



Fermilab Coil Fabrication Status and Non-Conformity Report

Fred Nobrega

9th HL-LHC Collaboration Meeting at Fermilab – 14-16 October 2019



Acknowledgment

- US HL-LHC Accelerator Upgrade Project (AUP)
 - Fermilab Coil Fabrication Team
 - ❖ Engineering:
A. Bracero, S. Krave, F. Nobrega, M. Parker, M. Yu,
 - ❖ Quality inspection:
O. Lira, R. Riley
 - ❖ Technician's:
J. Alvarez, A. Coon, B. Galan, P. Fox, D. Jennings,
L. Kaminskis, S. Ransom, M. Walls

FNAL Coil Status

AUP Coils to date = 14
 8 accepted
 2 quarantined
 2 rejected
 2 in progress

Coil Name	Wind Start	Potting Complete	Duration days	DRs	Comments
QXFP01		At BNL			
QXFP02		At BNL			
QXFP03	Jan 4, 2016	Jul 8, 2016	186	7	OK
QXFP04		At BNL			
QXFP05	May 10, 2016	Oct 10, 2016	153	11	OK
QXFP06	Jun 13, 2018	Oct 3, 2018	112	12	OK
QXFA101	July 20, 2016	Apr17, 2017	271	18	Quarantined, electrical
QXFA102		At BNL			
QXFA103	Oct 31, 2016				Rejected
QXFA104	Jan 31, 2017	Jul 10, 2017	160	10	
QXFA105		At BNL			
QXFA106	May 25, 2017	Oct 16, 2017	144	13	OK
QXFA107	Aug 8, 2017	Feb 14, 2018	190	11	Quarantined, electrical
QXFA108	Dec 6, 2017	May 7, 2018	152	11	Rejected
QXFA109	Feb 5, 2018	Jun 25, 2018	140	12	Quarantined, electrical
QXFA110	Apr 23, 2018	Aug 15, 2018	114	10	OK
QXFA111	Jul 5, 2018	Oct 19, 2018	108	6	OK
QXFA112	Aug 22, 2018	Dec 6, 2018	107	4	OK
QXFA113	Oct 11, 2018	Jan 25, 2019	107	8	OK
QXFA114	Dec 11, 2018	Mar 18, 2019	97	6	Quarantined, impreg process
QXFA115	Feb 11, 2019	May 13, 2019	91	7	OK
QXFA116	Mar 26, 2019	Aug 19, 2019	146	8	OK
QXFS10	May 1, 2019	Sep 3, 2019	110	9	OK
QXFA117	May 17, 2019	Oct 2, 2019	139	5	CMM in progress
QXFA118	Jul 24, 2019			2	Rejected
QXFA119	Sep 17, 2019			1	Winding L2

→ LARP Coils

New coil for MQXFP1b

→ LARP Coils

Saddles changed after curing
 (details of AUP rejected & quarantined coils in following slides)

No more saddle change

May be accepted shortly

New coil for short mirror MQXFS

Strand damage during winding

QXFA107 DR-11519, quarantined

Traveler Title:

464288 - A - HL-LHC Magnet QXFA Electrical Testing Traveler

Step No.:

14.5.4 - TEST: Coil to Saddles 1000 V

Serial Number(s):

QXFA-CL-107 - 0

Discrepancy Description:

A short was discovered from the RE OL Endshoe to Coil during the QXFA 107 Hipot test. The actual voltage readback during this test was 20 V to ground with a leakage current of 7.0 μ A.

Marcellus Parker - 6/1/2018

Cause of Nonconformance:

The cause of this nonconformance is failed insulation during Hipot.

Marcellus Parker - 6/1/2018

Unknown, perhaps chipped plasma coating on saddle and damage to cable insulation during saddle installation. Based on the data the resistance is ~ 3 mega-ohm.

Fred Nobrega - 6/25/2018

Disposition:

None at this time

Fred Nobrega - 6/25/2018

Corrective Action to Prevent Recurrence:

A design change to saddles to make them more flexible has been implemented on coil QXFA110 and subsequent coils. Also, all saddles delivered by the vendor with chipped plasma coating will be rejected and returned to vendor for rework.

Fred Nobrega - 6/25/2018

Corrective Action verify notes:

This corrective action has transpired

Marcellus Parker - 7/15/2019

- Coils 101-109 used saddles with some flexibility for winding and curing then replaced with solid saddles for reaction and impregnation.
- Coils 110 and subsequent use a redesigned flexible saddle that remains with the coil throughout fabrication.

