Coil Design and Fabrication

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2014-12-11

Outline

- **Introduction**
- **Coil Design**
  - Coil Pole
  - Coil End Parts
  - Coil Insulation
- **Coil Fabrication**
  - Winding and Curing
  - Reaction and Impregnation
  - QA & QC
- **Scale up to MQXFL**
- **Summary**

Introduction

- **Based on LARP successful R&D Quadrupole coil TQ/LQ/HQ/LHQ experience.**
  - Coil design
  - Tooling design
  - Fabrication technology and procedure
  - QA and QC
- **MQXFS coil is 1.51 m long, to verify the design, the tooling and the coil fabrication.**
- **MQXFL coil is the scale-up one in longitudinally with the same cross section and ends as MQXFS coil**

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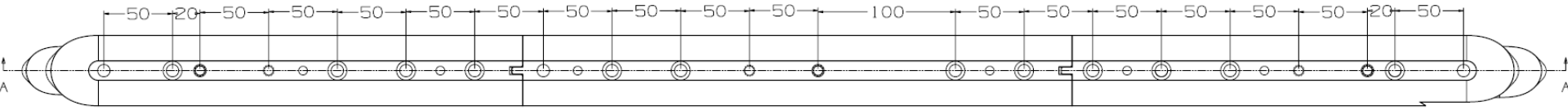
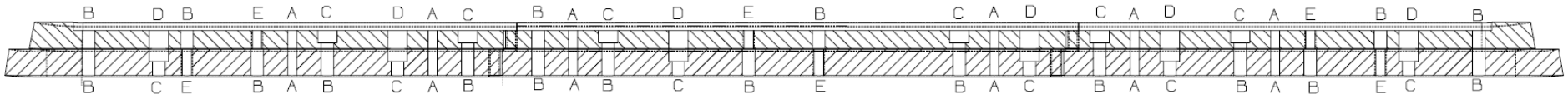
Coil Pole

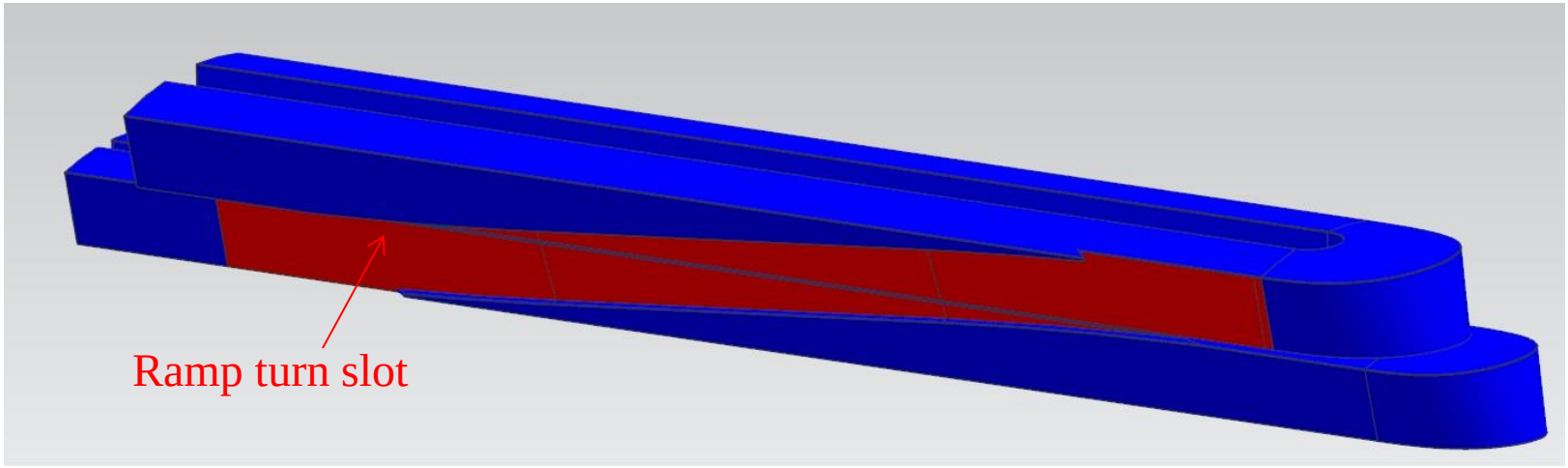


- ***> 80 % of the heat is evacuated via the pole piece with Φ8 mm holes and 50 mm spacing***



