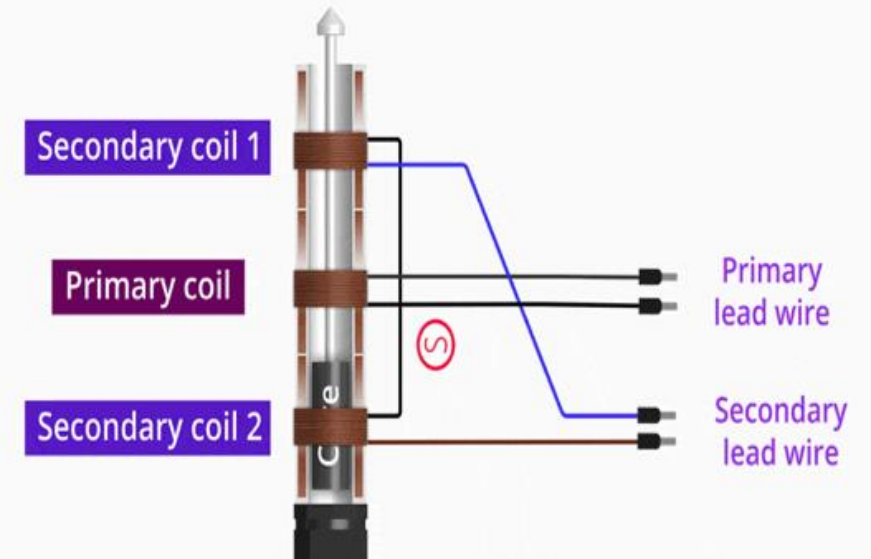
- Linear Range: +/- 25.4mm
- Excitation: 2-6 V_{RMS}
- Excitation: 0.4 - 10 kHz
- Sensitivity: 5 mV/V/0.0001"

LVDT Settings

- 6 wire LVDT
- High Impedance
- Linear Range: +/- 25.4mm
- Excitation: 3.5VRMS
- Excitation: 10 kHz
- Sensitivity: 196.8 mV/V/mm

A Linear Variable Differential Transformer (LVDT) is an electromechanical sensor that converts mechanical movement to electrical signals in the form of voltage or current.

This project uses an AC LVDT with voltage output meaning that is it an LVDT which is powered by and AC signal and converts its mechanical motion into a voltage signal.



Stepper Motor



Motor Ratings

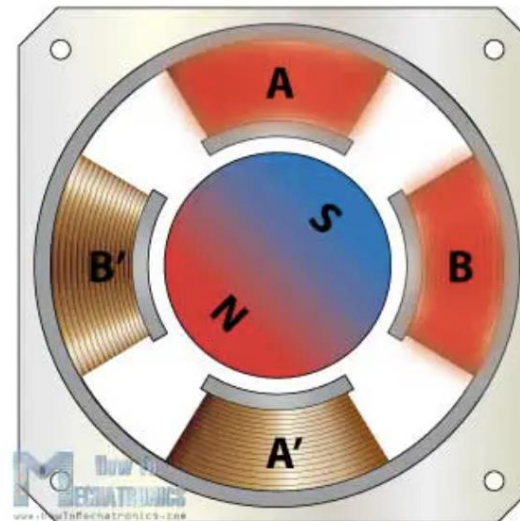
- 1.65 V DC
- 4.7 A
- 200 Full Steps/Rev

Motor Settings

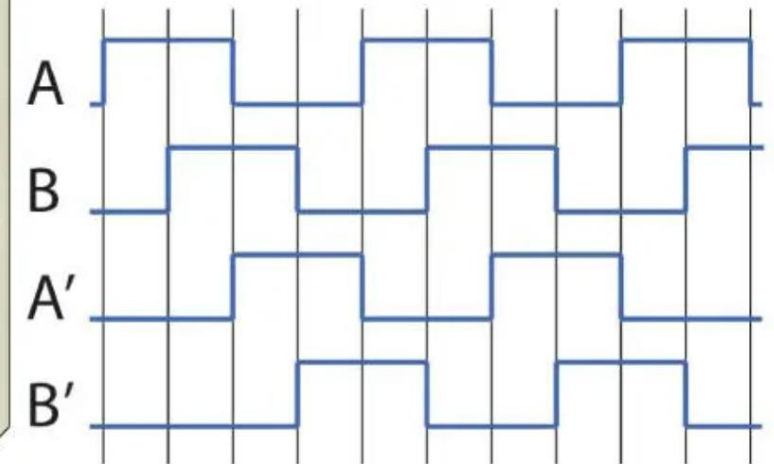
- 1.5A Maximal current
- 0.8A Reduced current
- 1.65V Nominal voltage
- 7Ω Motor coil resistance
- 1.6mH Motor coil inductance
- 0.1s drive on delay
- 0.15s drive off delay

Basic Operation

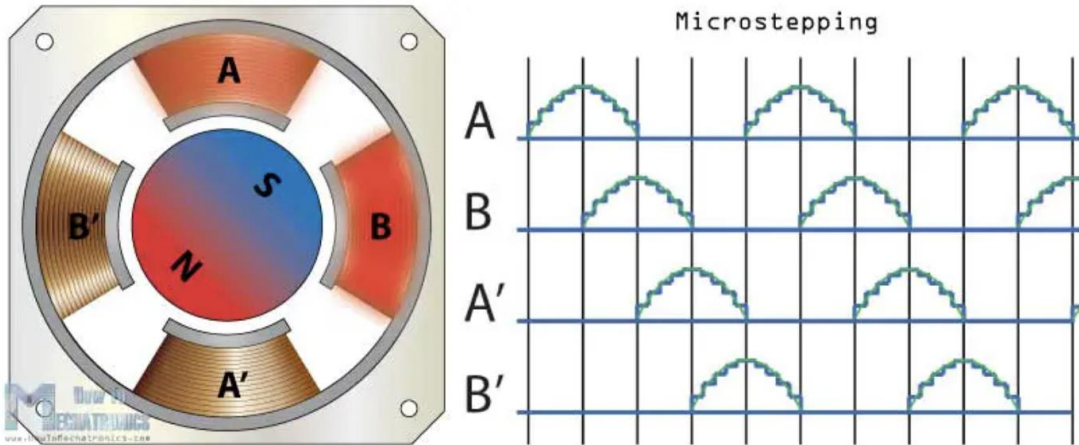
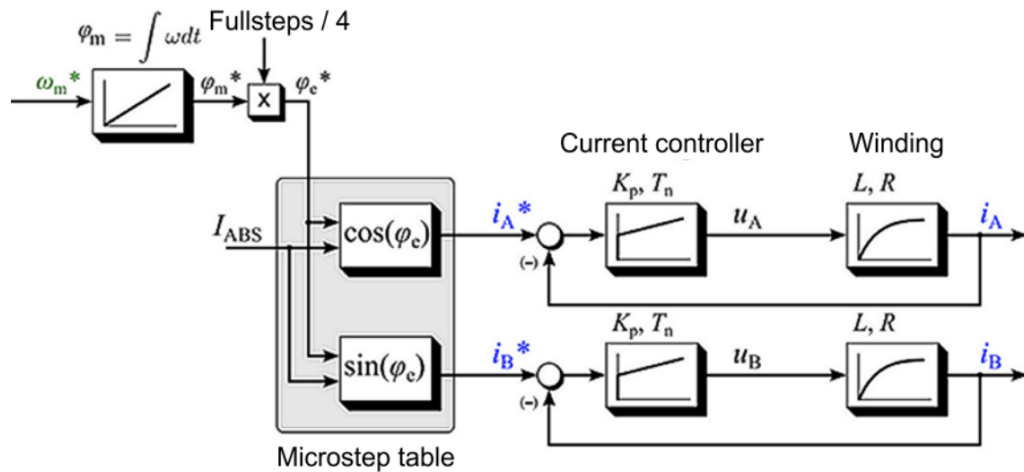
A stepper motor is a brushless motor that rotates in discrete steps. They are useful in that they allow for precise positioning and the ability to hold that position. Construction of a stepper motor involves a permanent magnet acting as a rotor surrounded by windings which make up the stator. The windings are activated by applying current to them creating electromagnetic poles which cause the movement of the rotor.



