Complete and Test a Full Scale Suitable Superferric Magnet

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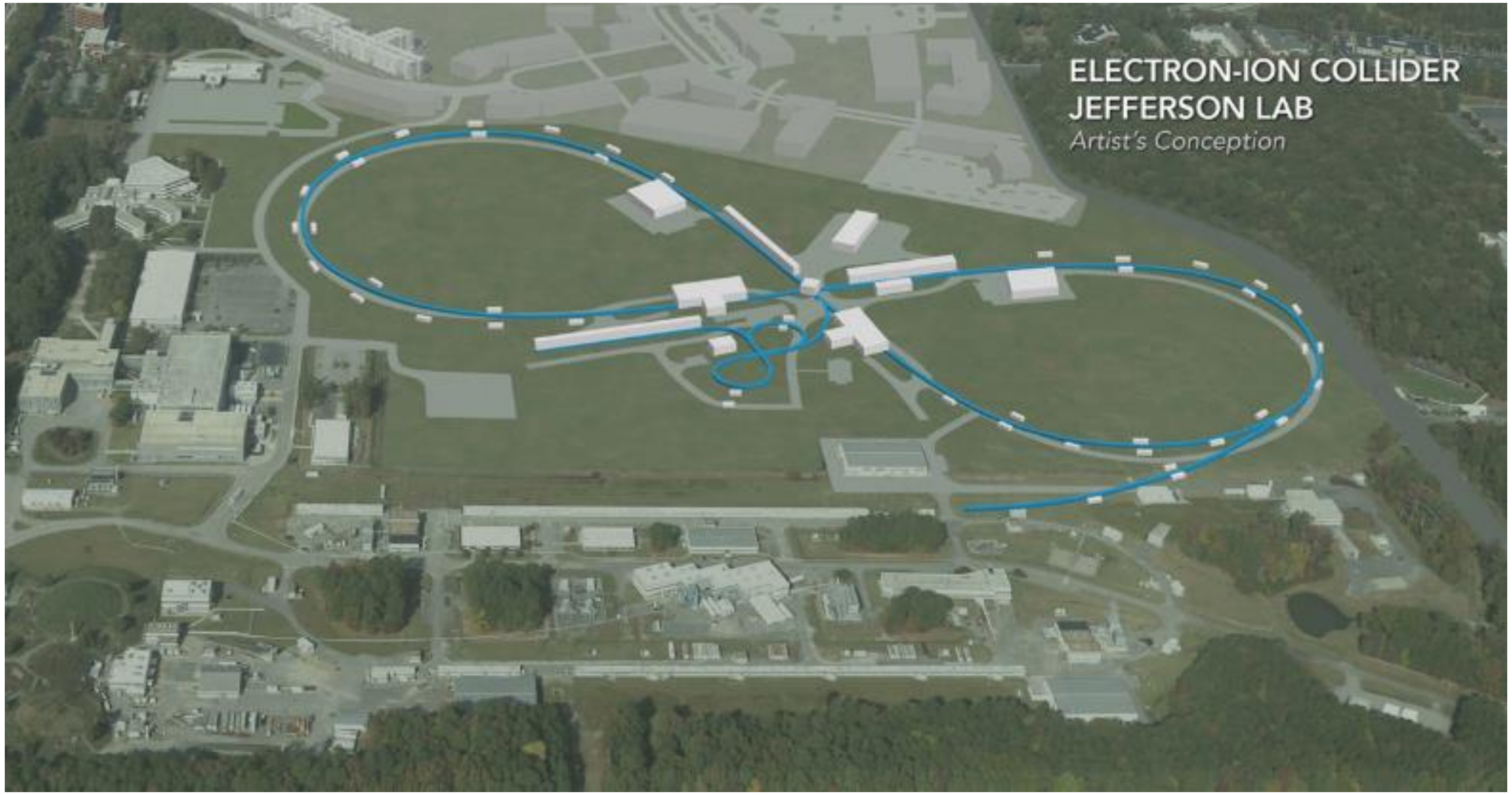


2018 Accelerator R&D PI Exchange Meeting

November 14, 2018

Jefferson Lab

U.S. DEPARTMENT OF ENERGY Office of Science

JSA

Complete and Test a Full Scale Suitable Superferric Magnet – TAMU/TJNAF

- **Description** – Advance 1.2m Model Dipole Superferric Magnet Construction
  - Fabrication of the FRP Structure onto which the coils will be wound
  - Fabricate a long length (125m) of Cable-In-Conduit Conductor (CICC)
  - Test wind several windings to validate accuracy of conductor placement on the FRP Structure
  - Perform technology validation analyses, write a test plan, and work towards selecting a test site
- **Status**
  - Base activities are complete. More investigation into SC magnet design alternatives is ongoing.
- **Main Goal**
  - Develop a 1.2m Superferric Model Dipole using CICC as a cost effective technology for JLEIC
- **Funding**
  - Not base funding
  - FY 2018 NP Accelerator R&D FOA – Not approved or funded
- **Budget**