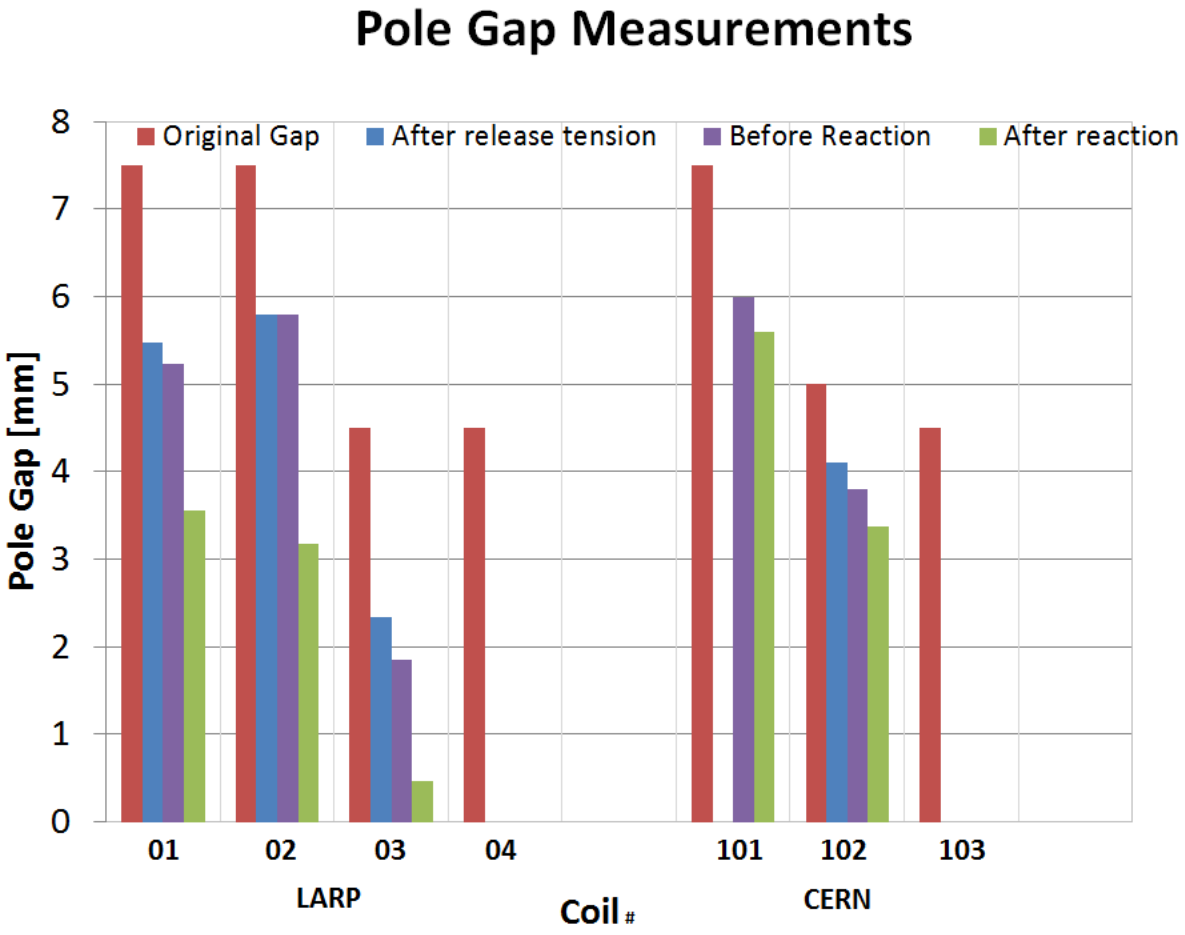
Pin Hole A: Ø6.35mm for 1/4" dowel pin
Clearance Hole B: Ø9.0mm thru for 5/16" or M8 SHCS
Clearance Hole C: Ø9.0mm thru, ⌴ 13.8mm, ↧ 8.8mm for 5/16" or M8 SHCS
Clearance Hole D: Ø13.8mm thru for 5/16" SHCS
Lifting Hole E: Ø M8x1.25 lifting threaded hole

Hole B,C,D and E will be used as cooling hole after magnet assembly



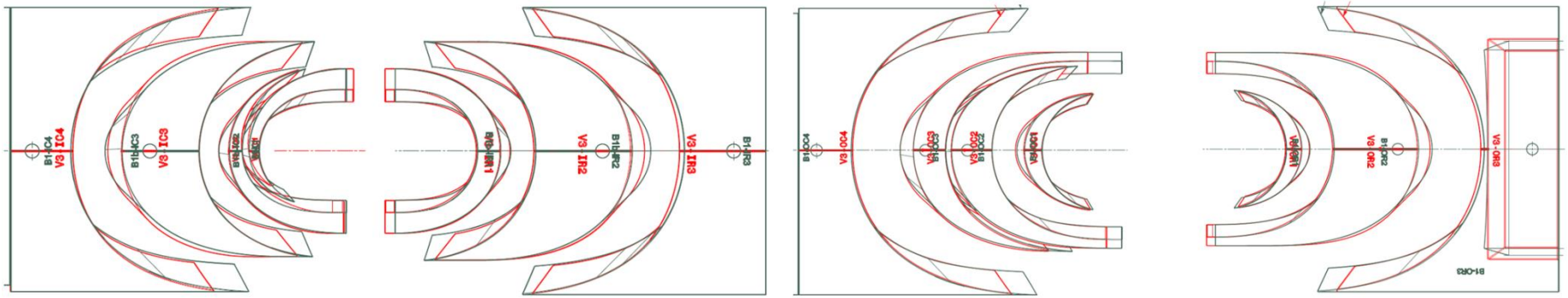
Pole Gap

- **Due to winding tension and thermal contraction during reaction, pole gap is required to release the strain energy.**
- **After reaction, the target for the pole gap is 0.**



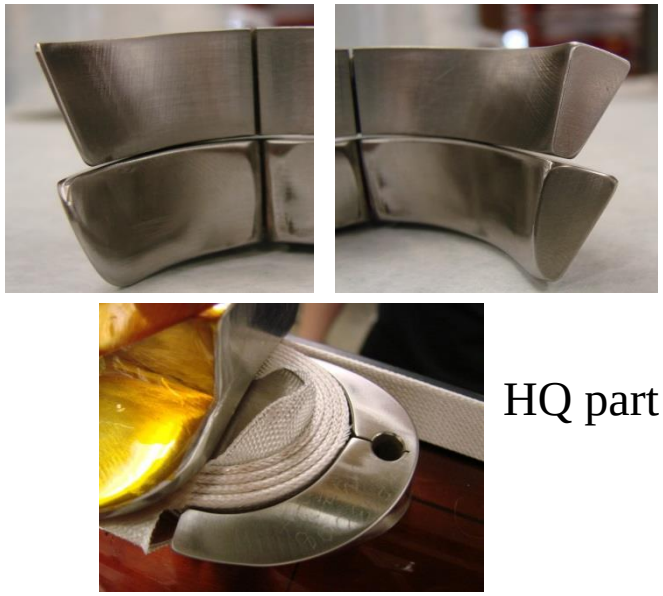
Coil End Parts

- **ROXIE and BEND designs**
  - No major differences
  - Exchangeable coil parts in group
  - Exchangeable coils

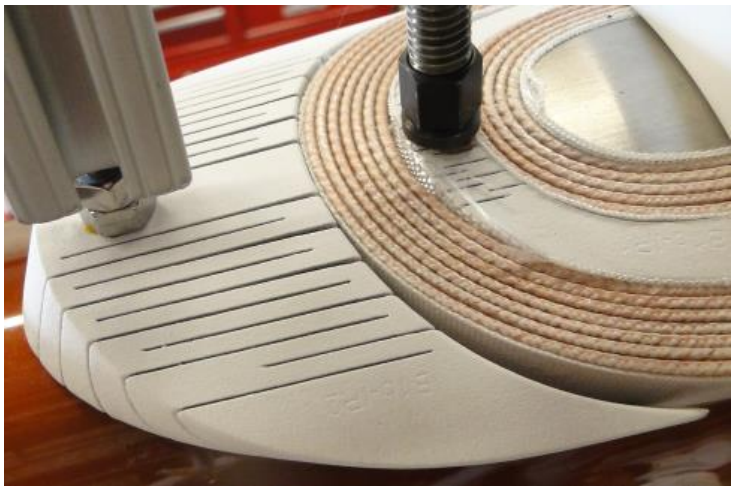


Slits in End Parts

- End parts are designed based on the nominal coil size after coil reaction
- During winding, the coil is not fully constrained inside the envelope. This effect is most pronounced at the ends. Prior to curing, the cable separates from radial surface of the mandrel in these areas (springback), causing the shape of the turn not to match the shape of the end parts.
- The springback is larger with larger coil aperture and cable size, and it is more difficult to install the end parts without ***removing a lot of material***.
- Therefore, flexible features (slits) have been introduced.

