FNAL Technological Choices; Cable Insulation and Coils

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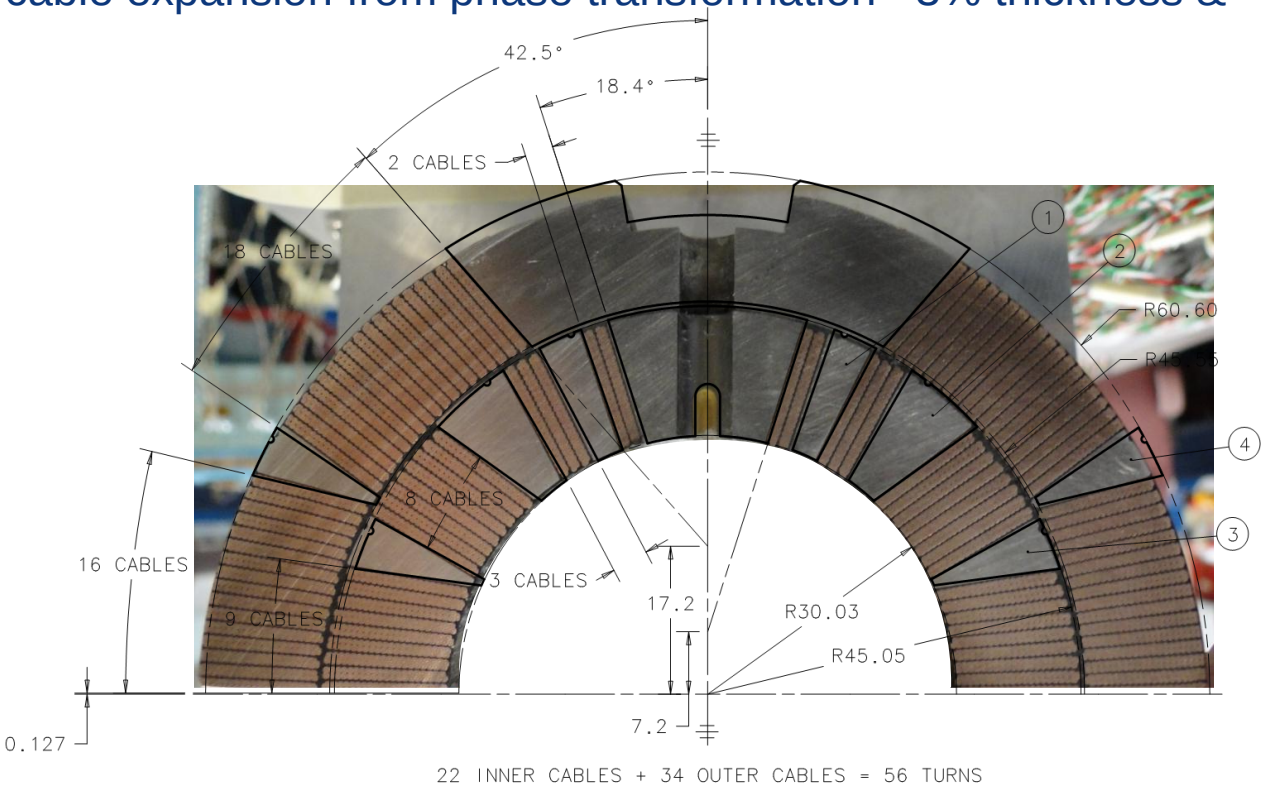
Outline

- Coil Parameters
- Cable insulation choices
- Coil Technology and Fabrication
- Coil size analysis
- Coil end part modifications
- Summary

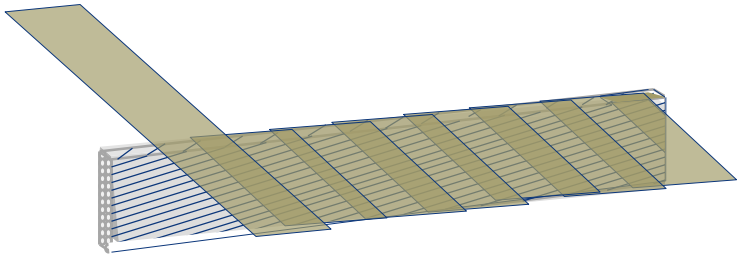
Coil Parameters

- The coil has:
  - 56 total turns, 22 inner, 34 outer
  - 3 inner layer wedges and 1 outer layer wedge, SS
  - SLS end parts, SS, provided by CERN
  - Splice-less layer jump transitions between the inner and outer coils.
  - Cable & wedge insulation 150 μm thick
  - Glued pole blocks
- Alignment notch in L2 pole pieces
- Nb_3Sn cable expansion from phase transformation ~3% thickness & ~1% width



Cable insulation choices

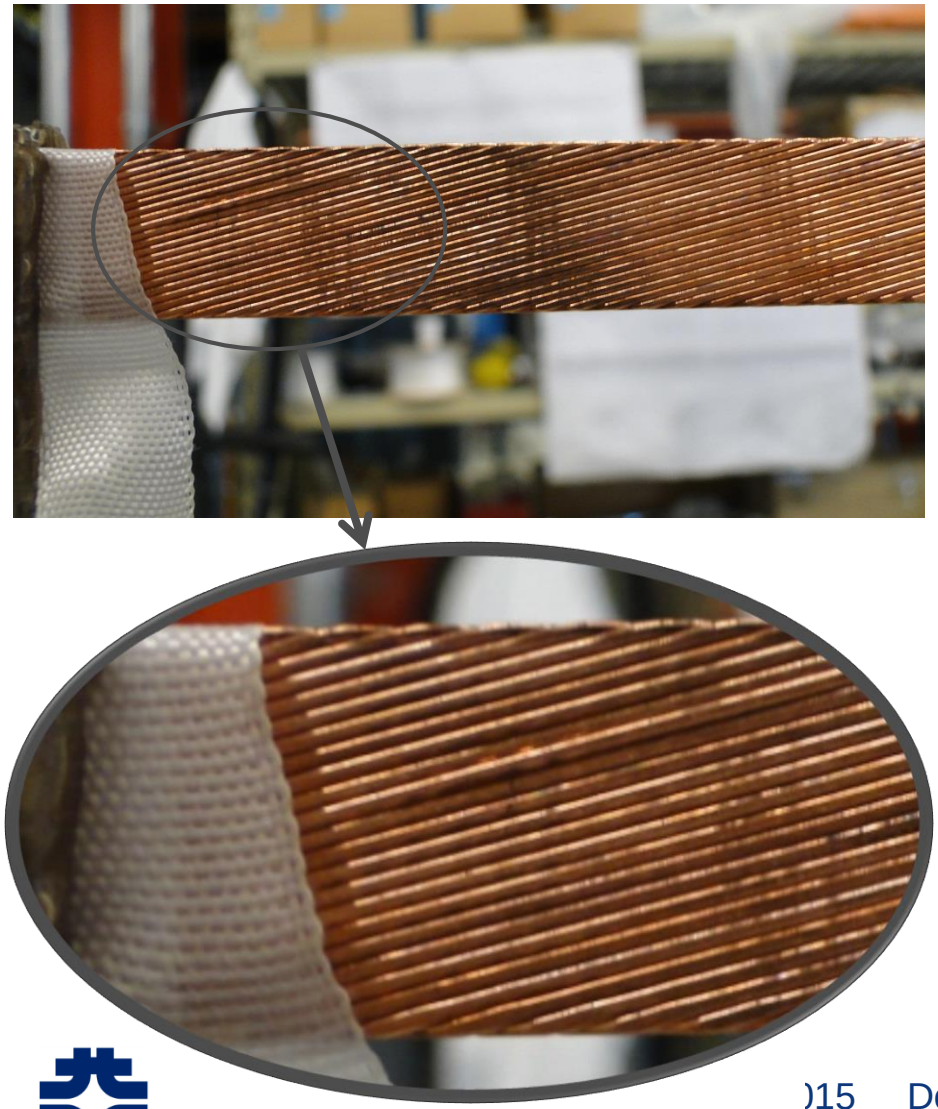
- Cable & wedge insulation half lap, using 75 μm thick E-glass

