

Winder Quality Requirements

Dune Consortium Meeting

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(on behalf of the Daresbury Lab Factory Technical Team)

Winder Quality Basics

- Wire tension target and its tolerances
- Wire measurement systems (Laser, DWA)
- Load-cell calibration
- Tension control system and live tension monitoring
- Winding recipes and winder calibration
- Winder frame checks and service/maintenance plan
- Winder head checks and service/maintenance plan
- Software repositories

Wire Tension Target and tolerances

- Current wire tension target 6.5 ± 1 N

7.51 ← denotes: tension > 7.5 N (tolerate 8.5 N max if average < 7.5 N)
7.50 ← denotes 5.5 N \leq tension ≤ 7.5 N
4.00 ← denotes: 4.0 N \leq tension < 5.5 N with length < 500 mm
5.49 ← denotes: 4.0 N \leq tension < 5.5 N with length ≥ 500 mm (re-tension)
3.99 ← denotes: tension < 4.0 N (re-tension)

- We should take into account measurements system uncertainties
- We should to take into account time relaxation per layer
 - A layer tension drops about ~ 0.2 N after the next layer is wind up

Wire tension measurement systems

- DWA and Laser system

- Both systems measure tension T by means of the wire fundamental frequency in Hz

$$T = 4\mu L^2 f_0^2$$

- For the LFA wire the error from the DWA and Laser systems are:
 - DWA ~ 0.5 N
 - Laser ~ 0.25 N

Wire tension system

(better understanding)

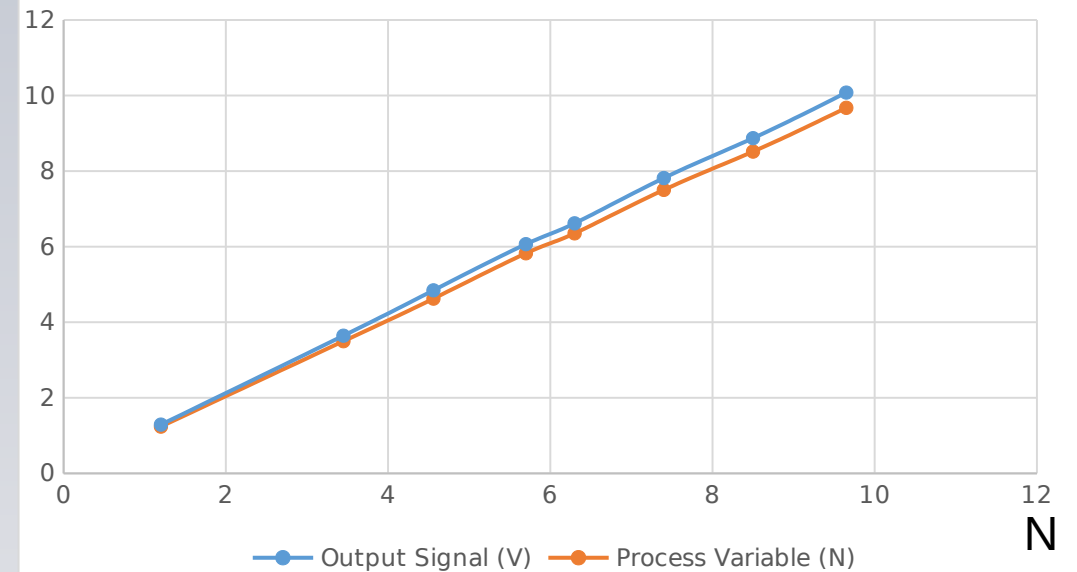
- We have a better understanding of the wire tension system.
 - Set of controlled pulling tests
 - We need to preserve the integrity of the wire at all times.
 - In the past, it was observed that momentarily the tension applied could exceed the maximum output of the live tension system (~ 10 N, depending on the load-cell calibration and mechanics)
 - We will raise an alarm every time we go above 10 Volts (~ 10 Newtons)
 - Good understanding of load-cell calibration on winder head
 - We need standard calibration across all winder heads.
 - Good understanding of winding process
 - Mechanical instabilities in the frame
 - Recipe movements (acceleration, deceleration, speed)
 - Live tension recording and analysis
 - Understand PID loop and corresponding tuning parameters

Load cell calibration (winder #2)

■ Much Improved calibration

- We now know the linear range reliably
- We know the hard stop is beyond the max amplifier output of 10 V
- The amplifier output is always slightly higher than the tension measured by load cell (in N), **10 V := 9.7 N**

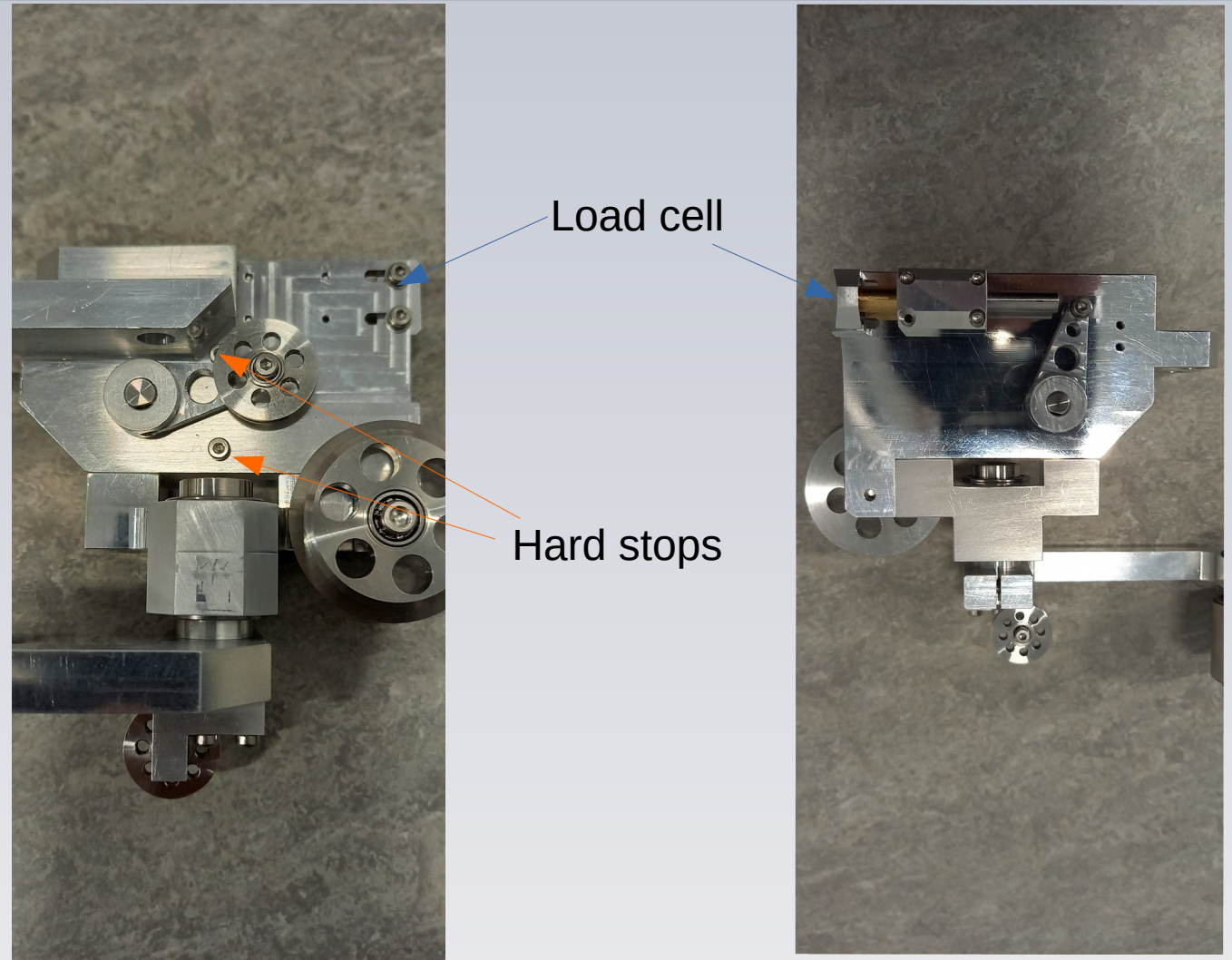
V,N Winder 2, load cell calibration May 2023



