U.S. MAGNET DEVELOPMENT PROGRAM

SMCTM1a test summary and next steps
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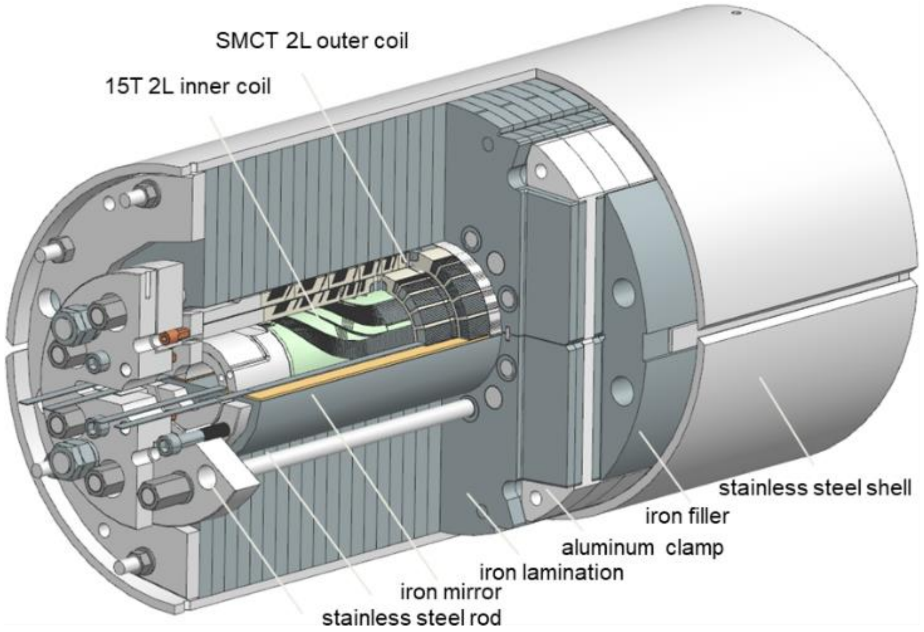
SMCTM1 test goals

- Prove the concept of SMCT dipole coil design in 4-layer mirror configurations
- Demonstrate the magnet can reach the targeted quench current at the set pre-load
- Study ramp rate and temperature dependences of magnet quench current

4-layer mirror magnet
- SMCT 2L outer coil
- 15 T 2L inner coil



Instrumentation – General overview

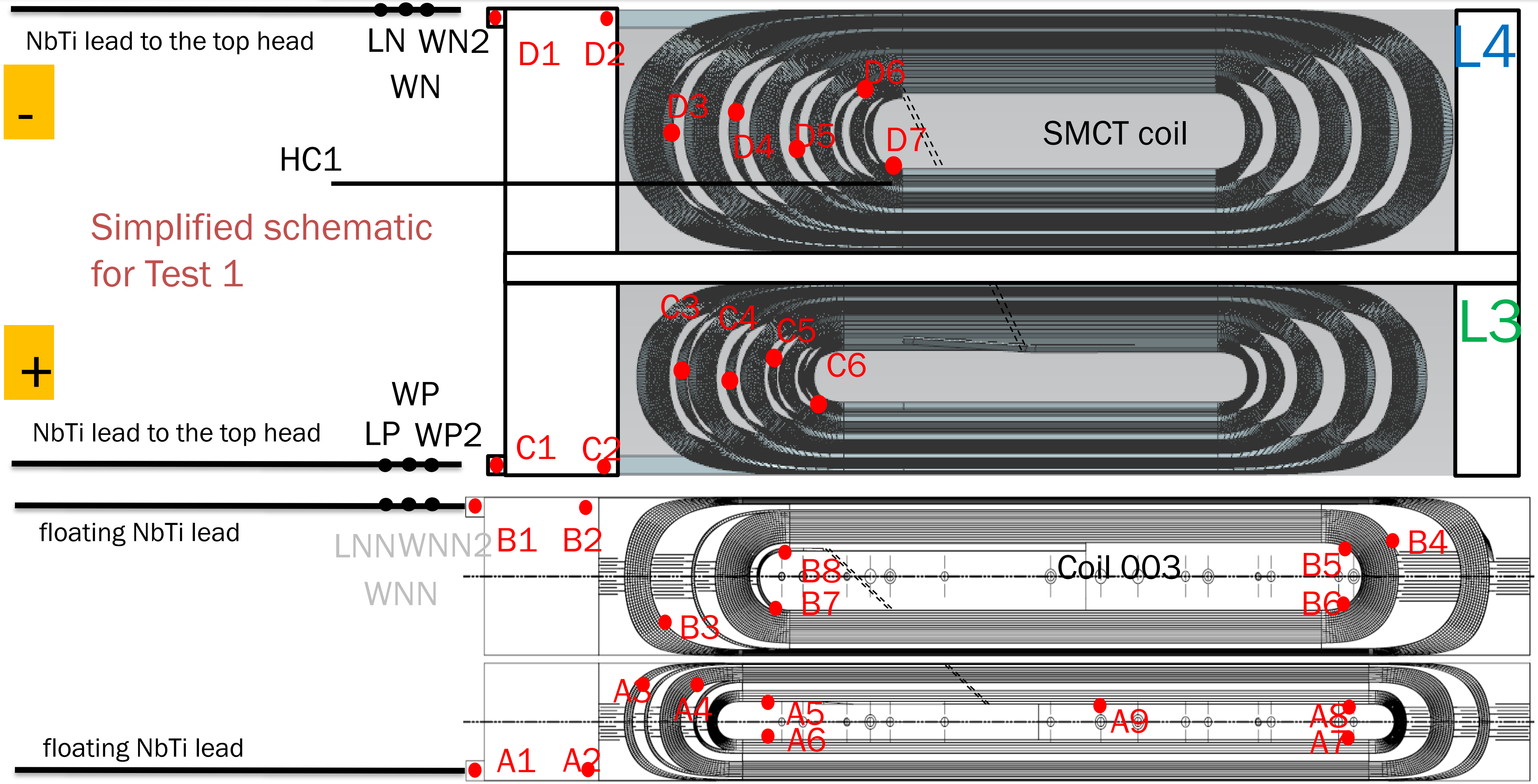
- Voltage taps – for quench detection and characterization;
  splice resistance measurements

- Strain gauges on coils, poles, bullets/rods and shell – strain monitoring during cool down, warm up and quenches to build the full stress picture vs conditions

- Protection heaters – for quench protection of the superconducting magnet
  - ✓ The magnet is basically protected by an energy extraction system
- Acoustic sensors - for independent quench characterization
- Fiber optics – strain measurements of the shell.
- Temperature sensors – outside magnet/coil temperature

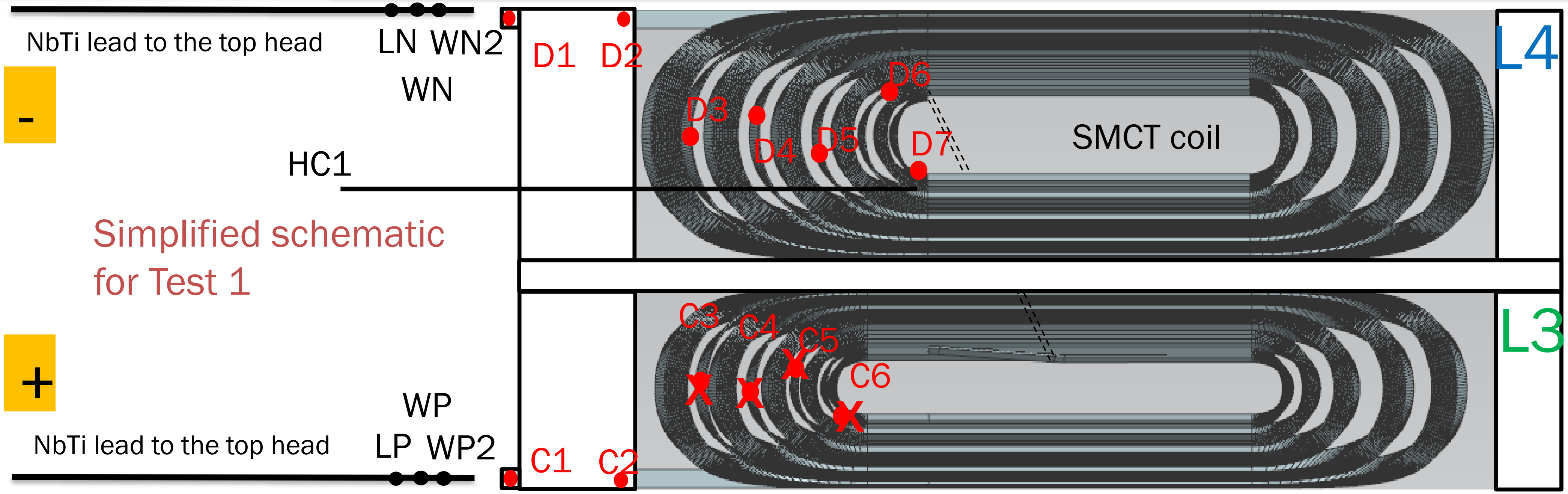
SMCTM1a test

Only the outer SMCT coil connected to power supply



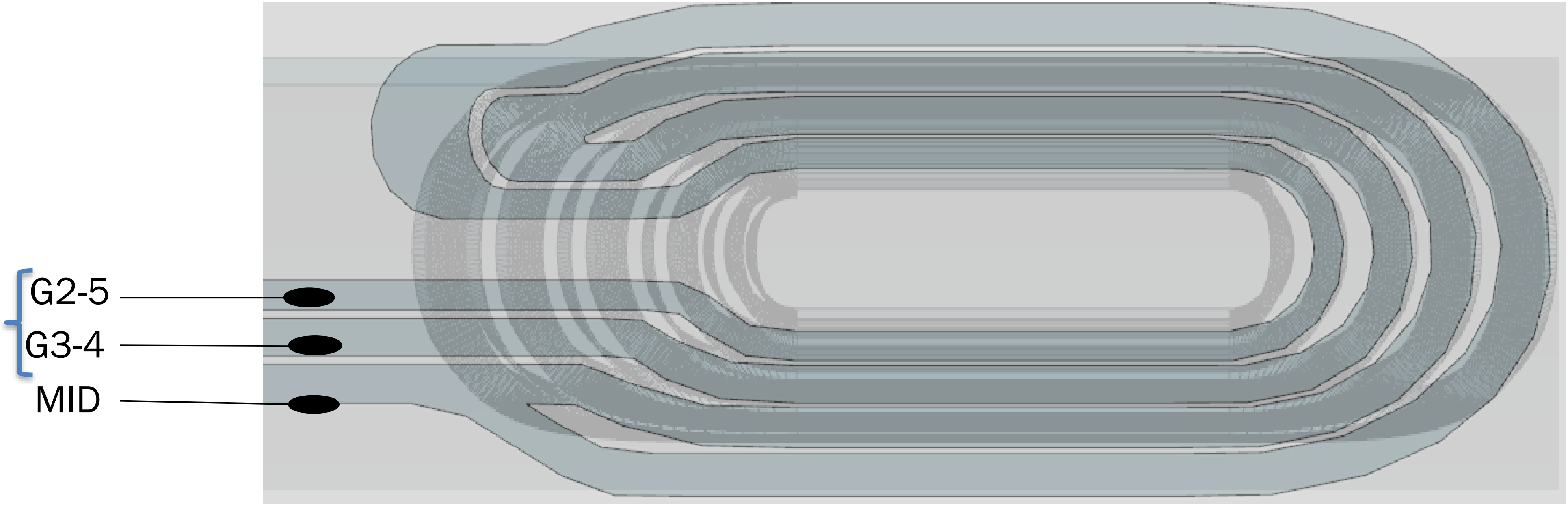
NbTi-Nb_3Sn splice

Voltage taps



Electrical check after magnet fabrication: C3-C6 taps are open
Locate quench in L3 layer will not be possible

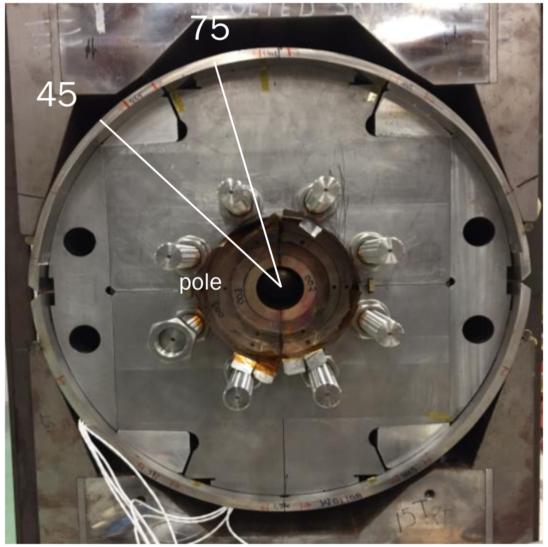
SMCT coil, outer layer, protection heater wires

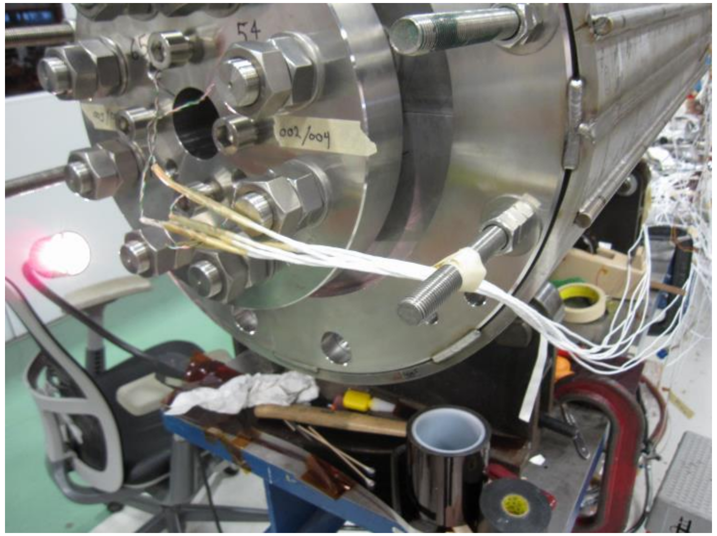


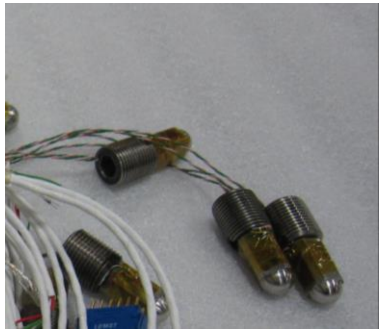
- Protection heater discharge at 340 V
- Dump resistor at 60 mΩ

