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Bi-2212 Cosine-Theta Insert Update

HTS Inserts meeting

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Outline

01

Design Optimization & Geometry

02

Magnetic and Mechanical Analysis

03

What so far: Winding Process

04

What so far: Reaction Process

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Timeline and Plan

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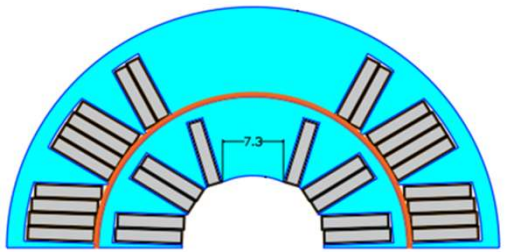
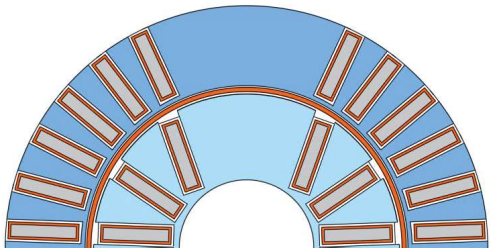
Design Optimization & Geometry

1. Design Optimization
2. Magnetic & Mechanical Analysis
3. What so far: Winding Process
4. What so far: Reaction Process
5. Plan Timeline

Design Optimization in ROXIE

- Brief comparison of the two versions of the Bi-2212 insert.
- The geometry optimization was performed in ROXIE varying the axial and transversal cross-sections.

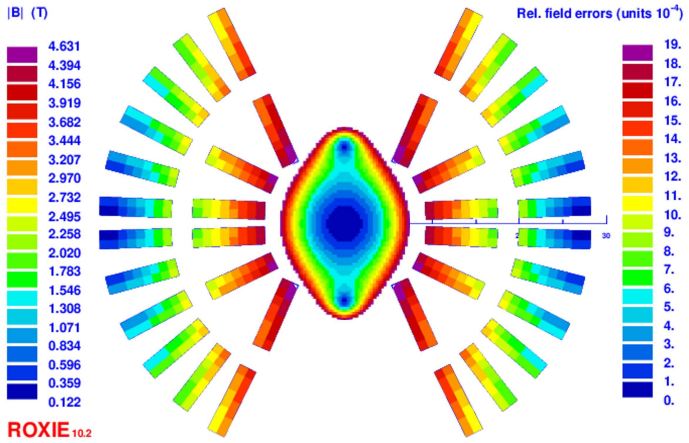




- 5 turns IL
  10 turns OL
- Winding from inside
- Bending radius ≥ 4mm
- Two separate Bi-2212 RCs

- 3 turns IL (ID:15.5 mm)
  6 turns OL (OD=57.6 mm)
- Winding from outside
- Bending radius ≥ 5.5mm
- One single Bi-2212 RC

- Trade-off between bending radius and “windability” with peak filed.