Nominal Wt. (N)	Output Signal (V)	Process Variable (N)	Notes
1.2	1.29	1.238	Still on the wire break switch
3.45	3.644	3.498	
4.56	4.845	4.625	
5.7	6.067	5.825	
6.3	6.617	6.353	
7.4	7.816	7.503	
8.5	8.872	8.517	
9.65	10.079	9.676	

Winder 2 Mechanical improvements

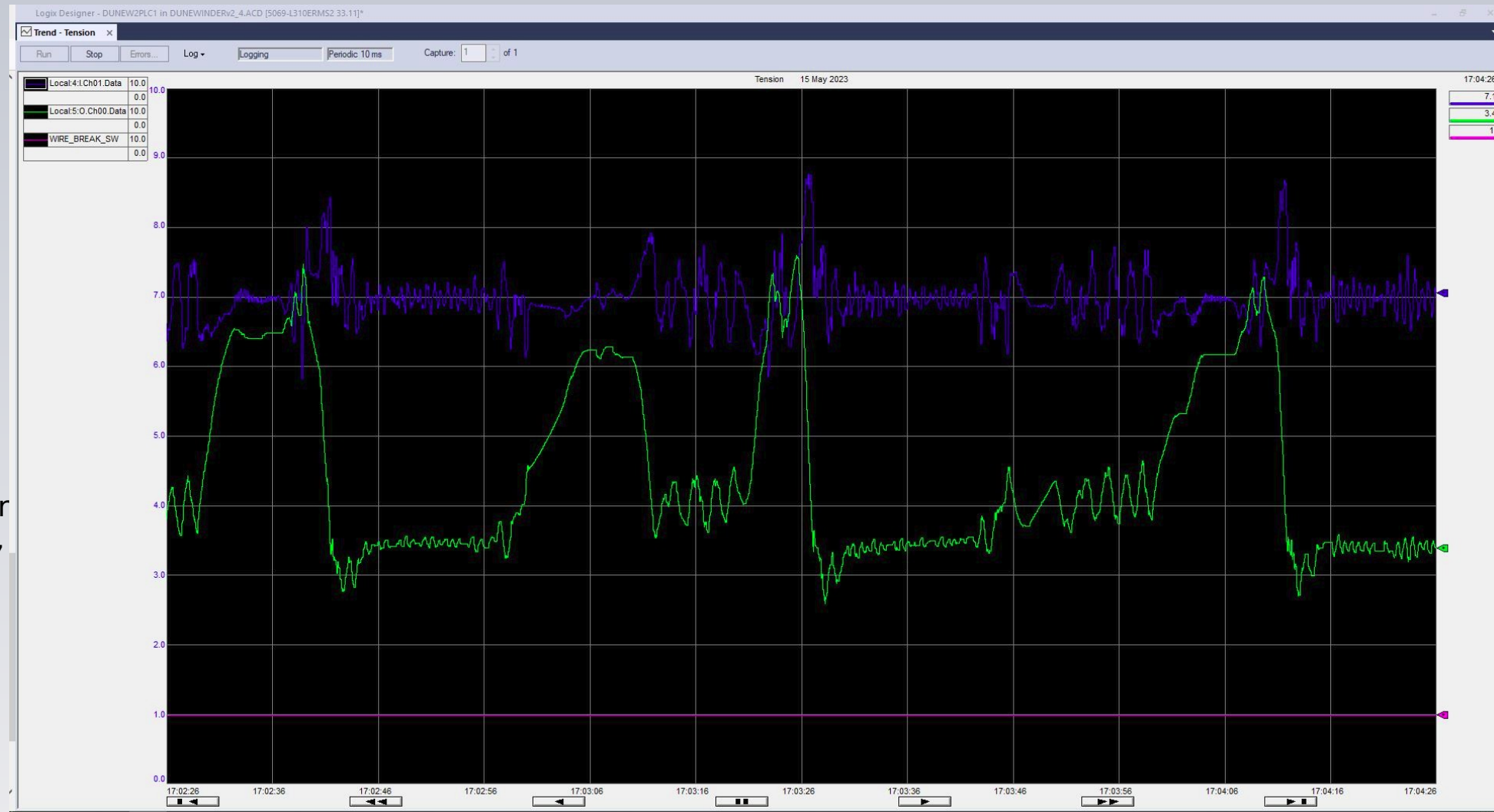
- Changes to load cell location
 - Moved load cell 3mm to match winder #1
 - Avoiding hitting the hard stop before 10 V output



Live tension monitoring

■ APA 6 X-Layer winding

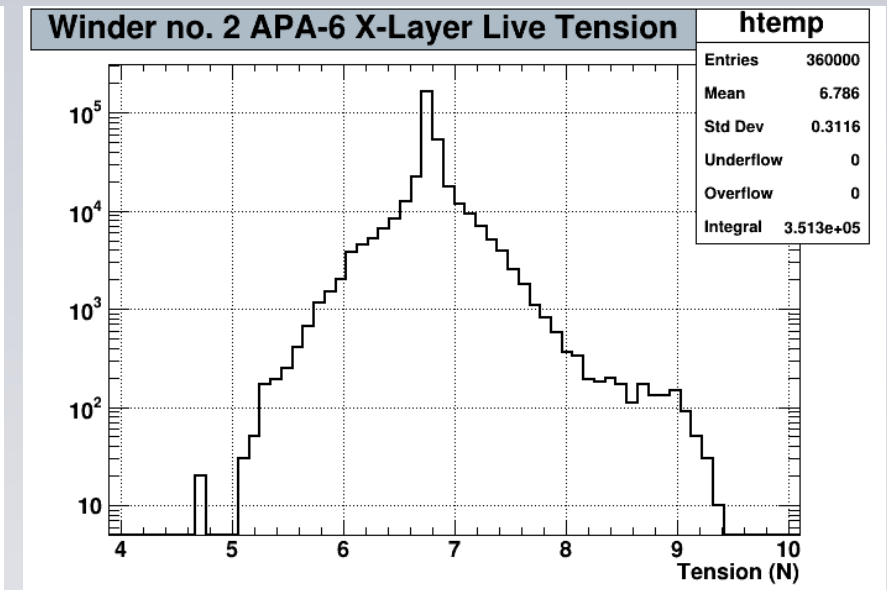
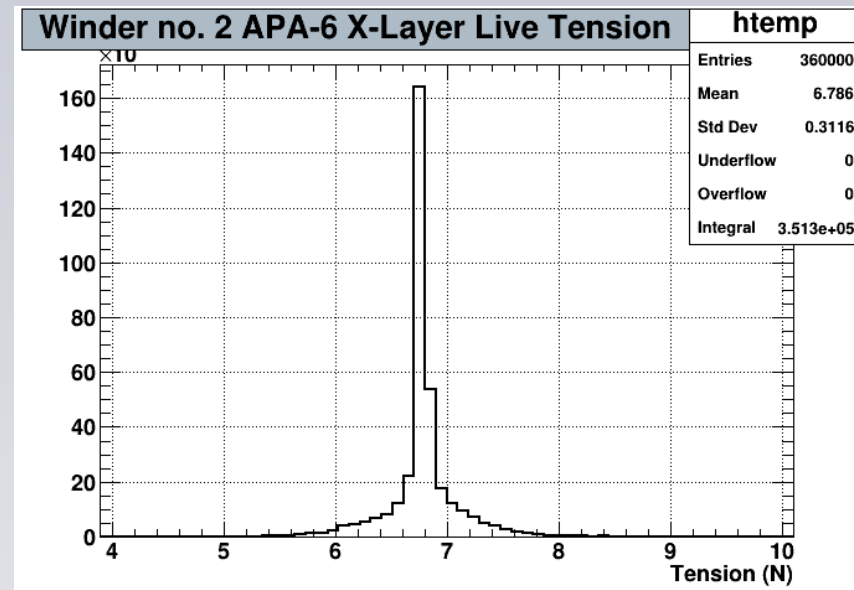
- Slowing down the transfer head movement only
- Oscillations on the long wire horizontally under control
- Peaks now much reduced when laying the wire when moving head from Side A to B and vice versa.
- Next is to adjust the set point to reduce the number of wires needed re-tension, and aiming to be closer to the target tension.