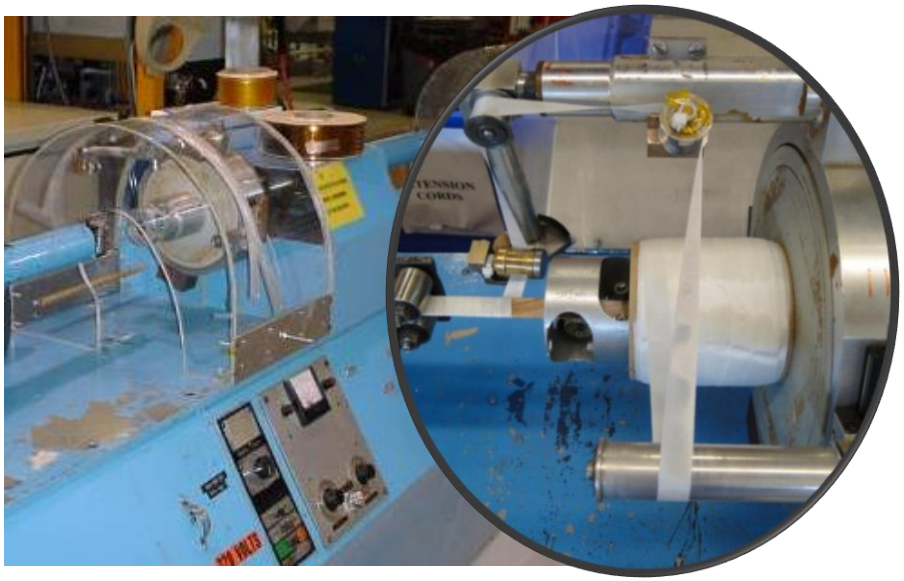


- Cable test stack program: mechanical, thermal and electrical testing of stacks at room temperature and 4.5 K using cables of various types.

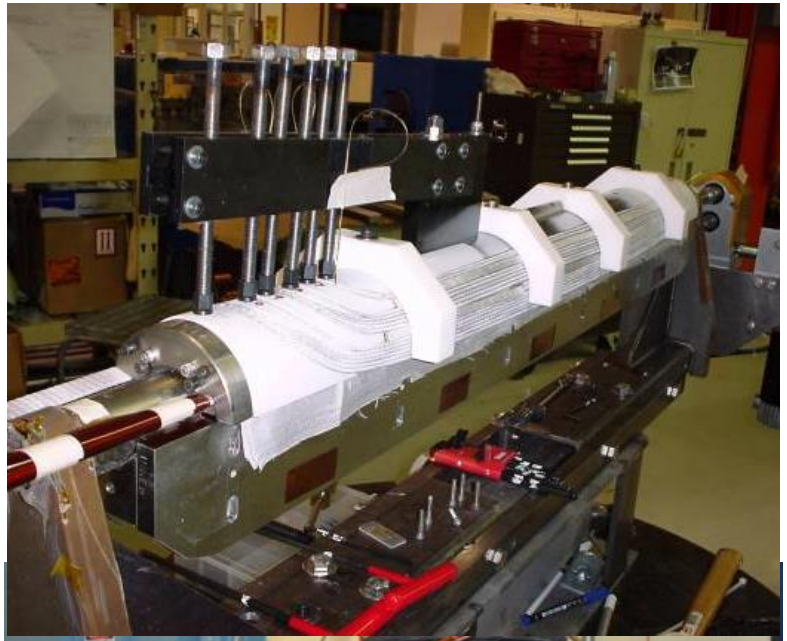
- The cable insulating line have been used in IB3 for all short models since the Tevatron.

