A HIGH-PRECISION MOTION SCOPE DATA STREAMING PIPELINE FOR LCLS-II FAST WIRE SCANNER

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OUTLINE

I LCLS-II FAST WIRE SCANNER SOFTWARE UPGRADE

II A HIGH-PRECISION MOTION SCOPE DATA STREAMING PIPELINE

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LCLS-II FAST WIRE SCANNER SOFTWARE UPGRADE

LCLS-II Fast Wire Scanner Upgrade

Wire Scanner:

- Wire scanner is one of the primary diagnostic tools to measure the transverse profile of the electron beam at LCLS-II.
- LCLS-II has 20 operating fast wire scanners:
  - Controlled the Aerotech Ensemble controller with position feedback;
  - Aiming to measure the beam transverse profile.
- LCLS-II is capable of delivering X-ray pulses at repetition rates up to 1MHz:
  - The motion control software for LCLS-II fast wire scanners is upgrade at 2023 to meet the measurement requirement.

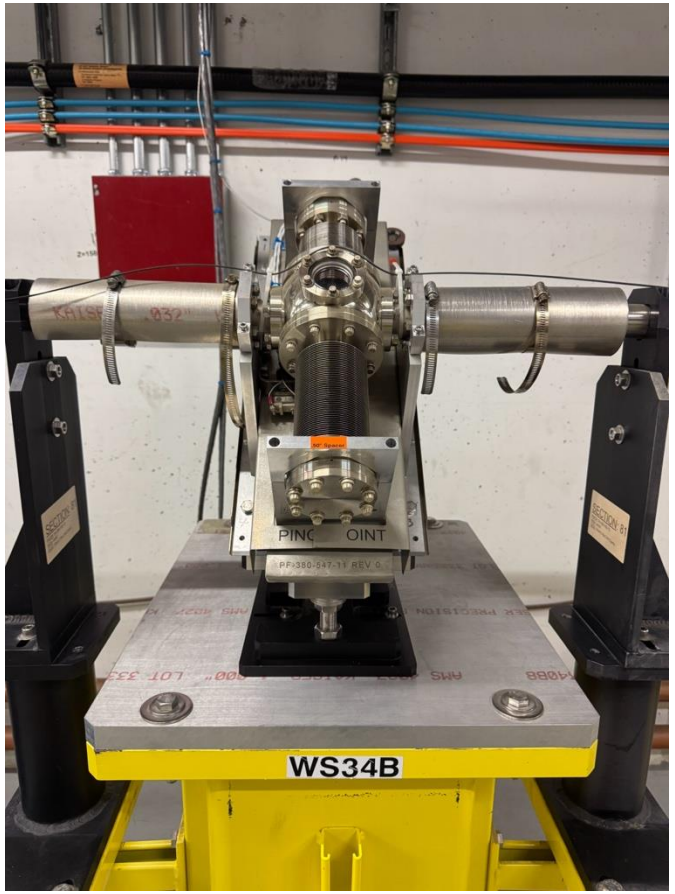

Fig.1: LCLS-II Wire Scanner in Undulator Hall

LCLS-II Fast Wire Scanner Upgrade

Design Requirement:

- LCLS-II beam repetition rate can be continuously adjusted from 1Hz to 1 MHz.
  - Step mode: Wire scanner approaches scan start position with 10mm/s, then scans with a desired speed less then 10mm/s;
  - Continuous mode: Wire scanner moves to the top position with only the desired speed.

Software Architecture:

- Aerotech controller execute motion profile, and monitor faults that may occur;
- EPICS Layer controls scan modes, set parameters to Aerotech controller.

