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Nb_3Sn cos-theta IR magnets with stress management

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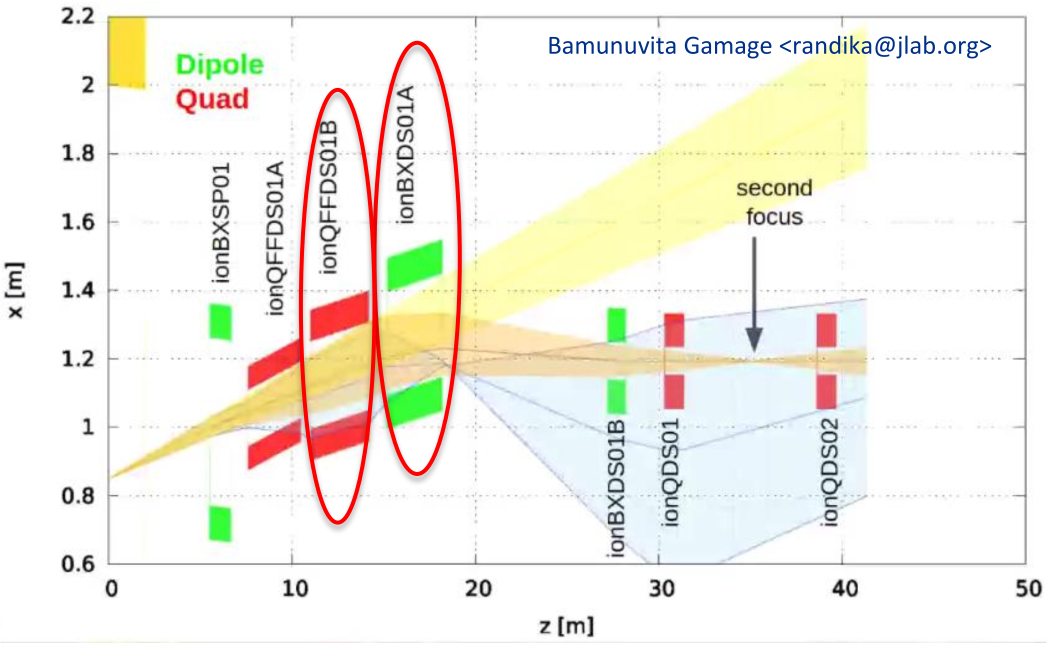
TRIUMF 2021 EIC Accelerator Partnership Workshop

26 - 29 October 2021

2^{nd} IR layout and Nb_3Sn IR magnet parameters



Element	Type	B, T	L, m	ID, mm	Beam pipe, mm	He channel, mm	Coil ID, mm
QFFDS01A	Q	-7.83	2.900	164	3	2	174
QFFDS01B	Q	9.10	3.200	256	3	2	266
BXDS01A	D	8.47	3.000	300.0	3	2	310
BXDS01B	D	-5.24	1.000	110.0	3	2	120

Presentation plan:

- **Part 1**. Magnet feasibility and SM justification for Nb_3Sn D and Q magnets
- **Part 2**. Status of SMCT technology development by US-MDP at Fermilab
- Conclusion

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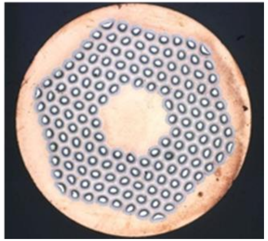
Part 1.

Magnet feasibility and Stress Management (SM) justification.

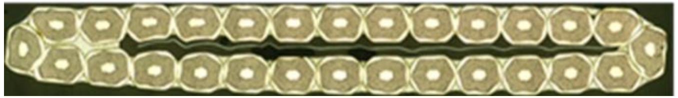
Nb_3Sn wires and cables

- **Nb_3Sn composite wire**
  - IT (RRP)
  - OD=1.0 mm
  - Cu matrix, D_{eff}~23-85 mcm
- **Rutherford cable**
  - N<40-42 (max 60)
  - PF~85-87%
  - SS core
  - Cabling I_c degradation <5%
- **Properties**
  - SC after HT reaction, brittle
  - flux jumps, large M
  - I_c sensitivity to transverse P_{tr}
- **Nb_3Sn magnet technology**
  - W&R
  - coil stress and strain control during fabrication, assembly and operation