Cable Mechanical Stability, MBH08





Coil Technology - Winding

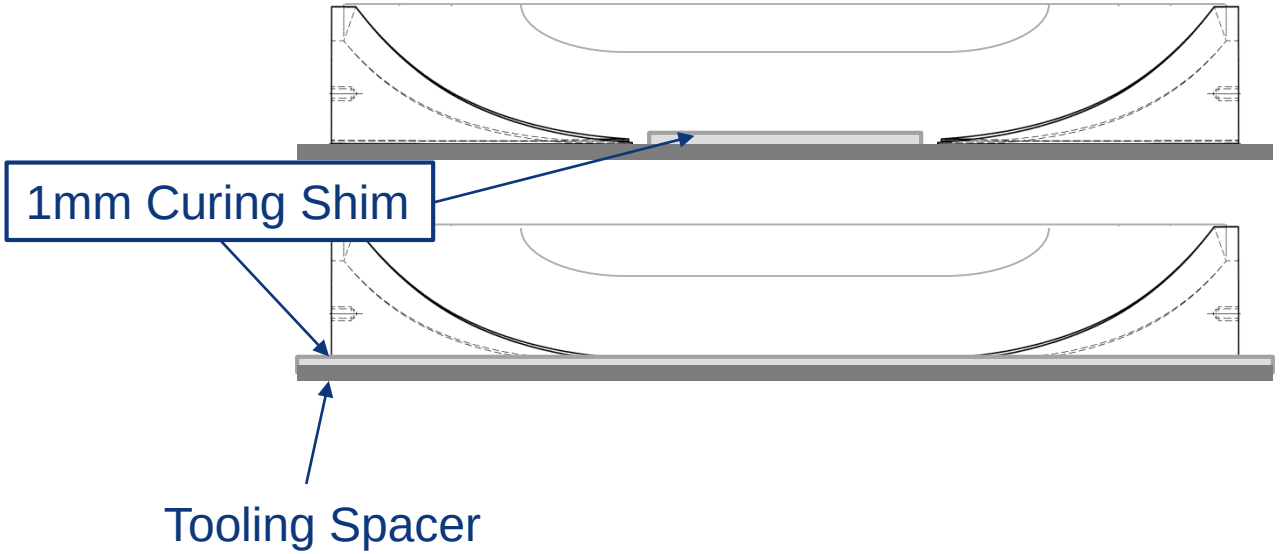


- Rotating winding table is used.
- Coil winding tensions is ~156 N.
- Pole gap is maintained during winding and curing.
- Stored coil winding tension is near zero prior to reaction.
- CTD-1202X ceramic binder used during winding of end turns to support cable to help prevent popped strands and cable collapse.
- Binder applied to entire coil prior to curing of each layer.
- Outer coil layer is wound on cured inner layer.
- Coil end part surface is leveled to cylindrical shape with use of fiberglass paste and cured
- Interlayer insulation is cylindrical shaped and cured before installation.

Coil Technology - Curing

- Cure cycle for coil with CTD-1202X ceramic binder is 150° C for 30 min. at ~27MPa.
- Straight part of the coil is compressed with 1 mm mid-plane curing shim. Shim size is approximate sum of cable expansion during reaction and used to pre-compress insulation with binder.
- Coil end parts and saddles area – without curing shims

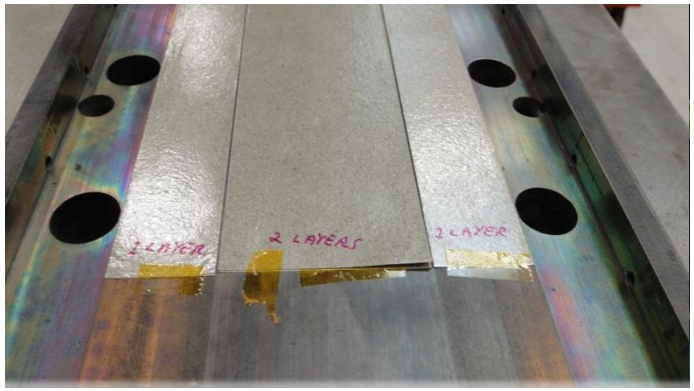
Curing Shim Change
End Part Modification



MBHSP01

MBHSP02

Coil Technology - Reaction



Coil preparation to reaction:

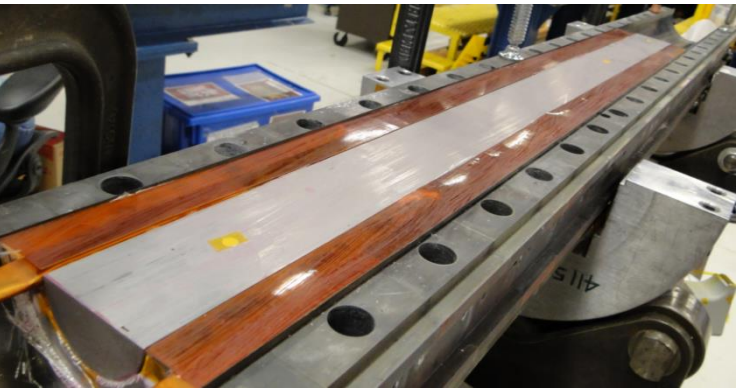
- Install two layers of 0.125 mm MIKA all around coil surfaces inside reaction fixture,
- Cured coil has smaller cross-section dimension than reaction fixture for free expansion and fixture must be completely closed by bolts.
- Coil leads are supported by slots of fixture.

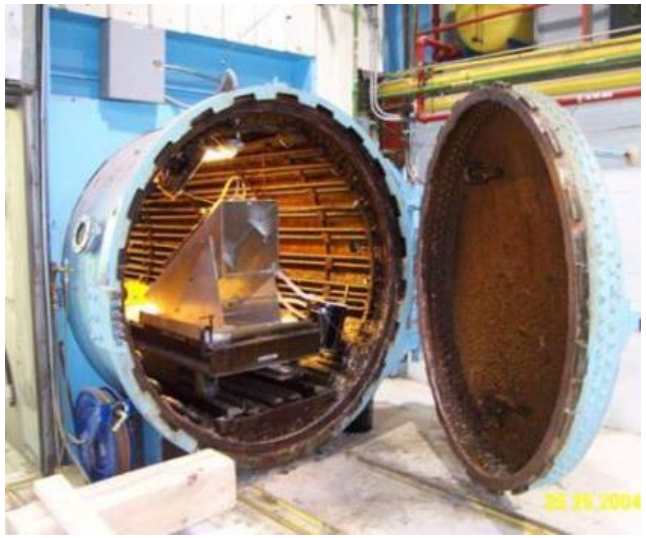
Reaction cycle is in an argon atmosphere and :

- at 210° C for 72 hours,
- at 400° C for 48 hours
- and 640° C for 48 hours.

The heat treatment lasts about 9 days including ramp up and cool down.

Coil Technology - Impregnation





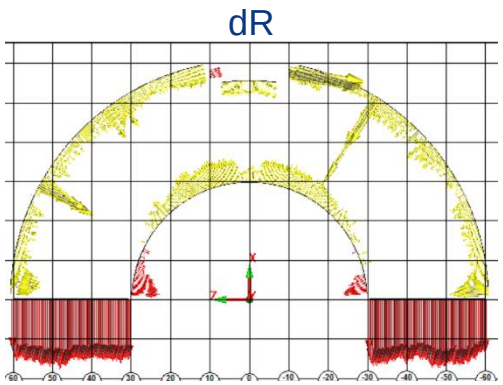
- Coil preparation to impregnation:
  - ✓ Splice NbTi leads to Coil leads and insulate them by 0.125 mm Kapton,
  - ✓ Splice voltage taps to coils accordantly,
  - ✓ Put strip heaters on outer surface of coil,
  - ✓ Put 0.125 mm fiberglass cloth on outer and inner coil surfaces,
  - ✓ Put 0.125 mm mold/released Kapton in midplane.
  - ✓ Mold release all part of impregnation fixture, close it with bolts and seal by O-rings with RTV.