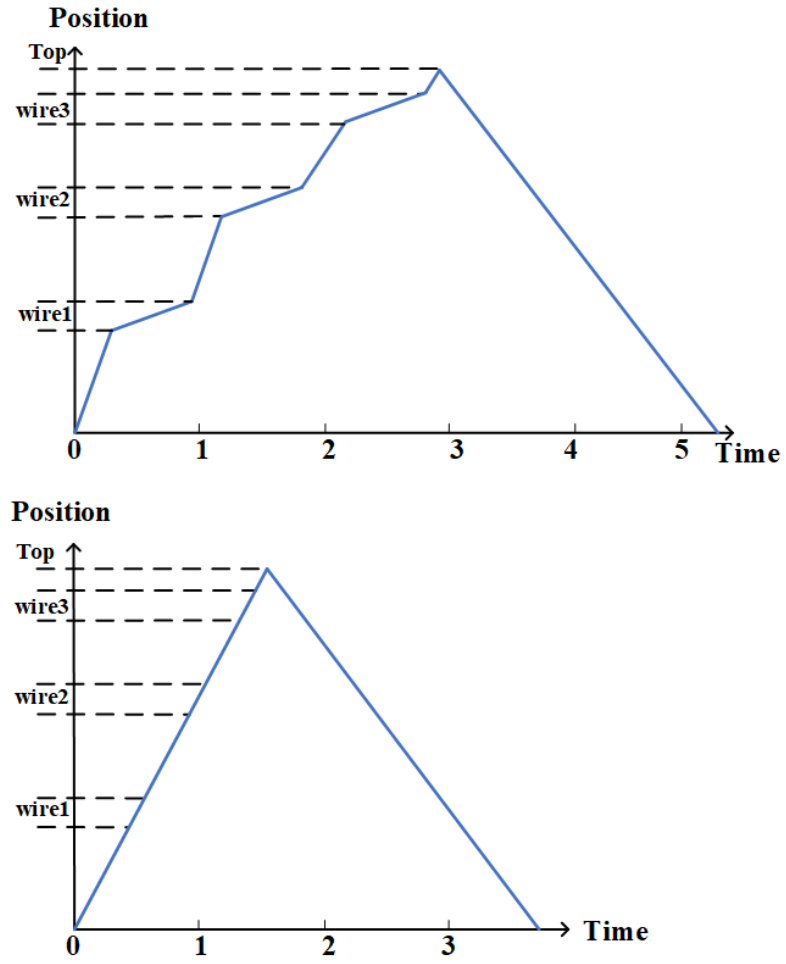

Fig.2: Step Scan Trajectory and Continuous Scan Trajectory

LCLS-II Fast Wire Scanner Upgrade

Filed Commissioning:

- Wire scanner moved in 1.4mm/s in step mode and takes 13.7s move to the top position;
- In continuous mode, the wire scanner can be accelerated into 400mm/s within 77μs and decelerated to 0mm/s within 26μs;
- All the 20 fast wire scanners' motion control software in LCLS-II have been upgraded.