Full Step Drive



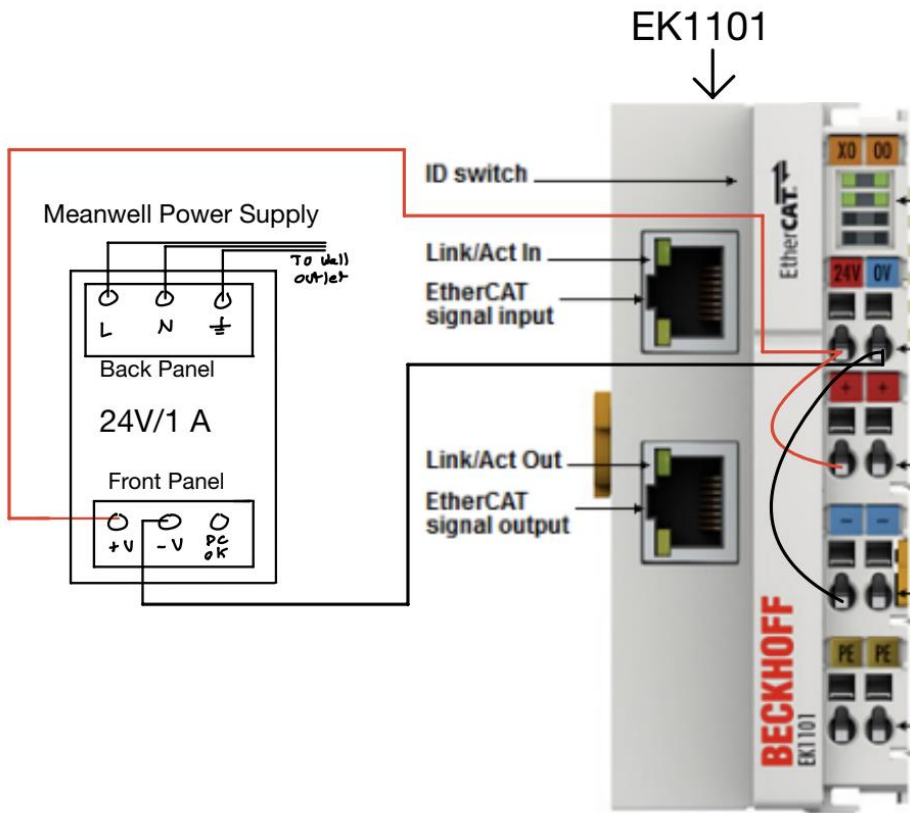
Microstepping and Drive Control



The SLO stepper motor along with the EL7037 drive enabled microstepping to be used in this project. For a 200 step/rev motor like the one used in this project is $\frac{360}{200} = 1.8^\circ$ of rotation per step. The EL7037 drive allows the motor an additionally 64 microsteps per step when connected leading to a microstep size of $\frac{1.8^\circ}{64} = 0.028^\circ$

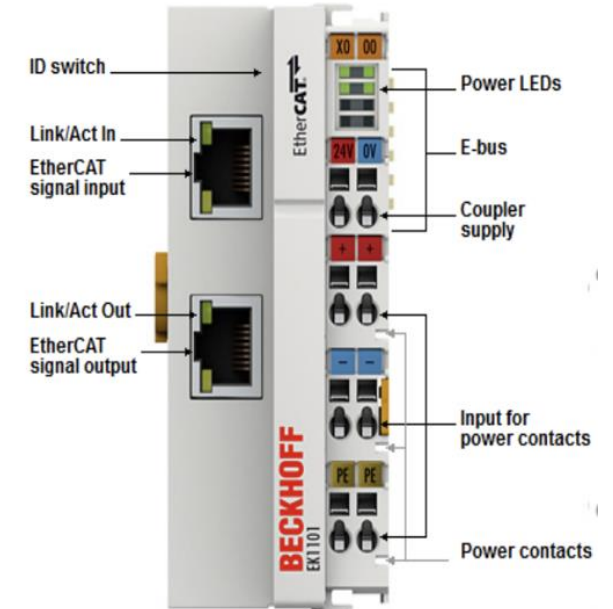
Beckhoff Devices - EK1101

Wiring



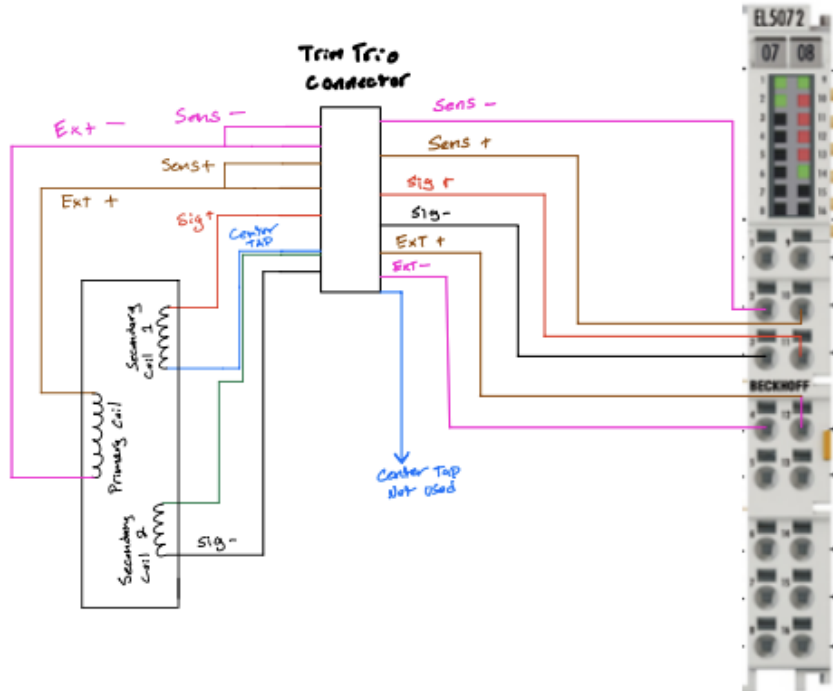
Device

The EK1101 is an EtherCAT coupler. It acts as a link to the EtherCAT protocol at the fieldbus level. The EK1101 attaches to our analog input modules and allows the user to then connect those modules to a PC via EtherCAT protocols