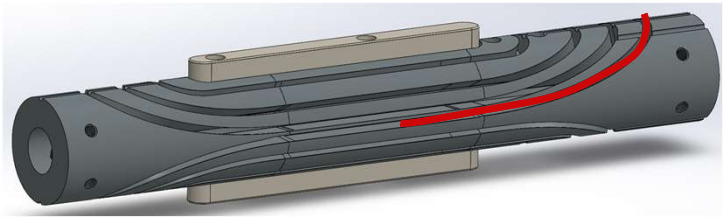


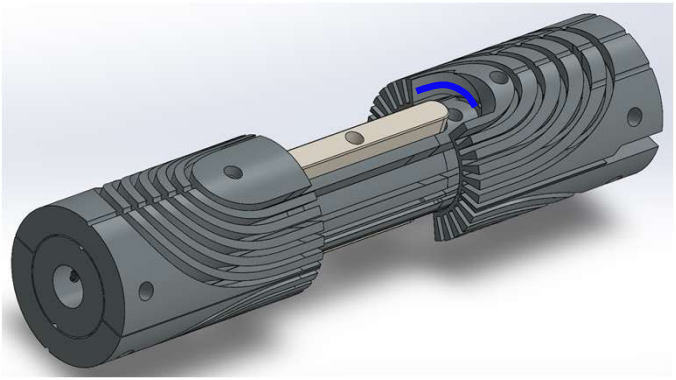
BI-2212 INSERT PARAMETERS AT 4.2 K

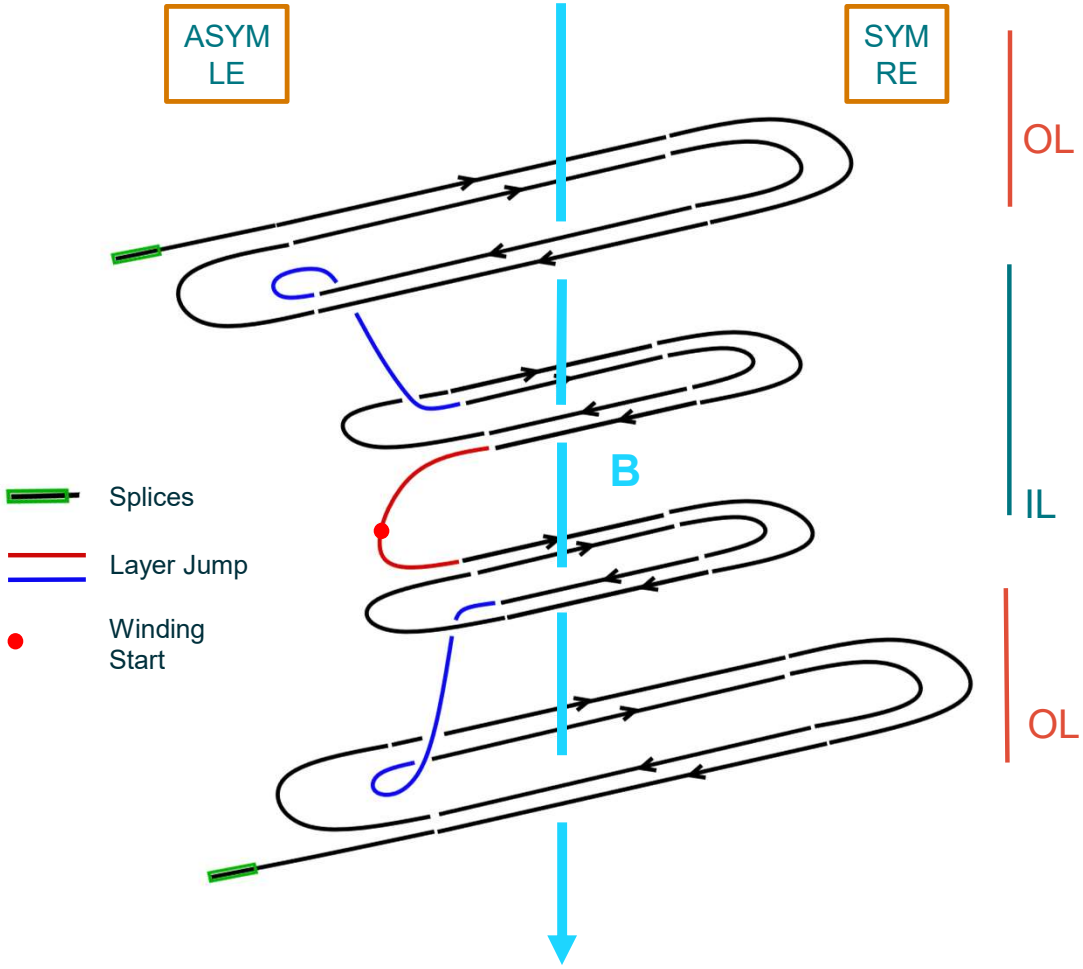
	HTS Insert	
	Inner coil	**Outer coil**
Bore field [T]	4.36	
Peak field [T]	4.85	3.95
Current [kA]	10.0	
Inductance [mH/m]	0.21	
Stored Energy @10 kA [kJ/m]	10.7	
F_r [MN/m]	0.07	0.04
F_a [MN/m]	-0.06	-0.09
Number of turns	3	6

Turns Logic & Geometry

- The schematic view of the path the Bi-2212 Rutherford cable must perform.
- Keys, pins and screws hold the pieces together.