QXFA108 DR-11520, rejected

Traveler Title:

464288 - A - HL-LHC Magnet QXFA Electrical Testing Traveler

Step No.:

14.1 - Perform continuity checks using a FLUKE Multimeter with the sound function OFF. Contact Engineer if something different than OL (Over Load) is displayed.

Serial Number(s):

[QXFA-CL-108 - 0](#)

Discrepancy Description:

Multiple coil-to-pole shorts were discovered using a Fluke Multimeter during the post-impregnation continuity check. This Short is consistent with a previous DR written in response (DR 11491) to a failed continuity check prior to impregnation. The Previous DR was to be resolved through the implementation of the impregnation procedure. This post-impregnation continuity check affirms that the aforementioned resolution was unsuccessful.
Marcellus Parker - 6/1/2018

Cause of Nonconformance:

The cause of this Nonconformance was due to failed insulation between the first turn of the coil and the first pole piece.
Marcellus Parker - 6/1/2018

Possible excess binder at near the pole pieces that pyrolyzed during reaction.
Fred Nobrega - 6/26/2018

Disposition:

Due to the multiple shorts this coil is not suitable for magnet assembly. Coil is REJECTED and be will set aside. Unclear at this time what other use if any this coil may serve. Possibility include use as a test coil for a future CMM purchase, cut up for 2D cross section studies, cut up to reuse end parts.
Fred Nobrega - 6/26/2018

Corrective Action to Prevent Recurrence:

Beginning with coil QFXA110 apply binder from mid plane towards the pole stopping the application of the binder at the 3rd turn from the pole. A detailed note is in chapter 4.20 of QXFA-CL-109 HL-LHC Magnet QXFA Coil Winding and Curing Traveler 464311 Rev. H.
Fred Nobrega - 6/26/2018

QXFA109, quarantined

- All QXFA109 DR's closed → all issues resolved.
- Coil shipped to LBNL
- Incoming LBNL electrical measurements passed
- Inner layer RE saddle short to coil at coil assembly
- Coil quarantined and shipped to FNAL