Live tension monitoring (APA6 X-Layer)

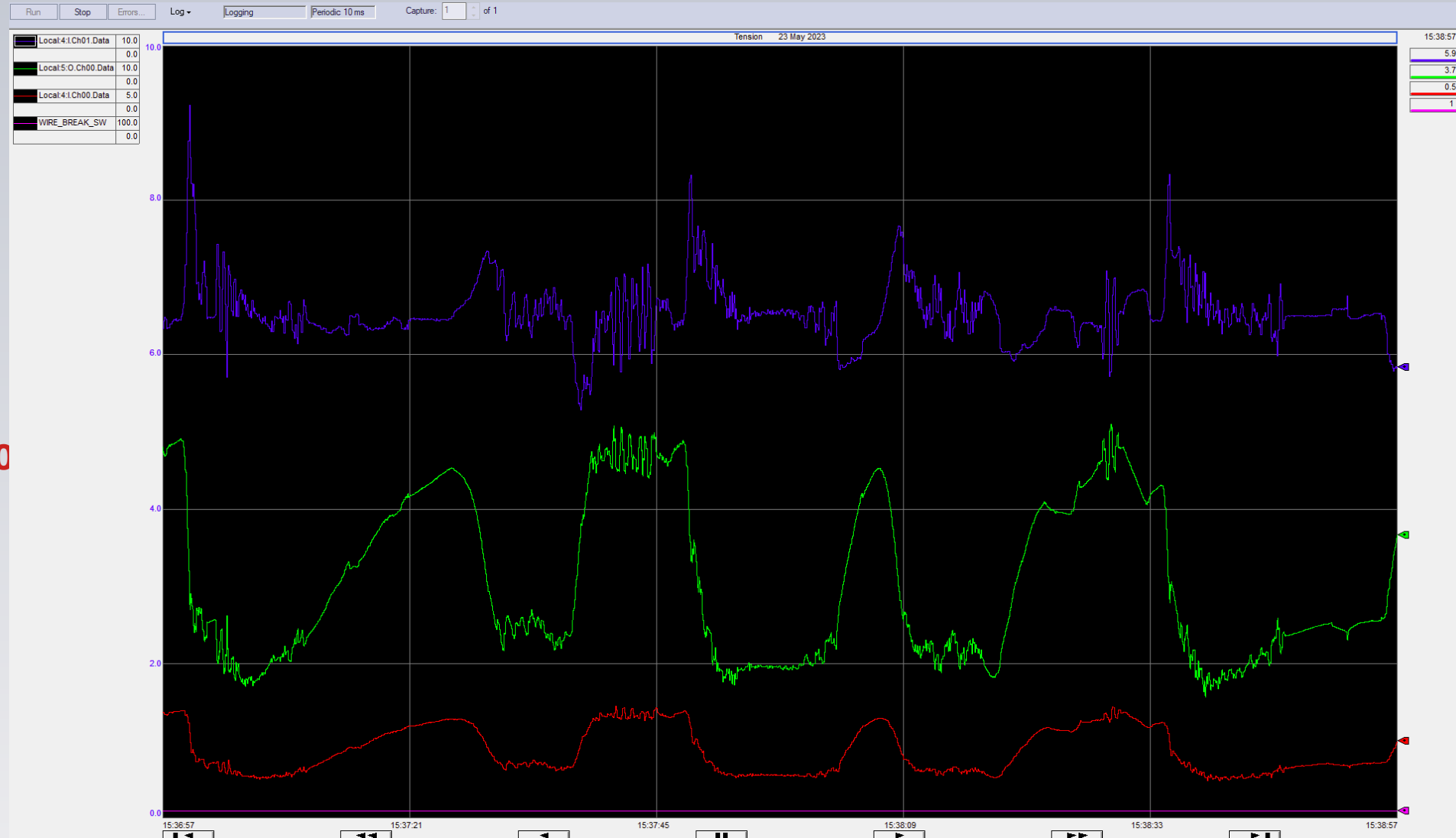
■ APA 6 X-Layer winding

- After Change in recipe
- Slowing down the transfer head movement only
- Oscillations on the long wire horizontally under control
- Peaks now much reduced when laying the wire when moving head from Side A to B and vice versa.
- Next is to adjust the set point to reduce the number of wires needed re-tension, and aiming to be closer to the target tension.



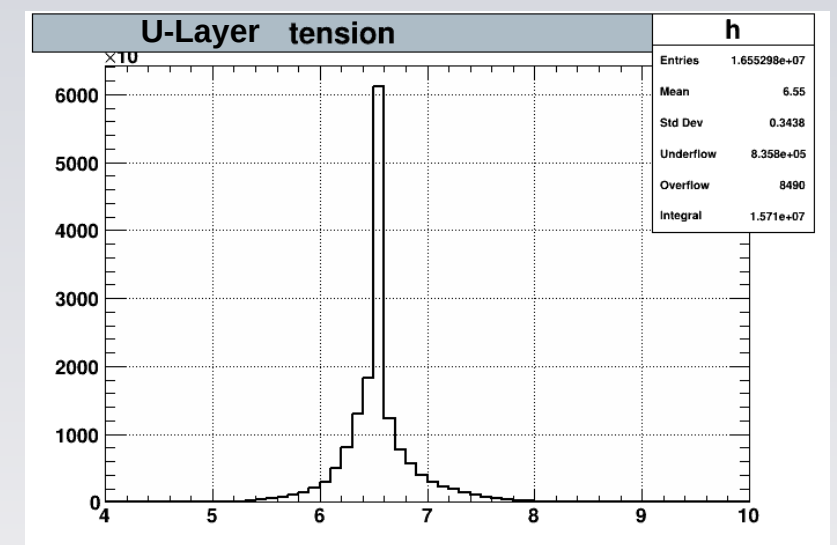
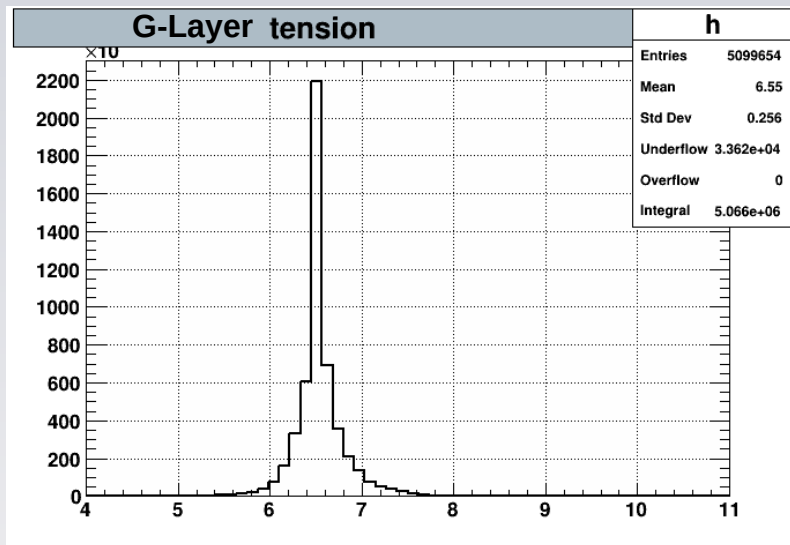
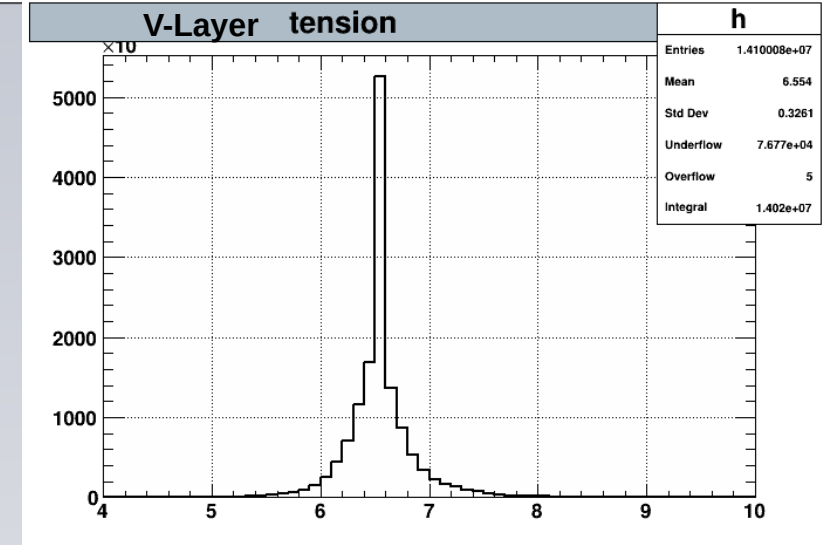
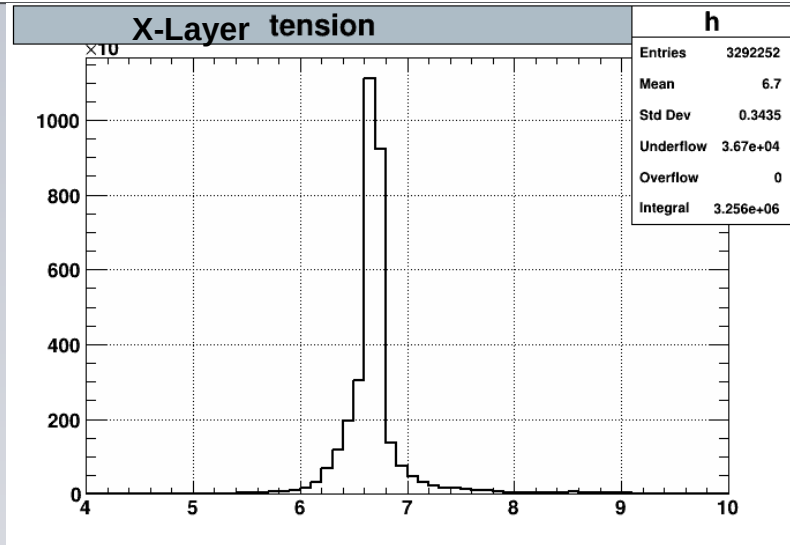
Winder 1, APA 8 U-Layer (Timed)