Strain gauges

- 64 strain gauges installed:
  - 15 on coil 3 on the pole and midplane. Lead and return end
  - 16 on the skin: 8 upper/ down, Longitudinal and azimuthal orientation @ 45 and 75, on the lead end and return end of the magnet
  - 28 bullets on the rods



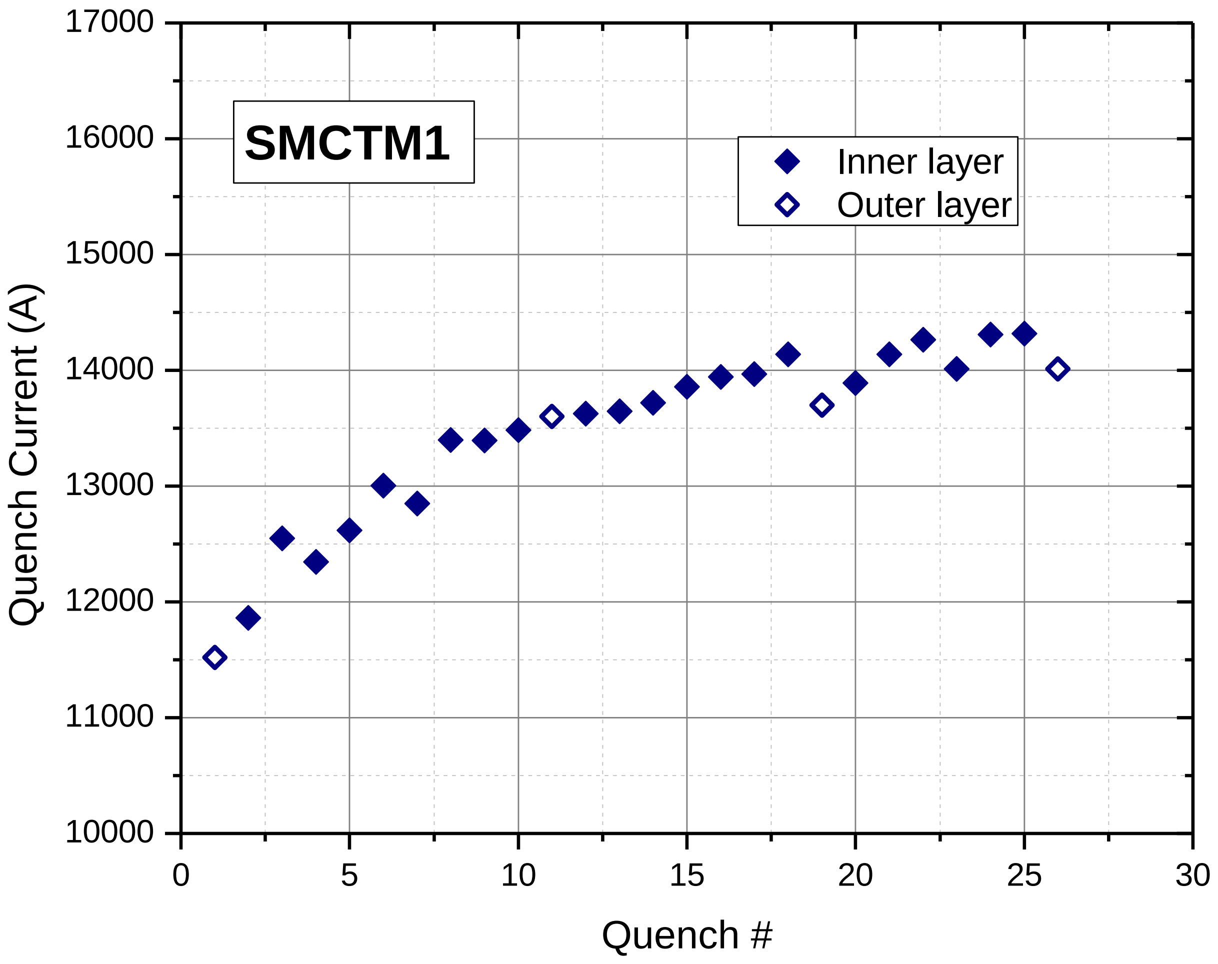


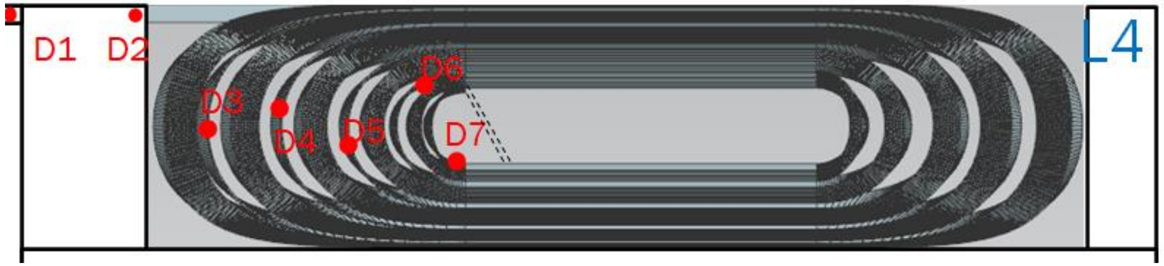


SMCTM1a Test plan

- **Room Temperature preparation**
  - Electrical checkouts and Hi-pot
  - Hi-pot schedule: Coil to ground (with heaters grounded or floating) at 1000 V, PH to ground (with coils grounded or floating) at 1000 V.
  - Initial RRR measurements: check CVT, FVT and Lead signals
- **Cool down**
  - Restricted cool down: temperature difference between the magnet top and bottom should not exceed 50 K
- **System checks at 4.5 K with 60 mΩ dump resistor:**
  - Cold Electrical Checkout and Hi-pot, Quench Detection Checkout
  - the AQD/DQD balancing
  - Ramp to 1000 A, adjust Cu-I AQD balance and perform manual trip
  - Heater induced quenches at up to 5 kA

SMCTM1 Training at 1.9 K





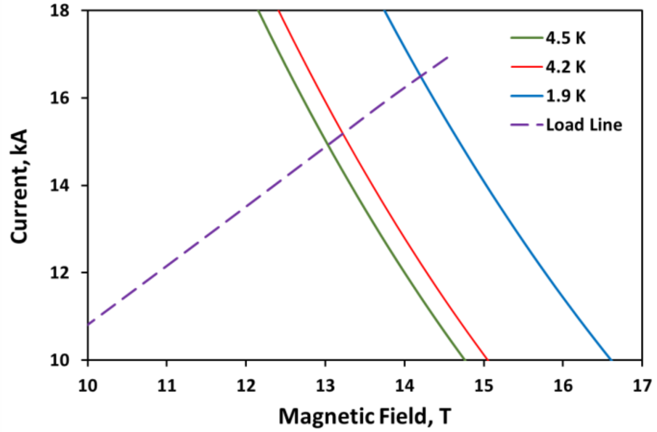
Outer layer quenches:

- 1st quench was in the D4-D5 segment
- 3 more quenches in the D6-D7 segment (pole turn)

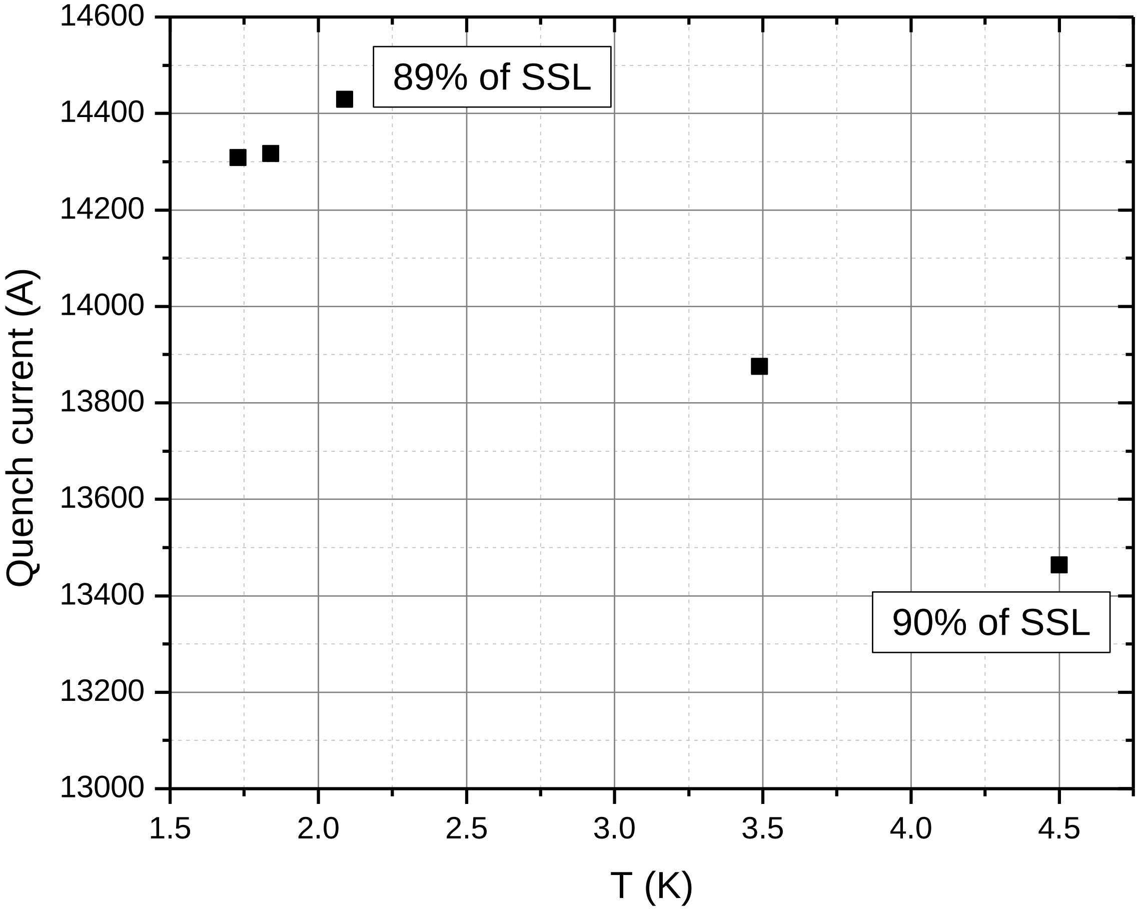
Remaining quenches were all in the inner layer:
Position is unknown because VTs were open