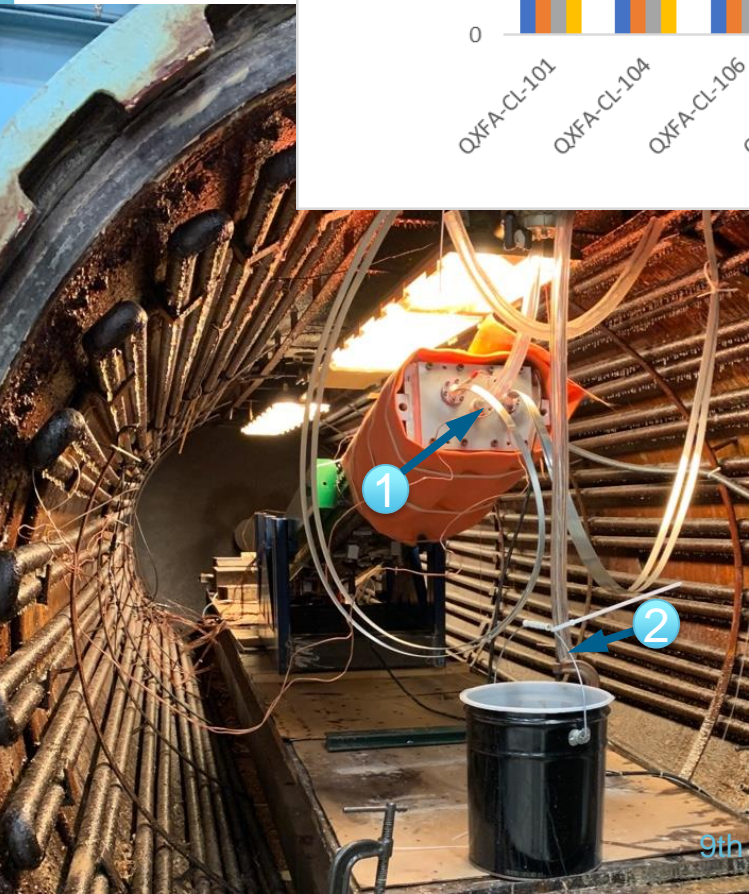
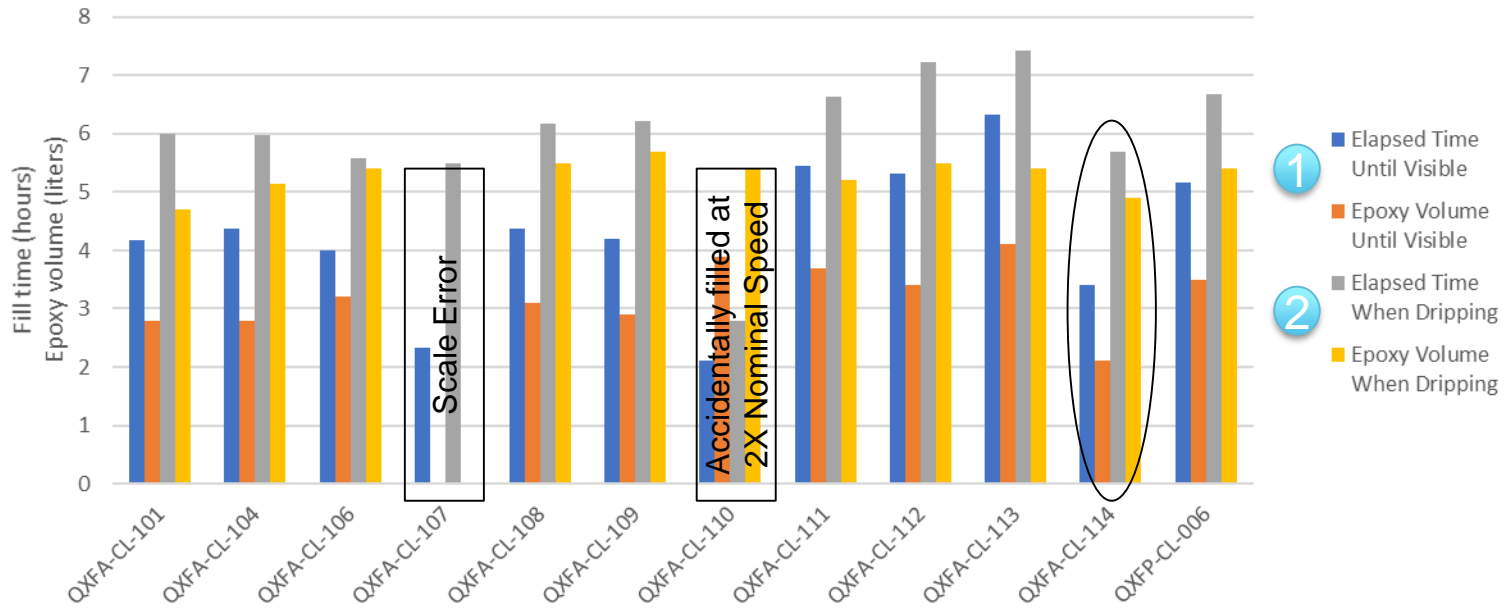
DR Number	Document	DR Status
11415	QXFA-CL-109-0--464311--HL-LHC Magnet QXFA Coil Winding and Curing Traveler	Closed
11417	QXFA-CL-109-0--464308--HL-LHC Magnet QXFA Preparation for Coil Winding and Curing Traveler	Closed
11434	QXFA-CL-109-0--464311--HL-LHC Magnet QXFA Coil Winding and Curing Traveler	Closed
11438	QXFA-CL-109-0--464311--HL-LHC Magnet QXFA Coil Winding and Curing Traveler	Closed
11488	QXFA-CL-109-0--464312--HL-LHC Magnet QXFA Reaction Traveler	Closed
11492	QXFA-CL-109-0--464312--HL-LHC Magnet QXFA Reaction Traveler	Closed
11501	QXFA-CL-109-0--464288--HL-LHC Magnet QXFA Electrical Testing Traveler	Closed
11522	QXFA-CL-109-0--464313--HL-LHC Magnet QXFA Splice / Epoxy Impregnation Traveler	Closed
11528	QXFA-CL-109-0--464288--HL-LHC Magnet QXFA Electrical Testing Traveler	Closed
11537	QXFA-CL-109-0--464313--HL-LHC Magnet QXFA Splice / Epoxy Impregnation Traveler	Closed
11581	QXFA-CL-109-0--464327--HL-LHC Magnet QXFA Shipping to Lawrence Berkeley National Lab Traveler	Closed
11750	QXFA-CL-109-0--464288--HL-LHC Magnet QXFA Electrical Testing Traveler	Closed