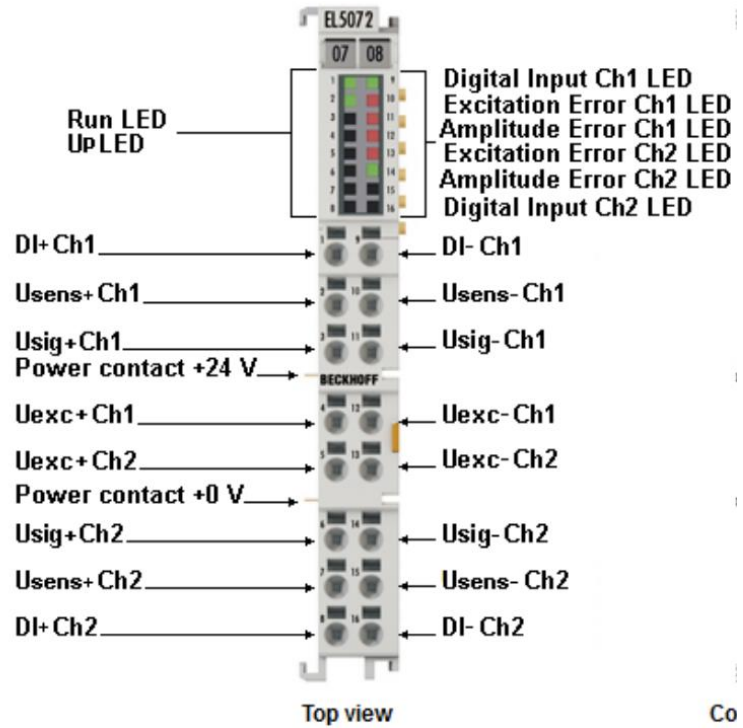
Beckhoff Devices- EL5072

Wiring



Device

The EL5072 is a 2 channel LVDT interface. It allows for adjustable excitation frequencies and voltages and is compatible with 4, 5, and 6 wire LVDT configurations. It measures LVDT positional value as a 32 bit integer variable.

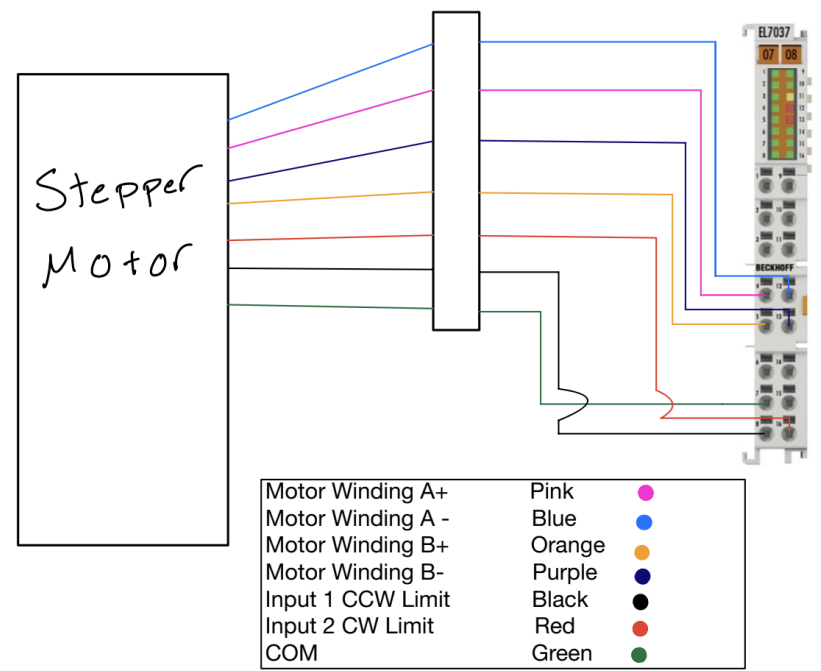


Beckhoff Devices- EL7037

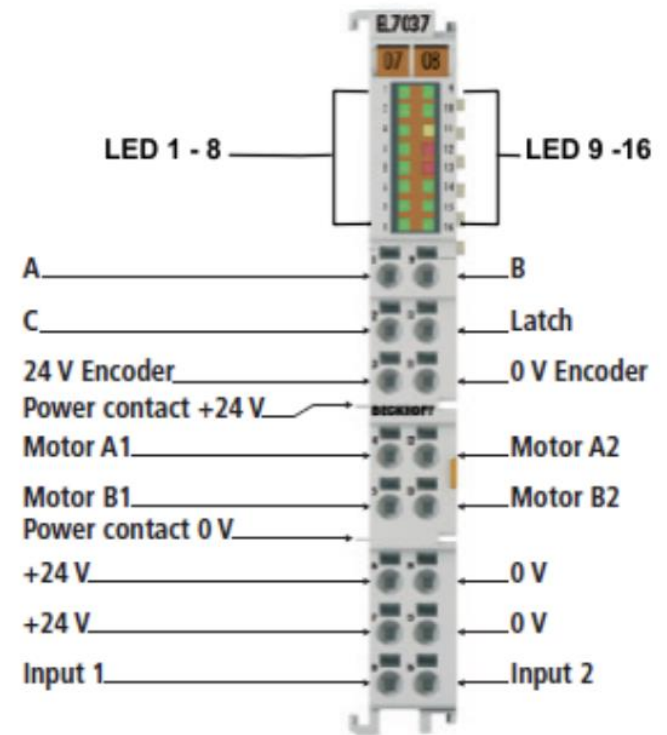
Wiring

Device

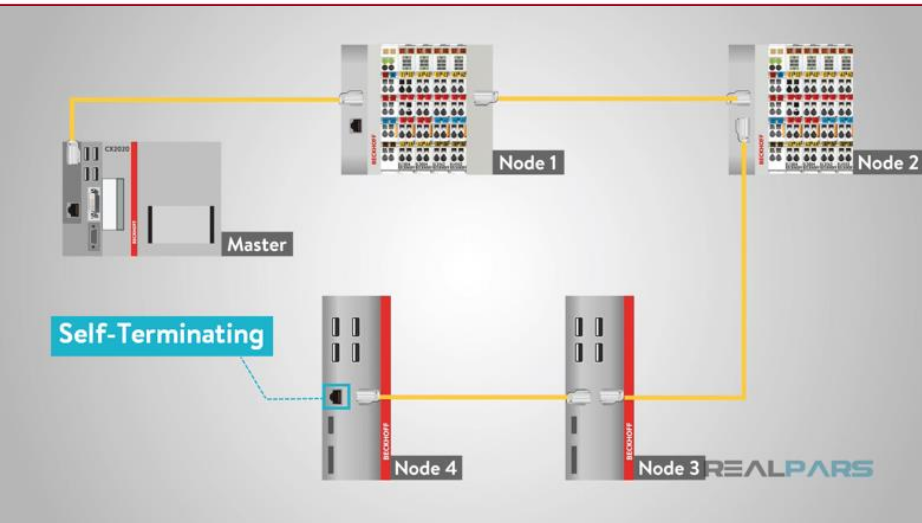
Connection



The EL7037 is a 1 channel stepper motor drive. It has adjustable parameters including operating currents, voltages and frequencies. These parameters are set to match motor and applications. It contains inputs for 2 limit switches.