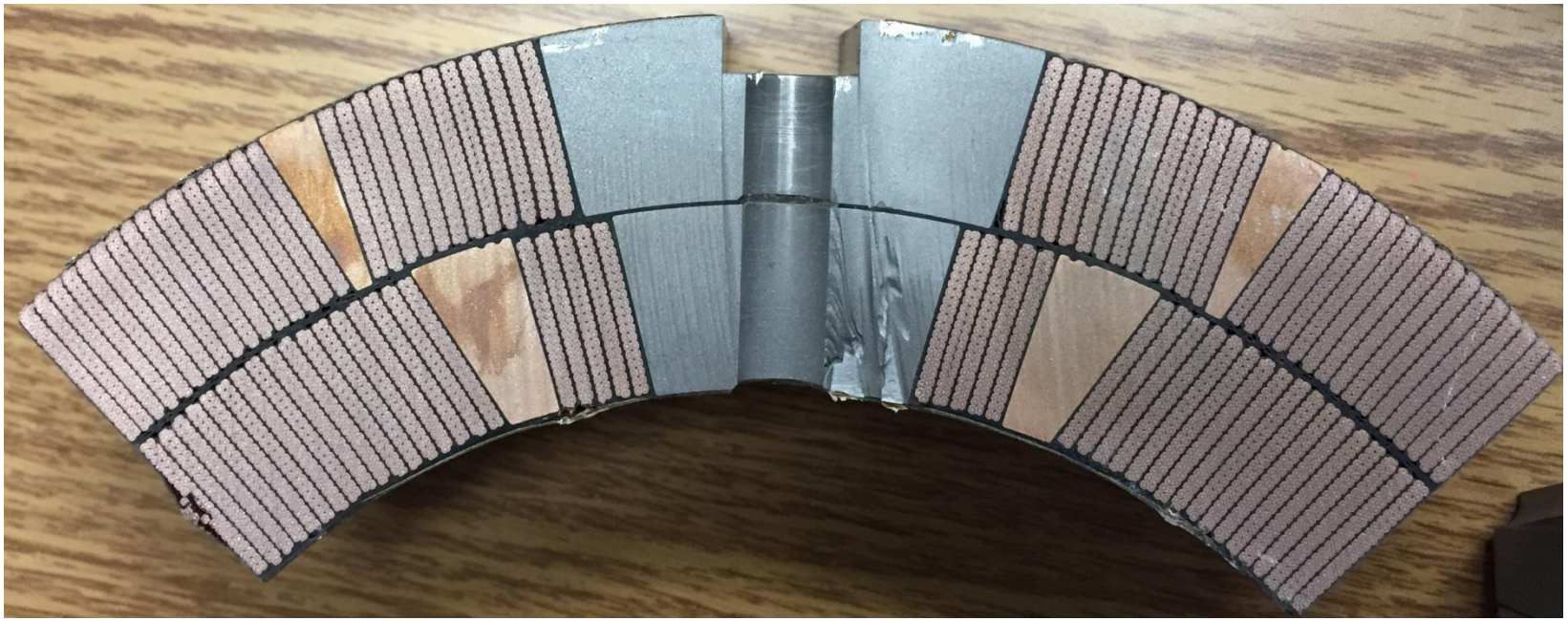


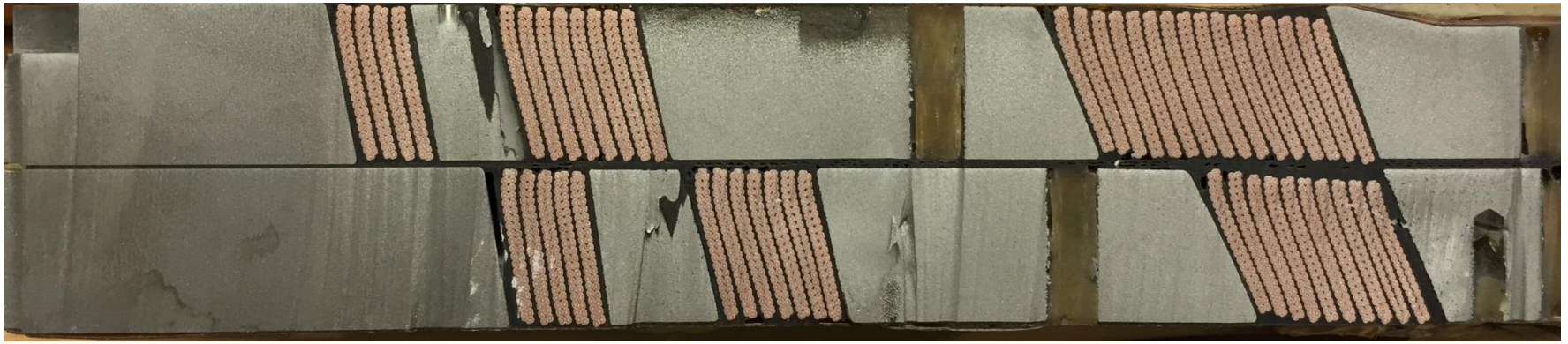
HQ part



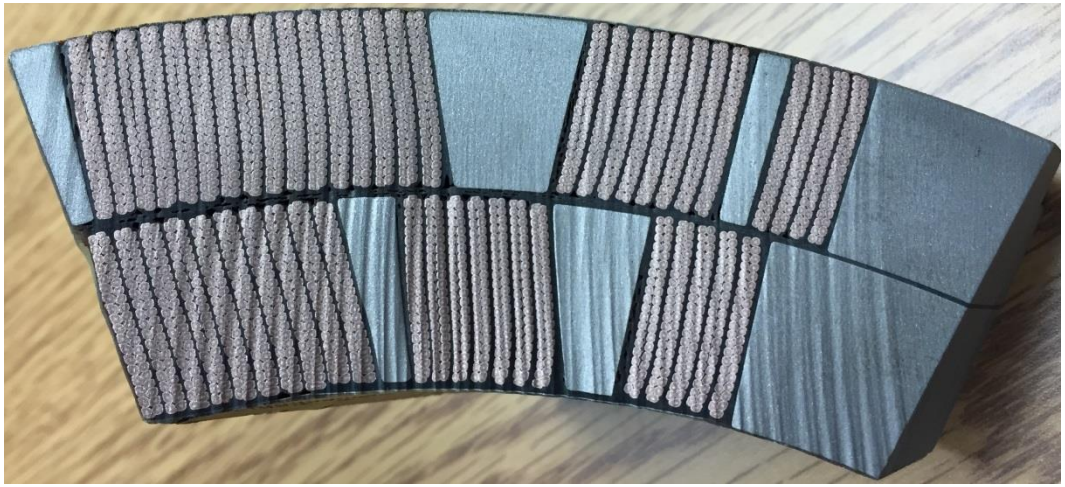
MQXF part

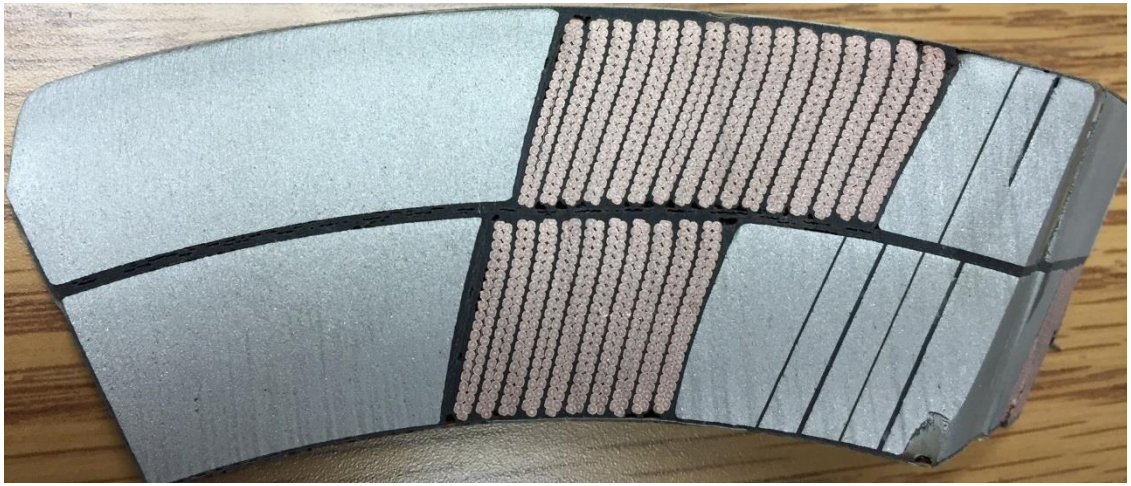
MQXF Coil 01 Autopsy





MQXF Coil 01 Autopsy

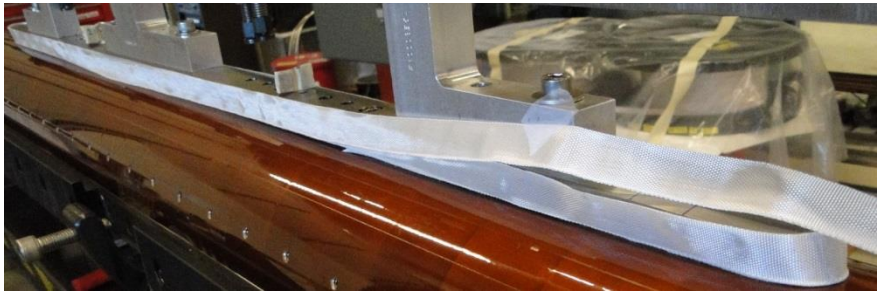




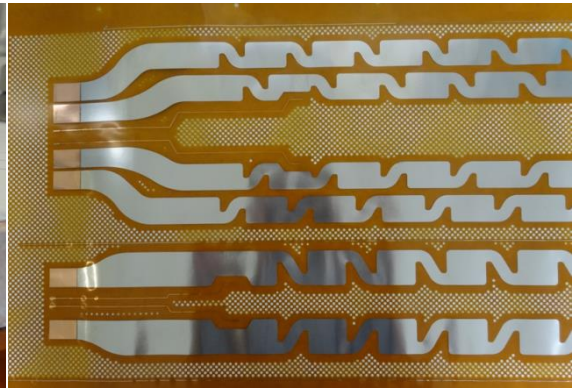
- No popped strands
- End parts fit well

Coil Insulation