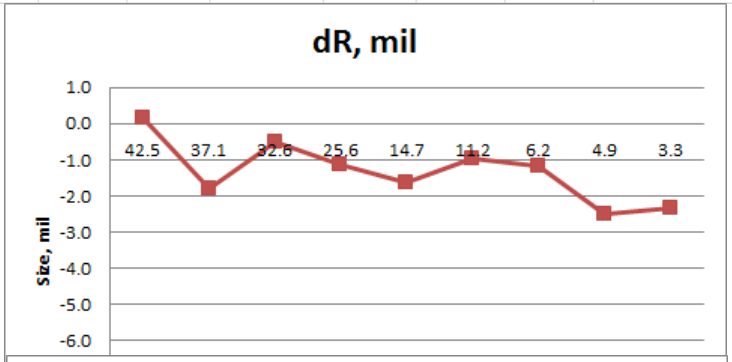
- Impregnation is with CTD101K and is done in the IB2 vacuum oven at 30-50 μm Hg with epoxy temperature of 60° C.

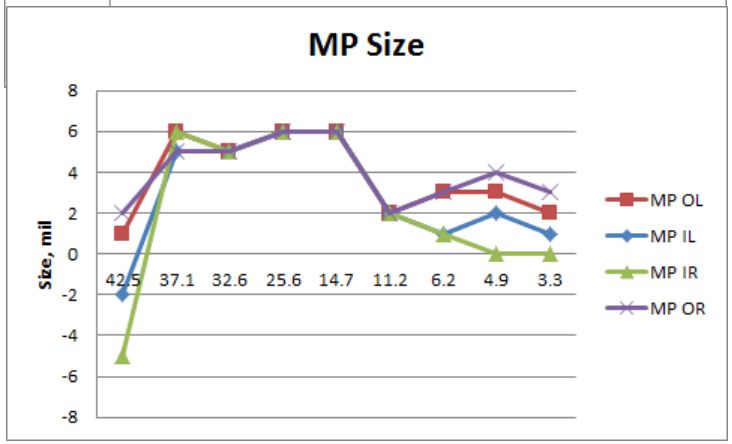
- Curing of the impregnated coil is done in a different oven at 125° C for 21 hours.

Coil Size Measurement by CMM

#11														
	QC Data	Rc	Raundnes:	Rd	dR, mm	dR, mil	MP OL	MP IL	MP IR	MP OR	L, mm	L, in	Size avr	dMP avr, mil
1	RE saddle	60.731	0.138	60.727	0.004	0.2	1	-2	-5	2	11.633	42.5	-0.8	-1
2	RE Pole	60.681	0.19	60.727	-0.046	-1.8	6	5	6	5	150.285	37.1	3.7	5.5
3	SS	60.714	0.119	60.727	-0.013	-0.5	5	5	5	5	264.125	32.6	4.5	5
4	SS	60.698	0.108	60.727	-0.029	-1.1	6	6	6	6	442.775	25.6	4.9	6
5	SS	60.686	0.28	60.727	-0.041	-1.6	6	6	6	6	720.08	14.7	4.4	6
6	LE Pole	60.702	0.256	60.727	-0.025	-1.0	2	2	2	2	807.611	11.2	1.0	2
7	LE saddle	60.697	0.11	60.727	-0.03	-1.2	3	1	1	3	935.475	6.2	0.8	2
8	SP	60.664	0.092	60.727	-0.063	-2.5	3	2	0	4	966.981	4.9	-0.2	2.25
9	SP	60.668	0.16	60.727	-0.059	-2.3	2	1	0	3	1007.994	3.3	-0.8	1.5





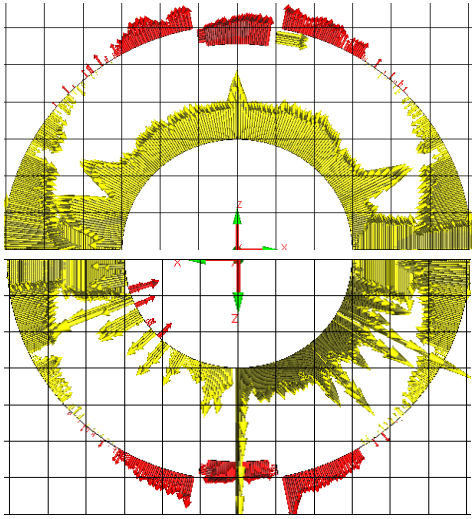


Size of Coil #11

Coil size analysis

MBHSP01

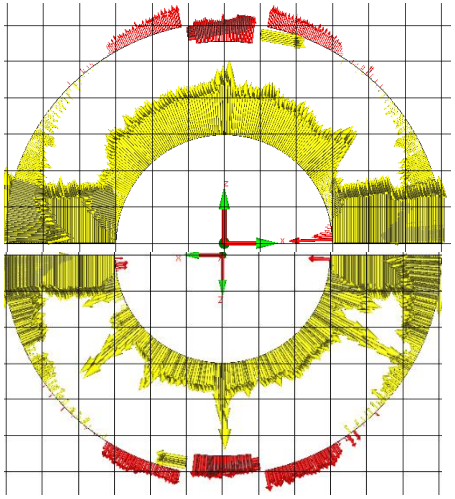
MBH02
445 mm from RE



MBH03
435 mm from RE

MBHSP02

MBH05
479 mm from RE

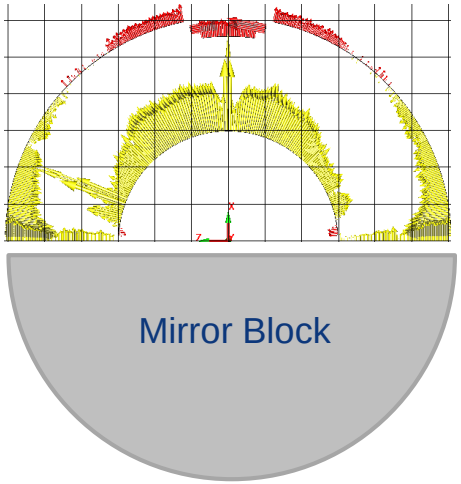


MBH07
467 mm from RE

(Old sizing)