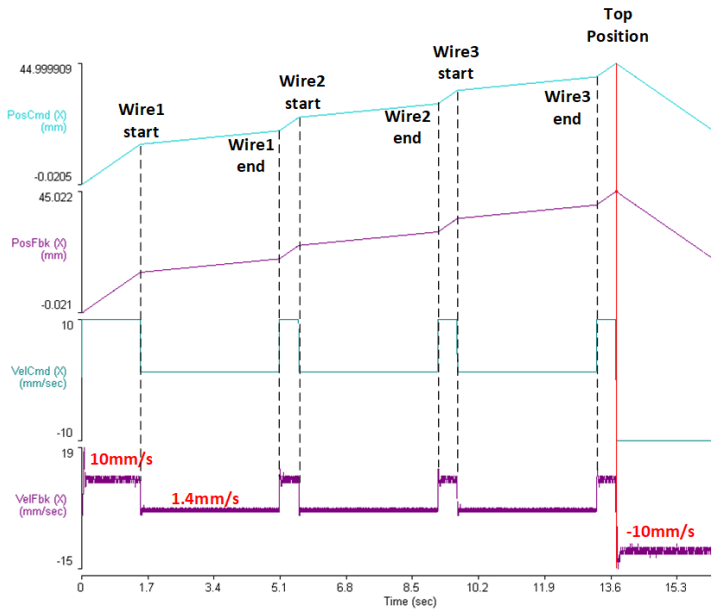

Fig.3a: Step Scan Scope Data from Controller

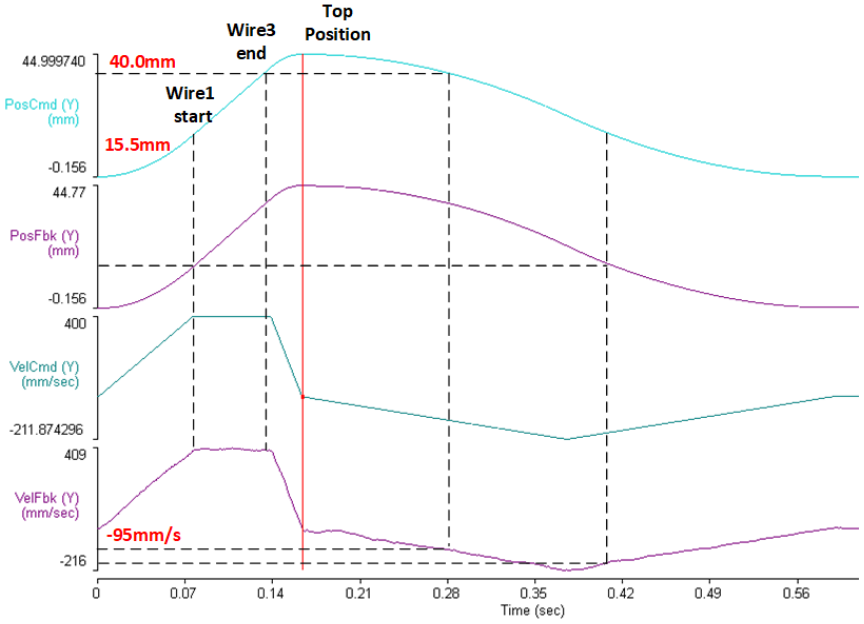

Fig.3b: Continuous Scan Scope Data from Controller

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A HIGH-PRECISION MOTION SCOPE DATA STREAMING PIPELINE

Motion Scope Data Streaming Pipeline

Disadvantage of current motion scope data:

- Scope data from Aerotech controller:
  - High-precision but has to be physically connected to the controller via Ethernet cable.
- The motion scope data from Archiver Viewer:
  - Data is low-resolution, with loss of detail;
  - Data can only be retrieved after few minutes.

Design Requirement:

- High-precision and high-resolution motion scope data must be acquired after scan;
- The data acquisition frequency must be dynamically adjusted to match beam rate up to 1MHz;
- The total scan duration can vary from under one second to over 3 minutes.

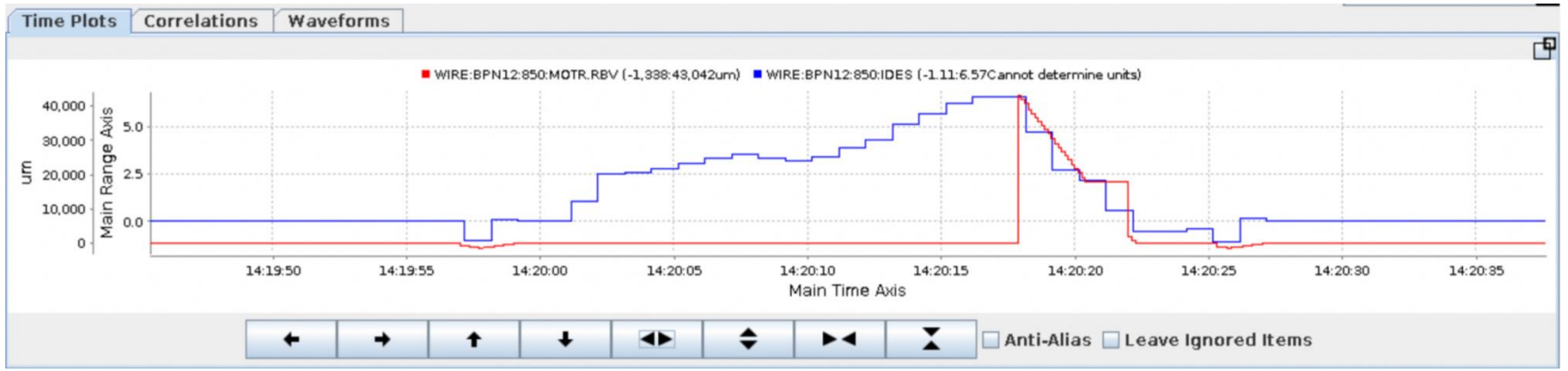

Fig.4: Step Scan Scope Data from Archiver Viewer

Motion Scope Data Streaming Pipeline

Software Architecture:

- Aerotech Layer:
  - Directly drives motion and collects hardware data;
  - Executes precise trajectories, captures signals in real-time, and ensures reliable scanner operation.
- Scope Data Layer:
  - Processes high-speed controller streams using Python asyncio package,
  - Converting acquisitions into EPICS waveform PVs for storage.
- EPICS Layer:
  - Coordinates overall motion control, integrates parameters with processed data;
  - Archives data efficiently in EPICS.

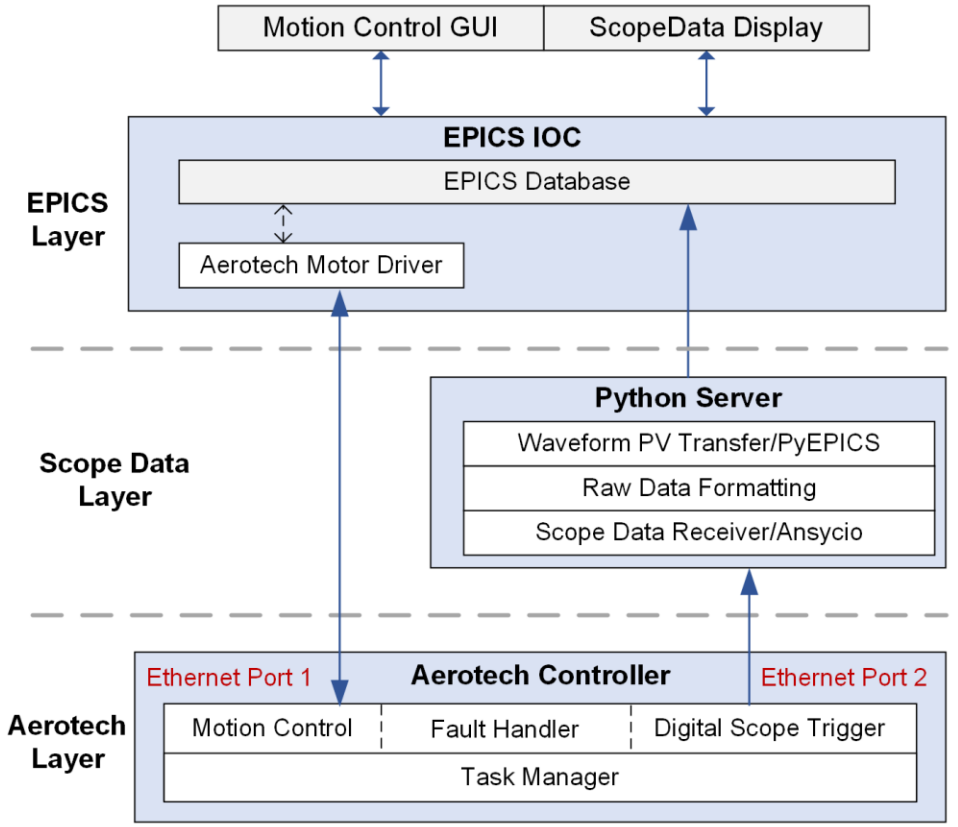

Fig.5: Scope Data Pipeline Software Architecture

Motion Scope Data Streaming Pipeline

Adaptive Data Down Sample:

- The Aerotech controller collects four types of scope data at 1000 Hz:
  - Position command
  - Position feedback
  - Current command
  - Current feedback
- To reduce transmission load, downsampling adjusts frequency based on scan velocity while maintaining sufficient resolution;
- After downsampling, datasets shrink to about 38,400 points total:
  - One set of the maximum data points of slow scan is 9600 per type.