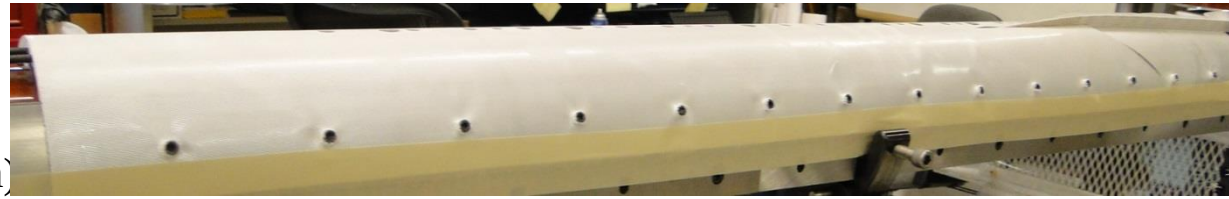
- **Coil to pole:**
  - 2 layers of S2 glass tape (total 0.36mm)
  - Cable insulation (0.15 mm)



- **Coil to end part:**
  - plasma coating (0.25mm)
  - 1 layer S2 glass tape (0.16mm)
  - Cable insulation (0.15 mm)



- **L1 to L2:**
  - 0.5 mm S2 glass sheet
  - Cable insulation (0.3 mm)
- **Coil to heater:**
  - 0.05 mm Kapton
  - Cable insulation (0.15 mm)