86% of SSL reached in 18 quenches

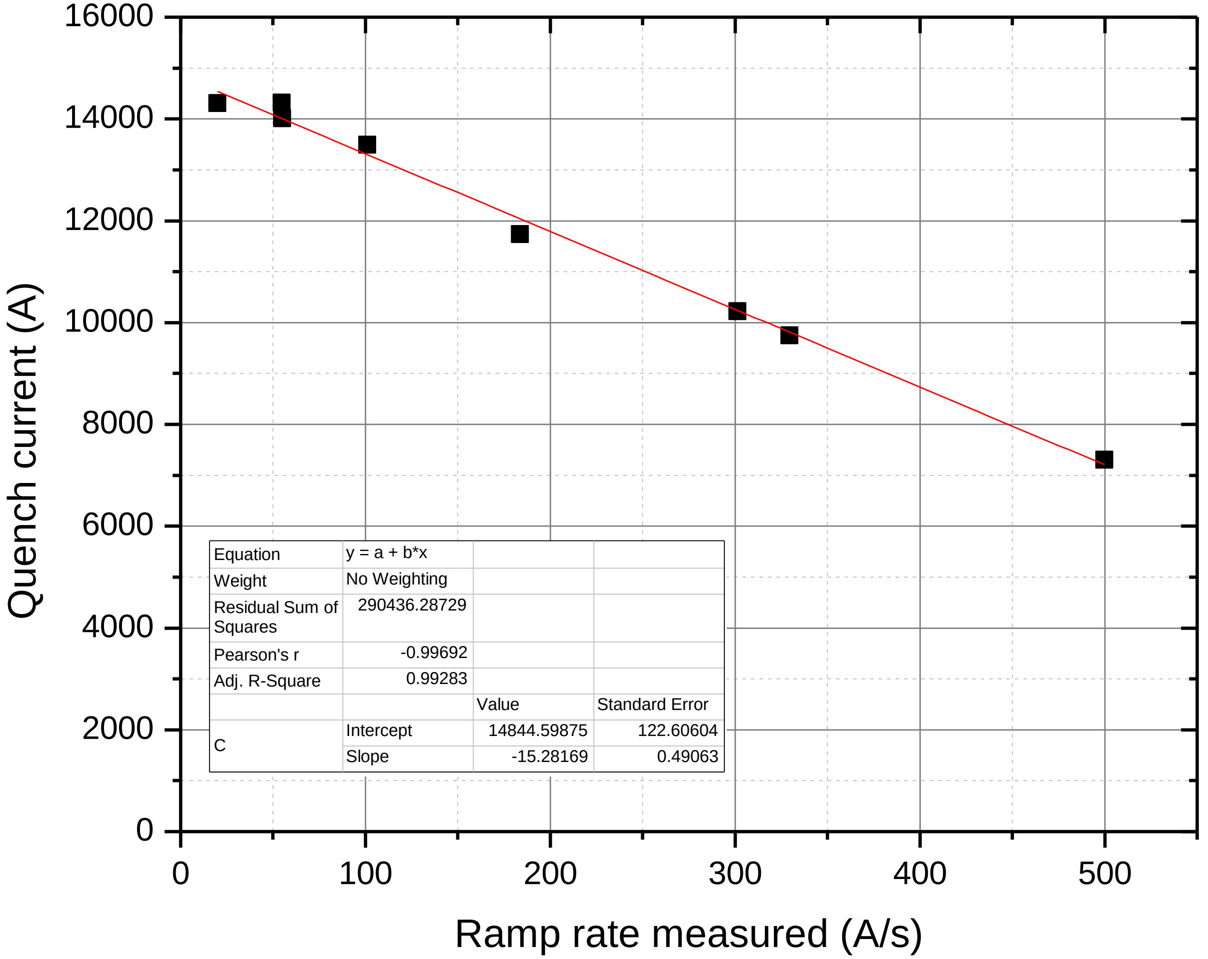
Temperature dependence



1.9 K		4.2 K		4.5 K	
kA	Tesla	kA	Tesla	kA	Tesla
16.47	14.21	15.15	13.23	14.89	13.04



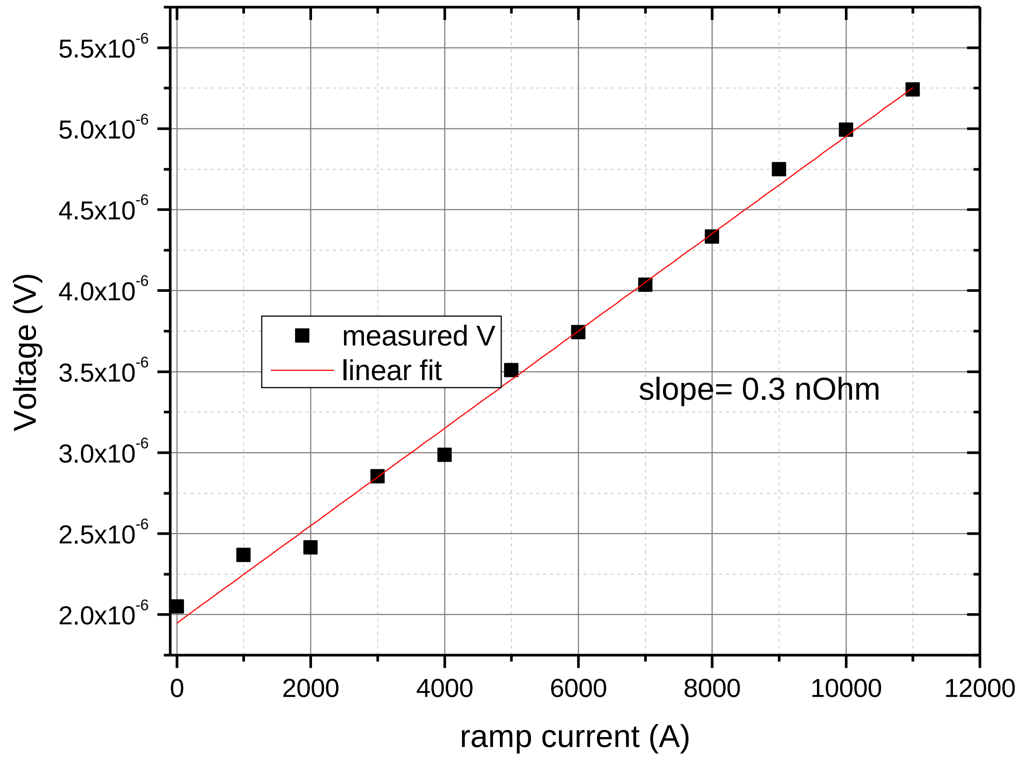
Ramp rate dependance

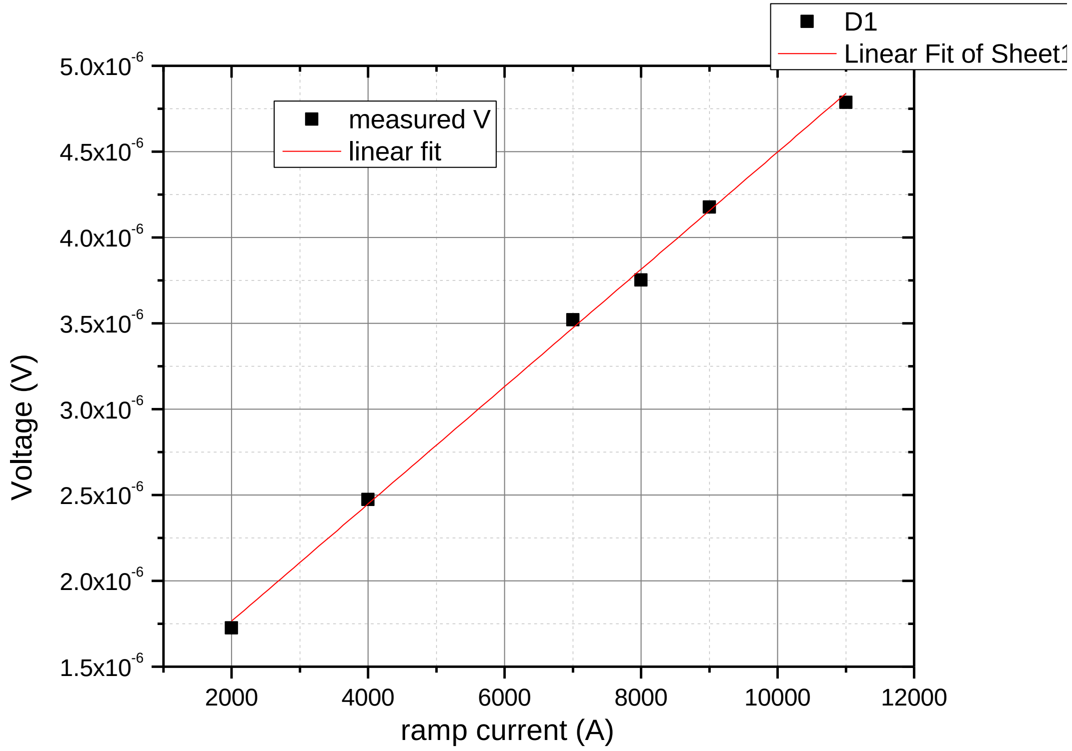


- **Linear extrapolation at 0 ramp rate: maximum quench current is 15 k**
- **13. 1 T; 91% of SSL at 1.9 K**

9% reduction of maximum achieved quench current with respect to SSL can be due to conductor degradation

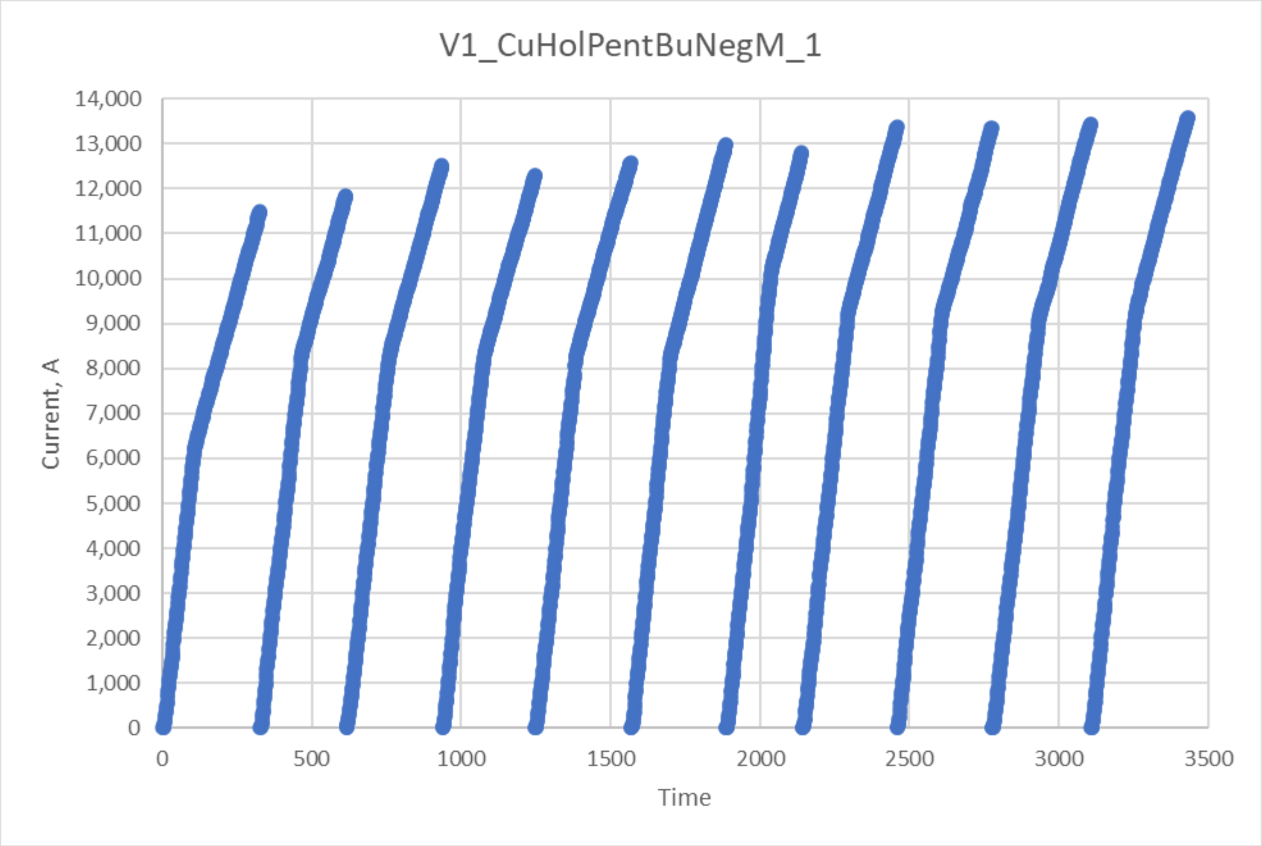
Splice measurements





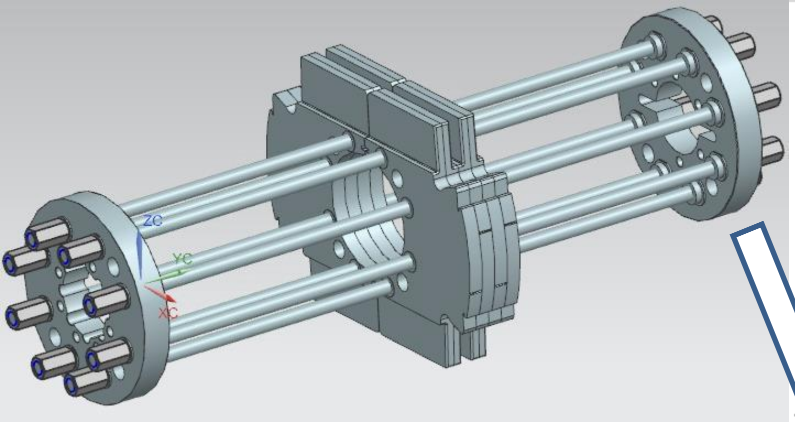
Splice resistance = 0.3 nΩ

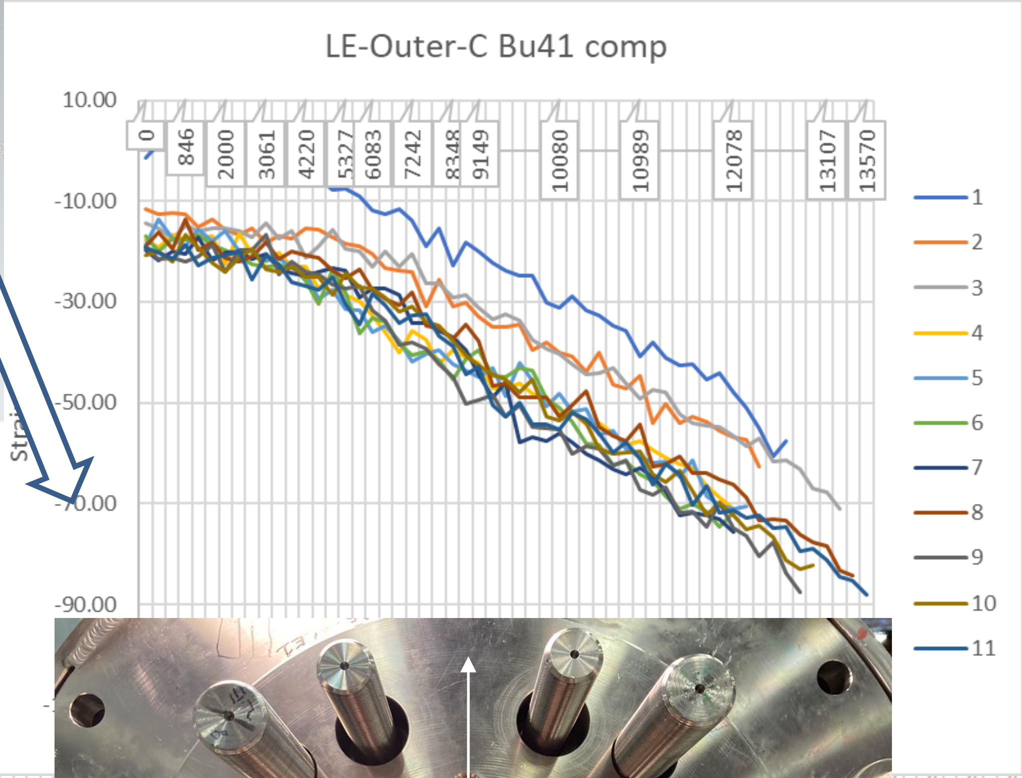
Strain gauge measurements: current ramps