EtherCAT Communication

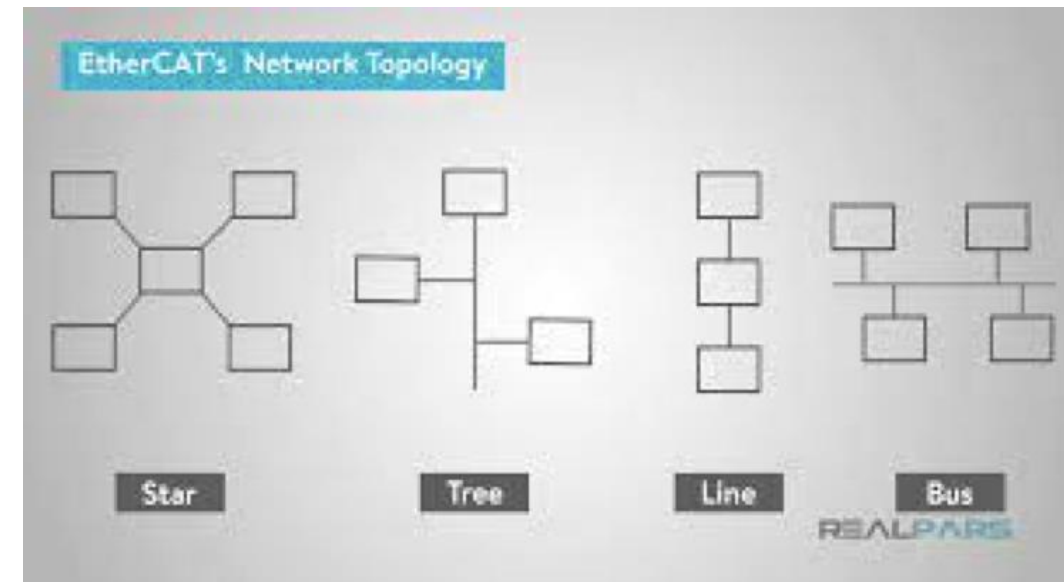


What is EtherCAT

Sometimes called the ethernet fieldbus ethernet is a low cost, high speed ethernet technology with flexible topology

Advantages of EtherCAT

- Many devices can be connected at once
- Internationally standardized
- Fast communication speed
- Multiple topology configurations can be used