MBHSM01

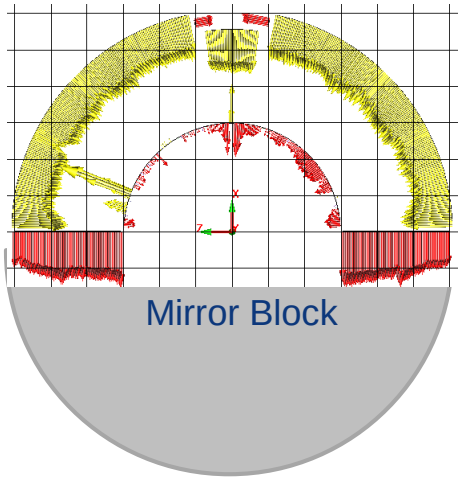
MBH08
447 mm from RE



(New sizing)

MBHSM01

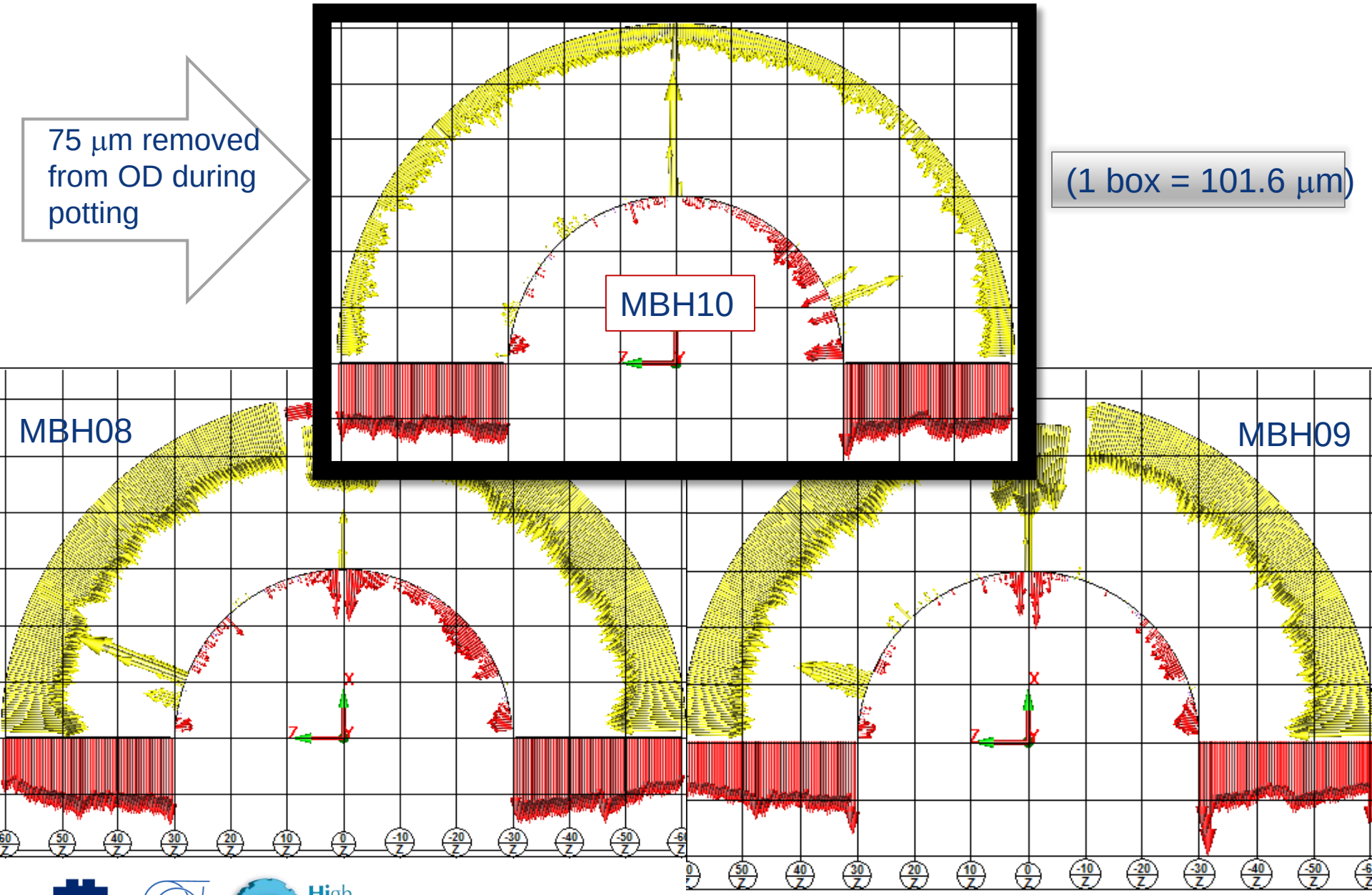
MBH08



(1 box = 101.6 μm)

Cross Section #4 at 447.026mm from RETURN END

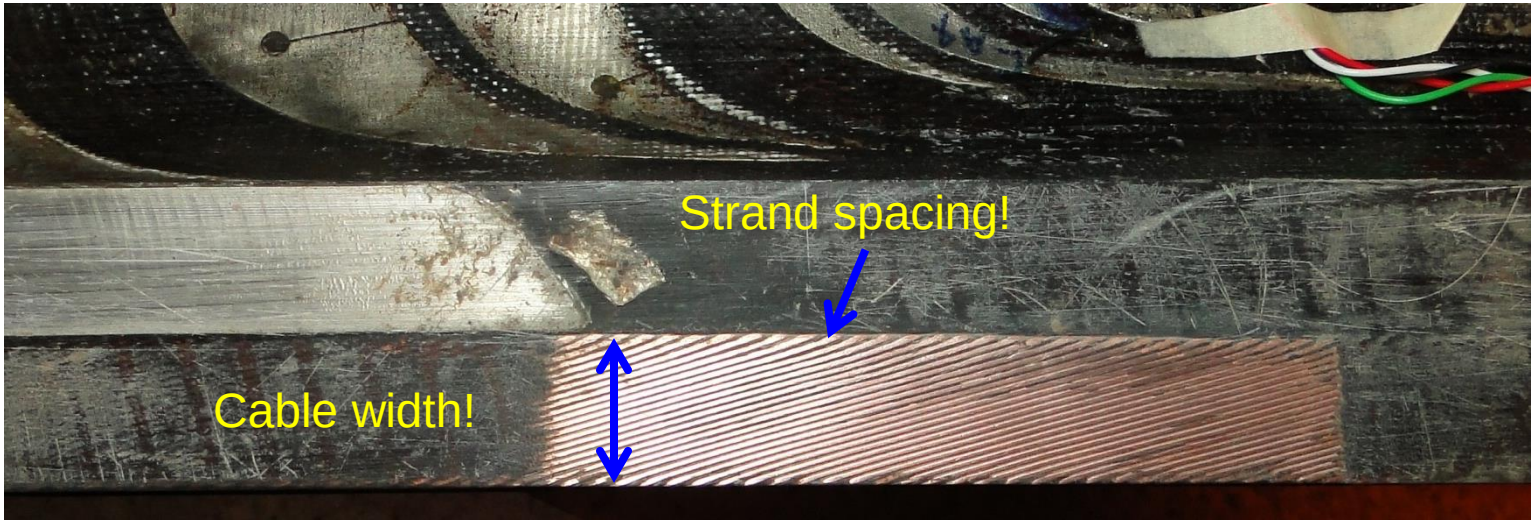
75 μm removed from OD during potting



(1 box = 101.6 μm)