- APA 8 U-Layer winding
 - Shows controlled behavior
 - Not hitting hard stop
 - No exceeding max load cell amplifier output of 10 Volts
 - **When exceeding 10 Volts alarm will be raised, machine will be stopped and that wrap will be discarded**



Winder #1 APA 8

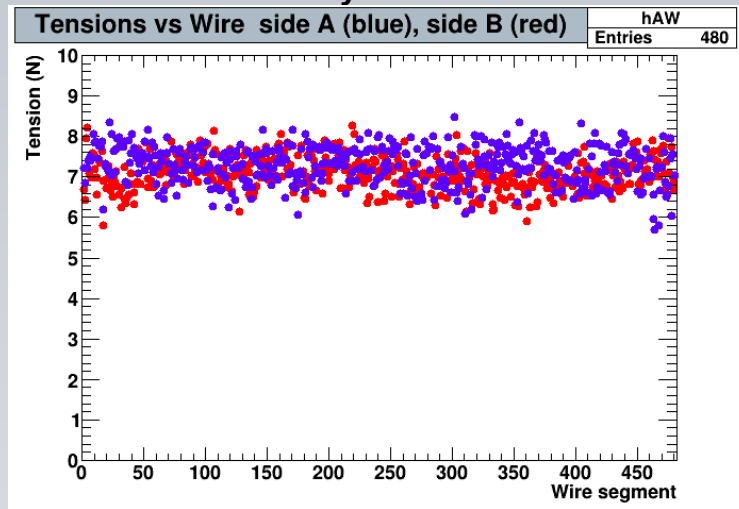
Live wire tension measurements



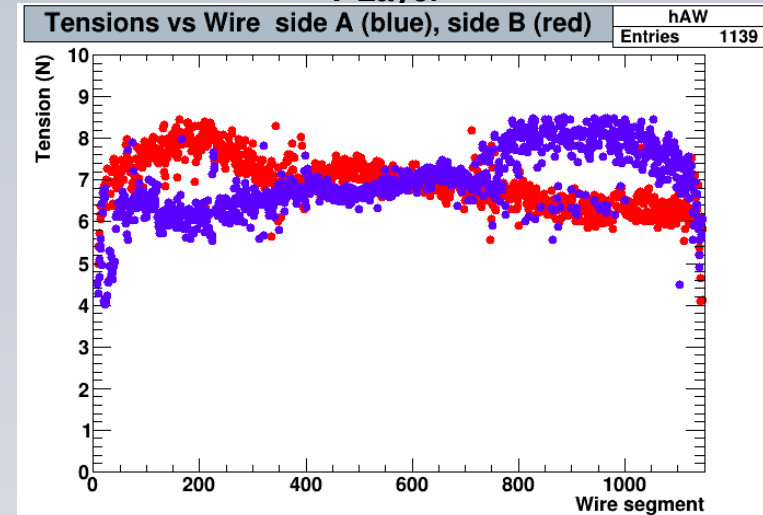
Winder #1 APA 8

Tension measurements with Laser system

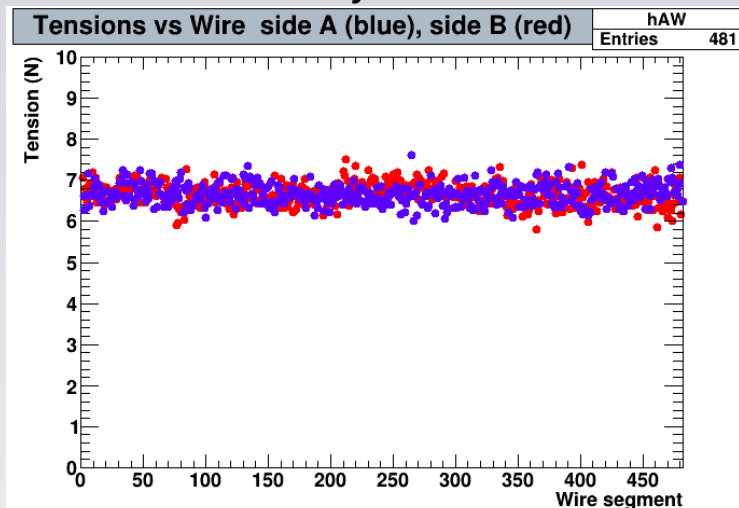
X-Layer



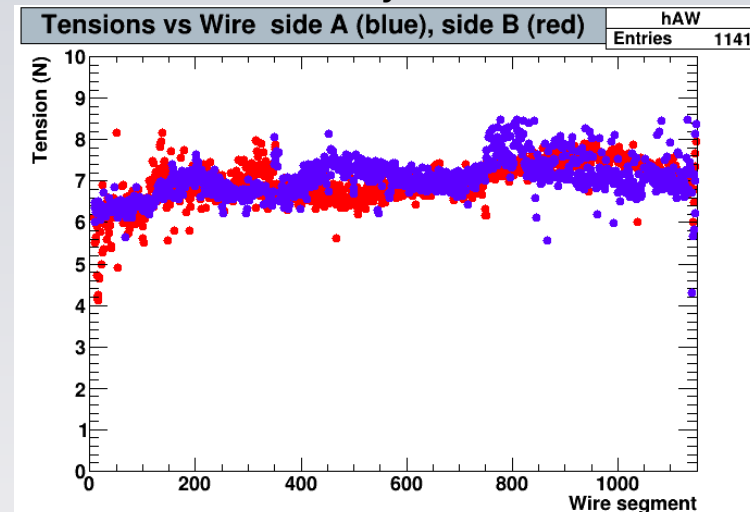
V-Layer



G-Layer



U-Layer



Winder #1 APA 8

Tension measurements with Laser system

APA Layer

G

Wire Segment to Head Board Mapping Tool

Winder Number

1

Winder Head

1

Measurement System

Laser #1

Measured Tensions (Side A)