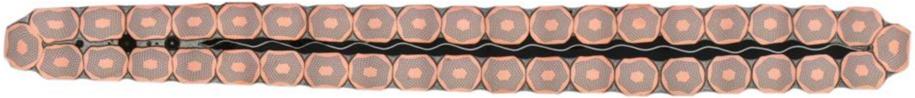


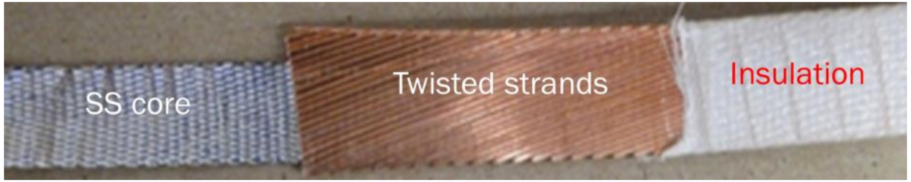
1 mm RRP150/169

28-strand cable with SS core

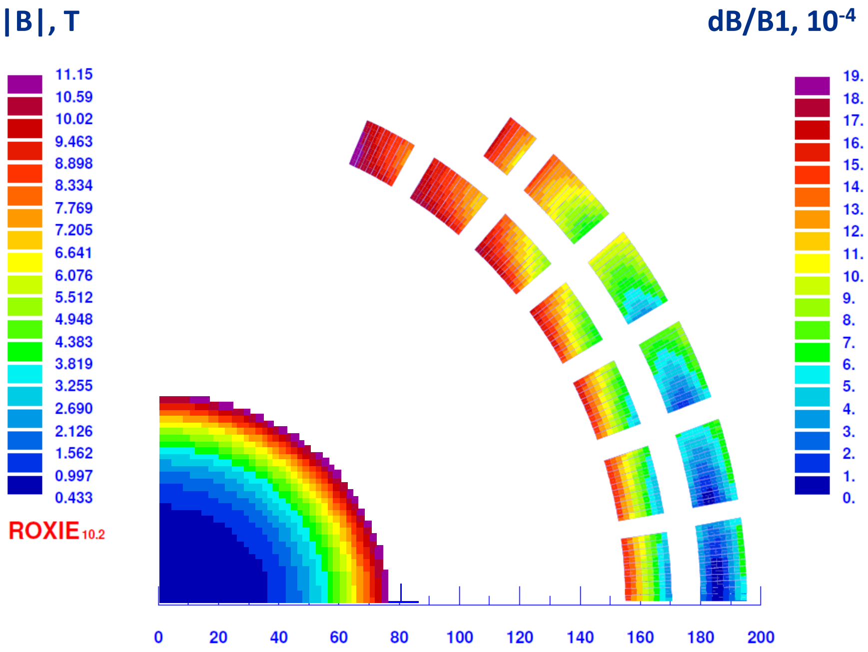


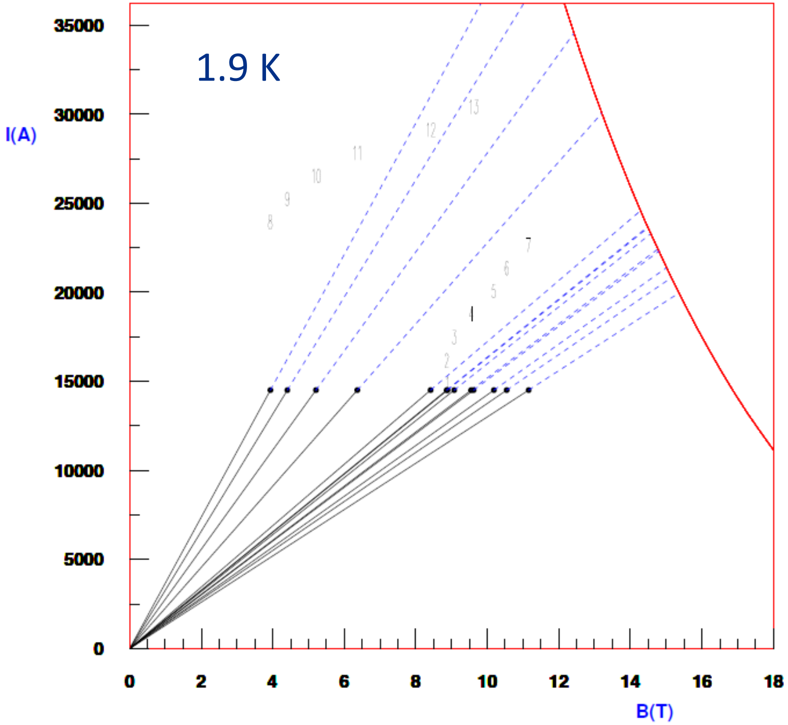
40-strand cable with SS core

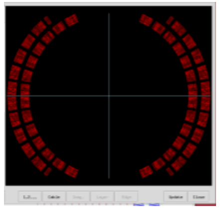




Dipole ionBXDS01A



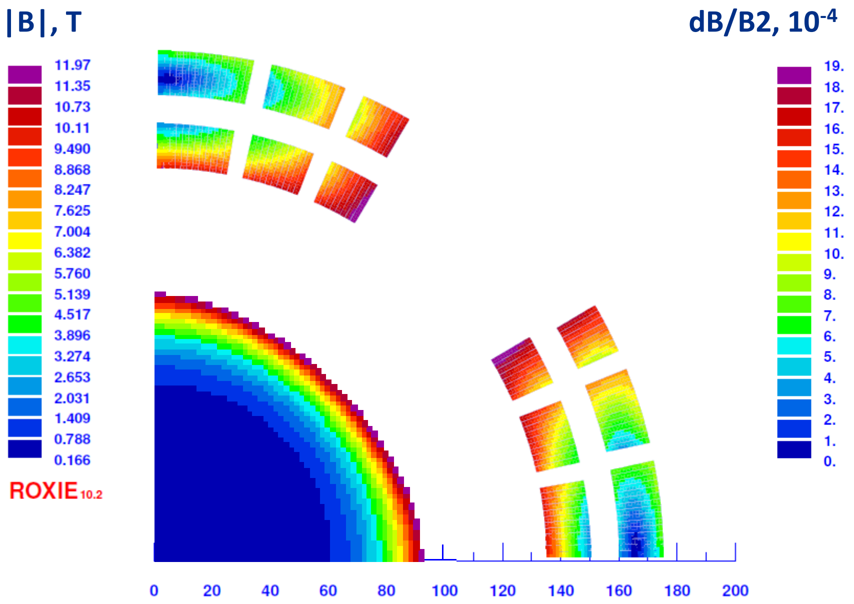