	FY 2017	FY 20XX	FY 20XX
a) Funds allocated	$XXXk		
b) Actual costs to date	$XXXk		

Complete and Test a Full Scale Suitable Superferric Magnet – TAMU/TJNAF

- **Milestones**

Milestone	Schedule	Status
Completion of analyses in support of a robust magnet design	August, 2018	COMPLETE
Fabrication of 125m length of CICC	August, 2018	COMPLETE
Wind 3-4 coil turns on the FRP structure using a short length (~10m) of CICC	August, 2018	COMPLETE
Final Report from TAMU	August, 2018	COMPLETE
Development of a test plan	January, 2018	Draft COMPLETE
Site selection for future testing	August, 2018	Postponed due to no follow on funding
Assess alternate Superconducting Magnet Technology to Superferric for JLEIC	August, 2018	Ongoing

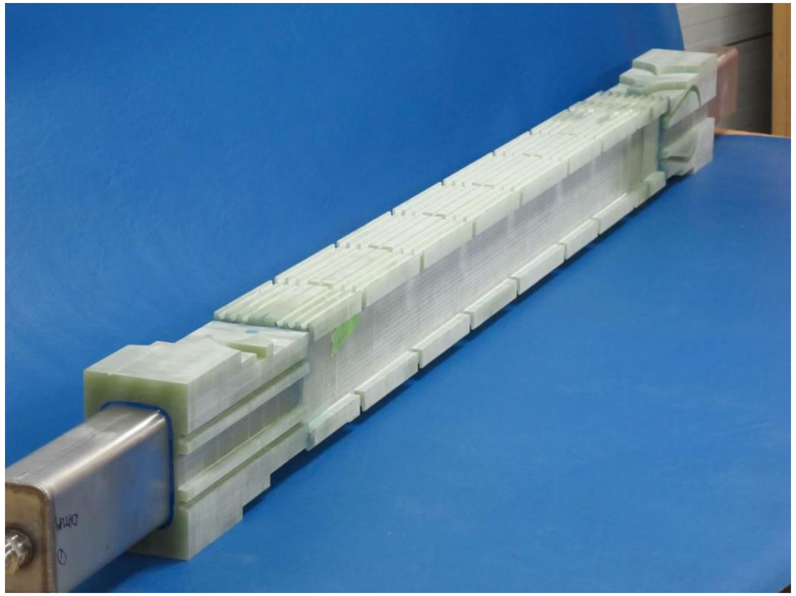
- **Jones Report Ranking**

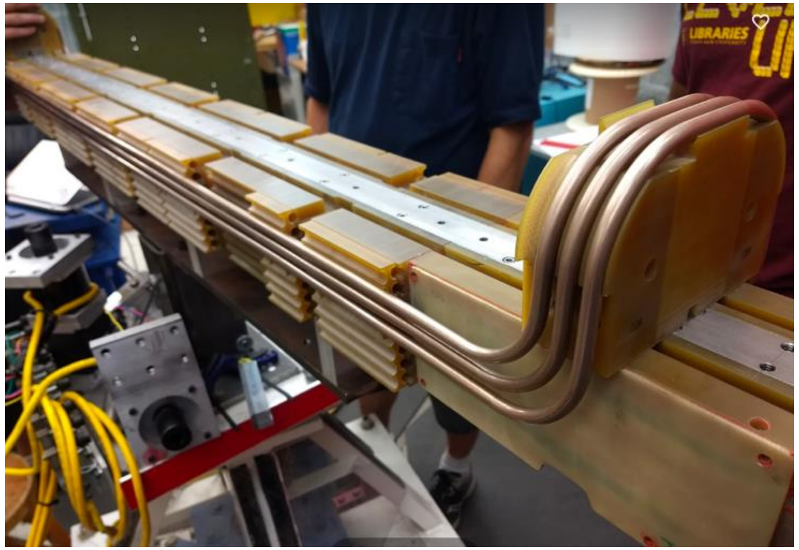
Row No.	Proponent	Concept / Proponent Identifier	Title of R&D Element	Panel Priority	Panel Sub-Priority
17	PANEL	JLEIC	Complete and test a full scale suitable superferric magnet	High	B

Note: Contract $ to TAMU has been committed and COMPLETED. All invoices have been paid.