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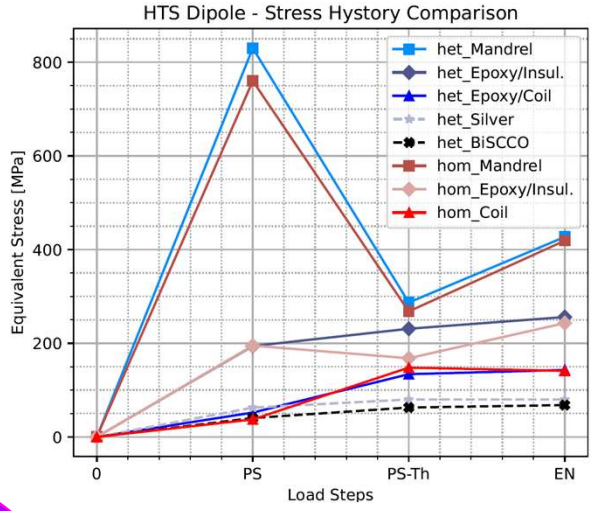
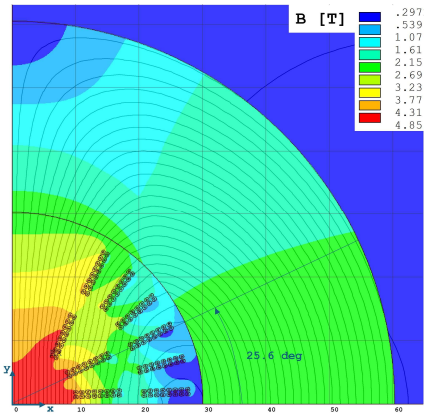
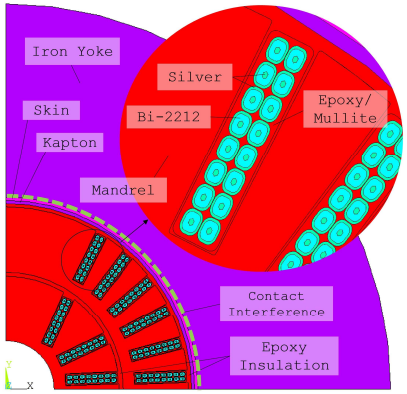
Magnetic and Mechanical Analysis

2-Layer Magnetic & Mechanical Analysis

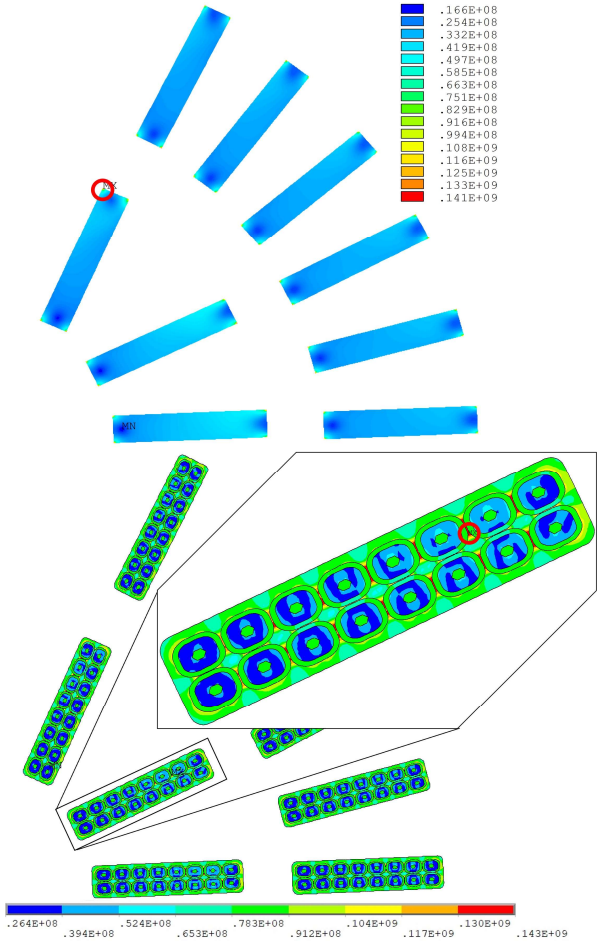
- The magnetic and mechanical analysis were performed in ANSYS APDL. Homogeneous and Heterogeneous models.
- Three load-steps: pre-stress, cool-down and energization (plot in each component)