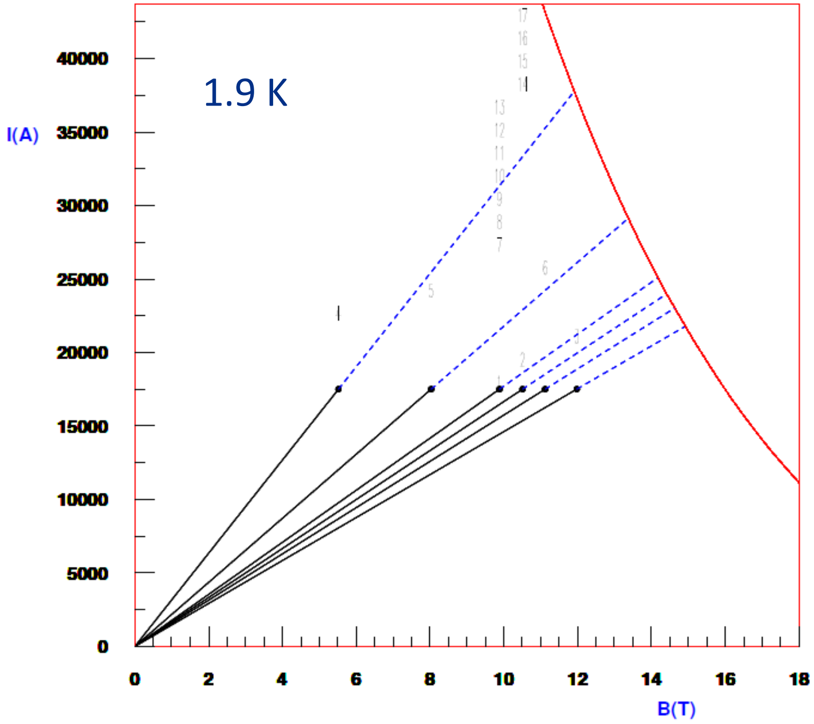


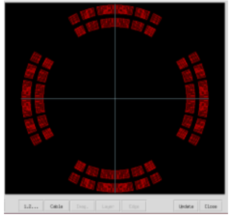
Dipole	Coil ID, mm	310
	Iron yoke ID, mm	200
	Coil current, kA	14.5
	Bore field $B0_{max}$, T	9.48
	Coil field B_{max}, T	11.47

Load line margin, %	72.6
Temperature margin @1.9K, K	6.02
Inductance, mH/m	11.5
Stored energy @B_{max}, MJ/m	1.21