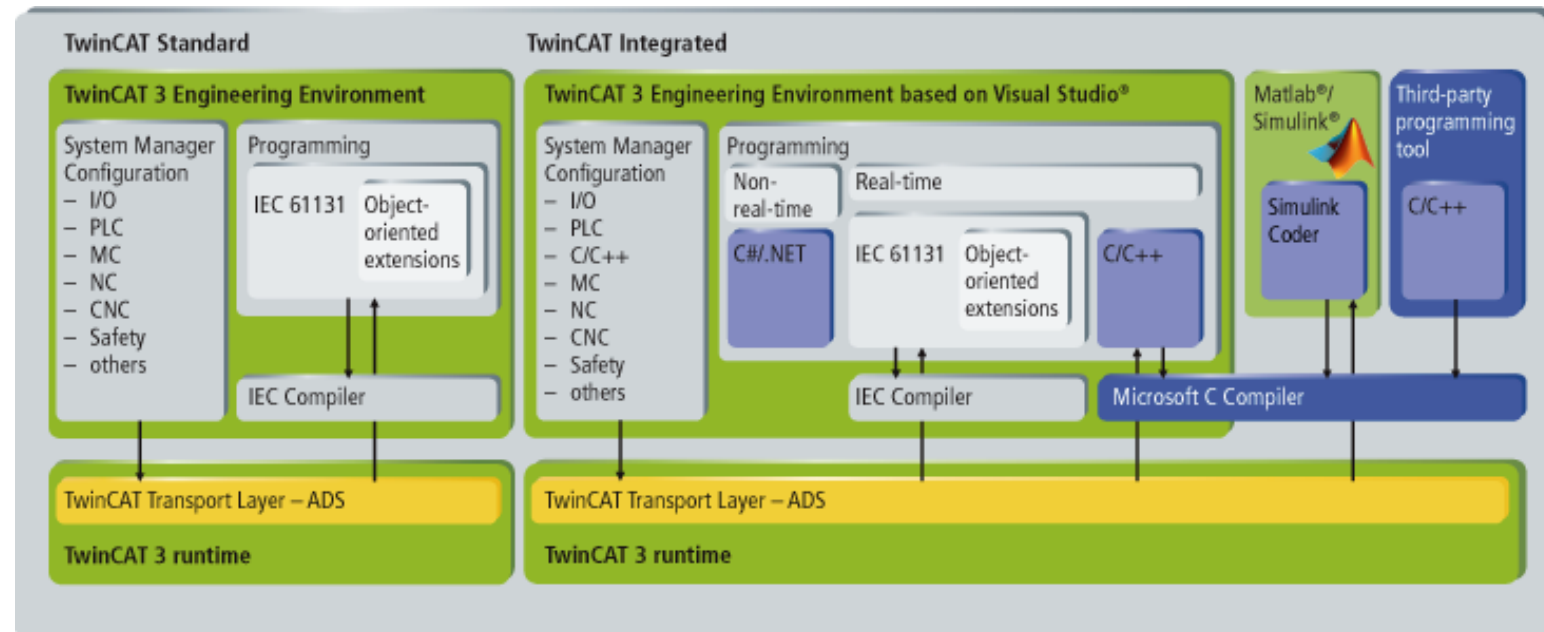


TwinCAT

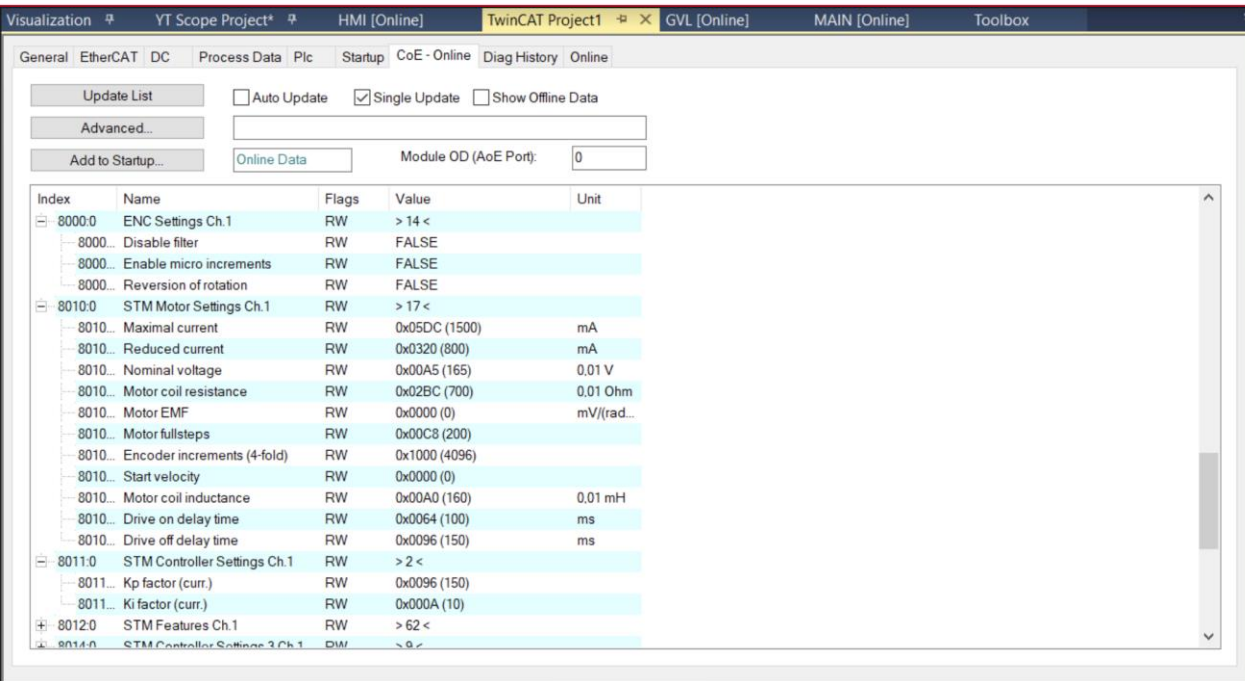


Communication in TwinCAT is achieved through an ADS (Automation Device Specification) Interface which manages and distributes all messages in the system through EtherCAT and TCP/IP connections.

TwinCAT 3 XAE (Extended Automation Engineering) is a software application developed by Beckhoff that integrates with Microsoft Visual Studios. The goal of TwinCAT is to simplify software engineering and to facilitate the easy control and PLC programming of Beckhoff devices. TwinCAT provides all classic PLC functionalities as well as compatibilities to outside applications such as C, C++, and Matlab.



Configuring Devices



Index	Name	Flags	Value	Unit
8000.0	ENC Settings Ch.1	RW	> 14 <	
-8000...	Disable filter	RW	FALSE	
-8000...	Enable micro increments	RW	FALSE	
-8000...	Reversion of rotation	RW	FALSE	
8010.0	STM Motor Settings Ch.1	RW	> 17 <	
-8010...	Maximal current	RW	0x05DC (1500)	mA
-8010...	Reduced current	RW	0x0320 (800)	mA
-8010...	Nominal voltage	RW	0x00A5 (165)	0.01 V
-8010...	Motor coil resistance	RW	0x02BC (700)	0.01 Ohm
-8010...	Motor EMF	RW	0x0000 (0)	mV/(rad...
-8010...	Motor fullsteps	RW	0x00C8 (200)	
-8010...	Encoder increments (4-fold)	RW	0x1000 (4096)	
-8010...	Start velocity	RW	0x0000 (0)	
-8010...	Motor coil inductance	RW	0x00A0 (160)	0.01 mH
-8010...	Drive on delay time	RW	0x0064 (100)	ms
-8010...	Drive off delay time	RW	0x0096 (150)	ms
8011.0	STM Controller Settings Ch.1	RW	> 2 <	
-8011...	Kp factor (curr.)	RW	0x0096 (150)	
-8011...	Ki factor (curr.)	RW	0x000A (10)	
8012.0	STM Features Ch.1	RW	> 62 <	
8014.0	STM Controller Settings 2 Ch.1	RW	> 9 <	

Electrical values entered into the EL7037 drive to operate the SLO Stepper motor at optimal performance

The CoE or CANopen over Ethernet interface offered by beckhoff allows the user to set parameter values of the drive specific to the equipment they are using.

Along with electrical parameters for the LVDT, EL5072 also allows manual configuration of gain and offset values to match travel range and center of the stage.

To determine the positional reading of the LVDT given a set user gain and offset is below

$$\text{Position}_{\text{Final}} = \text{Gain} * (\text{Position}_{\text{Raw}} - \text{Offset})$$

Note: This is not the equation that was given in the datasheet which appears to be wrong

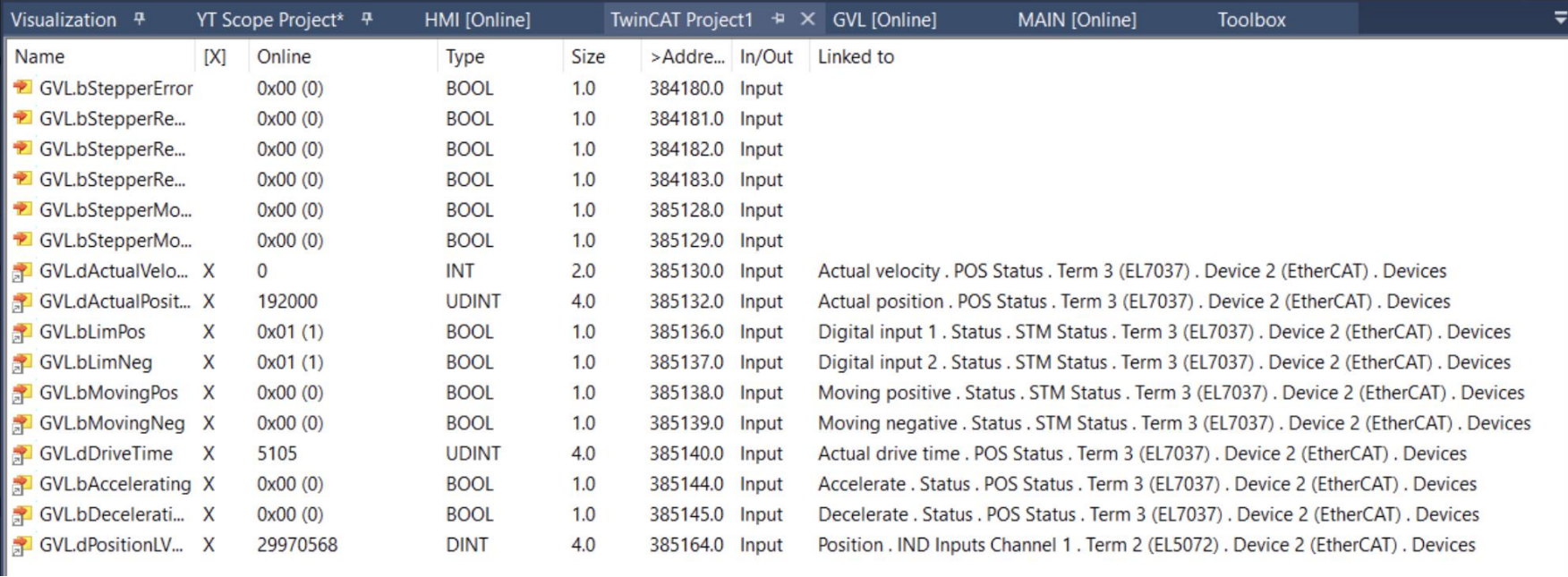
PLC Program – Linking Variables

Linking Requirements

In TwinCAT input and output variables from the drive (i.e. Actual Position, Velocity Control, Emergency Stop) are connected to the PLC task through the declaration of variables and the subsequent linking of those variables to the real variable values stored in the drive.