Electrical Checks

SQXF01	Coil			Hipot Checks					
PHA01	2000 / 2000			Actual / Target					
PHA02	2000 / 2000	PHA01	PHA02	(< 1 uA leakage)					
PHB01	2000 / 2000								
PHB02	2000 / 2000			PHB01	PHB02	PHB03	PHB04		
PHB03	2000 / 2000								
PHB04	2000 / 2000							LE IL Endshoe	RE IL Endshoe
LE IL Endshoe	1200 / 1200	1000 / 1000	1000 / 1000						
LE OL Endshoe	1200 / 1200			1000 / 1000	1000 / 1000	1000 / 1000	1000 / 1000	600 / 600	
RE IL Endshoe	1200 / 1200	1000 / 1000	1000 / 1000						
RE OL Endshoe	1200 / 1200			1000 / 1000	1000 / 1000	1000 / 1000	1000 / 1000		600 / 600
Pole	500 / 500								

Both LARP and CERN coils

- All standard test (up to 2 kV) - passed
- Heaters-to-coil up to 5 kV – passed
- Impulse test up to 5 kV – MQXFS 01 passed up to 4.6 kV; 101 passed up to 5 kV

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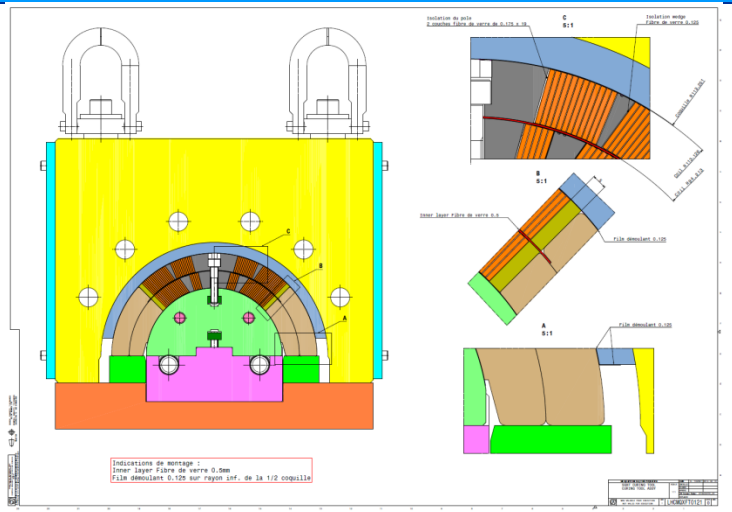
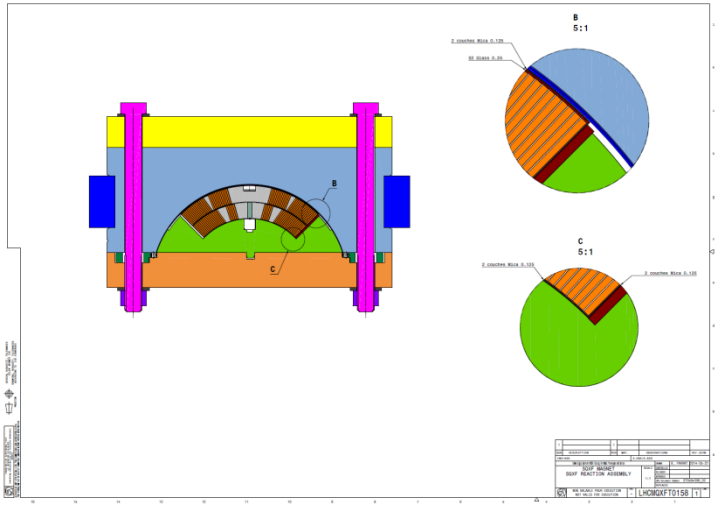
Tooling design

- **Cable dimension after reaction and 150 μm thick insulation**
- **Coil cured in larger cavity**
- **Coil closed in reaction fixture in larger cavity**
- **Coil after reaction and during impregnation in nominal cavity**
  - Theoretical pressure ~5 MPa