Quadrupole ionQFFDS01B



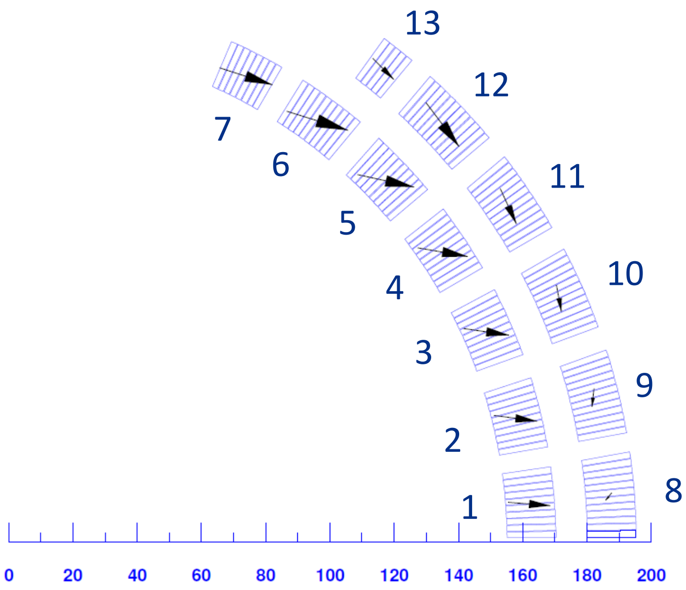




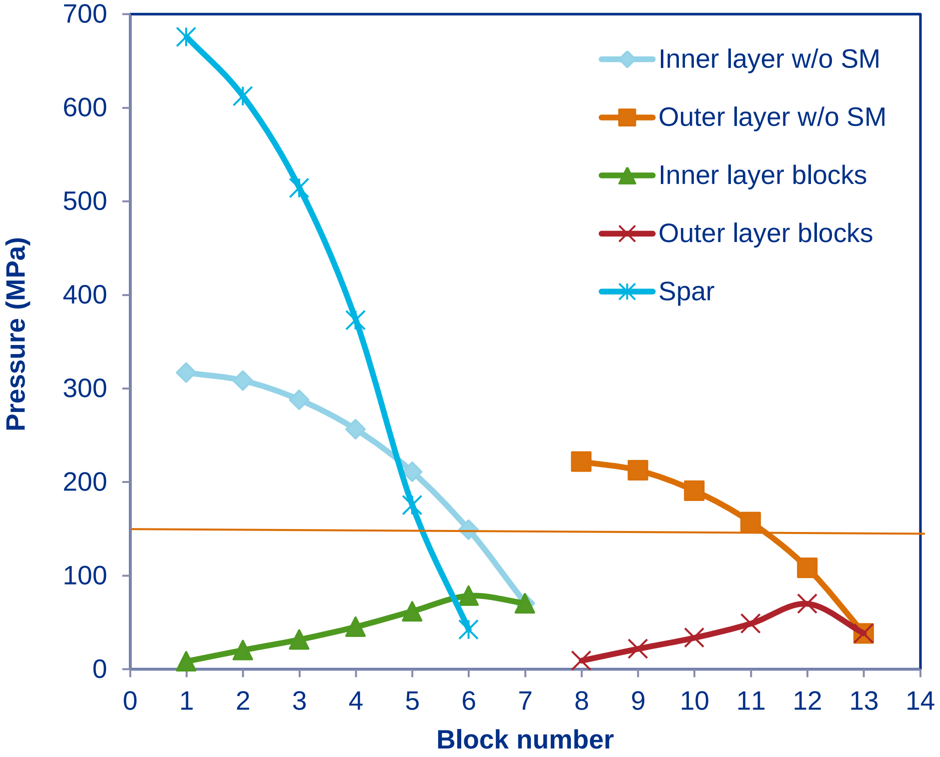
Quad	Coil ID, mm	270
	Iron yoke ID, mm	180
	Coil current, kA	17.5
	Field gradient G_{max}, T	74.39
	Coil field B_{max}, T	11.98

Load line margin, %	80.3
Temperature margin @1.9K, K	4.75
Inductance, mH/m	18.9
Stored energy @G_{max}, MJ/m	2.90