1.2m Model Dipole Fabrication at TAMU

- Goal of a fast ramping, lower cost magnet technology
- FY'17 R&D
  - Construction of FRP Structure
  - Fabrication of 125m of CICC
  - Trial Winding
- Funded activity COMPLETE!
- See Peter McIntyre's presentation for details.





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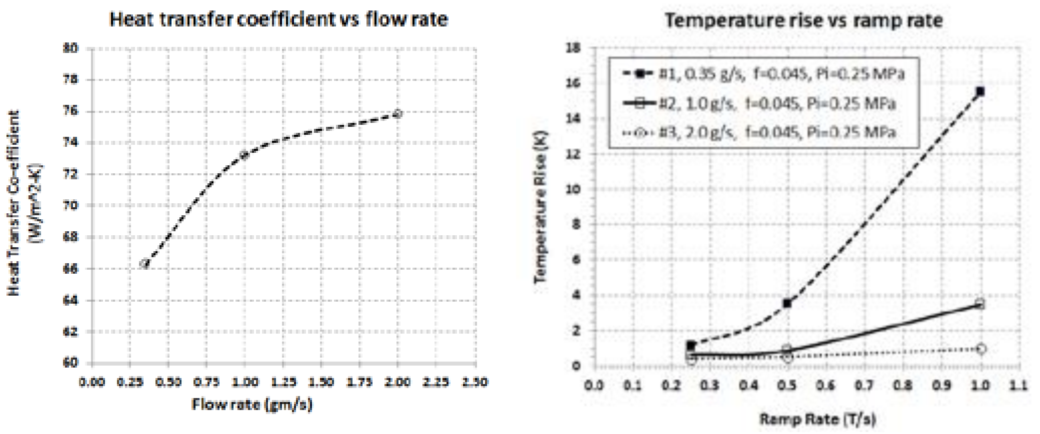
Technical Analyses

- Completed analyses for:
  - CICC withstanding vaporization of LHe
  - AC Losses during Fast Ramping
  - Quench Analysis
  - Stability Assessment

Helium Heat Transfer and CICC Temperature Rise



Results of SF Model Coil AC Losses vs Ramp Rate

Loss Component	Location	1 T/s	0.5 T/s	0.25 T/s
Charging Time	Based on ramp rates to reach full field	3 s	6 s	12 s
Eddy current (coupling and Magnetization) loss – filaments and strands (J)	Induced currents between SC filaments due to external field changes and between strands	84.43	42.21	21.11
Hysteretic loss (J)	Induced currents within SC filaments	8.973	8.973	8.973
Penetration loss (J)	Superconductor surface	1.765	1.765	1.765
Self-field loss (J)	Induced currents between SC filaments due to changes in the transport current	3.679	3.679	3.679
TOTAL AC LOSS, E_{Tot_ac} (J)		98.85	56.63	35.53
TOTAL AC LOSS, Q_{Tot_ac} (W) – *Only during ramp*		**32.95**	**9.44**	**2.96**
TOTAL LOSS, Q_{Tot} (W) *(Includes an assumed constant 4 W)*		**36.95**	**13.44**	**6.96**

Brief Summary of Quench Analysis

Parameter	Case#1	Case#2
Operating temperature (K)	5.02	
Current sharing temperature (K)	6.99	
Temperature margin (K)	1.97	
Short sample performance (%)	62.8	
Length of MPZ (mm)	0.161	
MQE (mJ)	3.57	
Conductor length for quench (m)	42.5	2.84
Hot spot temp. (K)	52.0†	74.8‡
Temp. at the point of initiation after event (K)	>2000*	110.6**
Max. voltage, Line to GND (kV)	> 2.5	1.3
Max. MIITs at 200 K	!	16.2
MIITs estimated with dump resistor	!	1.19
Time require to run the magnet to 0 A incl. detection time (ms) *for design*	!	< 48

†in 21.3 ms, ‡in 40.88 ms, *in 768 ms, **in 51 ms, ! no significance

Summary of SF Model Dipole Stability

Parameters evaluated	Passed	Remarks
Short sample performance (SSP) in %	Yes	< 75 (62.8)
Temperature margin (Sharing temperature) K	Yes	>1.5 (1.97)
Stable for Beta (Adiabatic stability)	Yes	
Adiabatic flux jump stability	Yes	
Dynamic stability	Yes	
Stable in term of twist pitch	*No*	*needed < 10.5 mm*
Stable for finite element size	Yes	
Cryogenic Stability	*	*Not for the CICC*