The majority of the current ramps were performed at

- 50 A/s up to 6/ 7 KA
- 20 A/S at higher current

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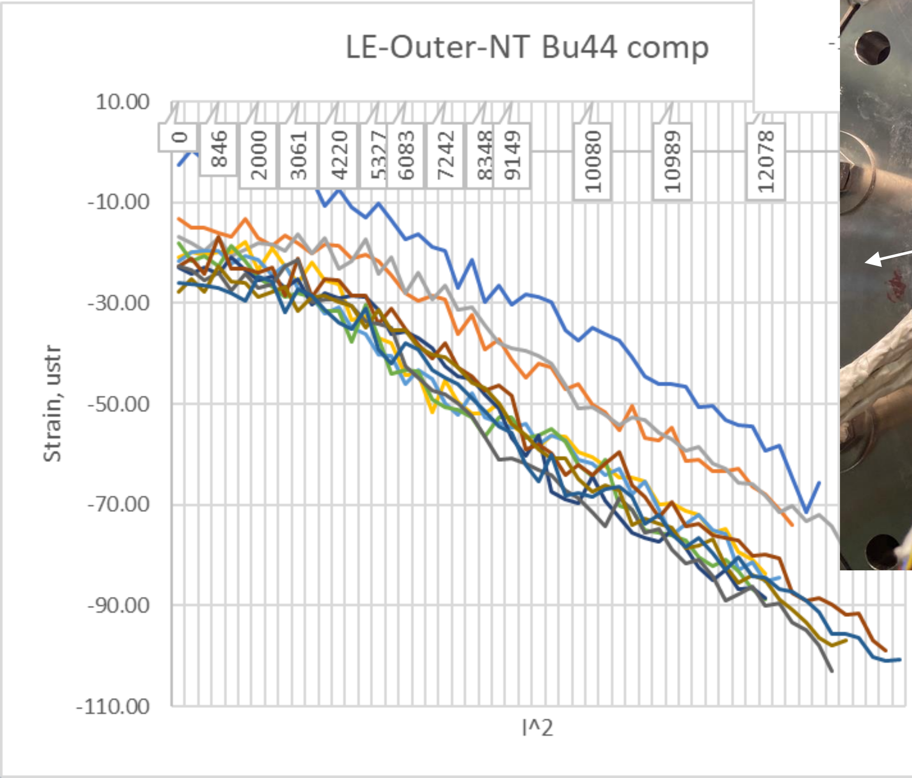
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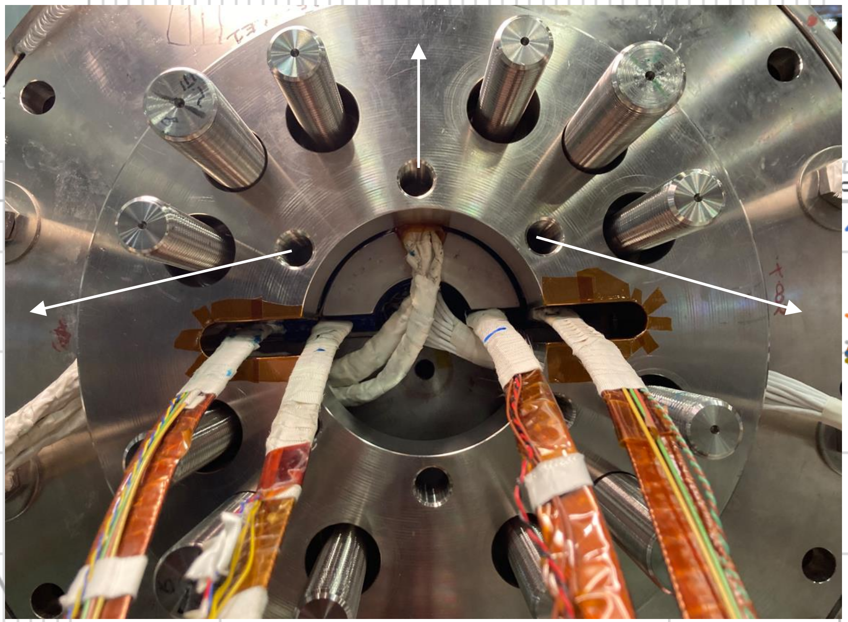

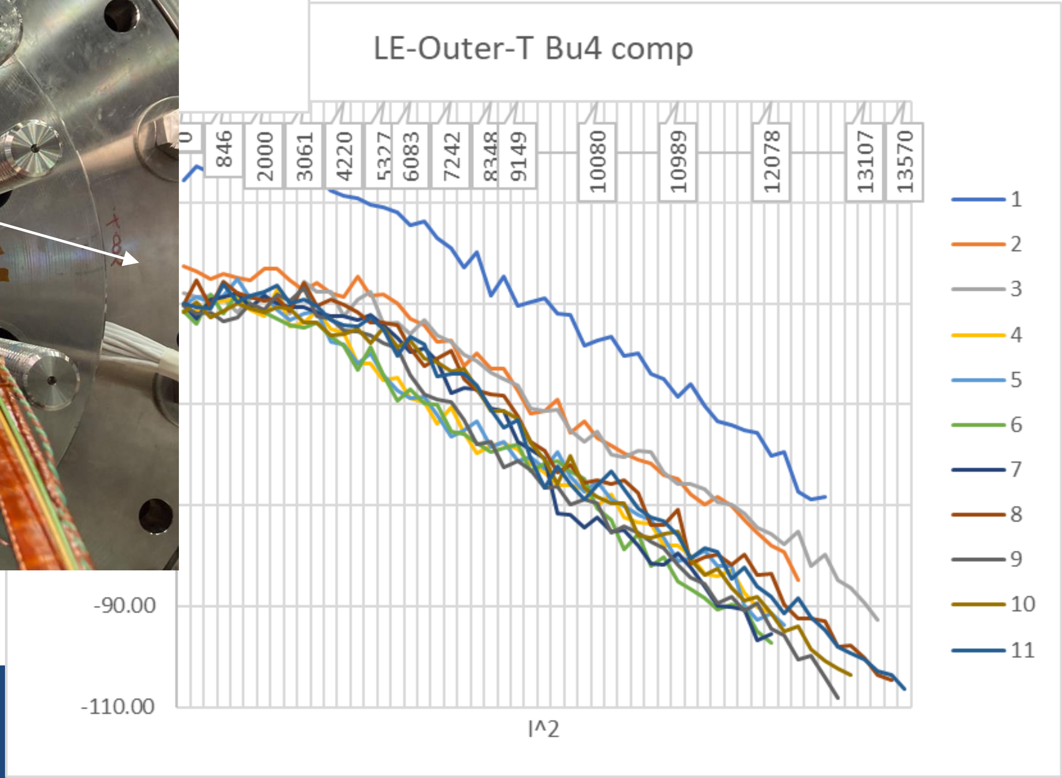
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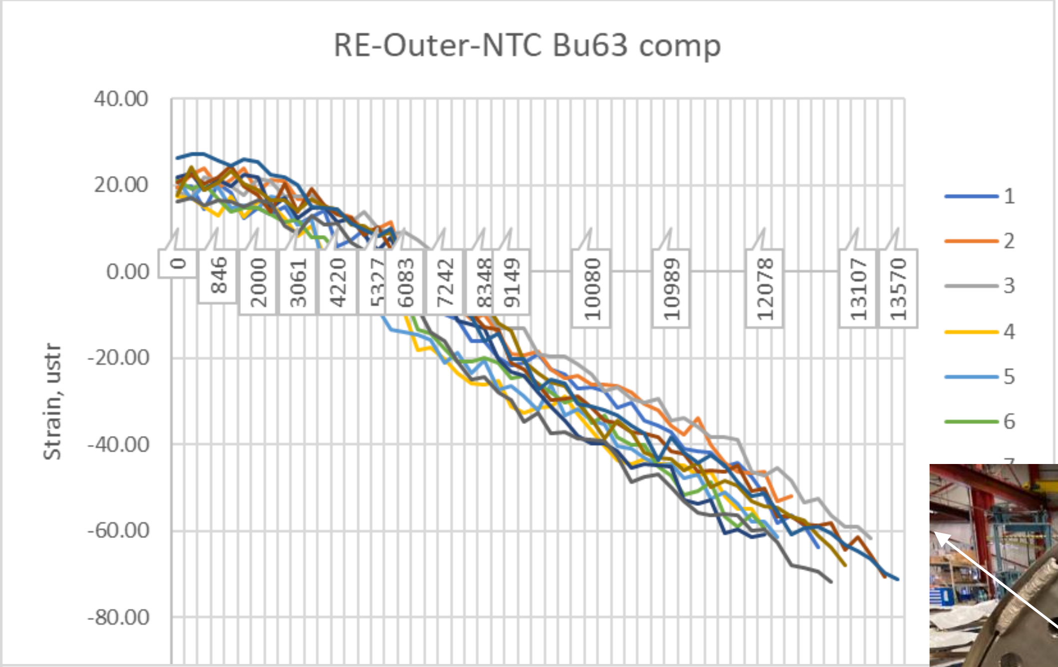
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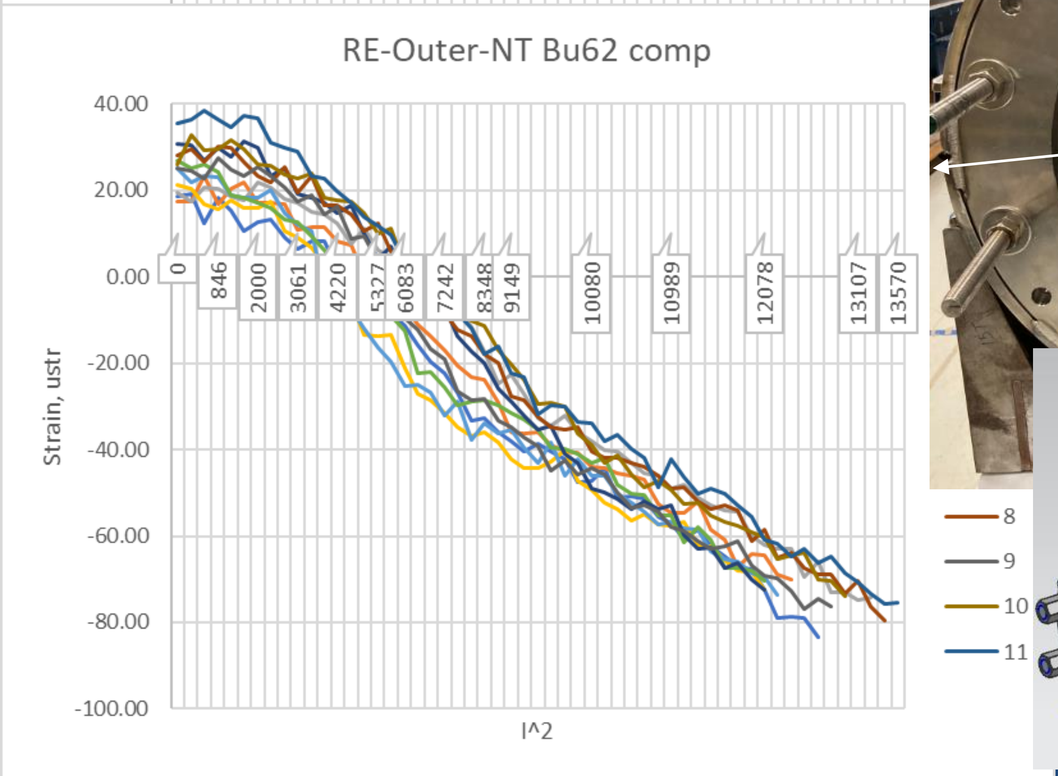
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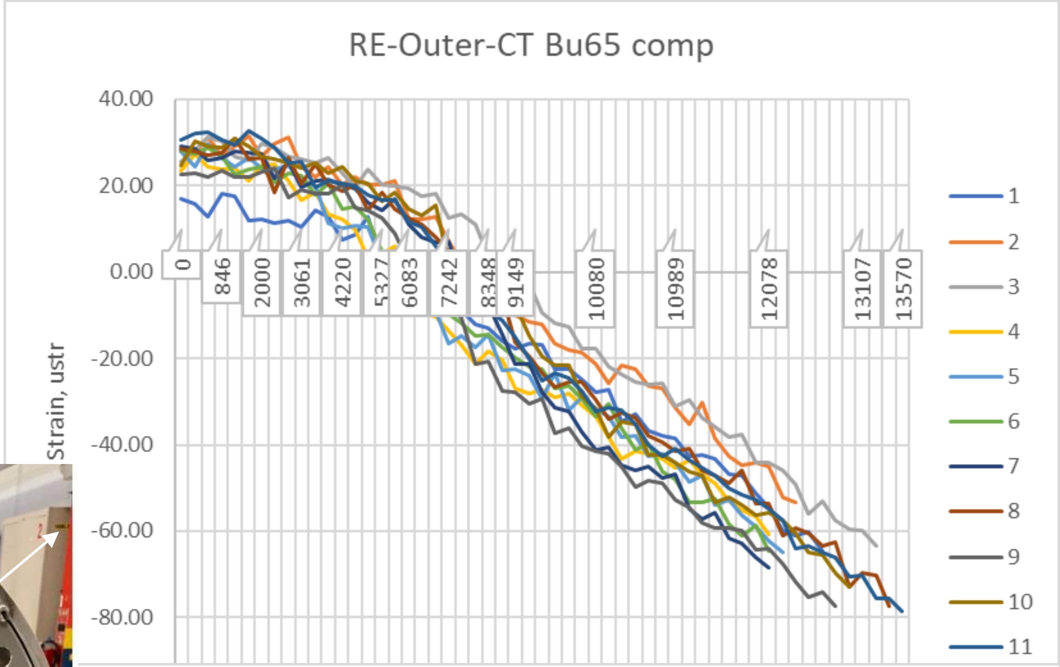
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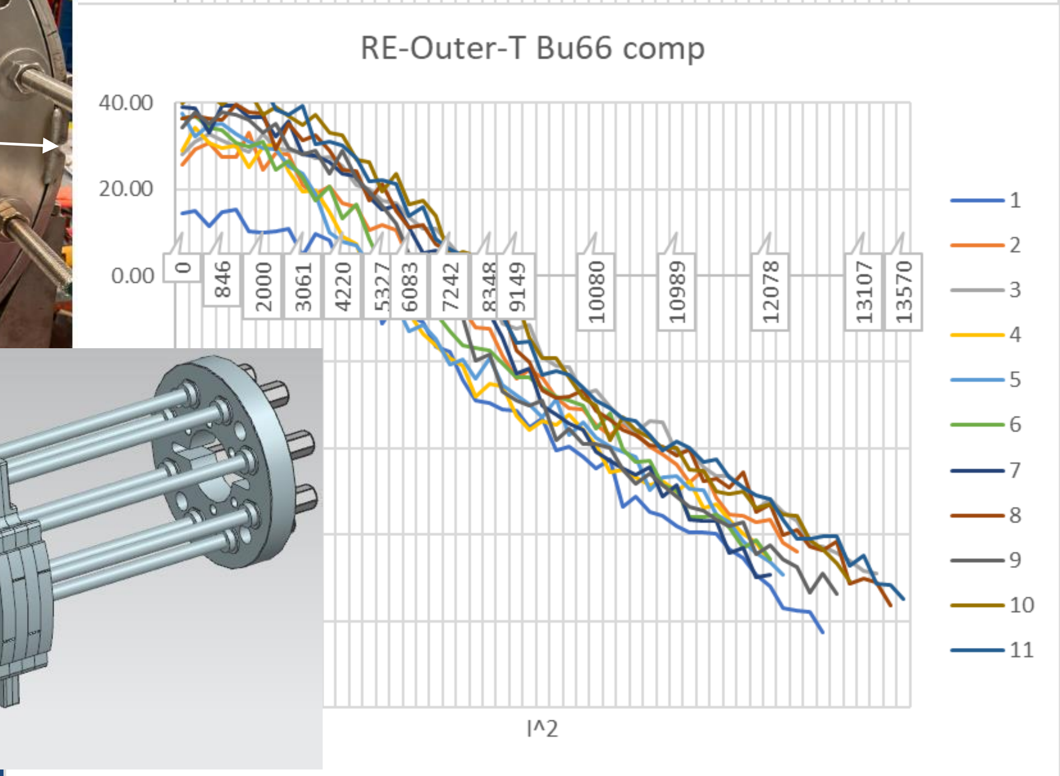
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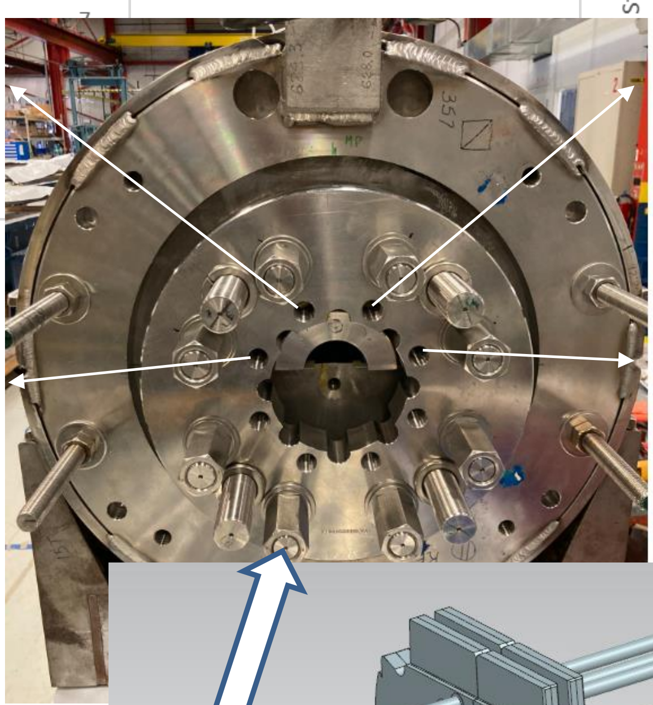