Dipole ionBXDS01A



Lorentz forces in the coil



Pressure in the coil

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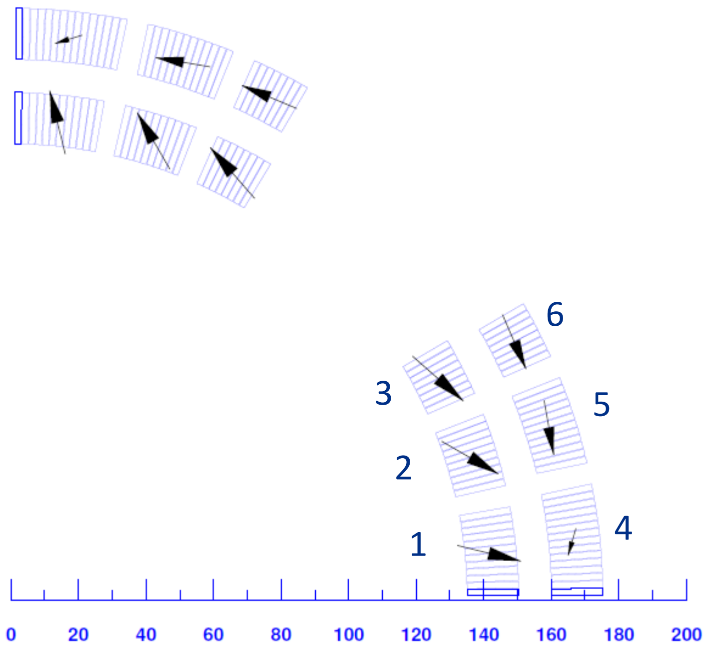
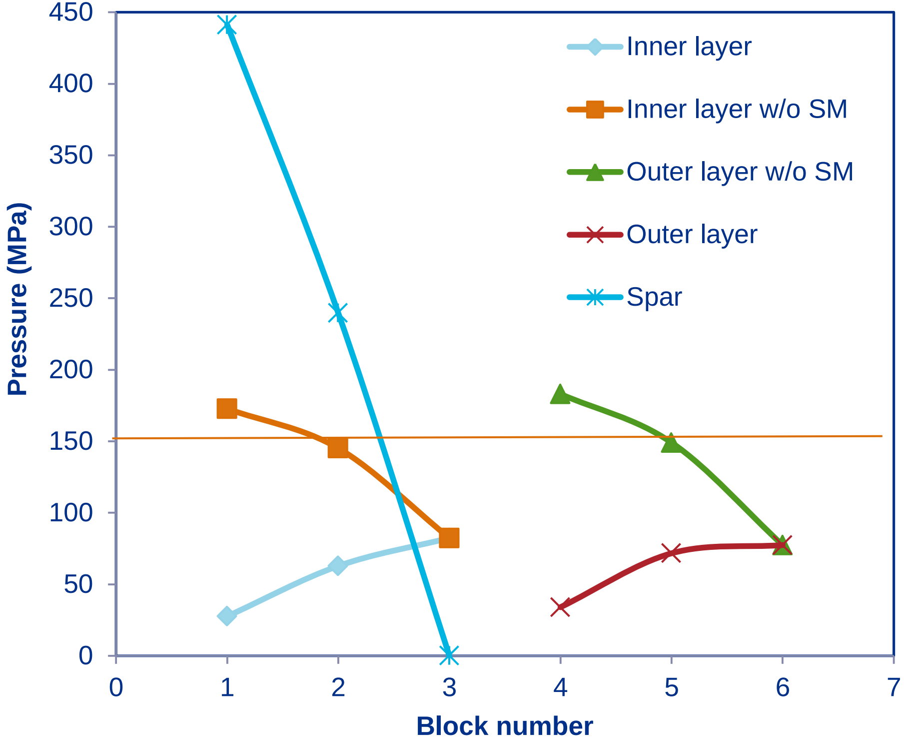
Quadrupole ionQFFDS01B



Lorentz forces in the coil



Pressure in the coil

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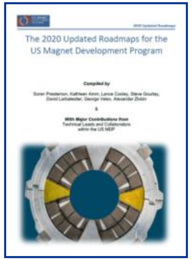
<u>Part 2.</u>

Status of the SMCT technology development by US-MDP at Fermilab.

US-MDP Nb_3Sn SMCT R&D goals and milestones

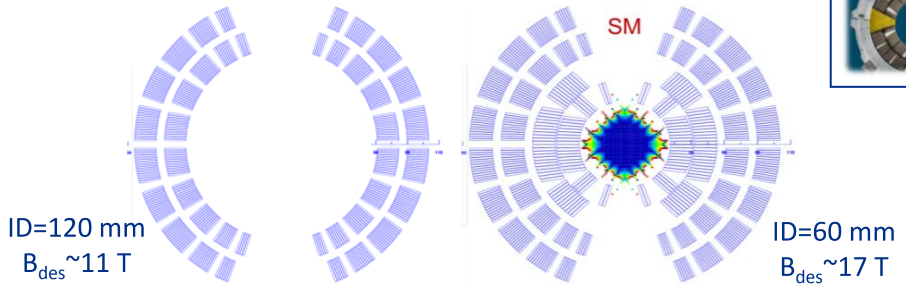


- **SMCT approach was proposed in 2017. In 2020 it is in US-MDP.**
- **SMCT R&D goals:**

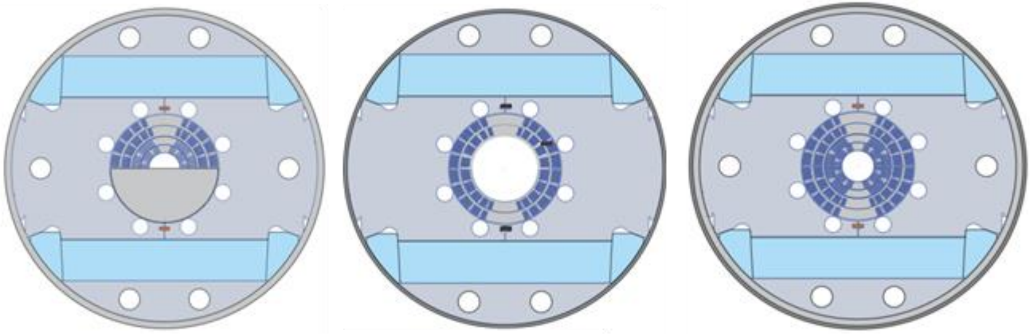
a) develop and demonstrate a new approach to manage radial and azimuthal stresses in brittle cos-theta coils, through the study and reduction of magnet training;

b) demonstrate a bore field up to 11 T at 1.9 K with 120-mm aperture in two-layer Nb_3Sn dipole magnets with stress-managed coils;

c) demonstrate up to 17 T at 1.9 K with a 60-mm aperture in a four-layer Nb_3Sn dipole magnet with stress-managed outer coils.