Scan Velocity (mm/s)	DS Factor	Scan Time (s)	Data Points (one type)
0.04 – 0.5	50	300 – 480	9,600
0.5 – 1	40	200 – 300	5,000 – 7,500
1 – 1.5	30	120 – 200	4,000 – 6,667
1.5 – 5	20	60 – 120	3,000 – 6,000
5 – 10	15	30 – 60	2,000 – 4,000
10 – 20	10	3 – 30	300 – 3,000
20 – 40	5	1 – 3	200 – 600
≥ 40	3	≤ 1	≤ 333

Table 1: Downsample Factors by Scan Velocity

Motion Scope Data Streaming Pipeline

Scope Data Streaming Pipeline Workflow:

1. **Initialize Scan**: IOC retrieves beam parameters, sends motion settings to the Aerotech controller;
2. **Start Motion**: Controller enables motor, triggers digital scope, and begins acquiring motion data;
3. **Complete or Fault detected**:
   - If success: motor returns home and deactivated,
   - If failure: fault handler retracts motor safely while continuing data collection;
4. **Store and Retrieve Data**: Controller saves scope data locally, then EPICS IOC triggers Python program, retrieves scope data from controller;
5. **Plot Results**: Plot Scope data on PyDM GUI, and archive data into EPICS Archiver Appliance.