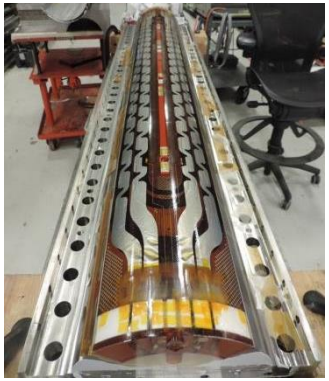




Coil fabrication status

LARP coil #1
completed

LARP coil #2
completed



LARP coil #3
is being impregnated at BNL

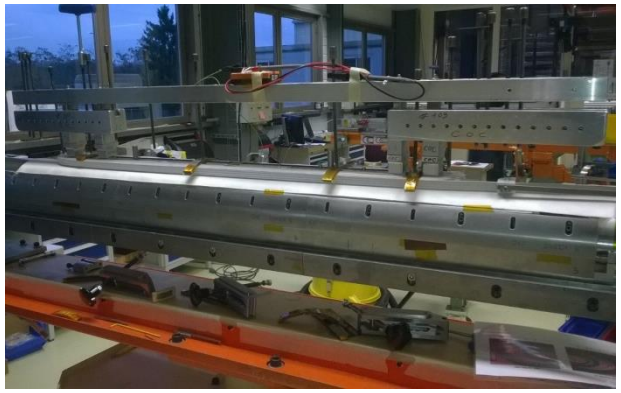
LARP coil #4
Is being wound

CERN coil #001 (Cu)
completed

CERN coil #101
completed

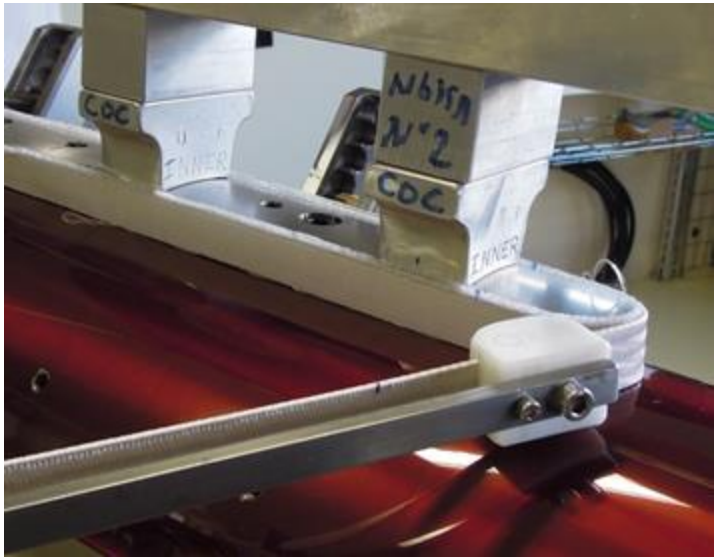
CERN coil #102
prepare for impregnation

CERN coil #103
Is being wound



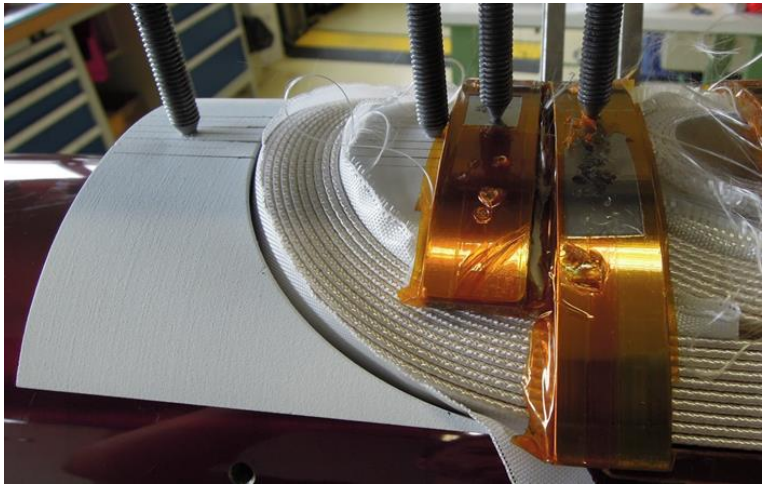
Winding and Curing at CERN

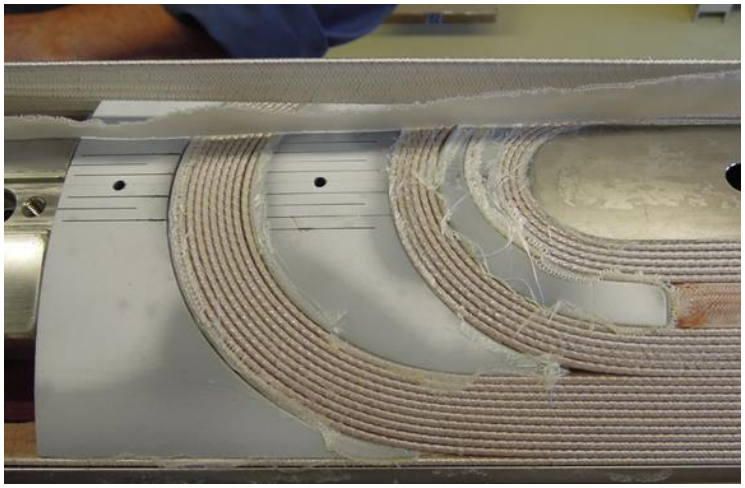
- Wind the coil with the tool, but without binder
- No popped stranded