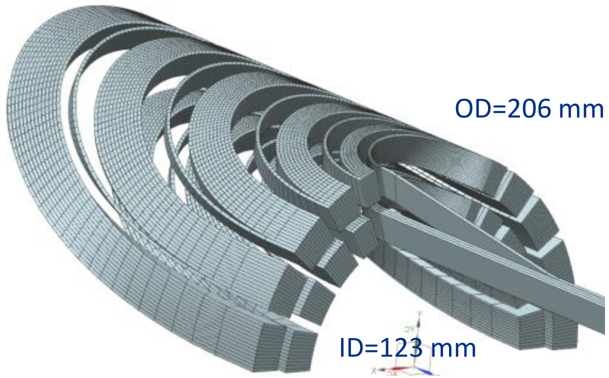


Cos-theta dipole coils with stress management (SMCT)

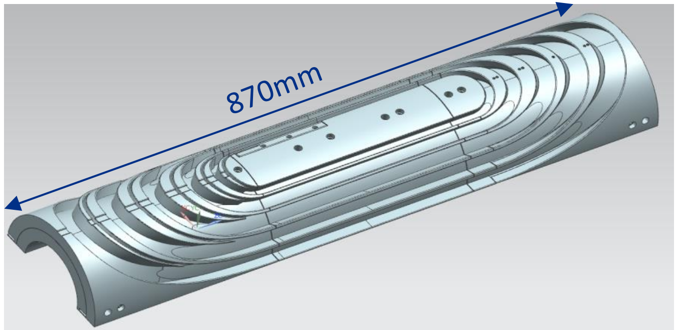


[1] V.V. Kashikhin, I. Novitski, A.V. Zlobin, IPAC-17, Copenhagen, Denmark, May 2017, p. 3597
[2] I. Novitski, J. Carmichael, V.V. Kashikhin, A.V. Zlobin, FERMILAB-CONF-17-340-TD.

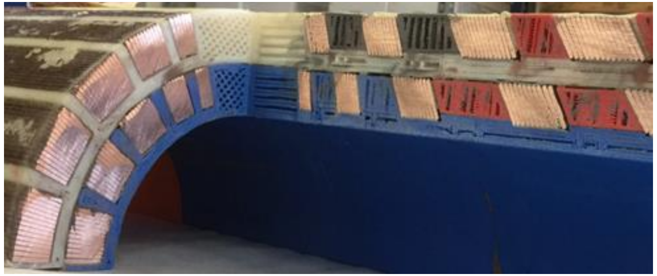
SMCT coil design and practice coil



Large aperture dipole coil



Stress management coil structure



Practice coil winding/impregnation/ QC

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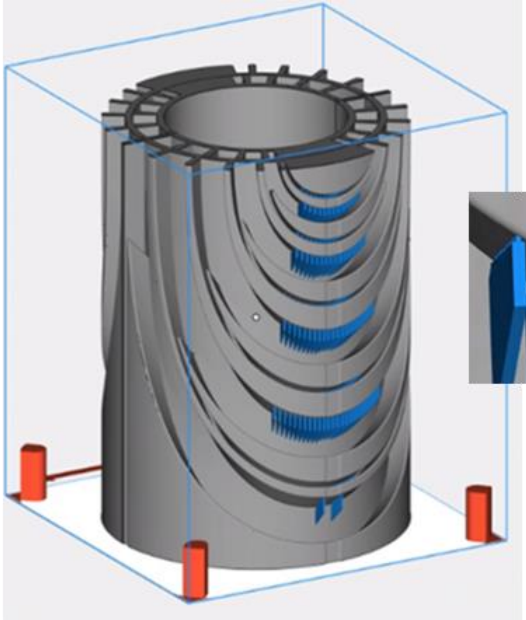
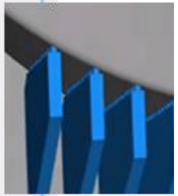
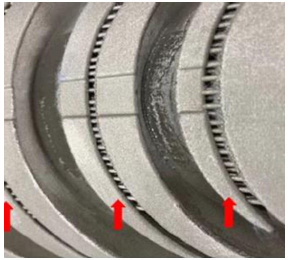
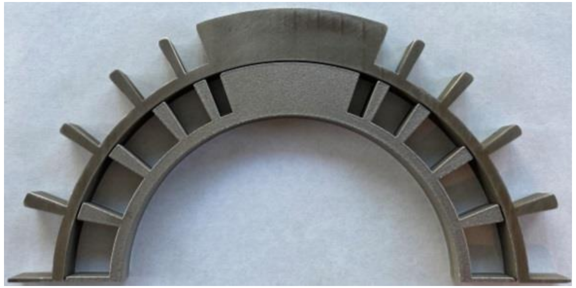
SMCT coil part fabrication by GE Additive