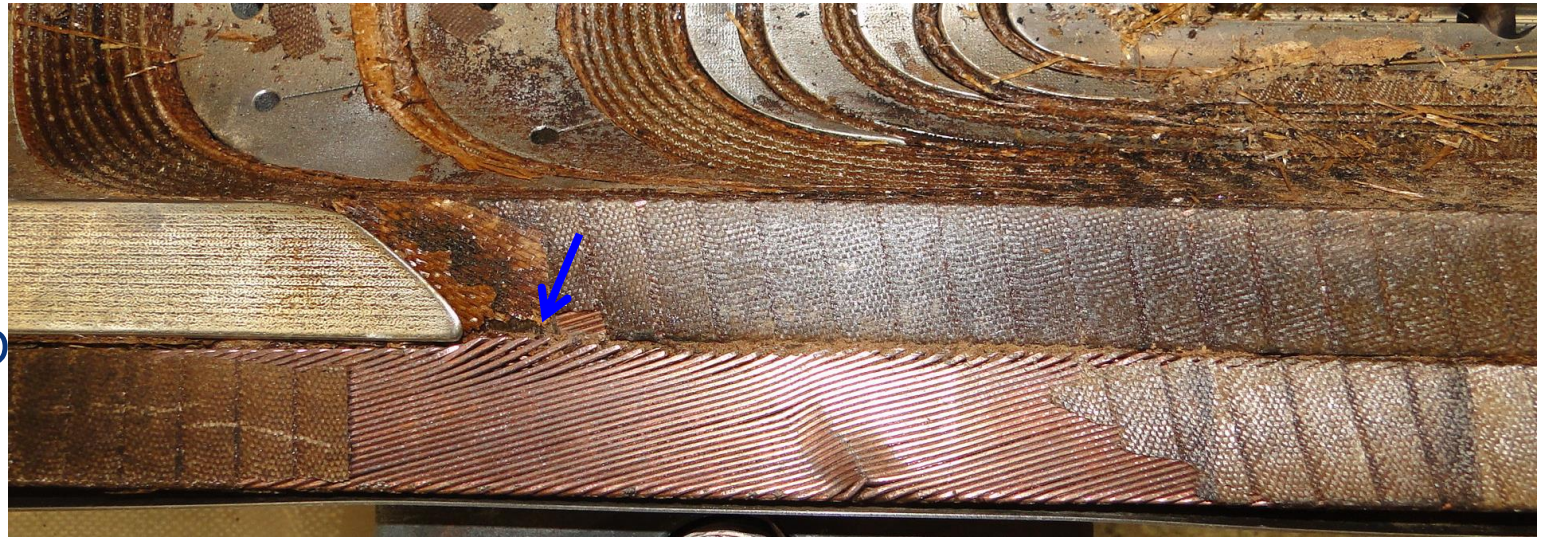
MBHSP01 Autopsy

MBH03 Used in MBHSP01. Strand spacing observed in MBH04.

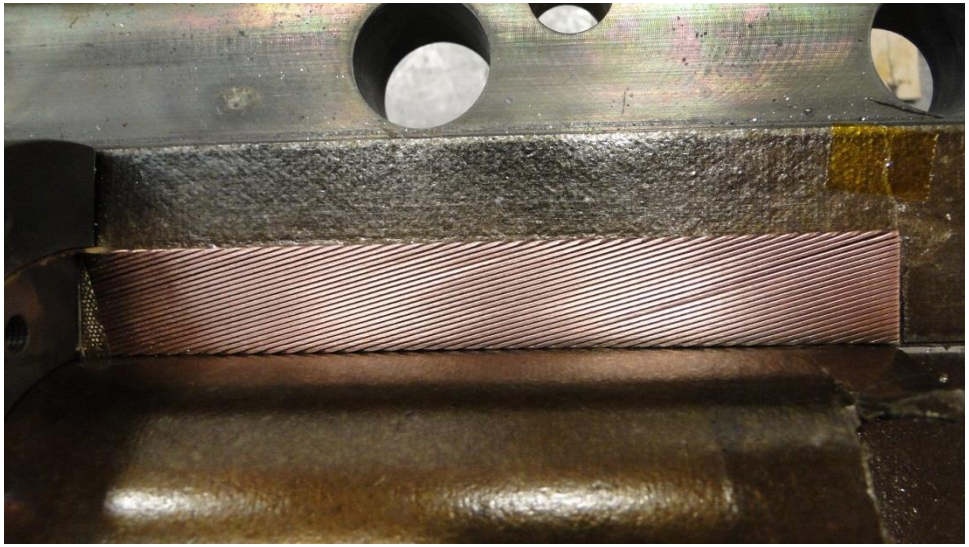


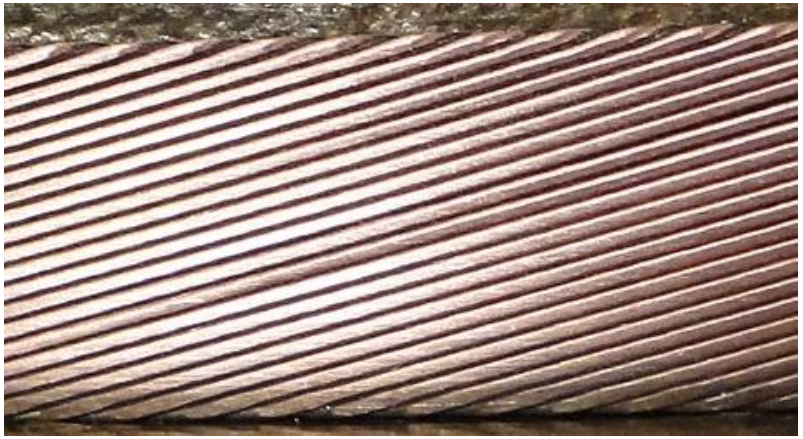
Reacted MBH04 (scrapped)