6.29,6.61,6.34,6.61,7.12,6.3,6.34,6.68,6.68,6.88,7.6,6.6,8,6.85,6.53,6.48,6.21,6.6,6.73,6.47,6.47,6.52,6.66,6.37,6.55,6.73,6.5,6.66,6.68,6.98,6.93,7.7,26,6.63,6.53,7.19,6.95,6.63,6.98,6.97,6.35,6

Entries: 481

Min.: 6.00

Max.: 7.68

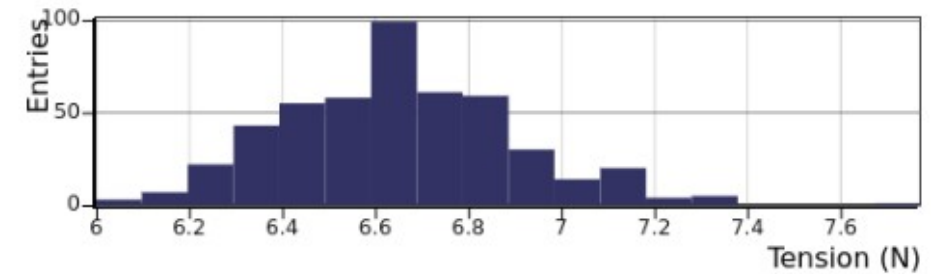
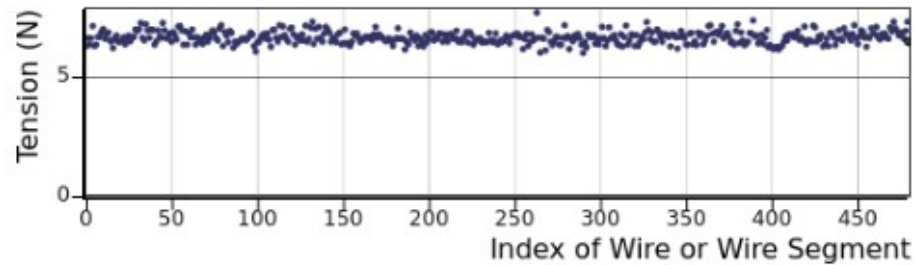
Mean: 6.65

RMS: 0.25

OoB(L): 0

OoB(H): 0

NaNs: 0



Measured Tensions (Side B)

7.04,6.7,6.52,6.42,6.66,6.87,6.65,6.75,7.1,6.6,7.02,6.45,6.61,6.75,6.61,6.73,6.82,6.48,6.58,6.88,6.73,6.53,6.73,6.78,6.55,6.6,6.73,6.52,6.78,6.61,7.07,6.97,6.65,6.76,6.55,6.8,6.83,6.61,6.82,6.93,

Entries: 481

Min.: 5.80

Max.: 7.56

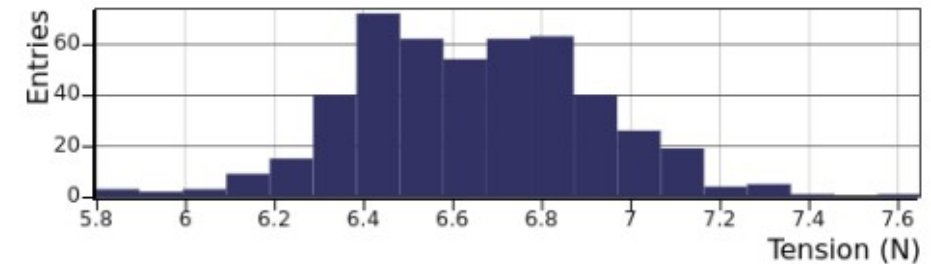
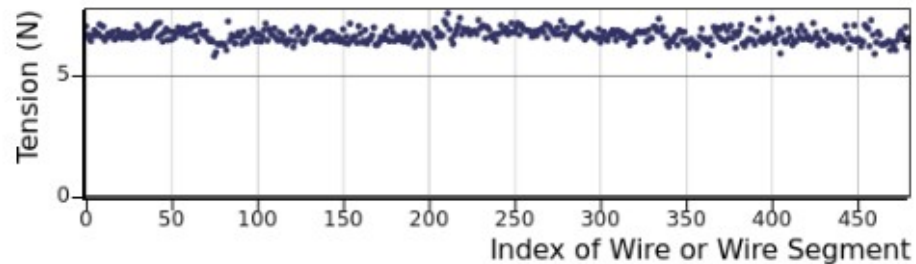
Mean: 6.65

RMS: 0.27

OoB(L): 0

OoB(H): 0

NaNs: 0



Winder #1 APA 8

Tension measurements with Laser system

APA Layer

U

[Wire Segment to Head Board Mapping Tool](#)

Winder Number

1

Winder Head

1

Measurement System

Laser #1

Measured Tensions (Side A)

6.39,6.06,6.4,6.21,6.39,6.22,6.2,6.36,6.52,6.4,6.29,6.31,6.08,6.17,6.12,6.38,6.28,6.7,6.28,6.3,6.34,6.22,6.11,6.31,6.25,6.33,6.35,6.31,6.5,6.45,6.25,6.24,6.26,6.21,6.39,6.36,6.36,6.3,6.38,6.85,6.3

Entries: 1141

Min.: 4.26

Max.: 8.49

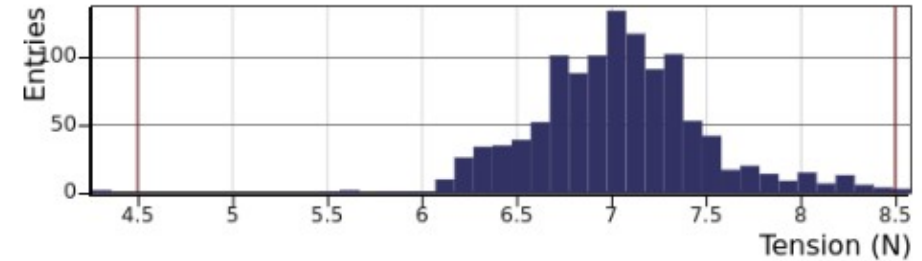
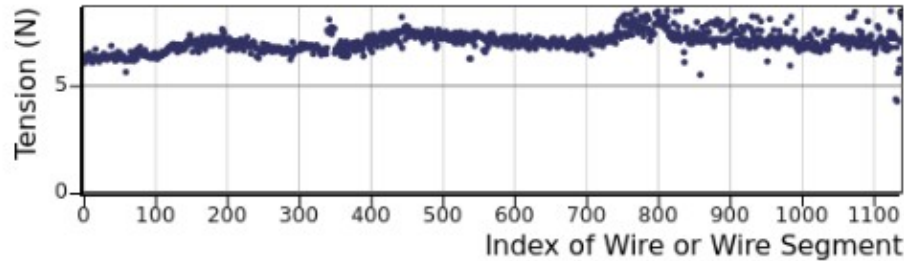
Mean: 7.04

RMS: 0.46

OoB(L): 2

OoB(H): 0

NaNs: 0



Measured Tensions (Side B)

6.19,5.53,5.5,5.6,5.81,4.73,4.17,4.15,4.26,4.68,4.65,5.73,5.93,4.99,6.29,5.28,6.93,5.34,6.31,5.94,6.25,6.18,5.91,6.42,5.54,5.81,6.51,6.11,5.72,6.28,5.99,5.37,6.35,5.43,6.44,6.41,6.52,6.19,6.49,6