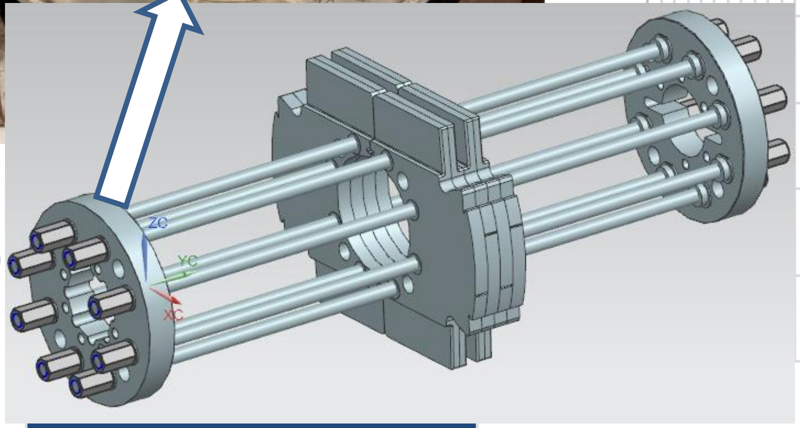

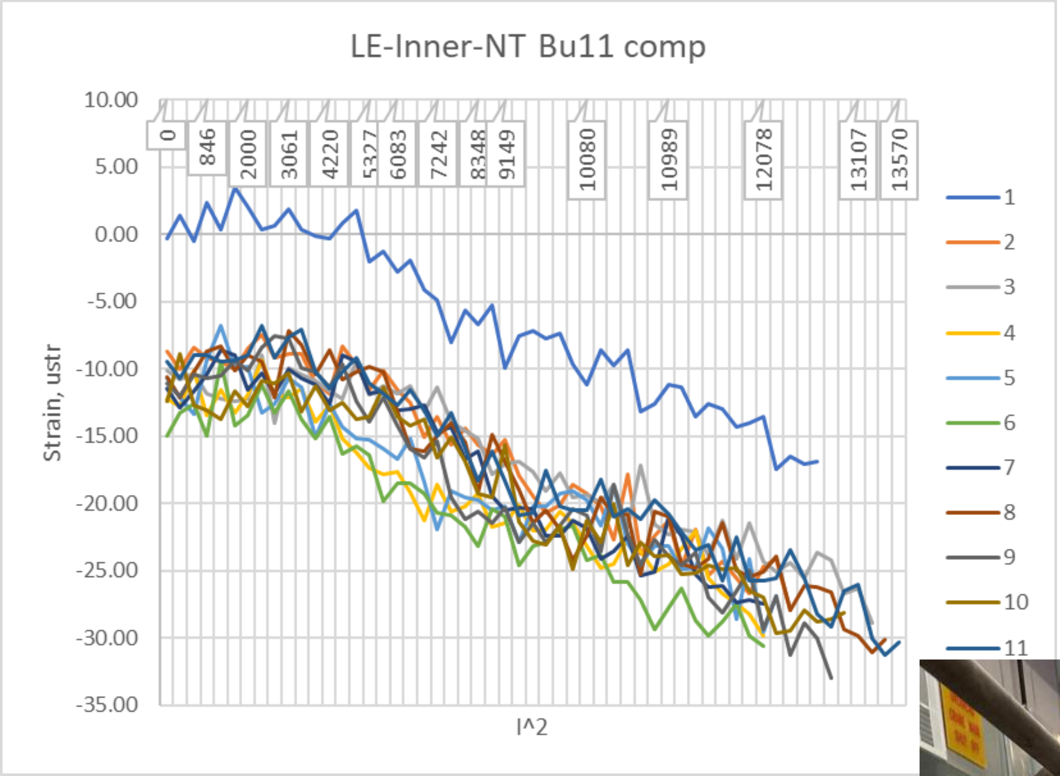
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-15.00
-20.00
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-30.00
-35.00
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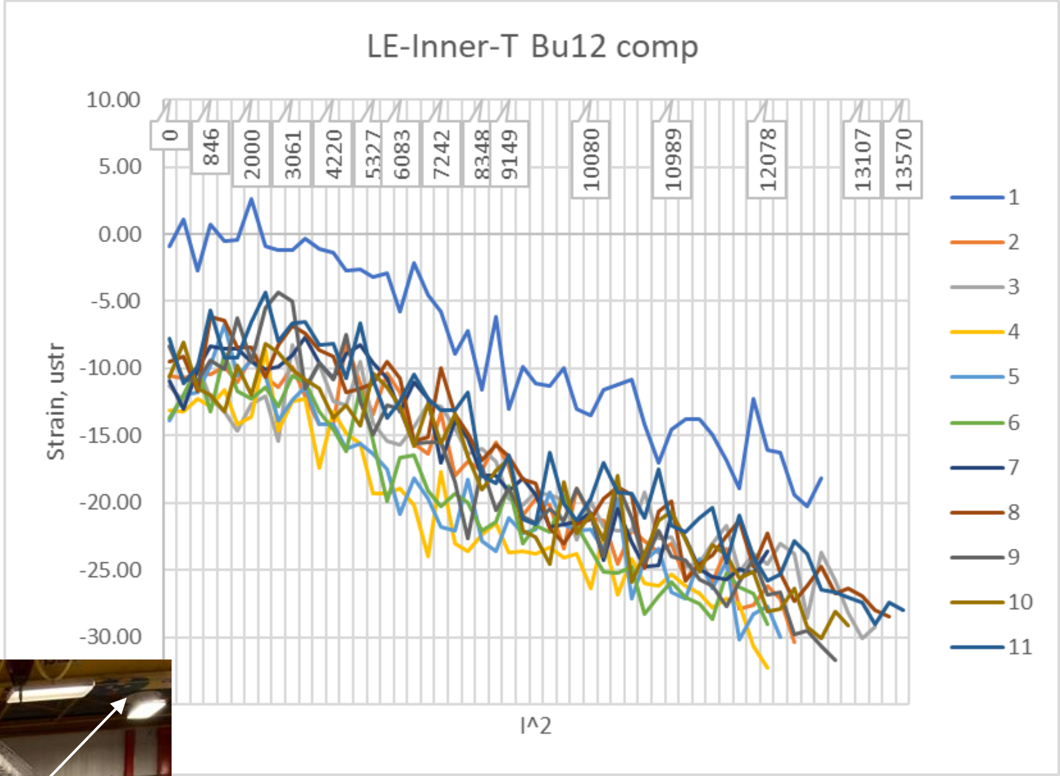
LE-Inner-T Bu12 comp
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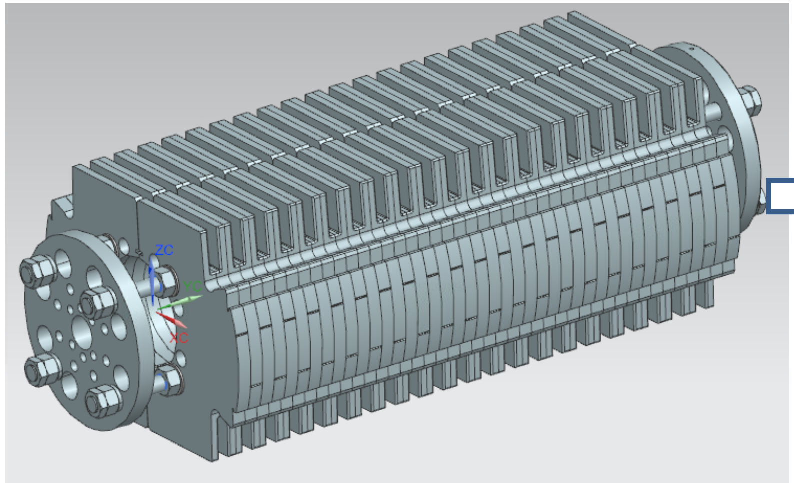