DR-11754, QXFA114 (First b6 Shimmed Coil), **quarantined**

- Coil A114 had epoxy visible sooner than typical
- Coil 114 had 30% less epoxy in coil than typical when epoxy visible by weight
- At the end of filling, we decided to complete a pressure cycle as used for the CLAS12 project to see if the epoxy level in the tube would change.
 - Pumped chamber to 1 torr and saw no change in epoxy level in tube. Returned chamber to atmospheric pressure.
- No other indicators of strange behavior

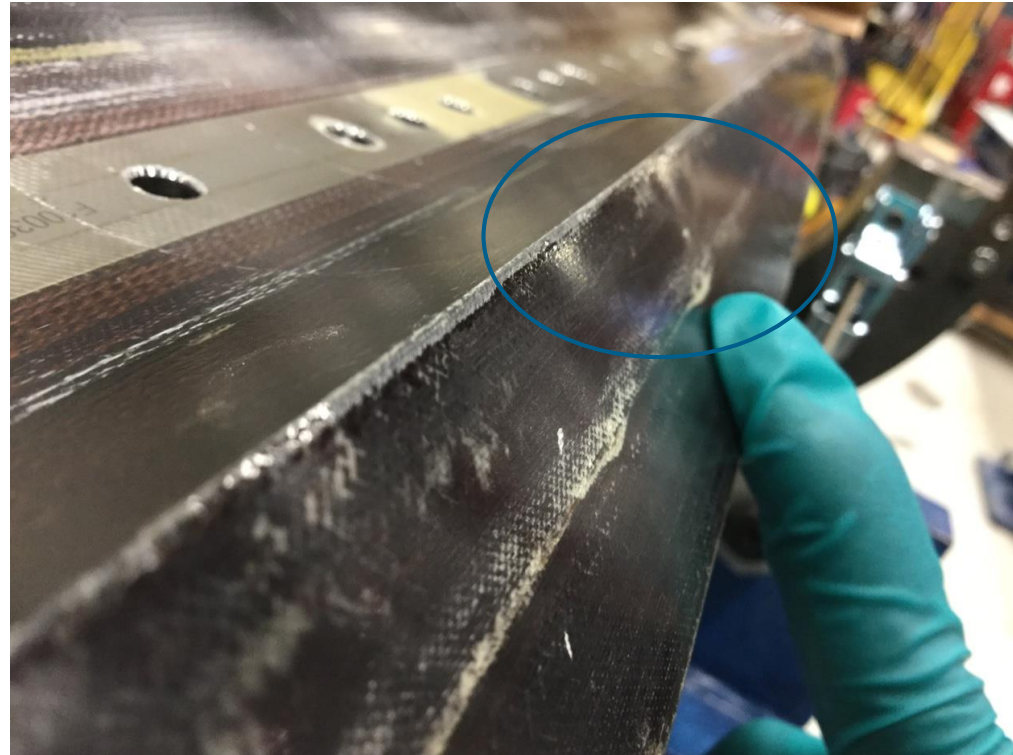


QXFA Coil Impregnation Time and Volume



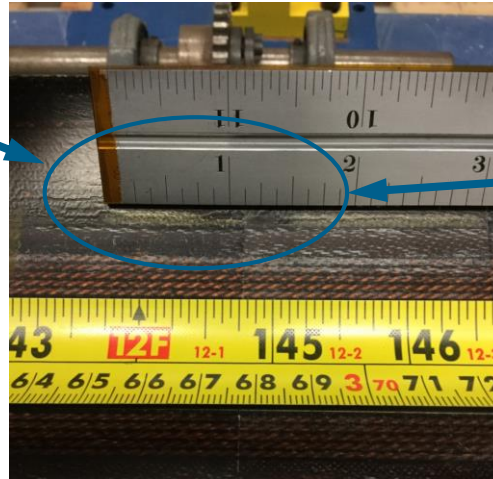
QXFA114 Visual Inspection

- Midplane G11 shim (125 μm) stuck to midplane shim SS tooling & delaminated from the coil in 2 places.



QXFA114 Visual Inspection

- Epoxy voids seen on ID of coil.