Entries: 1141

Min.: 4.15

Max.: 8.14

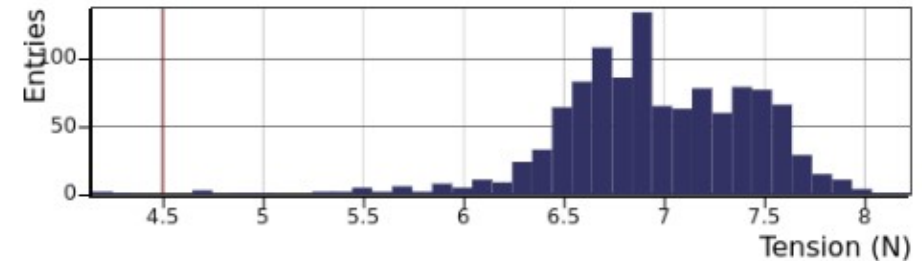
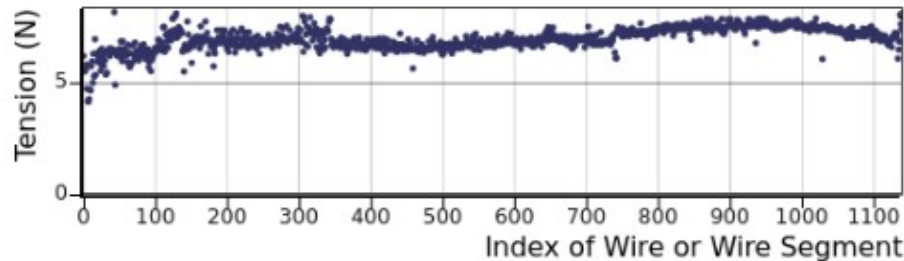
Mean: 6.95

RMS: 0.50

OoB(L): 3

OoB(H): 0

NaNs: 0



Winder machine maintenance plan

- Preventative maintenance plan (PMP)
- Total maintenance plan (TPM)
 - Regular alignment surveys (every 5 APAs)
 - Regular wear and tear inspections (every APA)
- Working on the procedures for this plan

Winder head service/maintenance plan

- PMP and TMP
 - Every time we change spool on head, we will do an inspection (~twice per layer)
 - Servicing of the head after every APA is completed
 - Changing contact pads every year
- Working on the procedures for this plan

Summary

- We will respect whatever wire tension guidance is approved
- Winder head and load-cell calibration quality requirements
 - We will not wind until we know
- We will protect the integrity of the wire at all time
 - Integrity of the wire (making sure the wire is far from plasticity regime)
 - Efficiency (automation and monitoring of some task, improve on speed)
 - Quality (wire tension within specs)
 - Keep on understanding of the tension system
 - But will keep measuring and looking to uncover any blind spots
- Working on procedures describing all the above

Winder Development Upgrade Tasks

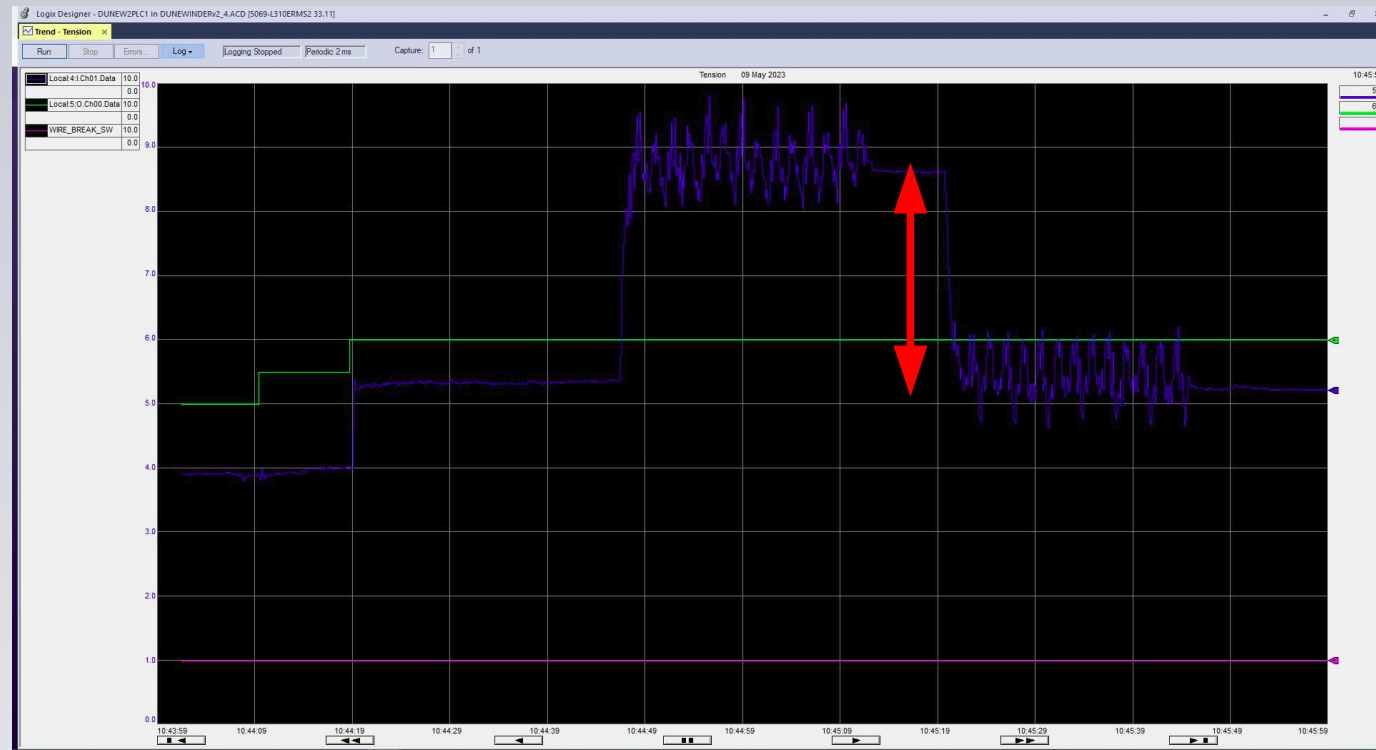
- Mechanical improvements on the winder head and to the winder machines
- Developing a Preventive Maintenance plan (PM), for both winder head and winder machine
- Upgrades, changes and maintenance to the whole winder controls software, this is, the PLC software for hardware control, the Python back-end and its JavaScript GUI, this is the software used by the operators for winding APAs.
- Improvements and maintenance to the tension control system parameters (PID Loop tuning).
- Calibration of the load-cell and amplifier of each winder machine/head permutations and its regular updates through the whole production. Standardize electrical wiring on each winder machine and winder head to be able to exchange heads on different winders as required by the factory operational needs.
- Implementation of a monitoring system for the indication of structural degradation and the predictive maintenance of structural components (CHASM system currently under RTO).
- Automation of tension measurement procedure with Laser Interferometer nearly done
- Working on DWA for tension measurement system.
- Automation of winder Calibration procedure using Cognex camera and its pattern recognition capabilities.
- Installation of Camera monitoring system for winding process with pattern recognition capabilities to aid the operator during winding process.
- Construction Database development and analysis software for tension data, its automation and data handling.