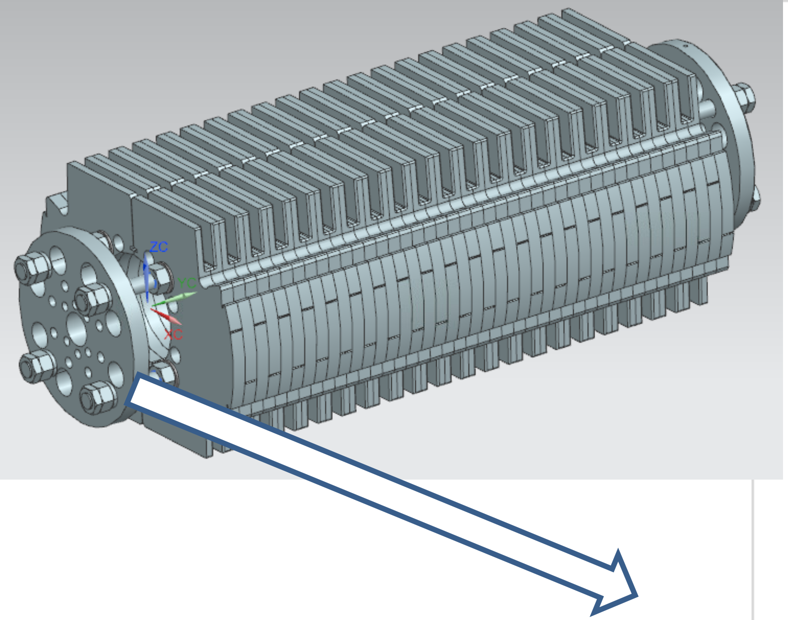

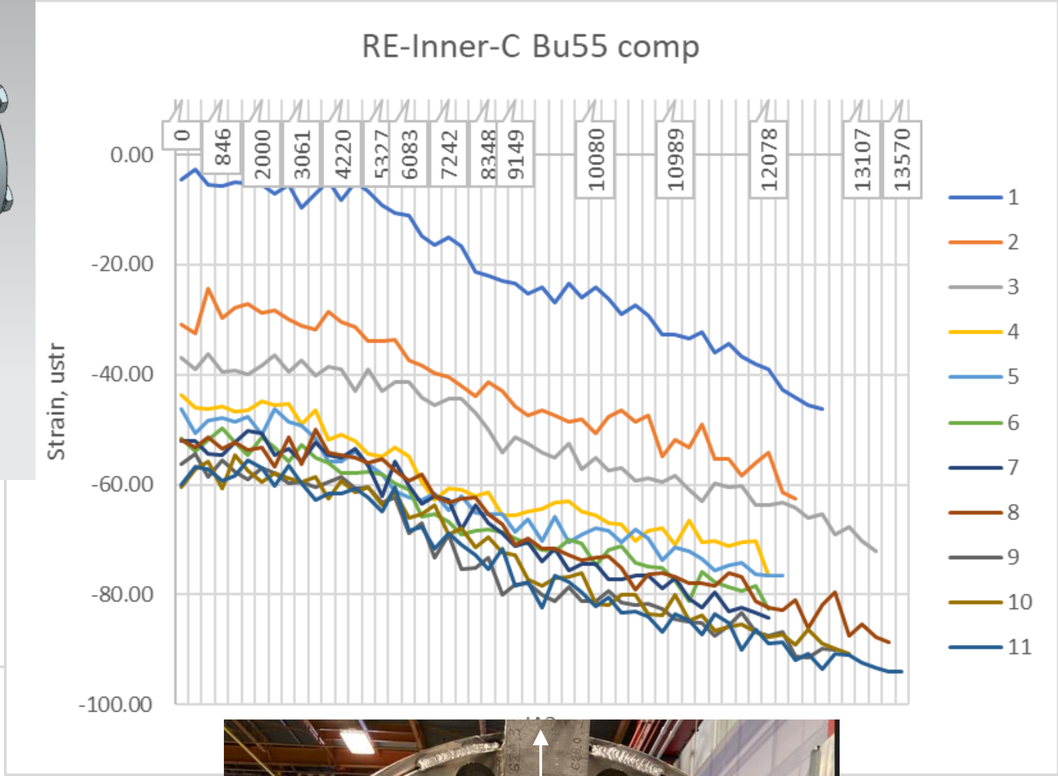
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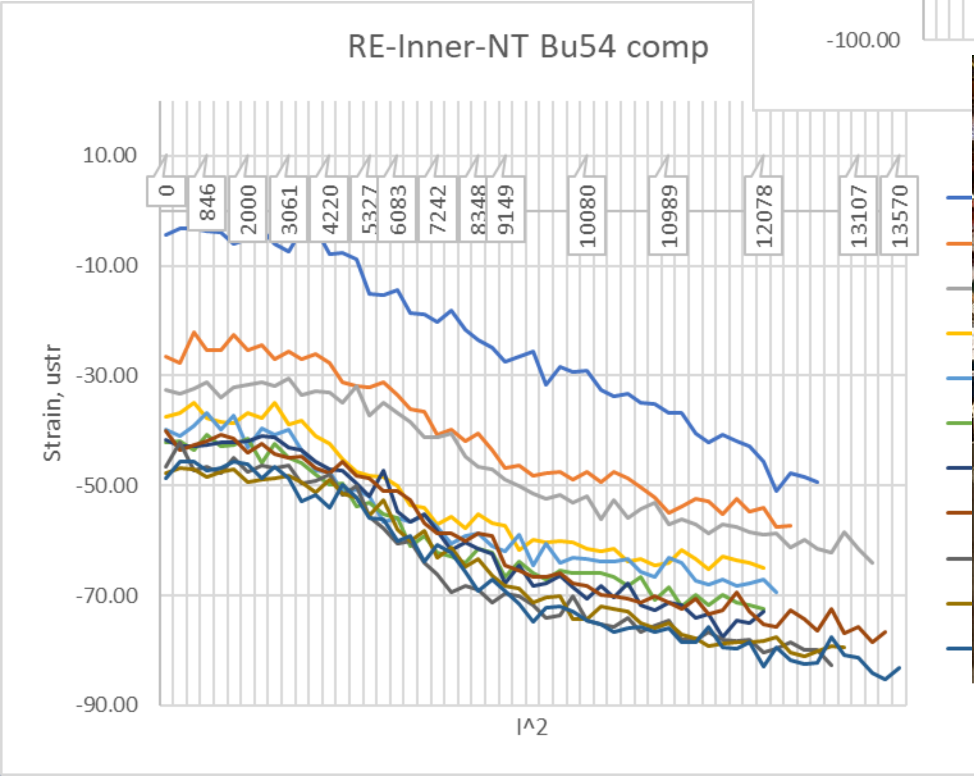
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-90.00
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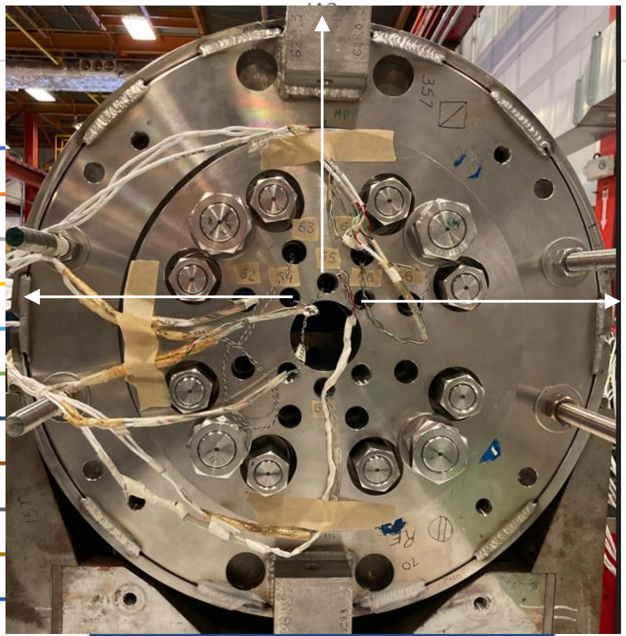