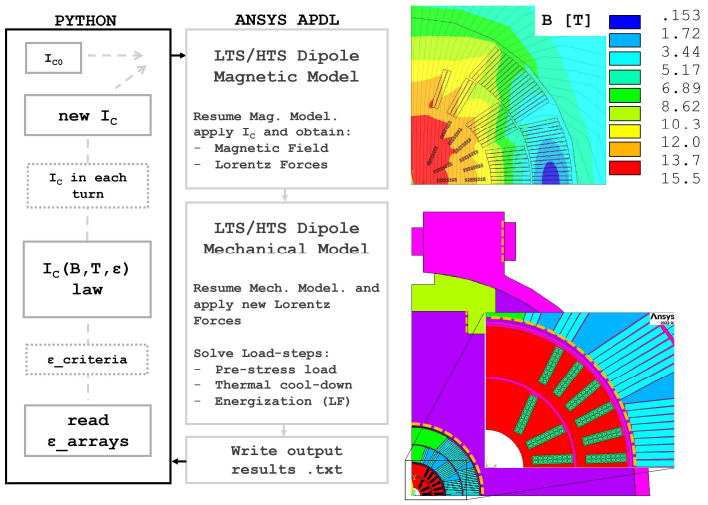
- Max eqv. Von Mises stress in the hom. model: 141 MPa
- Max eqv. Von Mises stress in the het. model with SP = 0.7:
  in Bi-2212 ~ 68 MPa
  in Silver ~ 80 MPa (p)
  in Epoxy ~ 143 MPa

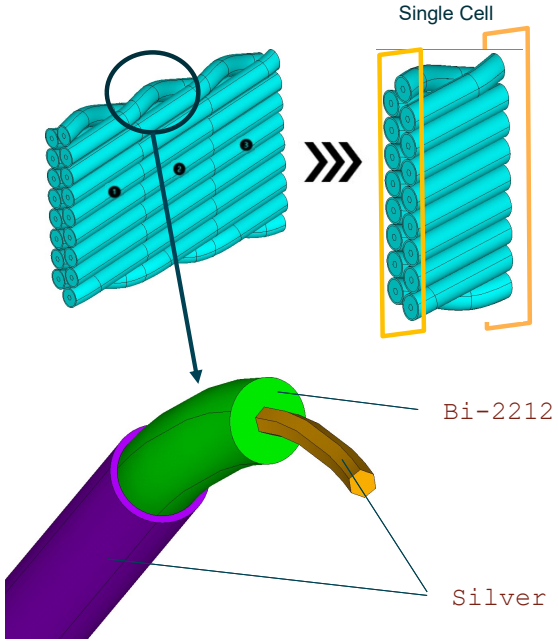


More details at: https://doi.org/10.1088/1361-6668/adb340

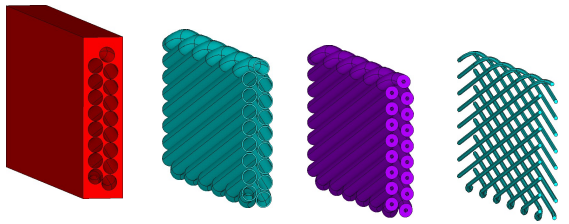
4-Layer Hybrid Magnet – Current Degradation

- The magnetic and mechanical analyses of the 4-layer hybrid magnet connected with Python to compute current degradation.
- Ten-stack analysis to validate the material properties can be improved with additional Bi-2212 Rutherford cable measurements and compared with the 3D stack ANSYS model. After mechanical measurements, microscopic imaging and ML techniques will allow further investigation of deformations and defects in the compressed Bi-2212 samples.