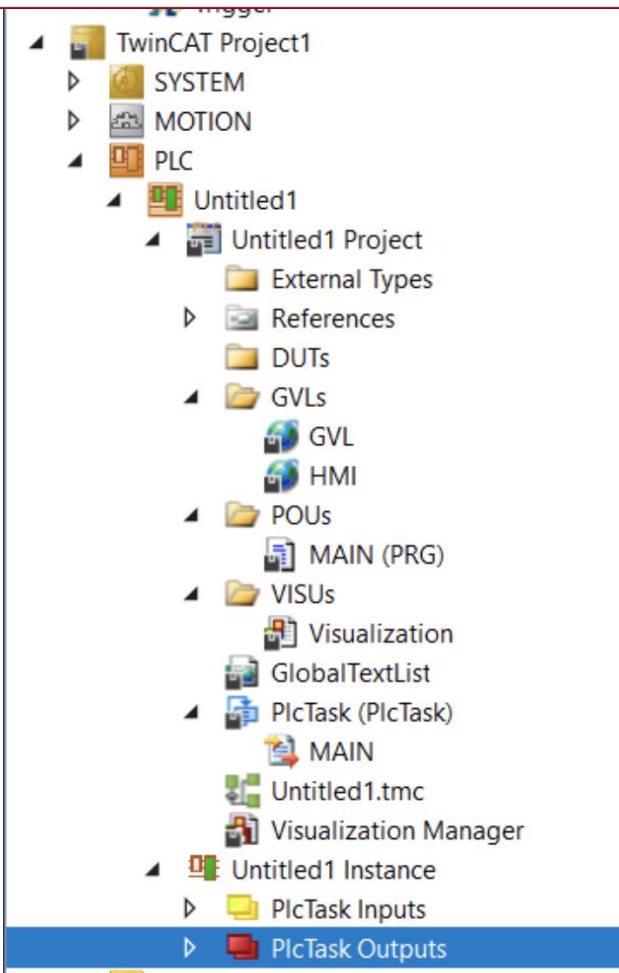
Linking Syntax

To successfully link a variable, it must be declared as either an input or an output (TwinCAT uses I for input and Q for output). Additionally, the variable that you want to link must be of the same datatype as the value in the drive which you are attempting to link it too.



Name	[X]	Online	Type	Size	>Addre...	In/Out	Linked to
GVL.bStepperError		0x00 (0)	BOOL	1.0	384180.0	Input	
GVL.bStepperRe...		0x00 (0)	BOOL	1.0	384181.0	Input	
GVL.bStepperRe...		0x00 (0)	BOOL	1.0	384182.0	Input	
GVL.bStepperRe...		0x00 (0)	BOOL	1.0	384183.0	Input	
GVL.bStepperMo...		0x00 (0)	BOOL	1.0	385128.0	Input	
GVL.bStepperMo...		0x00 (0)	BOOL	1.0	385129.0	Input	
GVL.dActualVelo...	X	0	INT	2.0	385130.0	Input	Actual velocity . POS Status . Term 3 (EL7037) . Device 2 (EtherCAT) . Devices
GVL.dActualPosit...	X	192000	UDINT	4.0	385132.0	Input	Actual position . POS Status . Term 3 (EL7037) . Device 2 (EtherCAT) . Devices
GVL.bLimPos	X	0x01 (1)	BOOL	1.0	385136.0	Input	Digital input 1 . Status . STM Status . Term 3 (EL7037) . Device 2 (EtherCAT) . Devices
GVL.bLimNeg	X	0x01 (1)	BOOL	1.0	385137.0	Input	Digital input 2 . Status . STM Status . Term 3 (EL7037) . Device 2 (EtherCAT) . Devices
GVL.bMovingPos	X	0x00 (0)	BOOL	1.0	385138.0	Input	Moving positive . Status . STM Status . Term 3 (EL7037) . Device 2 (EtherCAT) . Devices
GVL.bMovingNeg	X	0x00 (0)	BOOL	1.0	385139.0	Input	Moving negative . Status . STM Status . Term 3 (EL7037) . Device 2 (EtherCAT) . Devices
GVL.dDriveTime	X	5105	UDINT	4.0	385140.0	Input	Actual drive time . POS Status . Term 3 (EL7037) . Device 2 (EtherCAT) . Devices
GVL.bAccelerating	X	0x00 (0)	BOOL	1.0	385144.0	Input	Accelerate . Status . POS Status . Term 3 (EL7037) . Device 2 (EtherCAT) . Devices
GVL.bDecelerati...	X	0x00 (0)	BOOL	1.0	385145.0	Input	Decelerate . Status . POS Status . Term 3 (EL7037) . Device 2 (EtherCAT) . Devices
GVL.dPositionLV...	X	29970568	DINT	4.0	385164.0	Input	Position . IND Inputs Channel 1 . Term 2 (EL5072) . Device 2 (EtherCAT) . Devices