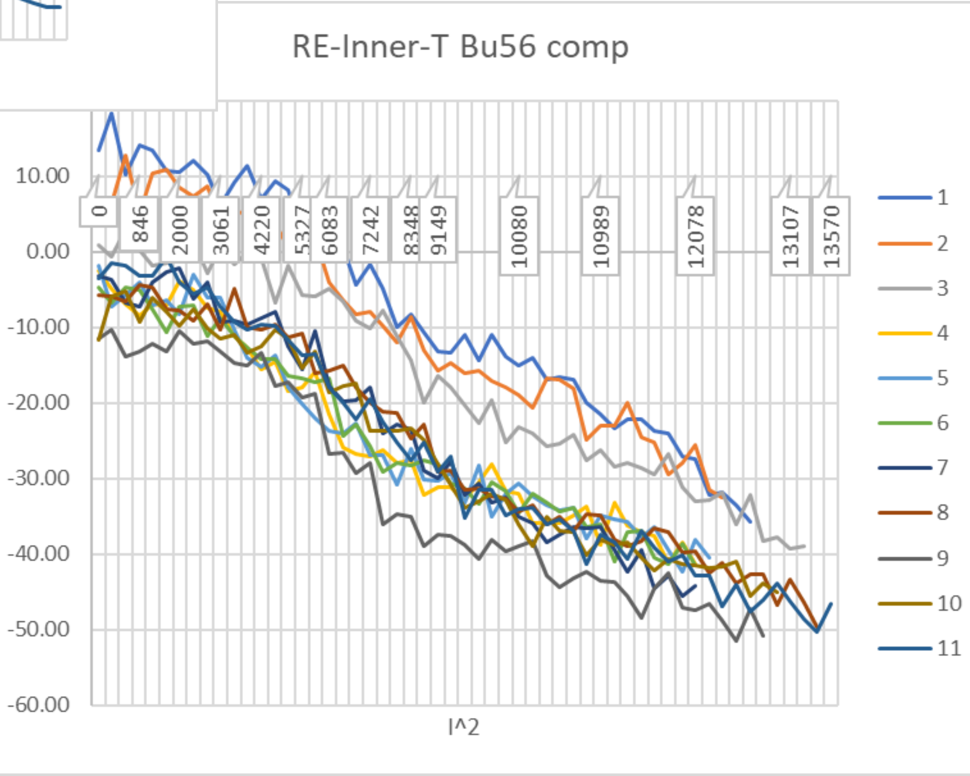
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-50.00
-60.00
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846
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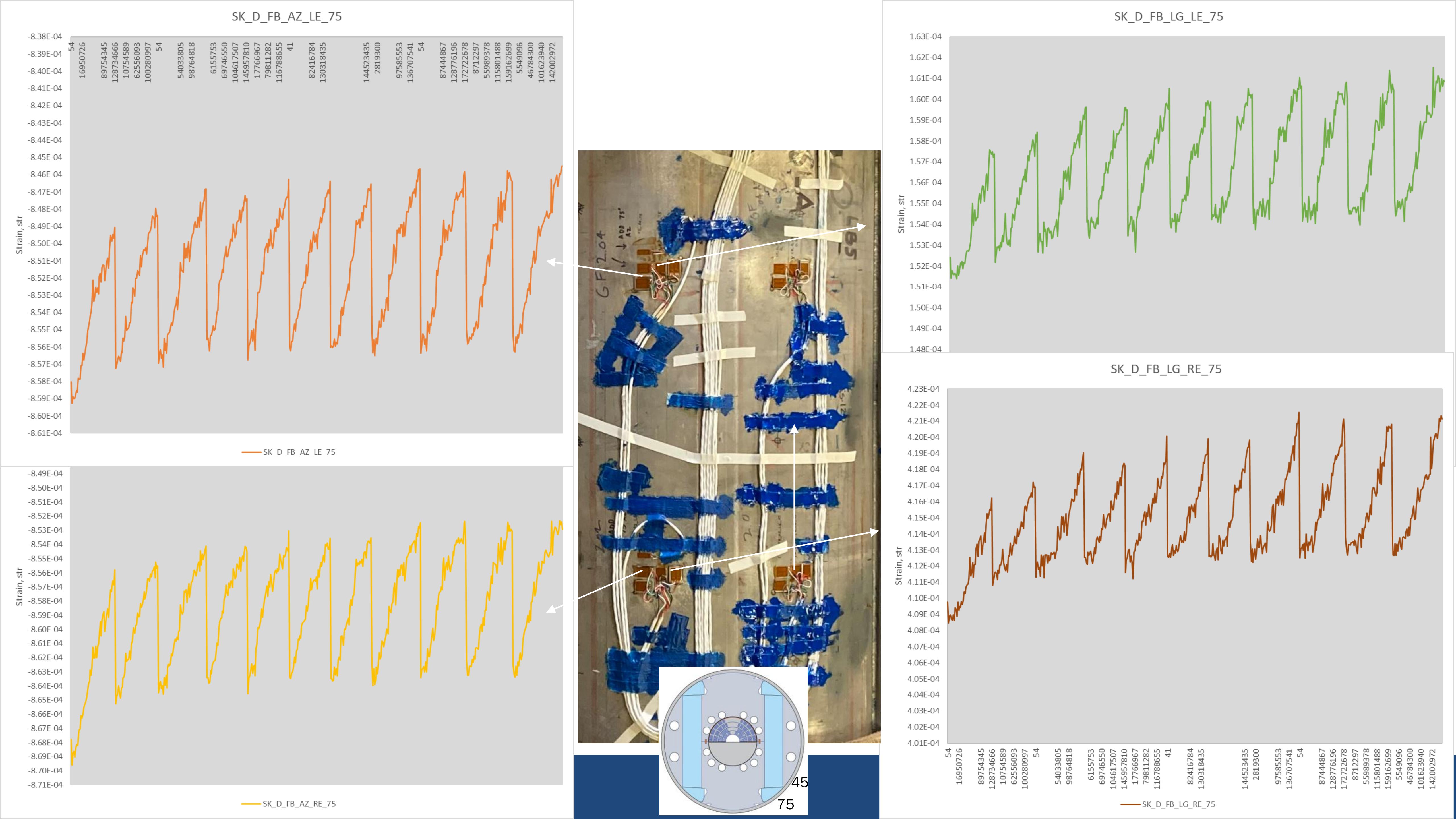
SK_D_FB_AZ_LE_75
Strain, str
SK_D_FB_AZ_LE_75
SK_D_FB_AZ_RE_75
Strain, str
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Strain, str
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Strain, str
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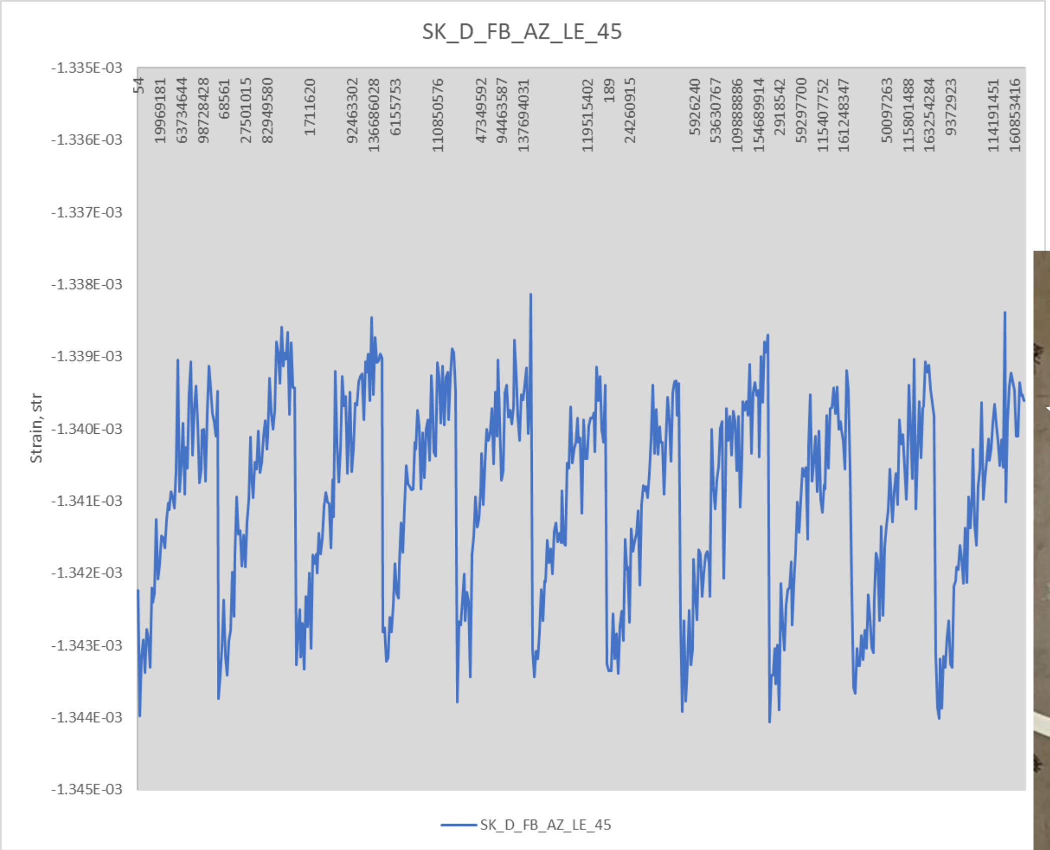
45
75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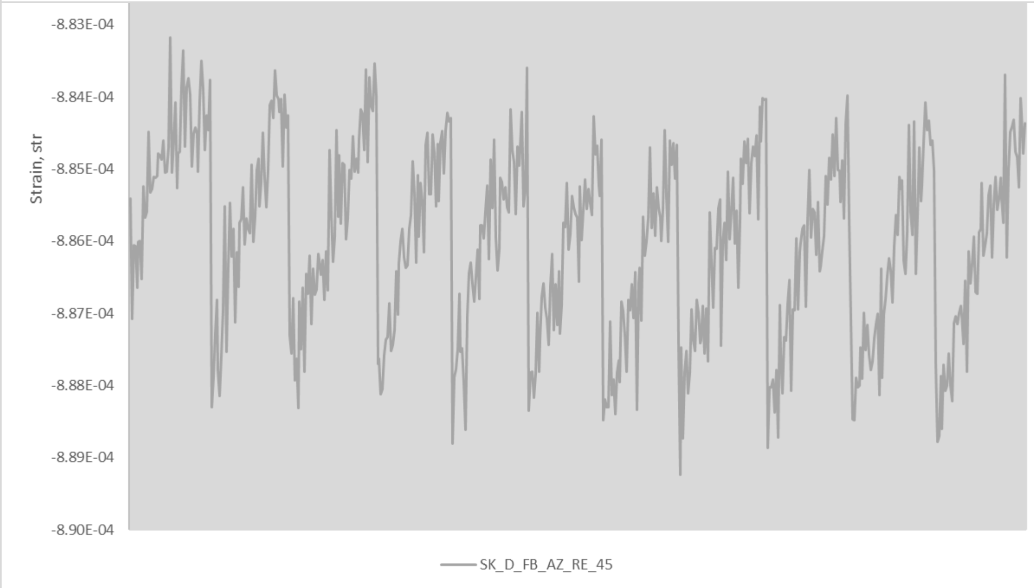
Strain, str
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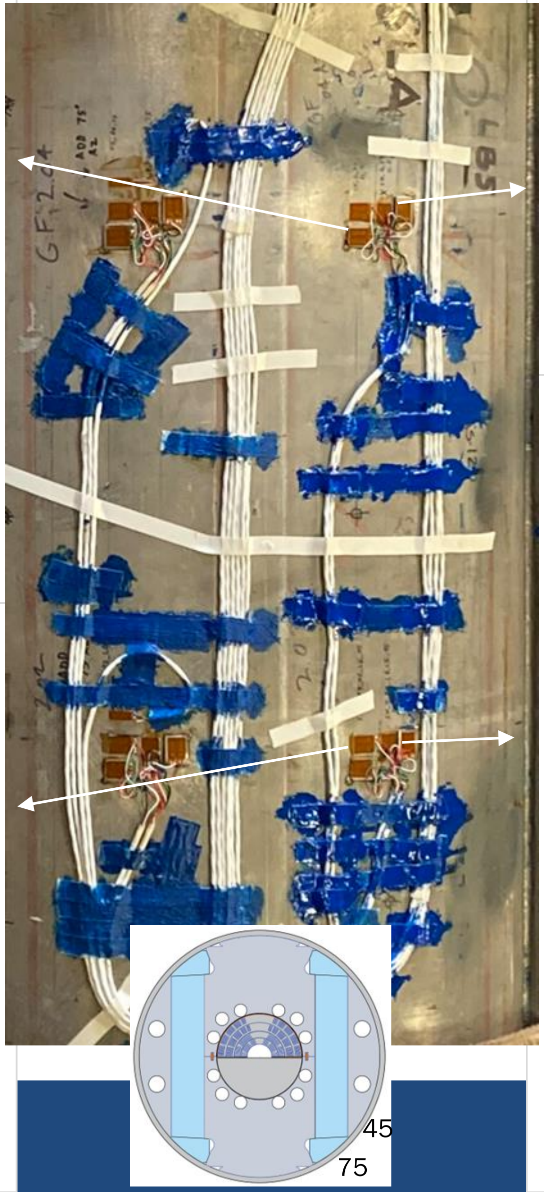
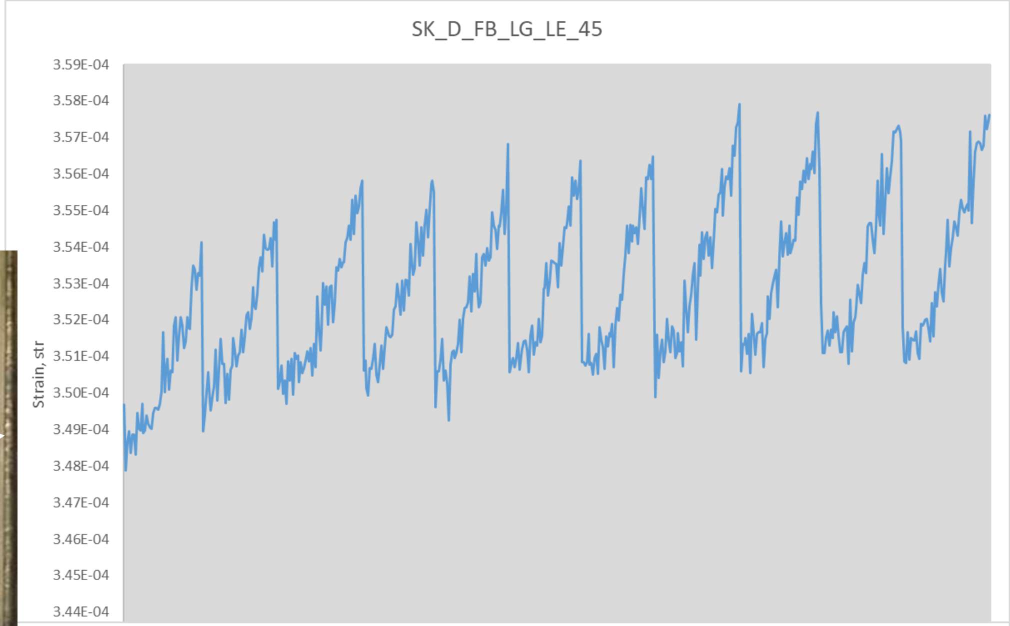

45
75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Strain, str
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3.53E-04
3.52E-04
3.51E-04
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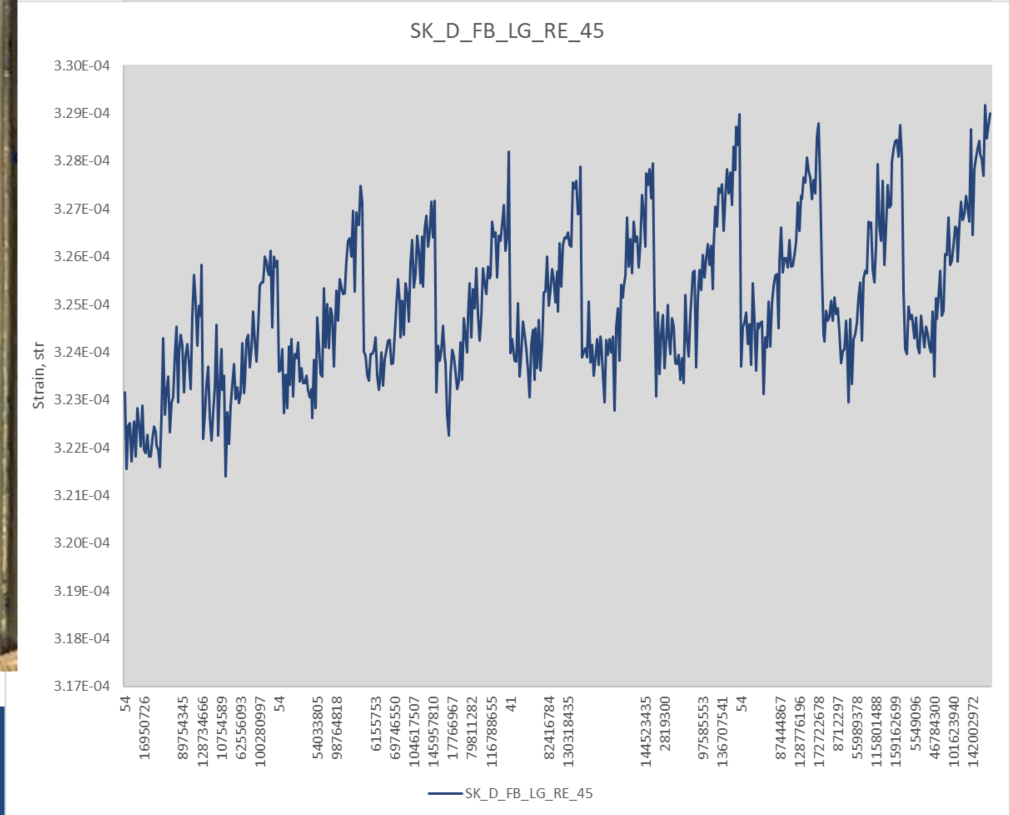
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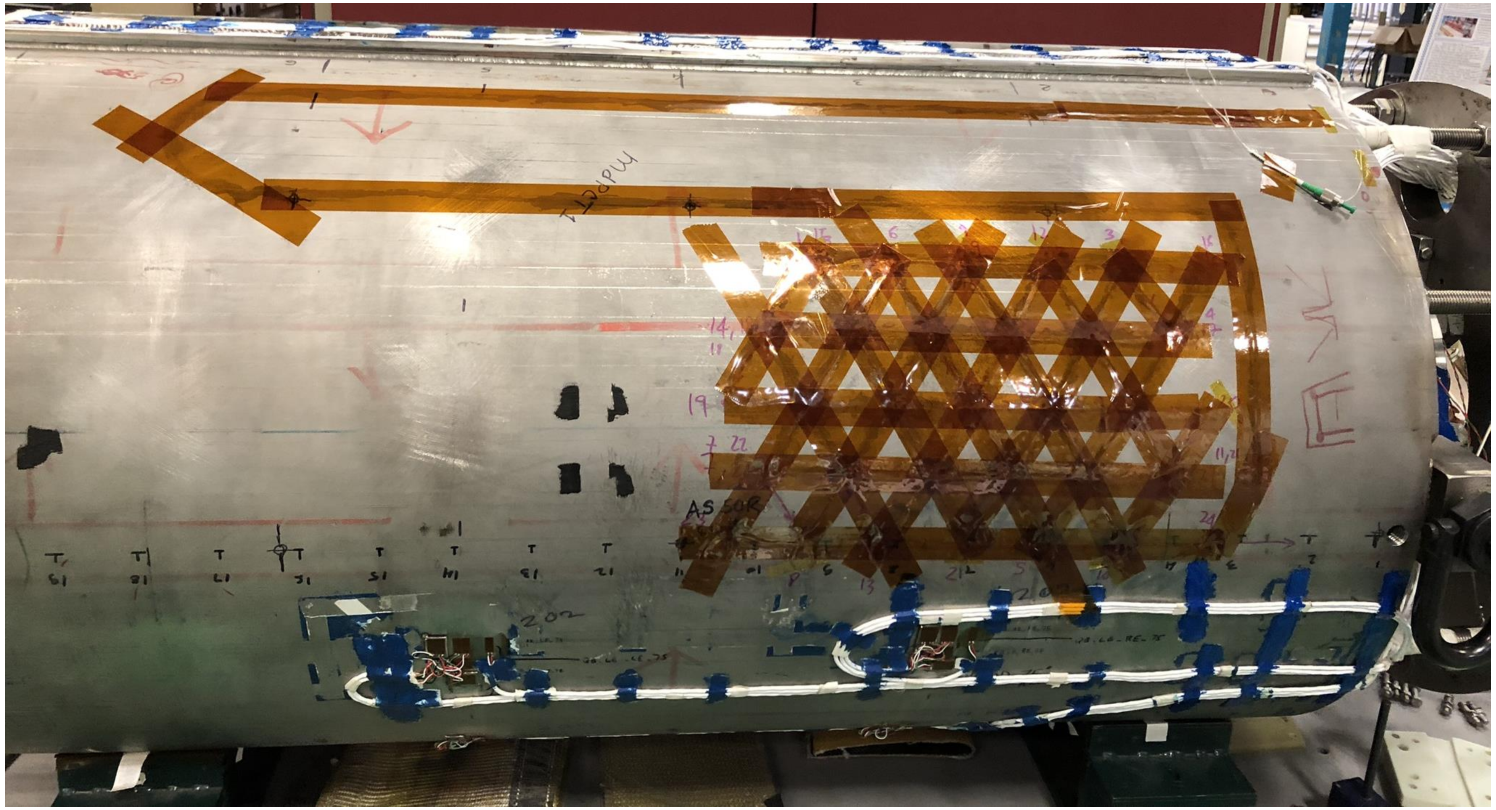
Fiber optics