- One surface bubble on coil OD



Non-Transition Side

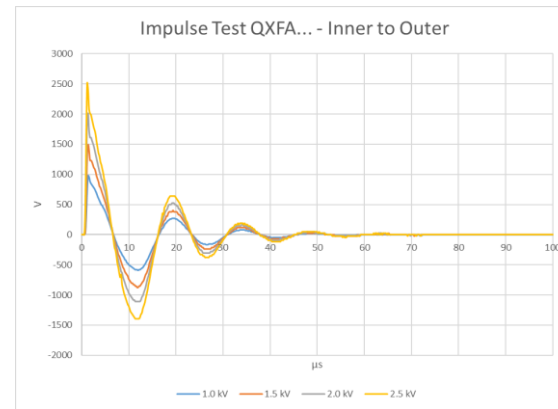
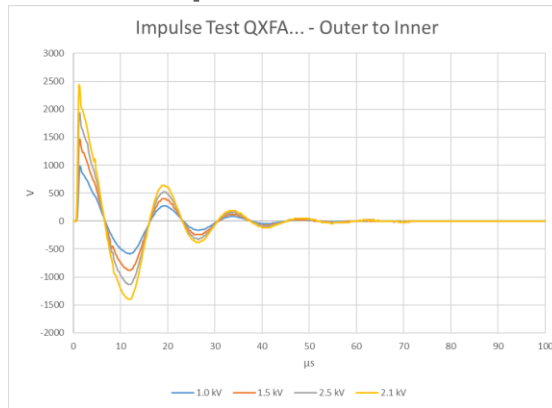
Location	Turn Number	Length of Void
1) 19 1/8"	6	1/4"
2) 24 1/8"	6	1/4"
3) 144 18"	6-7	1 1/8"
4) 145 7/8"	6-7	1 9/16"
5) 150 1/4"	6-7	3/4"
6) 161 1/2"	6	3 1/8"
7) 165"	6	2 7/8"

Transition Side

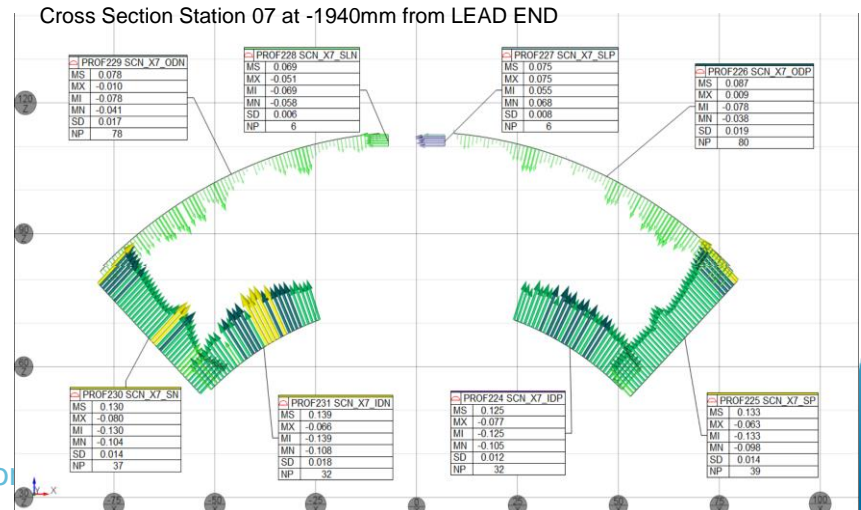
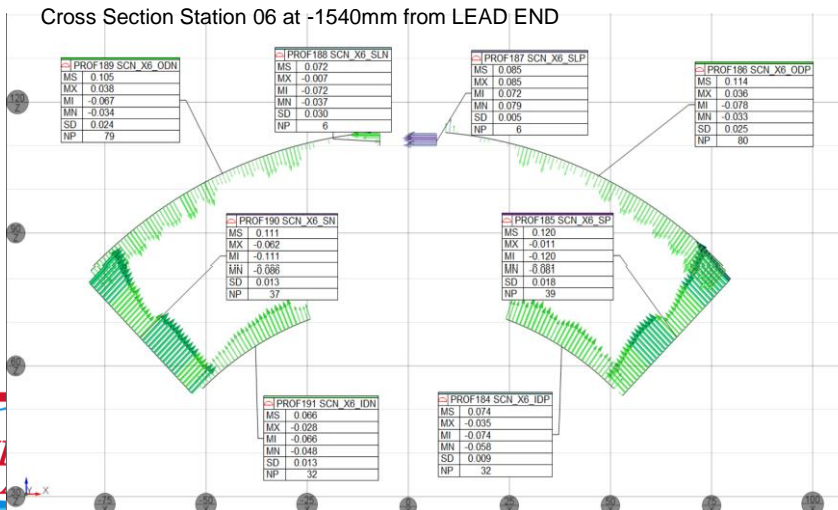
Location	Turn Number	Length of Void
1) 18 1/2"	6-7(Layer Jump)	4 1/4"
2) 29 1/2"	6	1/2"
3) 83 1/4"	11-12	3/8"
4) 139 5/8"	8	1/4"
5) 141 3/16"	8	1/8"
6) 141 3/4"	8-9	1/2"
7) 144"	8	1/4"
8) 146 5/8"	8	2 3/8"
9) 149 3/4"	8-9	2 3/8"
10) 151 3/4"	8	5/16"
11) 152 3/8"	8	7/16"
12) 153 1/8"	8	1/4"
13) 153 3/4"	8	1/2"