To define material properties, isolated and selected **4 components**:



More details at: https://doi.org/10.1109/tasc.2024.3502578

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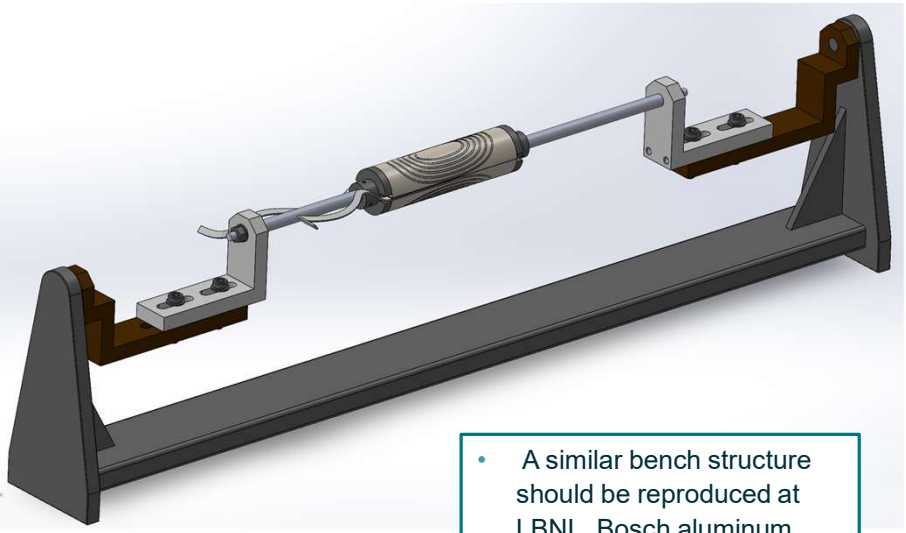
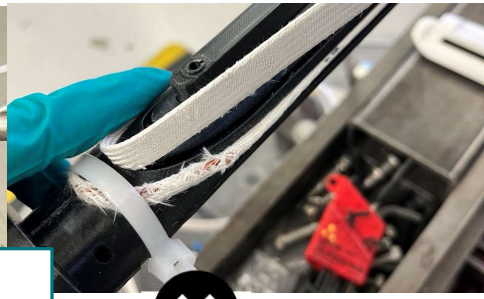
What so far: Winding Process

Structure and Winding Attempts

- Bi-2212 Rutherford cable was used only for small turns, not yet for the entire coil. Attempt with NbTi and Nb_3Sn.
- The winding process starts from the center of the cable in the middle of the inner-layer jump (red spot).



- A similar bench structure should be reproduced at LBNL. Bosch aluminum frames might be a solution.



- Nb_3Sn cable was bigger than the nominal dimension. Insulation broke due to zip ties.

- NbTi winding was challenging but successful. the cable is hard to bend and plastify. Frequent stop to wrap insulation.

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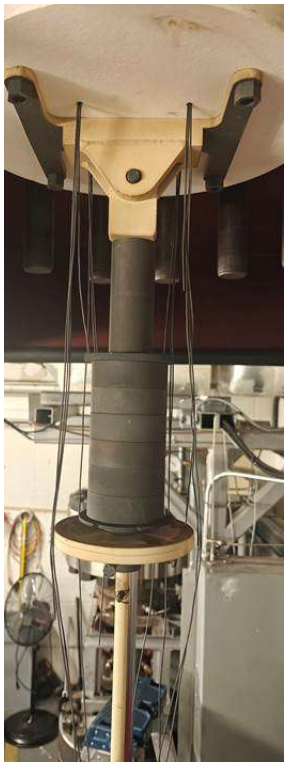
What so far: Reaction Process