THANKS

THANKS

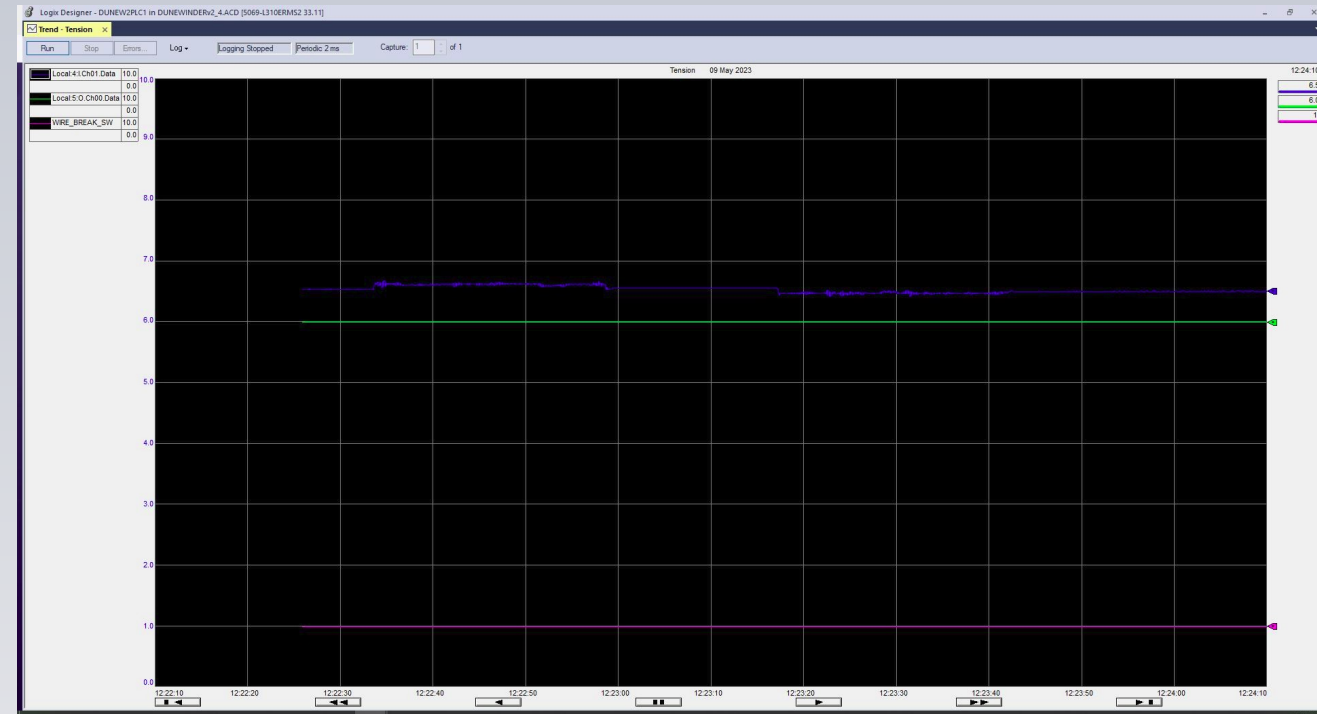
Winder 2, test 1

- Unwind to rewind test
 - Wire end is fixed to the winder frame and winding head is in constant current mode
 - Winder is moved horizontally
 - Large offset observed from unwind to rewind
 - A significant amount of ripple was observed, but from experience can be considered good, but there is room for improvement



Winder 2, test 2

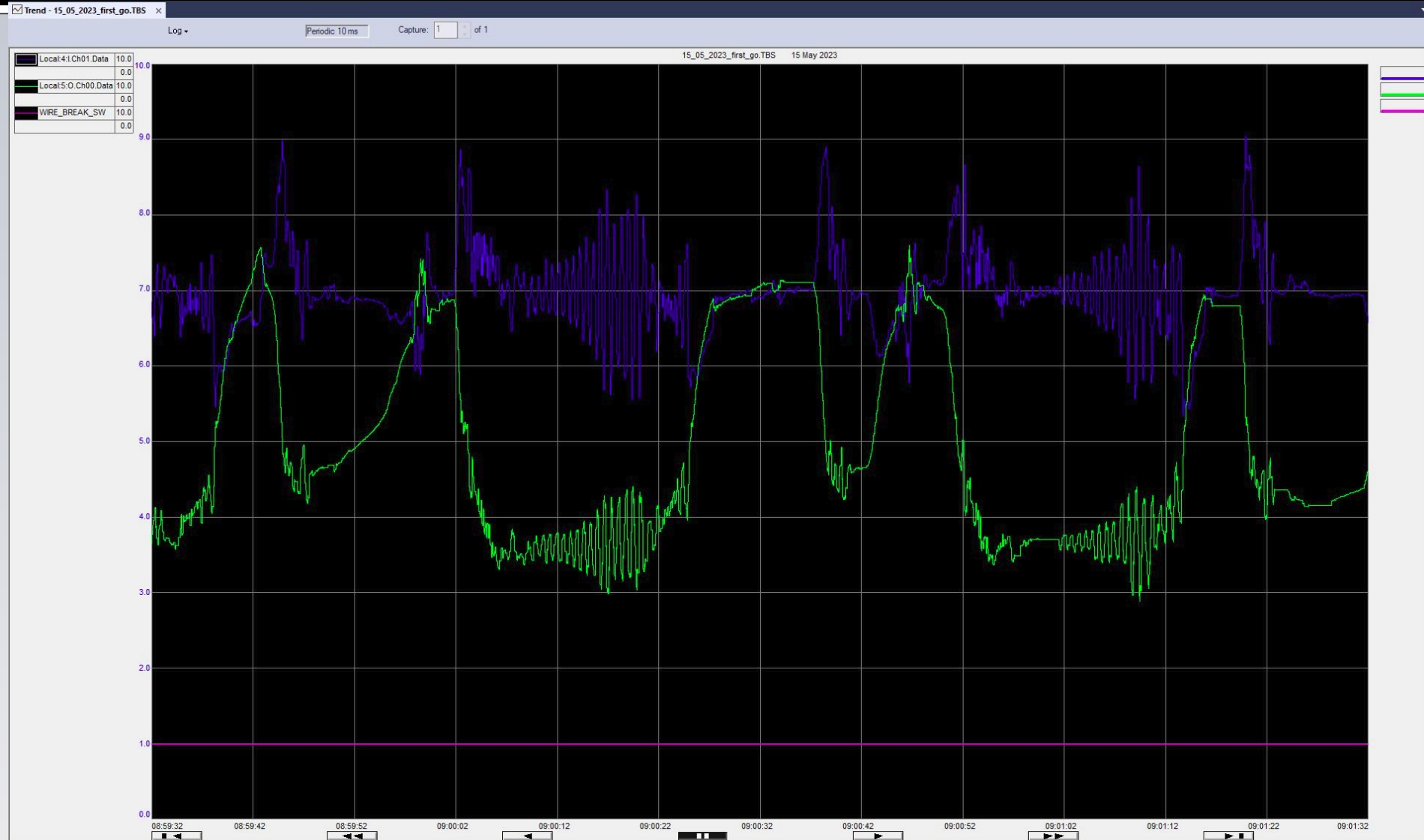
- Isolation test : pulleys and load cell
 - Section of wire cut. One end tied to winder frame. Wire is routed through all of the winding head including everything except the spool, timing belt, and motor. Other end has 6.5N weight hung.
 - Winder is moved up and down.
 - Small amount of offset from unwind to rewind,
 - Which indicates the offset seen on previous slides is from the spool, timing belt, or motor.
 - Almost no ripple was observed, which is very good