There is a 7 meter-long fiber installed on the mirror skin:

- Position was chosen close to the strain gauge
- Grid design will be used to measure strain map
- Part of the fiber cover the entire magnet length longitudinally and large arc azimuthally
- Validation of the VMTF new fiber line

Fiber optics

Fiber was pinched

Fiber was rekeyed:
4 m of patch cable
4. 5 min cable

2m
Feedthrough

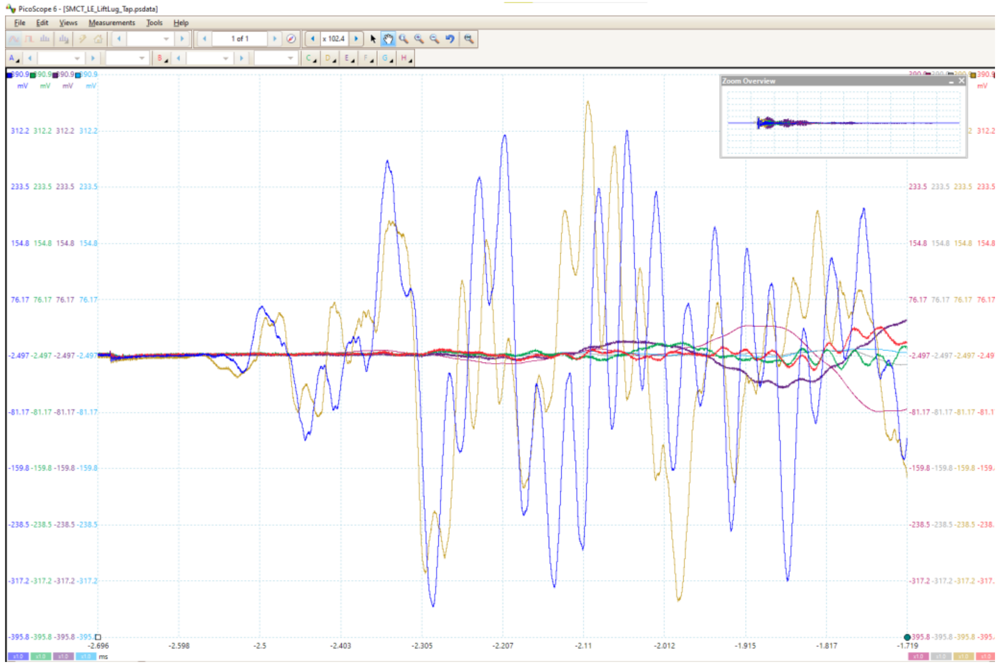
Acoustic sensors

Courtesy of S. Krave

- 1-4 are glued at MP 15mm from shell.
  - Positions nearest to midplane close to body of magnet allow longest t_delay from side to side for improving positioning resolution
  - Glued to small stainless blocks via stycast
  - Alternate location is glues to the end ring in adjacent location to allow clearance to fit in dewar
- 5-8 are glued onto rod ends
  - Possibly provide some L/r info, mostly longitudinal

Acoustic sensors

- Checkout was completed
  - All sensors working with appropriate amplitude
  - Taps on magnet corners show proper progression of waves from LE to RE, side to side.
    - example on right, tap on lifting lug
  - Acoustic wave reaches two side sensors (bl and y) in 112 µs at ~3800 m/s
    - Data collected at 1 MS/s for a minimum of 7 sensor channels.



No signal from the sensor during the ramp

Acoustic sensors issues during test

- Problem: Active usb cable failed during magnet ramping and balancing sporadically crashing computer
- Solution: Remove active USB cable and extend BNC/pigtails.

- Problem: Acquisition PC out of storage space
- Solution: Remove redundant data, Store data on external drive

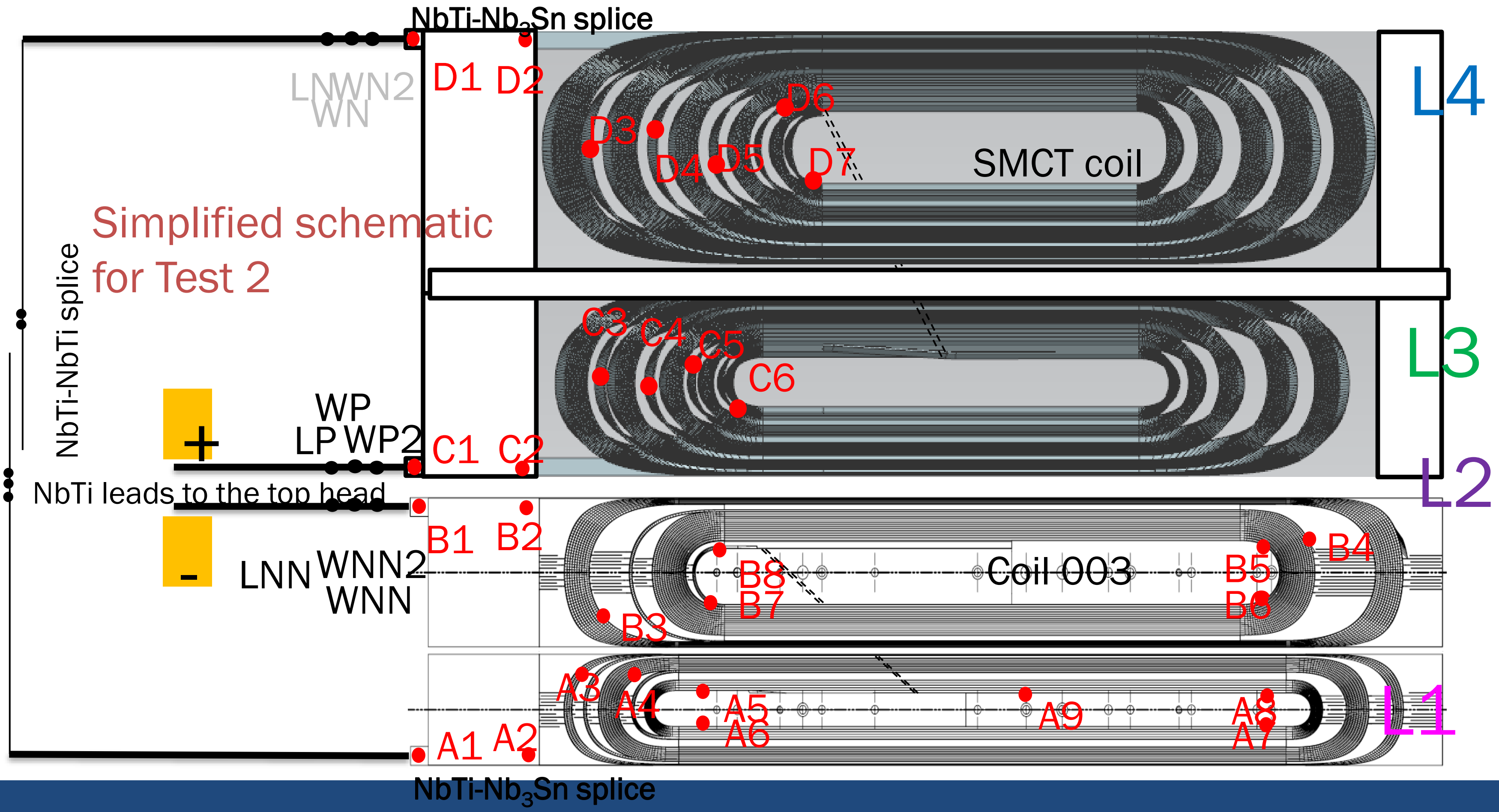
- Problem: Acoustic sensors draw too much power – transistors may be compromised. Typical power is ~1 mW each
- Solution: Isolate problem sensors and troubleshoot. Add current limiting resistor and isolate power per sensor. Redesign existing coupling board.

- Problem: 8 channel picoscope VI is buggy
- Solution: re-write software

Next steps

- **SMCTM1a: Second thermocycle**
  - Check Mirror magnet memory
  - Take RRR data

SMCTM1b test: both coils connected to the power supply



Test of SMCTM1b will be identical to SMCTM1a

Protection heater studies will be performed at the end of this test

The reference current levels for the protection studies are given below
Values will be recalculated based on the maximum Quench current achieved during training.
Heater performance studies: Minimum quench energy and protection heater delay
Goal: Find minimum heater power density needed to start a quench for different current levels

- The heater will be fired at gradually increasing power. Maximum power with 340 V.
- Minimum power density to quench is found. Quench delays is estimated varying HFU voltage between minimum and maximum power density

Current [kA]	1.4	2.28	4.20	5.6	7.0	8.4	9.8	11.2	12.6	14
I/Imax	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1

Summary

- The stress management dipole coil has been fabricated and is being tested in a 4L mirror magnet SMCTM1.
- Instrumentations consist in Voltage taps, strain gauges, fiber optics and acoustic sensors
- The SMCTM1a magnet reached 90% of SSL and the maximum field of 12.7 T.
    - Only 4 quenches in the outer layer of the SMCT coil
    - Temperature dependence and Ramp rate dependece behavior suggest some conductor degradation during coil fabrication and magnet assembly.
- The stress management design concept has been successfully validated
- Test will continue powering both SMCT outer and 15 T inner coil

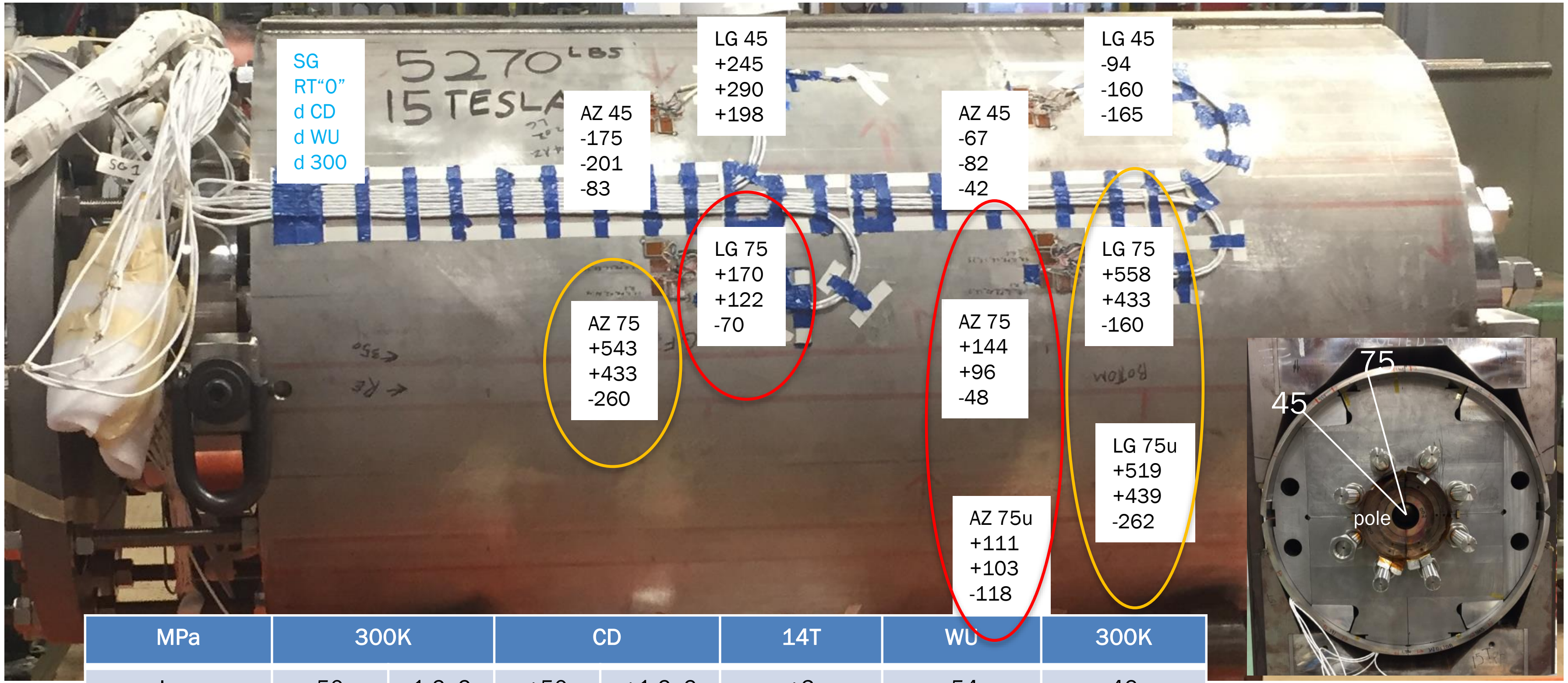
Back up

Strain gauges – warm up/cool down

Some readings are consistent with swapping channels

(but we couldn't find proof of that)

All normalized to ZERO just before cool-down, in microStrain



MPa	300K		CD		14T	WU	300K
clamp	50	1.6e6	+50	+1.6e6	+3	-54	46
skin	80-100	1.2e6	+110	+1.2e6	+20	-150	40-60