Direct Metal Laser Melting (DMLM) technology

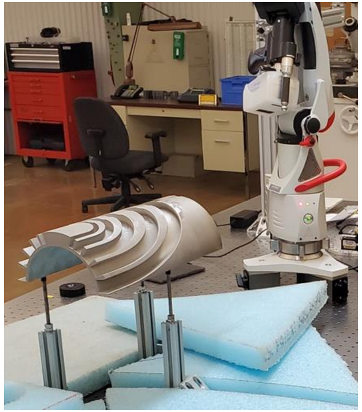
- 316L stainless steel powder
- Technological surface support in blue

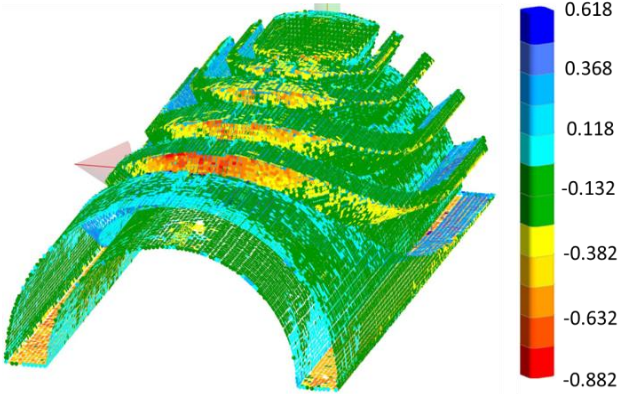
SMCT coil parts printed as two-layer cylinders

- surface support inside large blocks removed at GE Additive

Coil structure size control

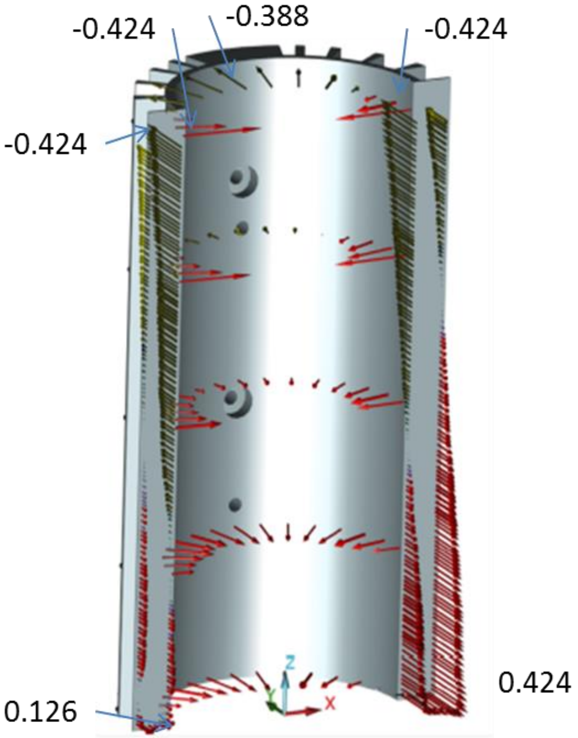
Control of SMCT coil end parts by micrometer on granite table.





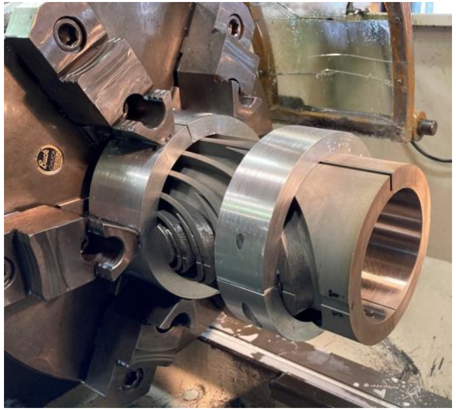
Laser Scanning measurements of surface deviation from CAD.