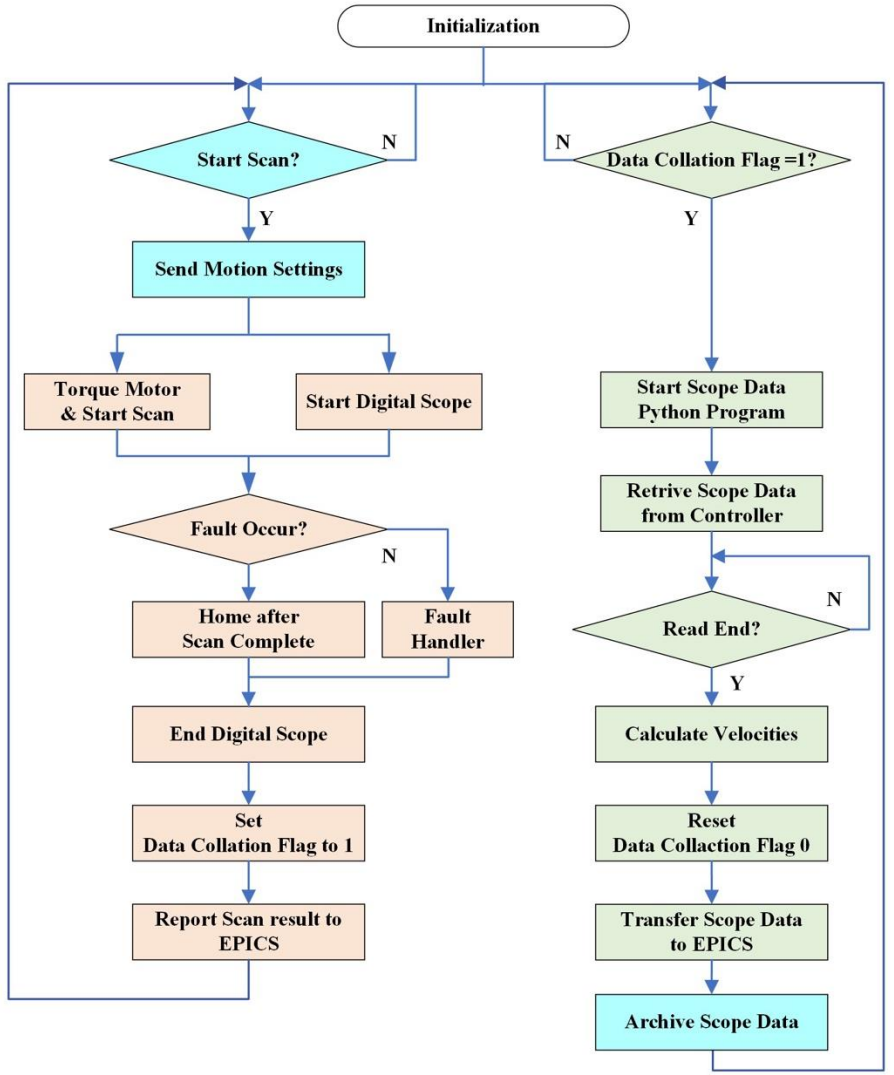

Fig.6: Scope Data Pipeline Workflow

Motion Scope Data Streaming Pipeline

Main Control Panel GUI:

- Displays beam and wire parameters to users with essential information in a simple manner;
- Provides expert-level data and functions in other 8 selectable widgets;
- Controller Task can be managed from GUI;
- A progress bar can indicates the status of scope data:
  - Scope Data Collecting;
  - Scope Data Retrieving;
  - Drawing Scope Data;
  - Scope Data Arrived.

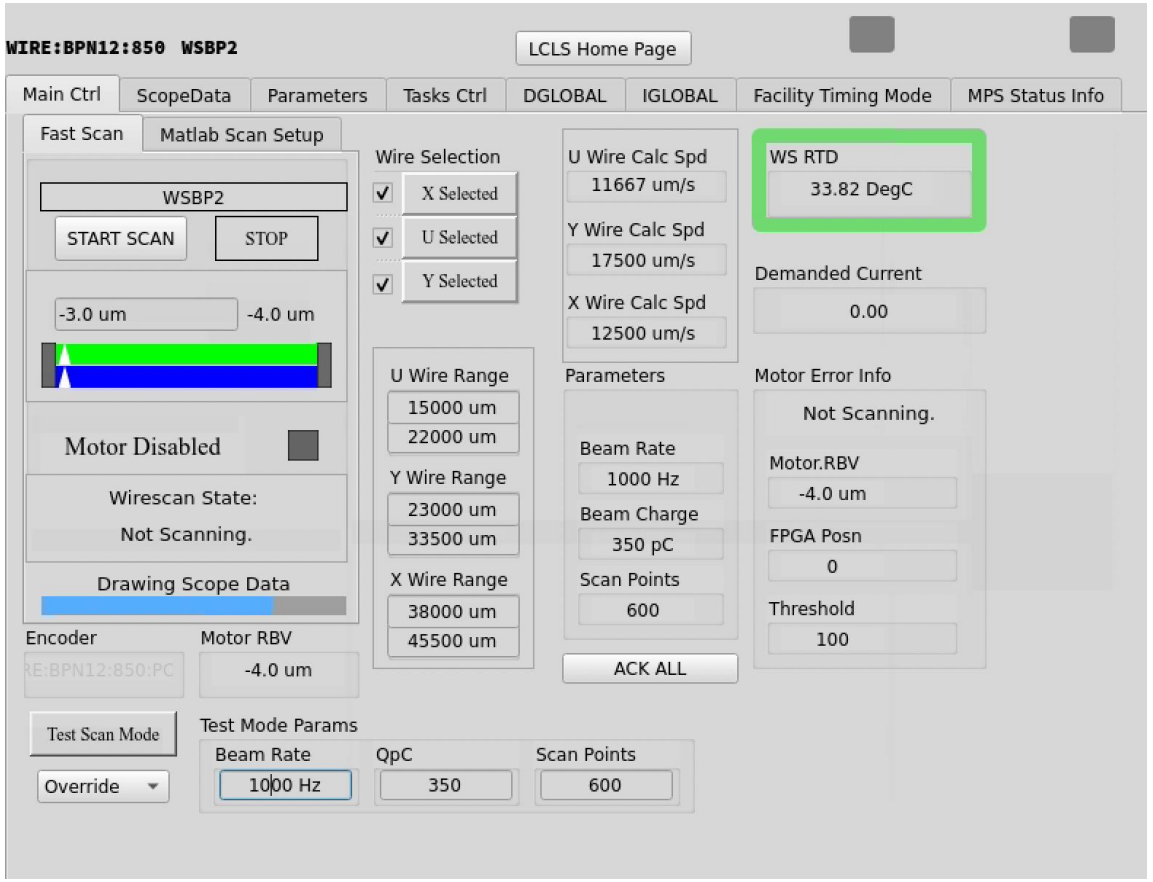

Fig.7: Main Fast Wire Scanner Control GUI

Motion Scope Data Streaming Pipeline

Scope Data Display:

- The scope data profile can be plotted after each scan with 6 motion parameters:
  - Add calculated speed command and speed feedback.