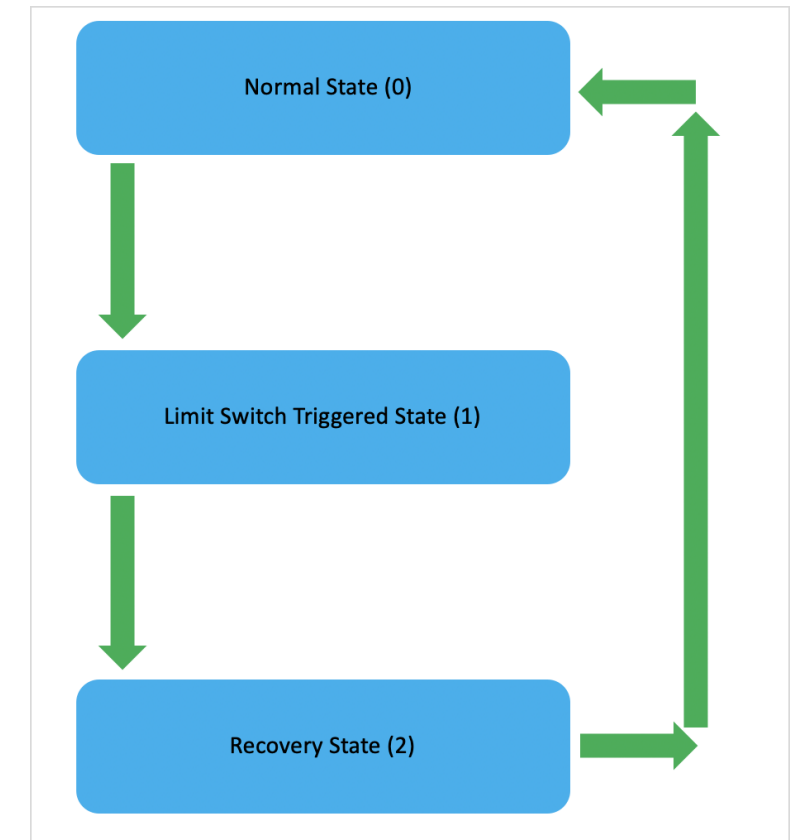
PLC Program Main Task



The main task of the PLC program is continuously repeats by the drive and has a maximum cycle time of 10 microseconds meaning that the PLC must be able to execute all instructions within that time.

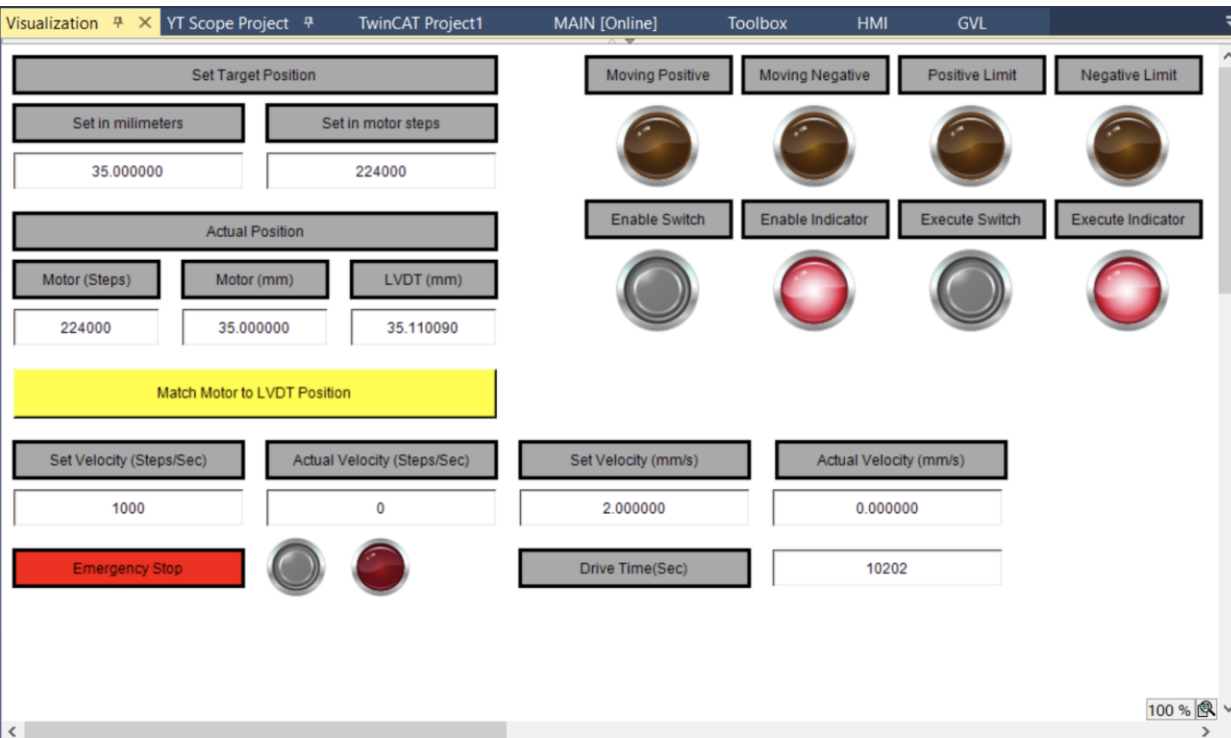
Running tasks in the Normal (0) State:

- Automatically updating position and velocity readings
- Conversions to the metric system from the base units of the drive
- Ability to set desired velocity and positional settings



Simple state machine describing behavior of the EL7037 drive when one of the limit switches is triggered

Human Machine Interface



An HMI visualization was created in order to enable easy control of the motor. The visualization interface further links the input/output variables described in previous slides to a series of switches, buttons, and entry boxes to allow users to easily read and write variables.

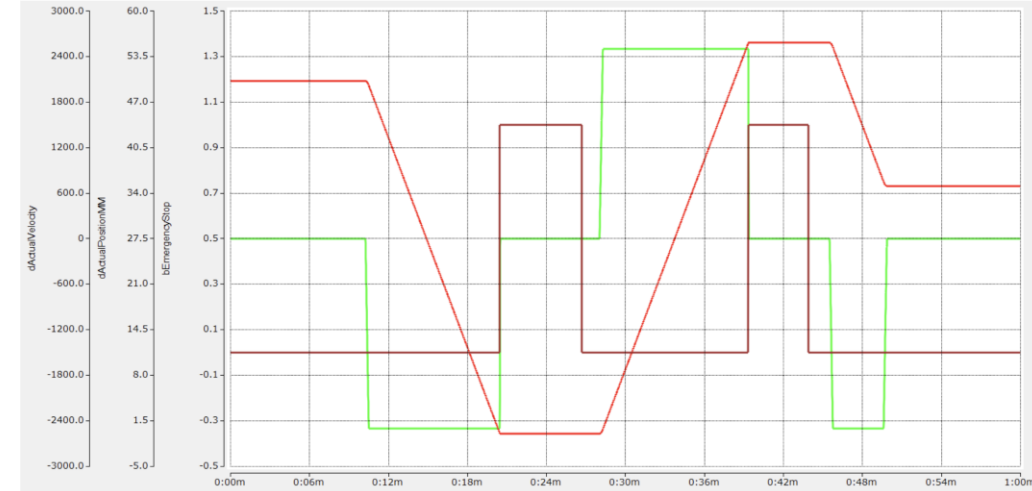
Functionalities

- Enable and Execute Switches for the Motor
- Set Target Position (in mm or steps)
- Set Target Velocity (in mm/s)
- Recalibrate internal motor position to LVDT reading
- Emergency Stop Switch
- Indicators for Limit Switches and Motion
- Drive time, Velocity and Positional Readings