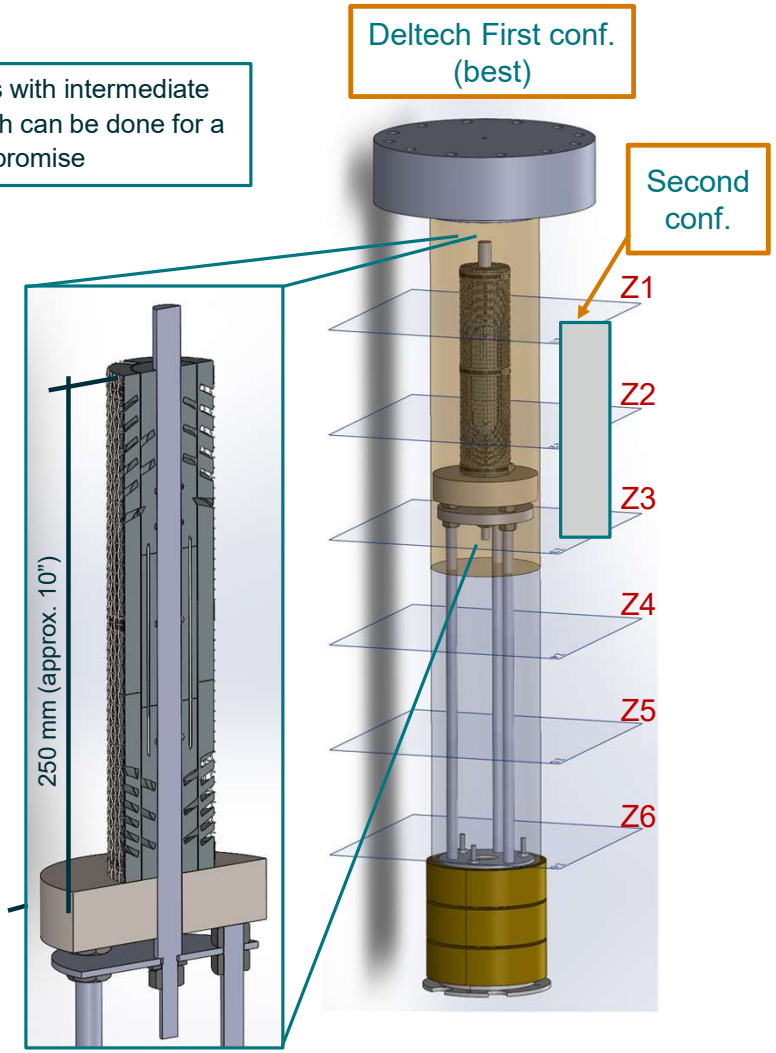
Reaction Process Planning

- Both Deltech and Renegade are online. For Deltech, rods are on the shelf for two configurations (two different lengths).
- Deltech may not be available for the entire summer
- Renegade has a 1/2“ central rod to sustain the whole insert. No need for tooling procurement.
- Pre-oxidation, furnace calibration and temperature check must be done before winding, all at once in one of the available furnace.

Inconel or aluminum bronze splice sustainers must be procured before conductor winding.



- Rods with intermediate length can be done for a compromise



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Insert Plan Timeline

1. Design Optimization
2. Magnetic & Mechanical Analysis
3. What so far: Winding Process
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Bi-2212 Insert Timeline Plan

Project	Duration	Resources	Time																
Bi-2212 Insert Realization Process (OPT 3)	weeks	$/work	2024			2025													
			oct	nov	dec	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec	jan	
Tasks			FNAL			LBNL													
Mandrel Machining																			
Mandrel QC Measurements	Done		x	X															
Finilize Mandrel - Post Machining	Ongoing				x														
Shipment	3-4 w					x													
Winding Process																			
Winding Tooling Procurement and Setup (TiO2 slurry)	Ongoing						x												
Mandrel pre-oxidation	2 w						x												
Cable and Instrumentation (Voltage Tap, Acustic Sensors, Optic Fibers) Check and Preparation	4 w							x											
Coil Winding	4 w							x											
Reaction Process																			
Shipment	3-4 w								x										
Furnace Availability:	3-4 months									x	x	x	x						
Reaction Tooling Procurement and Assembly	2-4 w								x	x									
Shipment	3-4 w										x								
Mellon Furnace 4 days process as burnout operation	1 w										x								
Calibration & Reaction in Deltech Furnace	2 w											x							
Post-reaction work	1 w											x							
Shipment	3-4 w												x						
Impregnation with Telene																			
Insert Impregnation (TELENE)	3 w													x					
Bi-2212 Dipole Insert Test																			
Testing Tooling Setup and Availability, Instrumentation	4 w														x				
Subscale Insert Testing Assembly	1 w															x			

Thank You

Back up – 3D Printing and Post-machining at FNAL

Inconel-718 mandrels realization process:

- 3D printing with laser powder bed fusion technology (LPBF).
- Annealing and aging post-processing
- Excess material removed with lathe machining (1 week sharp edge removal)
- EDM to split in half along the length
- Final post-machining modifications:
  -Update keys hollows in all 4 layers for torque resistance (optional)
  -Splices holders
  -Inconel-718 keys, pins and screws