3 coils have been wind and cured

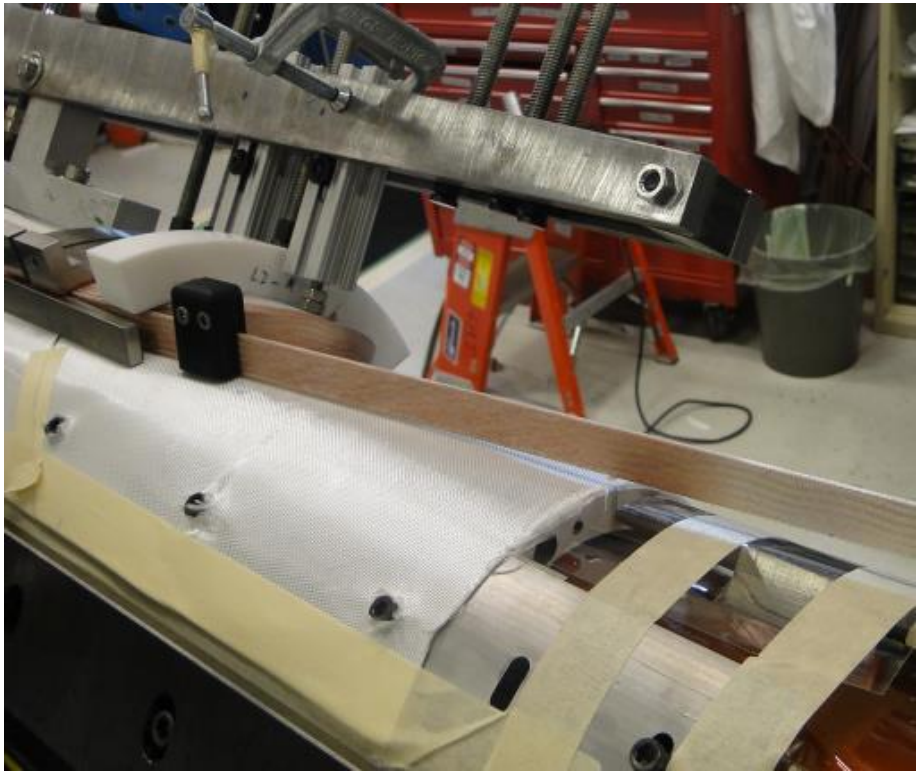
- End parts fit before/after curing





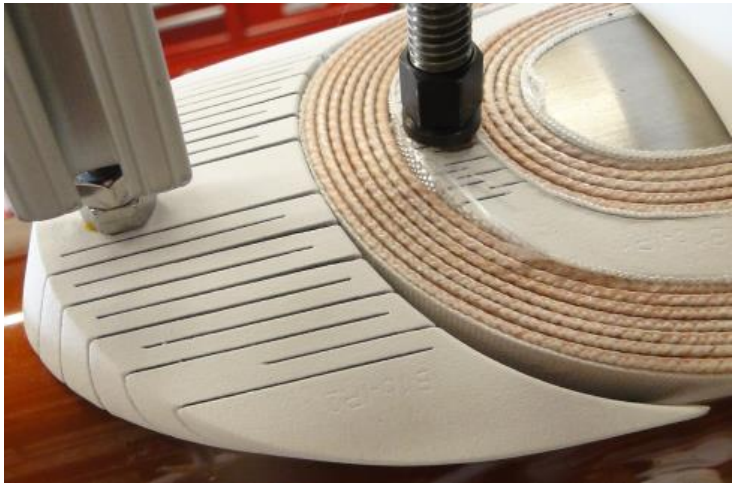
Winding and Curing at LARP

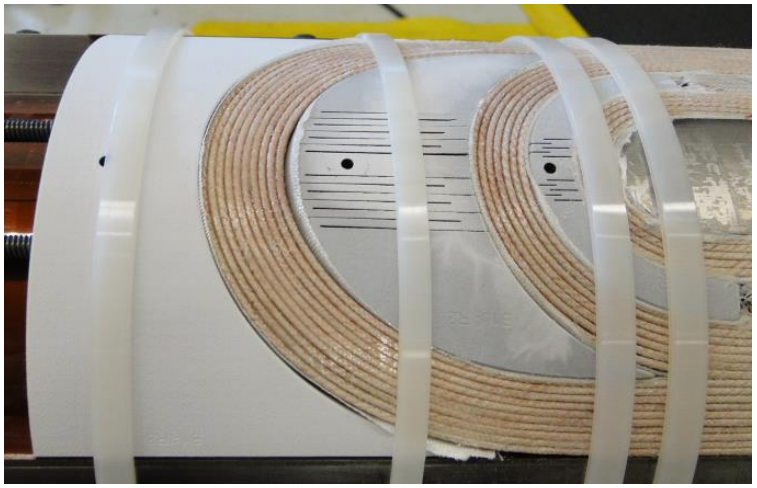
- Wind the coil with the tool and the binder
- No popped stranded



4 coils have been wind and cured

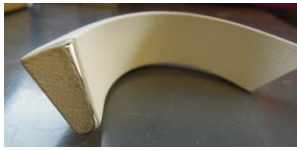
- End parts fit before/after curing

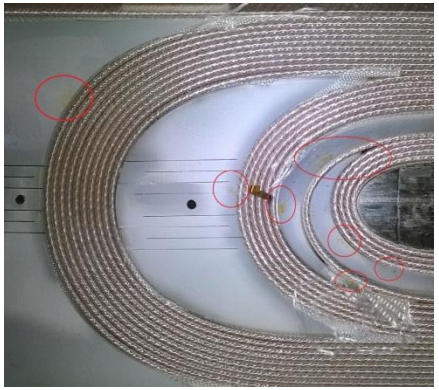


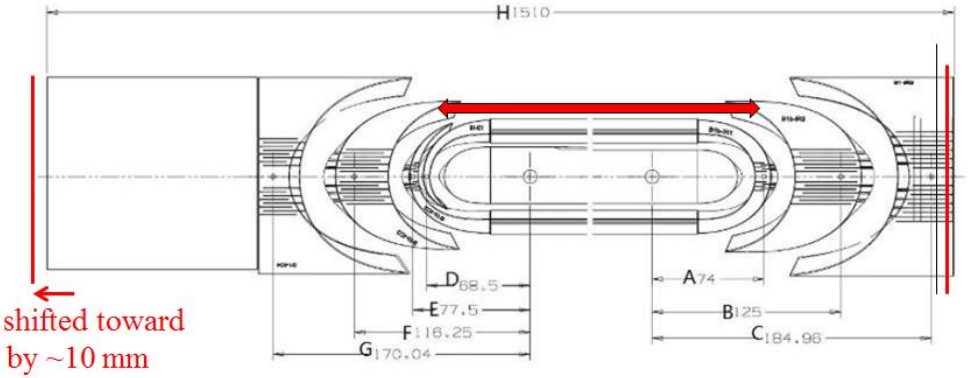


Lessons Learnt

- **Before coating the parts, grind all the sharp corners.**
- **The laser sintered part is porous, machine oil can be trapped and leak out after curing. Need to clean it before coating.**
- **After coating, the identification is not obvious to read. Some parts are too similar to each other which need a witness hole. And all the parts need to go through QC carefully for identification.**



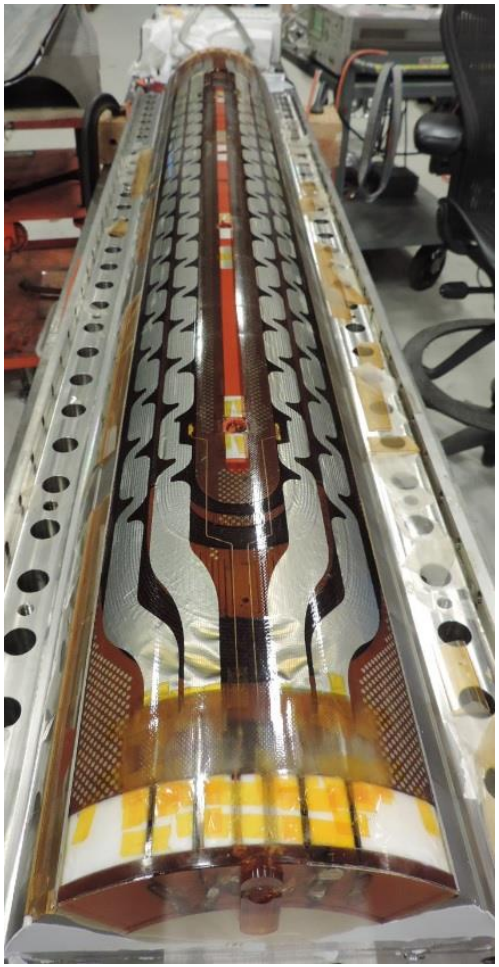




Reaction and Impregnation at CERN

- 2 coils have been reacted
- 1 coil has been impregnated.

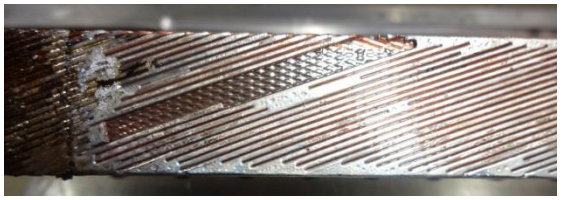
Reaction and Impregnation at LARP



- 3 coils have been reacted
- 2 coil has been impregnated.