QXFA114 Electrical Tests & CMM Measurements

- All final electrical test performed and passed
 - VTB01 is open



- CMM results are typical.

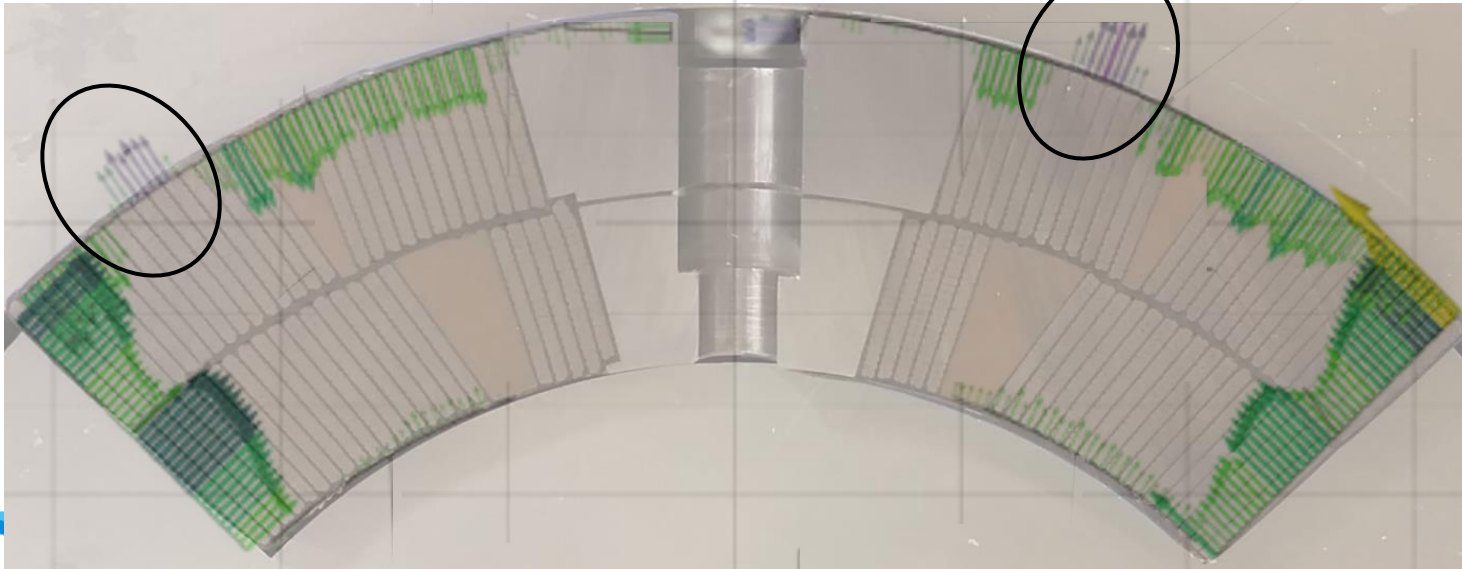


Status

- Investigated coil midplane adhesion to tooling midplane
 - Performed test of several SS midplane/G11 mold released samples to investigate poor tooling release after impregnation.
 - Performed 10-stack mold release test.
 - ✓ Zyvax mold release and FNAL waxy mold release performed as expected.
 - Unable to identify cause of tooling adhesion after impregnation.
- All impregnation process steps & equipment have been checked and reviewed.
 - Traveler steps
 - Pumps, scales, T/C's
 - ✓ No abnormalities found.
- ✓ Coil CMM and Electrical Tests are normal.
- Coil epoxy defects on ID, severity unknown.
- G11 midplane insulator delamination appears to be minor.
- Final disposition of coil and DR #11754 is by G. Ambrosio.