Winder 2, before PID loop tuning

■ APA 6 X-Layer winding

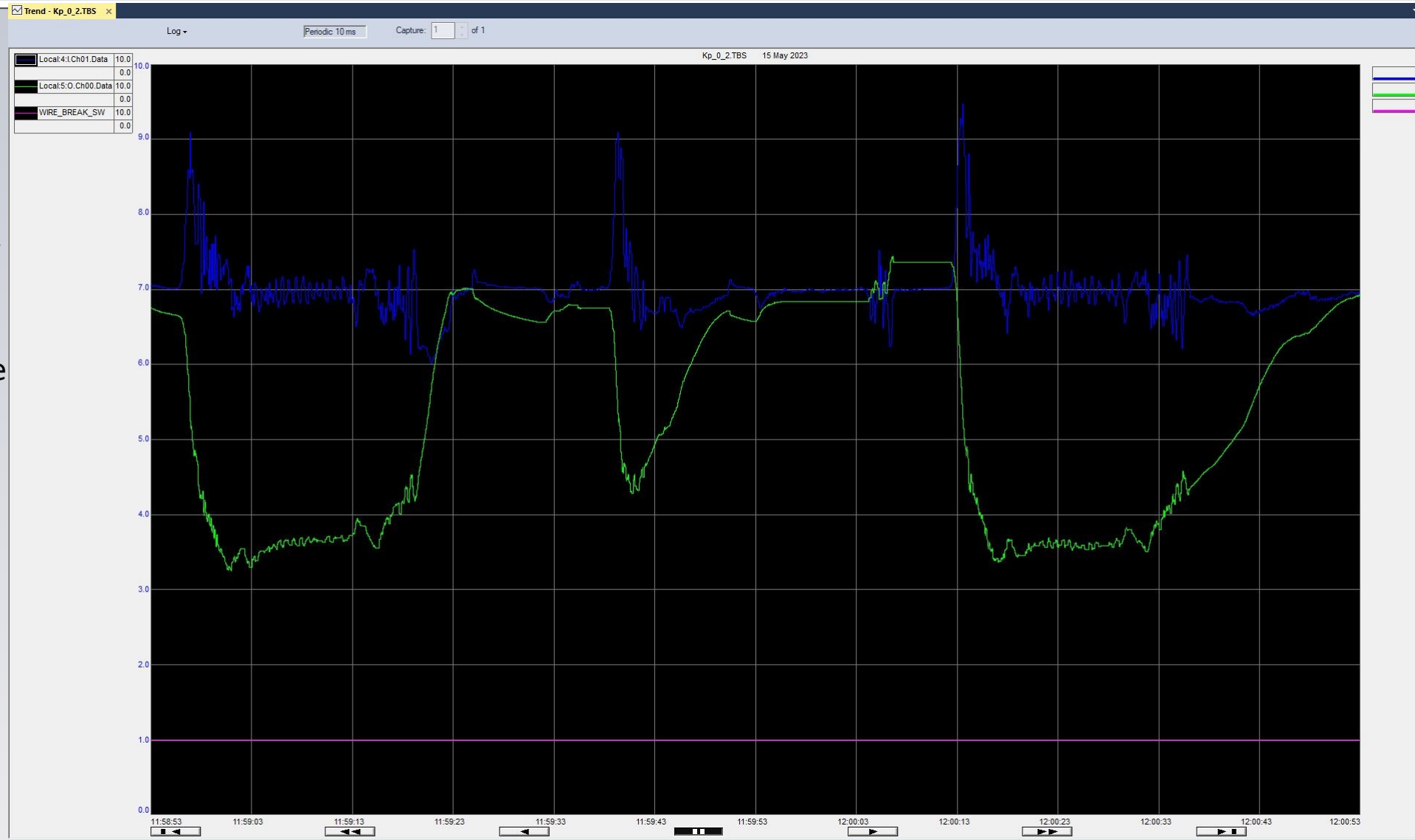
- Before PID loop tuning
- Quick build up of oscillations when laying the long wire horizontally
- Peaks observed when laying the wire during the first tenths of milliseconds during acceleration, also when moving head from Side A to B and vice versa.
- Need for PID loop tuning



Winder 2, after PID loop tuning

■ APA 6 X-Layer winding

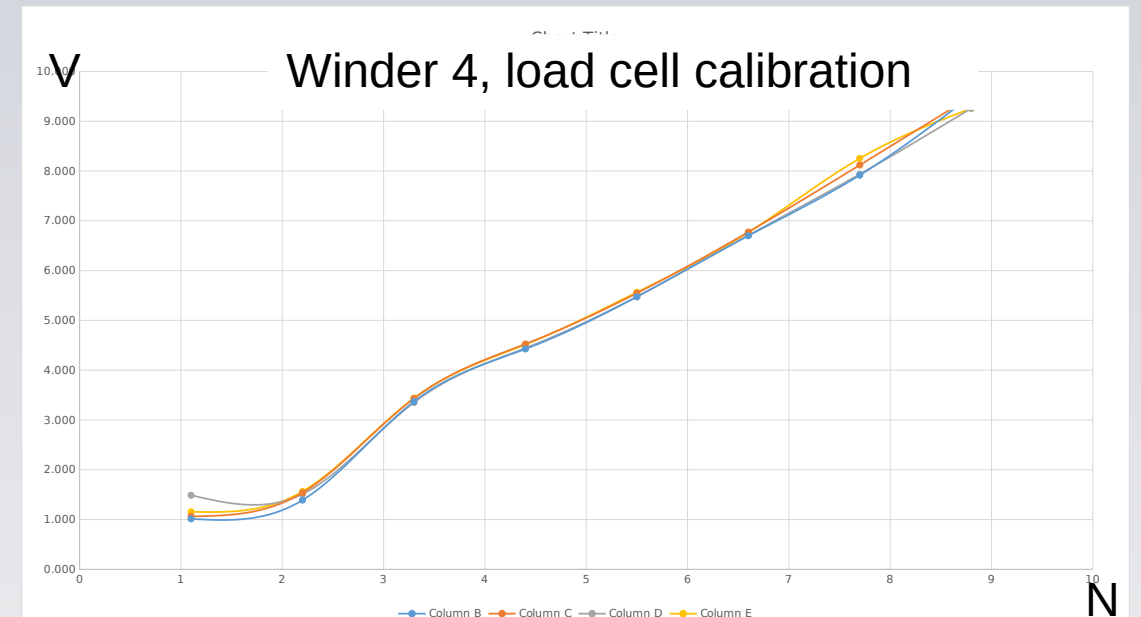
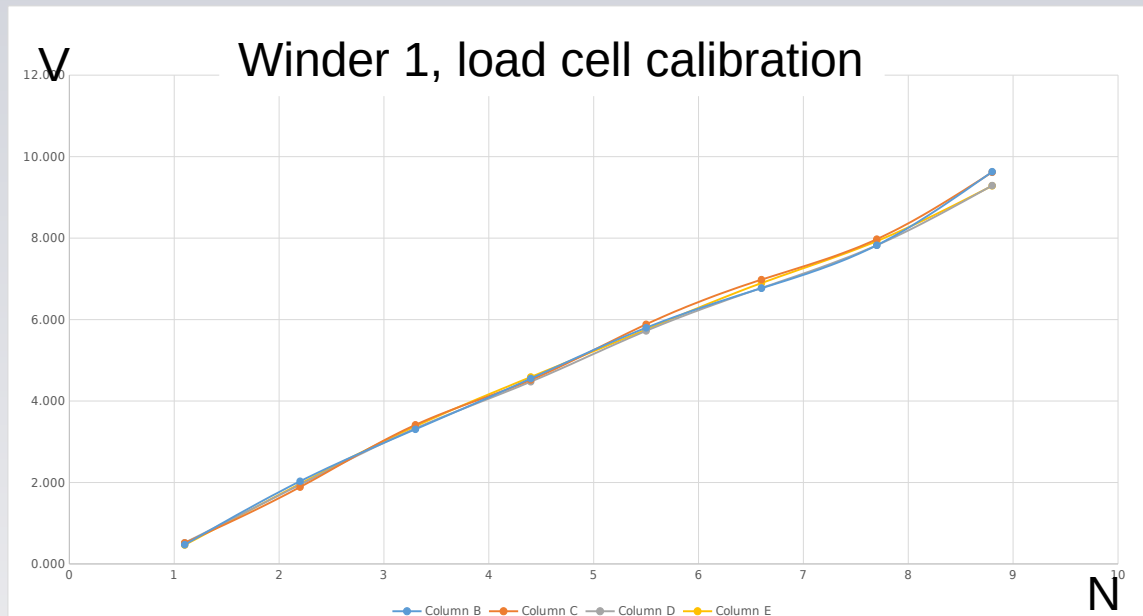
- After PID loop tuning
- Oscillations when laying the long wire horizontally under control
- Peaks observed when laying the wire during the first tenths of milliseconds during acceleration only when moving head from Side A to B and vice versa.
- Need for change in winding recipe



Understanding wire tension system

■ Winder head mechanics

- 23 moving parts: pulleys, sprockets, belt, spring, plunger, bearings, wire spool, brushed PMDC motor
- Load cell location and fitting determine the linear operational range between hard stops
- Each winder head behaves differently and tension system is non-linear
- Need to perform load cell calibrations and tests under controlled conditions and understand them



Winder #1 APA 8

Live wire tension measurements