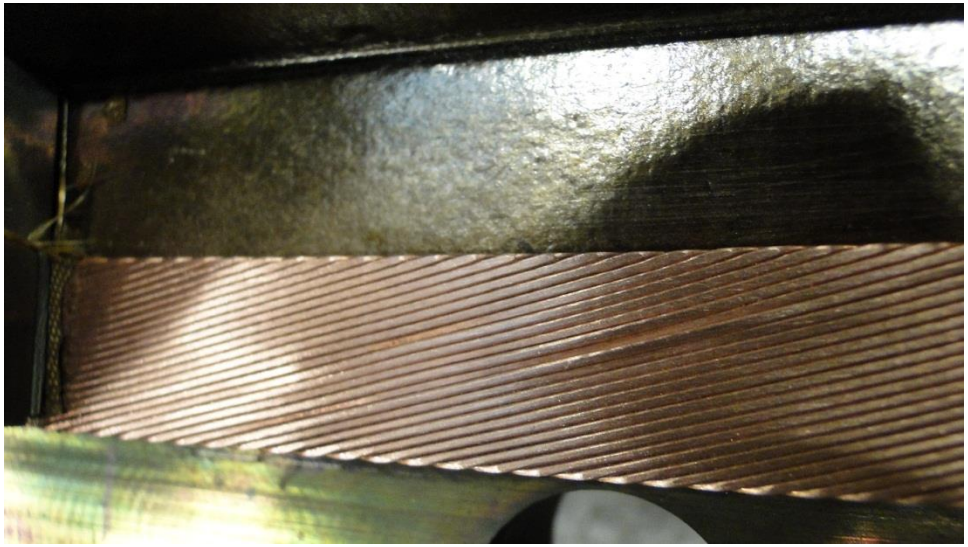
Later potted w/MATRIMID



Coil Leads, MBH08

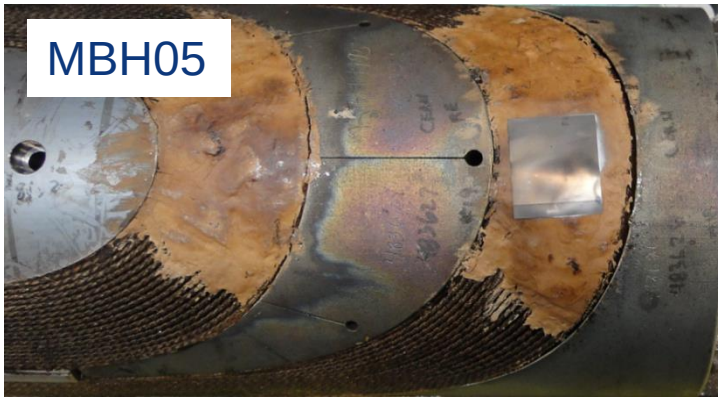






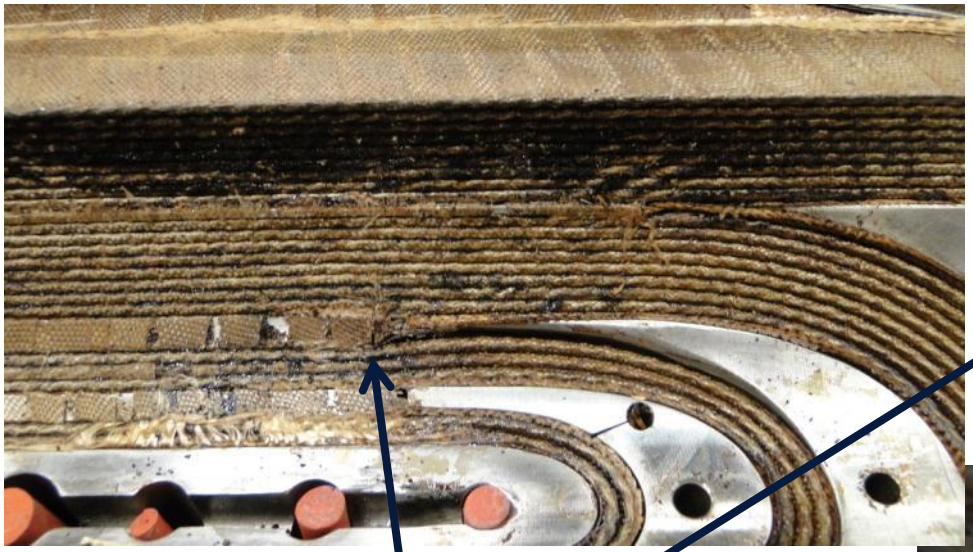
Coil End Parts Modifications

- MBH04 (2m) with 3mm gap after reaction, spacers not modified.
- MBH05,07 & 08 (1m) Spacer legs shortened by ~ 30 mm and modified for easy installation; gaps after reaction are reduced to ~ 1mm.
- All coil end part gaps are filled with a fiberglass before impregnation



Gaps between cable and end parts filled with S2-glass.