DR-11869, QXFA115 Ridge Anomaly, Accepted

- QXFA115 CMM measurements indicate a bump on the coil about 0.09 mm above the coil outer surface that runs longitudinally about 2 m long and is about 5 turns wide on the transition side of the coil.
- A similar but smaller bump is on the coil about 0.05 mm above the coil outer surface that runs longitudinally about 3 m long and is about 5 turns wide on the non-transition side of the coil
- CMM is used to measure 14 discrete cross sections of the coil.
- Pressure sensitive film (Fuji film) used to characterize surface.



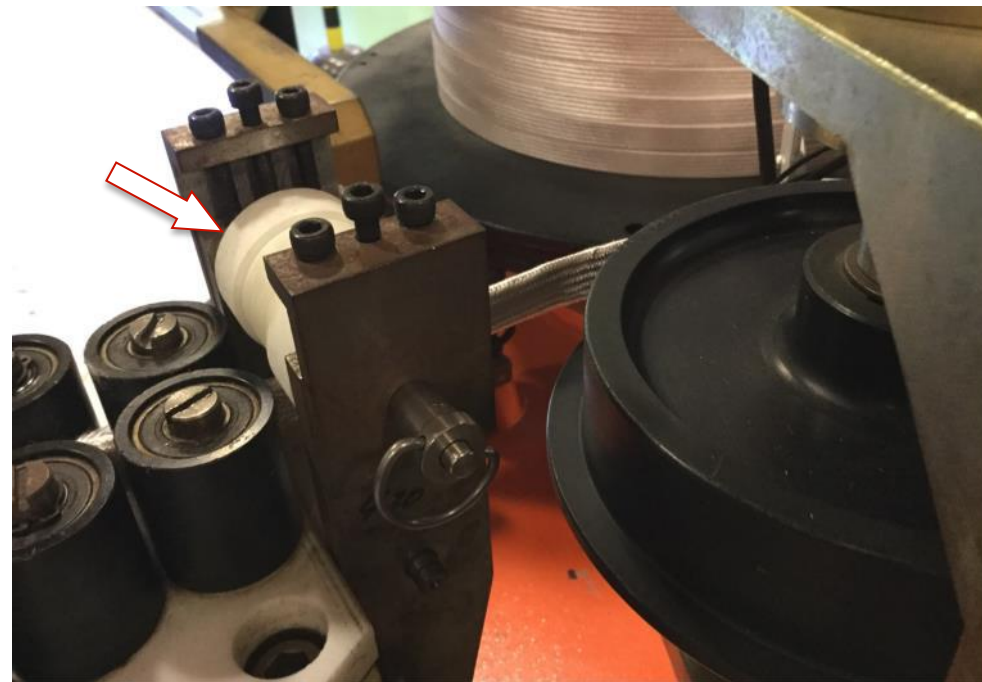
Status

- Bump source is S2 glass delamination
- CMM probe pressure is very light
- No signal from Fuji pressure film
- Coil accepted & shipped to LBNL.



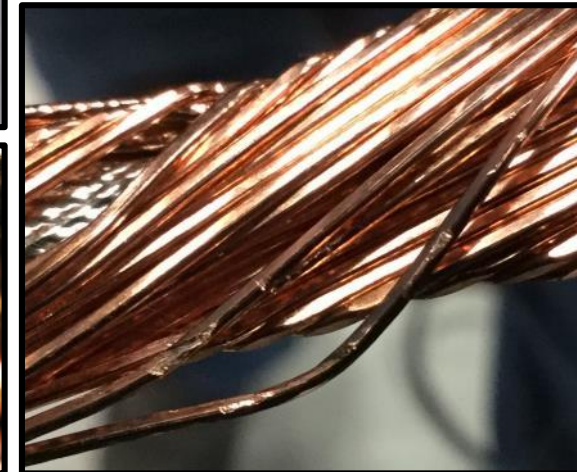
DR-11878, QXFA118 Roped Cable & Strand Damage, **Rejected**

- On August 15, 2019 outer layer cable roped
 - 15th turn on the transition side (2 turns after wedge)
 - Due to hard way bend against the white roller.