[1] I . Novitski et al., “Using Additive Manufacturing technologies in high-field accelerator magnet coils,” CEC-ICMC’21 invited talk and paper

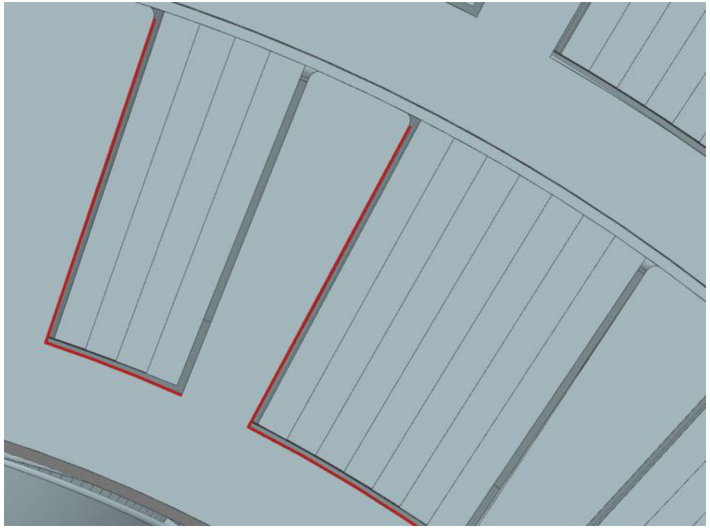


CMM measurements of surface deviation from CAD of SMCT coil straight section .

SMCT coil structure post-processing & winding preparation



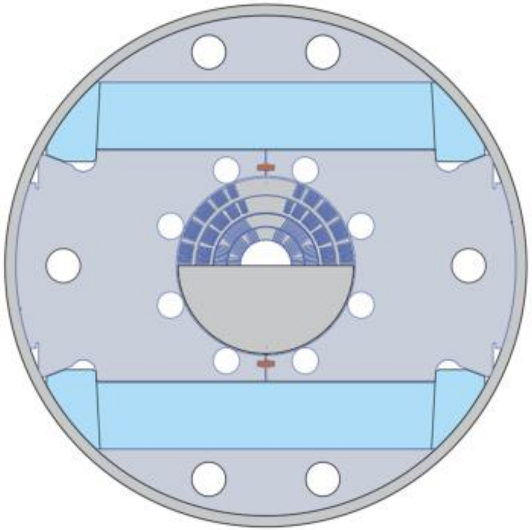
Coil part post processing



Winding preparation:

- Cable insulation
- Ultrasonic part cleaning
- Part assembly and surface adjustment
- Adding coil ground insulation

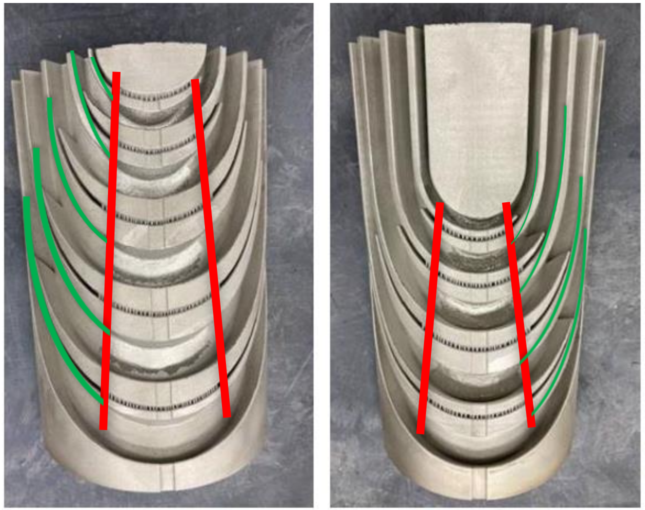
Magnet assembly and test plan



2022

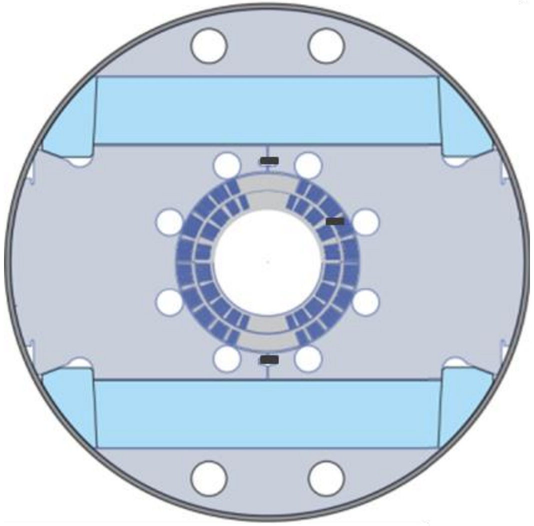
4L mirror

- 1st test of SMCT coil
- 2nd test of both coils



SMCT coil structure optimization

- Short interlayer transition to avoid support elements in transition channels
- More compact LE and RE
- Merge L1 and L2 coil structure



2023

120-mm 2L SMCT dipole with optimized coil structure

Conclusions

- The nominal values of B and G are achievable for the expected apertures in 2nd IR D and Q
- Magnet operation margins look reasonable
- ***Stress management on the coil level is critical***
- SMCT technology development and demonstration is in progress at Fermilab in the framework of US-MDP
- Experimental results are expected within next 2-3 years