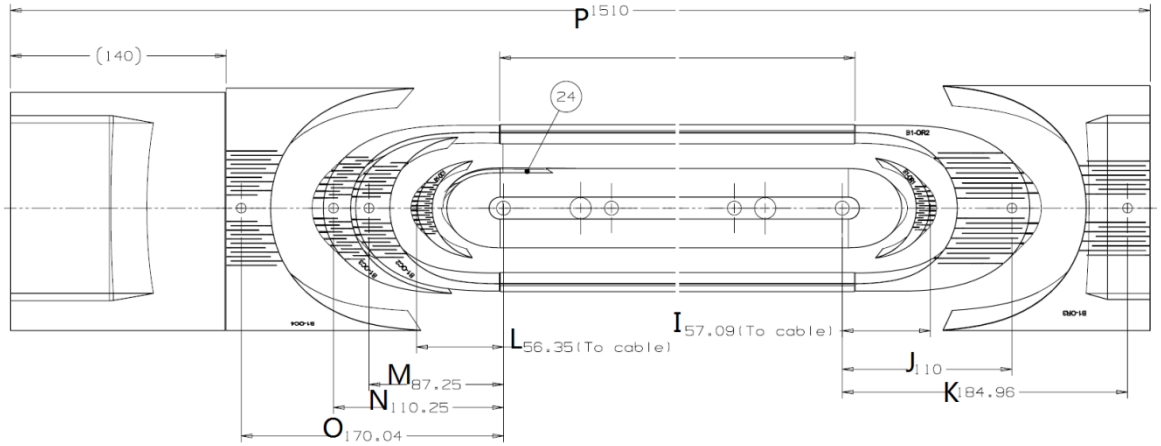
Lessons Learnt

- **Couple of strands broken during pre-tin the lead. Clean the soldering mold every time**
- **Dry spot and sucked area. Adjustments implemented to equipment and procedures**

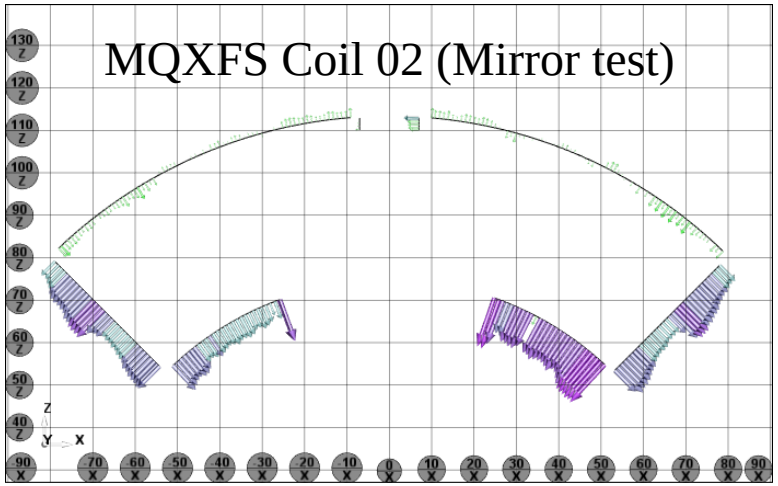


QA & QC

- **Measurements during fabrication**



- **CMM for the fabricated coil**



Average radial size = + 3.5 mils

Average azimuthal size = +2.5 mils

One square =
100 um (4 mils)

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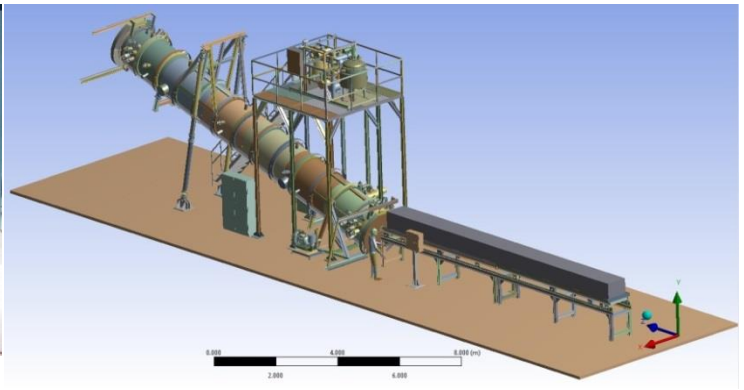
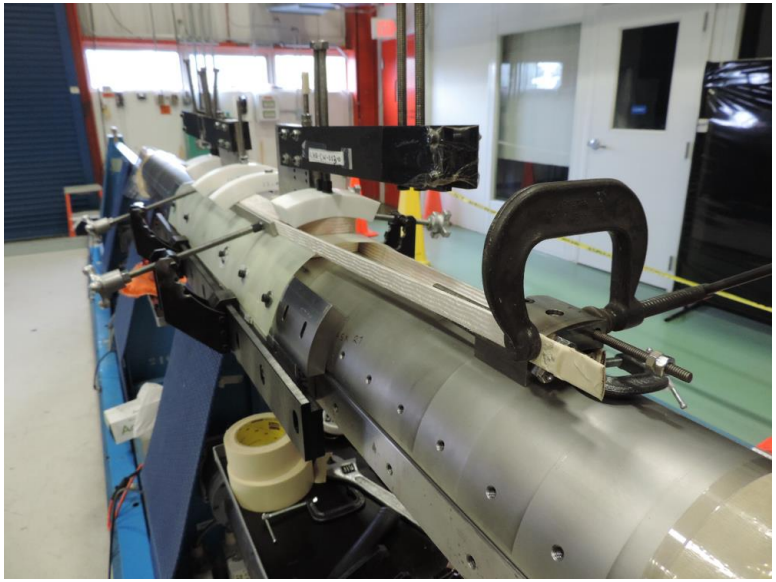
MQXFL Coil

- **Cross-section is same as MQXFS**
- **Q2 at CERN and Q1&Q3 at LARP with different coil lengths.**
- **Tooling is under procurement**



Selva-Winder at FNAL



- No popped strands or cable collapse during coil winding on the Selva winder which uses reverse bending of the cable (binder was used at the end).
- Inspection of the SS core of the cable wound on the existing coil winder and on the Selva winder showed no difference in appearance. Therefore reverse cable bending during coil winding did not produce additional effects.

Summary

- **Coil parts and insulation scheme has been well designed**
- **2 coils have been fabricated completely at both CERN and LARP and verified all the tooling and fabrication procedures. MQXFS coil 02 will tested in Mirror structure.**
- **We are capable to fabricate series of coils.**
- **We are preparing for scaling up to the long coil fabrication.**