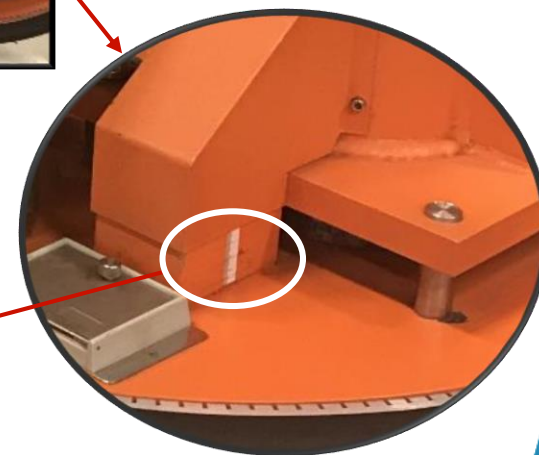
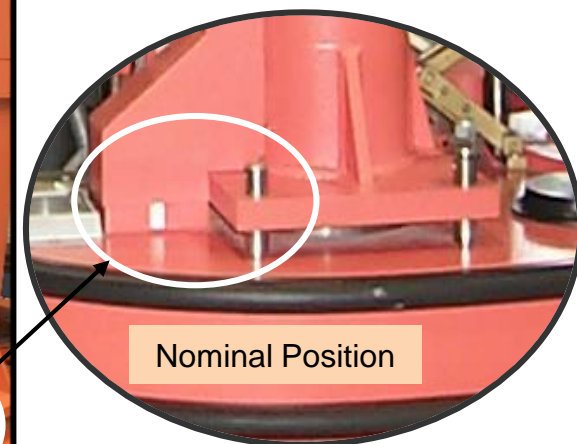
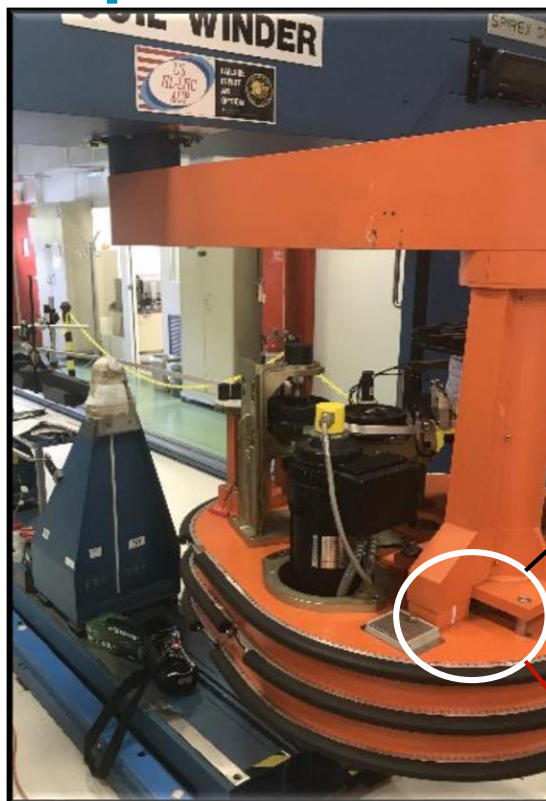
QXFA118 Strand Damage

- Strand damage likely caused by the strand dragging against top edge of vertical guide roller(s) after the cable collapsed.



QXFA118 Roped Cable Cause

- The boom height has a 4 cm range set at 2.5 cm from the bottom and used for both inner and outer coil winding.
- Winding the inner layer had no adverse impact on the cable.
- During outer layer winding, the winding mandrel is higher than the boom causing upward pressure on the white roller and eventual cable collapse.



Status

- Obtained final disposition of coil QXFA118
 - Reviewed by conductor & cable folks
 - Dispositioned by Giorgio Ambrosio
- Back wound coil to retrieve all parts: wedges, pole pieces, end parts
- Adjusted boom to nominal position
- **Designed & procured taller rollers**, due end of Oct.
 - Mitigate strand damage
- **Boom position checked prior to each coil winding.**
- Coil QXFA119, inner layer completed on Selva.