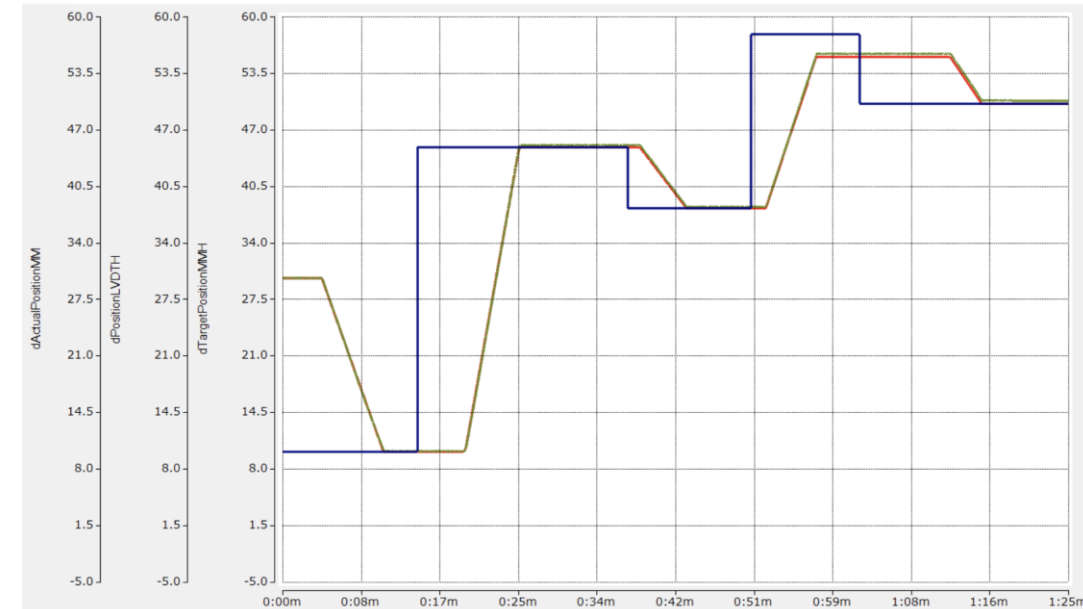
Scope View

- YT Chart
 - Execute
 - bExecuteMotion
 - Enable
 - bStepperEnable
 - Position
 - dActualPosition
 - Velocity
 - dActualVelocity
 - Drive Time
 - dDriveTime
 - Position (mm)
 - dActualPositionMM
 - LVDT Position(mm)
 - dPositionLVDT
 - Accelerating
 - bAccelerating
 - Decelerating
 - bDecelerating
 - Emergency Stop
 - bEmergencyStop

Scope view showing the motor being moved through its full range from limit switch to limit switch. Red indicates position, Green Velocity, and Brown emergency stop (limit switches).

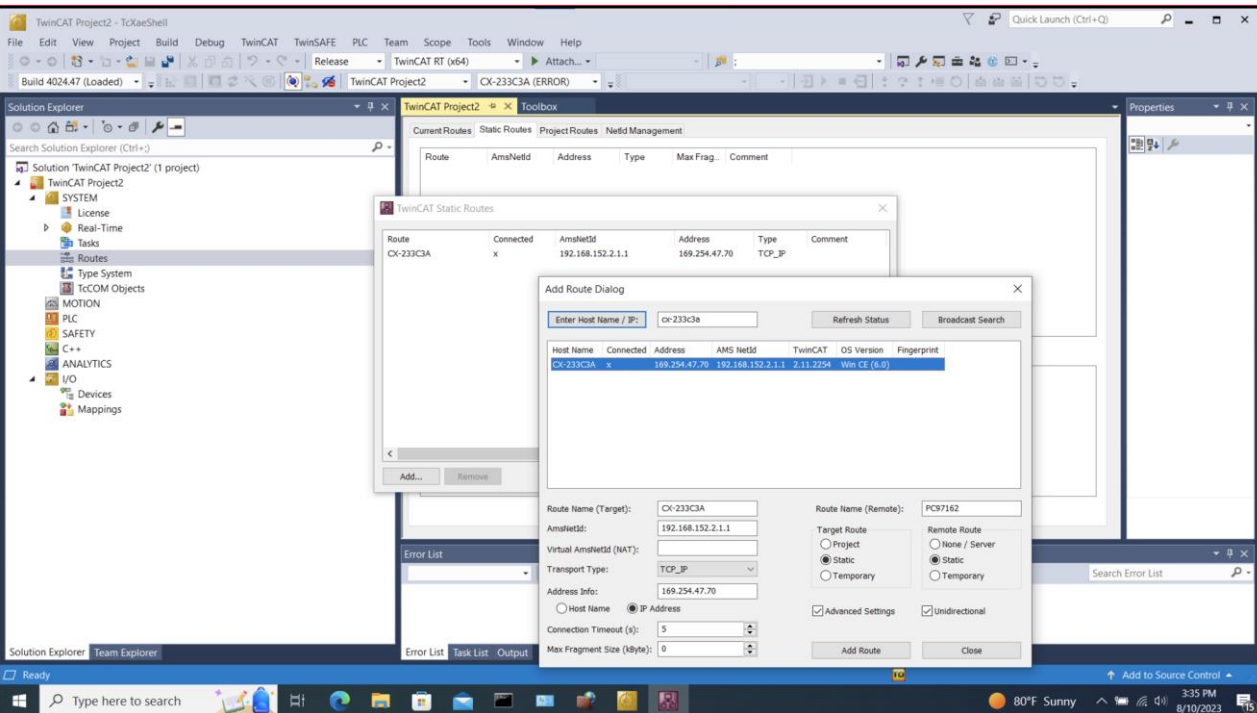


Scope view showing how motor position (Red) matches LVDT Position (Green) and that both positional reading reach the target position (Dark Blue) except when the target position is out of the range of the limit switches as seen around time 59 seconds.



Variables Entered Into Scope Viewer

CX5020-Future Steps



The final step of my project involved connecting to a CX5020 embedded PC. This involved the configuration of the IP address and AMS net ID of the CX5020 drive to allow connection with the PC. Once connected it is possible to upload the PLC project to the CX5020 and allowing this device to run the system instead of the laptop the project was developed on.

Next Steps

- Remote connection to CX5020
- Integration into the EPICS system at SLAC
- Motor tuning to reduce response delay

Sources and Acknowledgements

Acknowledgements

I would like to thank my mentor Namrata Balakrishnan, as well as James Bong, Daniele Caltabiano and the rest of the EED motion control team for their assistance with this project. Additional thanks to Shawn Alverson for the use of his laptop.

Sources

1. <https://download.beckhoff.com/download/document/io/ethercat-terminals/el5072en.pdf>
2. <https://download.beckhoff.com/download/Document/io/ethercat-terminals/el70x7en.pdf>
3. https://slac.sharepoint.com/sites/pub/Publications/Halo_Collimator_System.pdf
4. <https://howtomechatronics.com/how-it-works/electrical-engineering/stepper-motor/>
5. <https://www.motioncontroltips.com/faq-what-is-microstepping/#:~:text=Microstepping%20allows%20a%20motor%20to,motor%20to%20make%20it%20move.>
6. https://www.industrial-electronics.com/emct_2e_5i.html
7. <https://www.beckhoff.com/en-us/products/ipc/embedded-pcs/cx5000-intel-atom/cx5020.html>
8. http://www.chem.cmu.edu/groups/bier/procedure_files/lit/SLO-SYN.pdf

Full bibliography can be found with the final paper submission for my SULI project