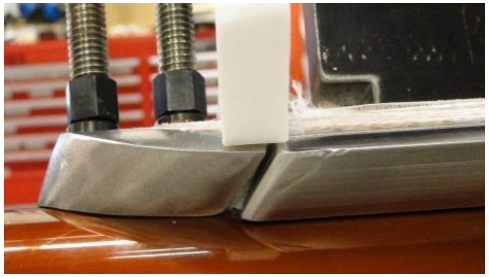
Coil Fabrication, MBH08



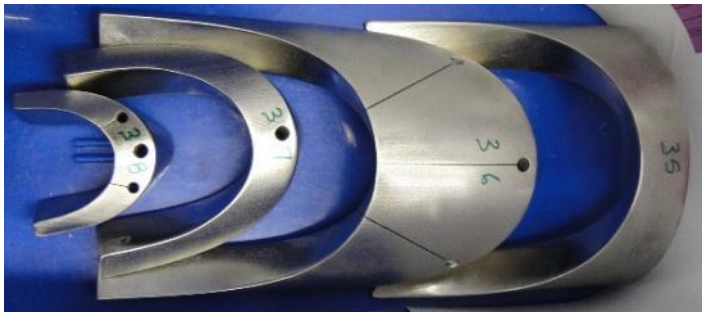
Stress Concentration

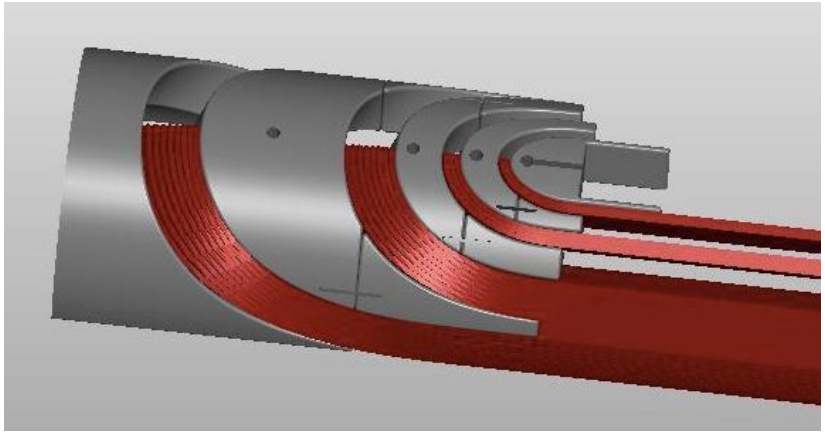
Modifications for Coils #9 & 10

- Coil end parts have been modified by shortening legs with an angle; (minimizing spacer machining for installation)
- Modified wedges were cut to the corresponding spacer angle too



End Part Designs for MBH11-15





CERN's Flexible Leg Design

Coil Fabrication MBH11-12

- Use tooling end saddles for curing
  → use nominal design saddle for reaction
- Add ceramic binder for each end turn
  → added cable stability
- Use flexible leg end parts with holes
  → minimizes end part modifications
  → improved cable support
  → lower effective end part modulus
- Increase impregnation radial space by 75 μm
  → increased coil radius by ~60 μm
- Continue with shimming react/impreg tooling
  → increases tooling volume for coil

Summary

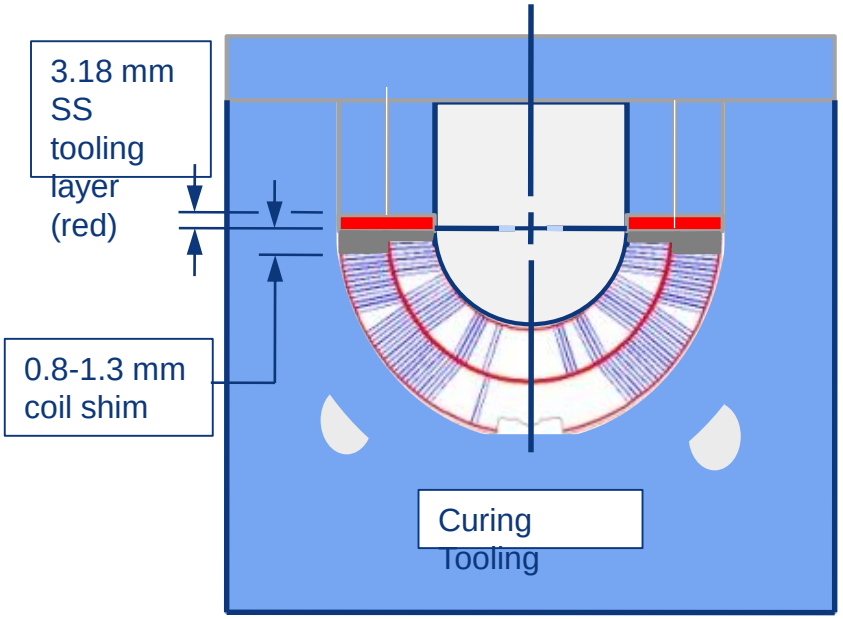
- 10 magnet coils have been fabricated (2x 2 m, 8x 1 m)
- Coil fabrication improvements:
  - Process
  - End parts
- All fabrication technologies & results shared with our collaboration partners

APPENDIX

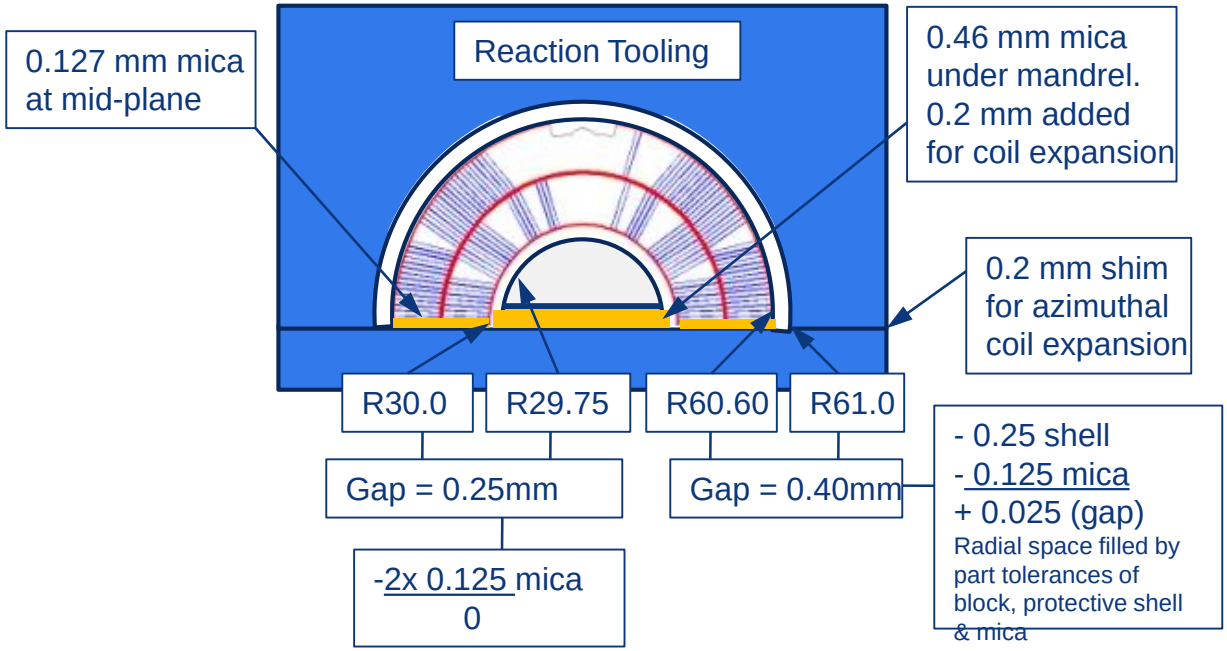
- Coil Curing
- Reaction
- Impregnation

Coil Curing

- Layer 1 = 21 turns
- Layer 2 = 35 turns
- Winding cable mid-thickness = 1.269 mm
- Mid-thickness expansion during reaction = 3%
- 3% of 1.269 is 0.038
- 21 turns = 0.8 mm shim
- 35 turns = 1.3 mm shim



Reaction Tooling



Impregnation Tooling