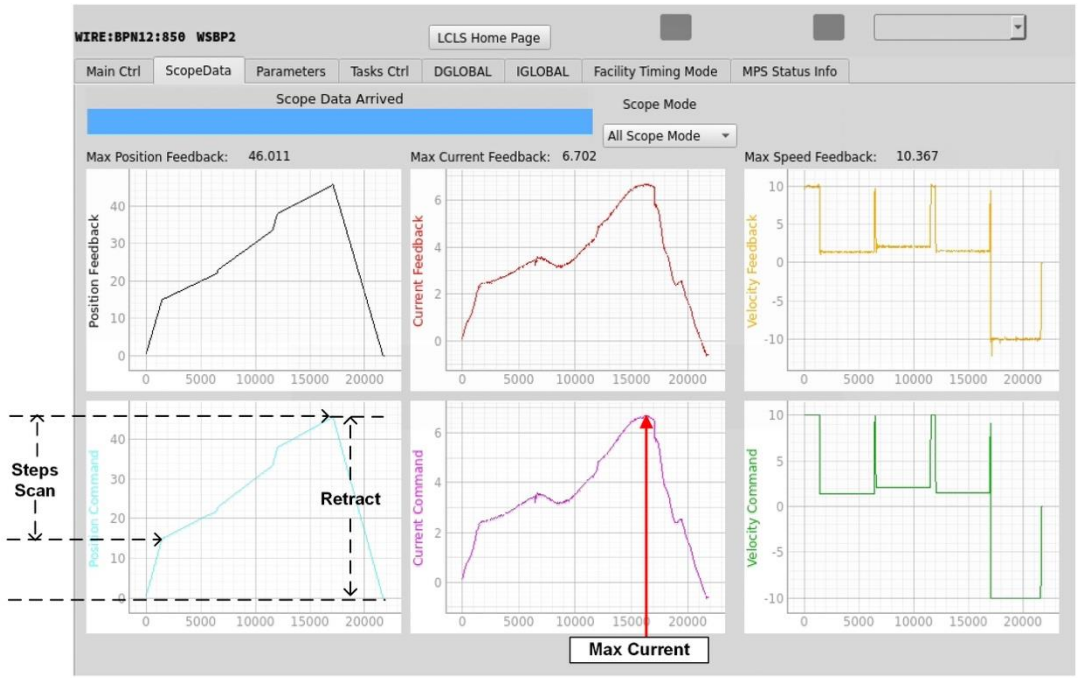

Fig.8: Scope Data Display with Step Scan

Scope Data Retrieval Time Test:

Beam Rates (Hz)	Velocity (mm/s)	Scan Time(s)	Retrieval Time(s)
10	0.175	172.1	78.7
60	1.05	72.0	29.4
120	2.1	26.5	24.0
2000	35.0	14.3	14.3
8000	140	7.9	11.0
20000	350	4.2	8.7
50000	<540	3.8	7.5

Table 2: Scope Data Retrieval Performance Test Results

Motion Scope Data Streaming Pipeline

CONCLUSION:

- The new designed LCLS-II fast wire scanner scope data streaming pipeline can acquire **motor position**, **current**, and **velocity** directly from Aerotech controller in real-time without data loss;
- After data downsampling, the data retrieval times is **below 30s** under nominal operating conditions;
- This data streaming pipeline **has been developed and deployed** into all **20** LCLS-II fast wire scanners;
- The **future plan** is to expanding this tool into LCLS-I wire scanners.

THANK YOU