(*) are calculated values

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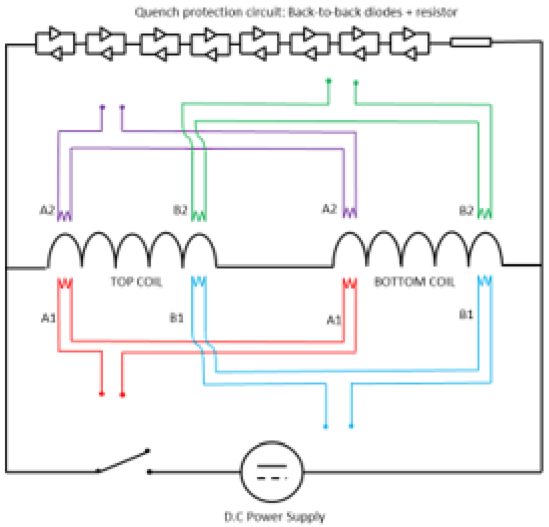
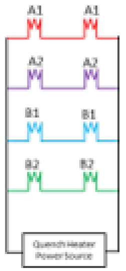
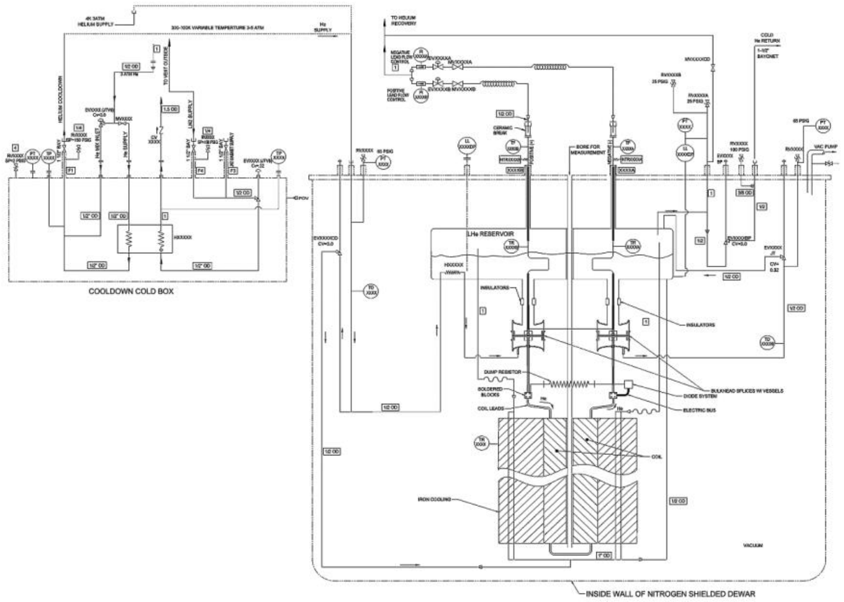
Test Plan – Site Selection

- Test Plan
  - Testing in operational configuration – flow through CICC
  - Field and Field Quality Measurements
  - Ramping at rates up to 1 T/sec
  - 3 domestic labs provided proposals and appear to have capability
  - Testing requires new test cryostat and LHe valve box







BACKUP SLIDES

Collider Ring Magnets

- Fundamental shift in Superconducting (SC) magnet technology: Superferric→Cos-Theta

- Ion Complex SC Magnets
  - 100 GeV Ion Collider Ring
  - Booster Ring
  - 200 GeV Ion Collider Ring
  - SC Magnet Reference Designs (RHIC, SIS300)
  - Costing Methodology

Ion Collider Ring SC Magnets – 100 GeV Ions

- All ***Magnets are Straight*** and have a ***Coil Aperture of 10 cm diameter***
- 2 Dipoles, 1 Quadrupole, and 1 Sextupole magnet are contained within a single cryostat
- Cryostat Size: ~11.4m Length x 0.61m Diameter:
- Operating Temperature: ***4.5 K***
- Dipole Bend Radius is 109 m, Sagitta at 100 GeV is 1.83 cm, Bend Angle is 2.1 degrees

Magnet Type	Number of Magnets	Magnet Strength (T, T/m, T/m^2)	Magnetic Length (m)	Conductor type	Conductor size
Dipole	254	3.06	4.00	NbTi Rutherford	9.73mm x 1.166mm, 30 strand
Dipole	5	4.67	4.00	NbTi Rutherford	15mm x 1.166mm, 36 strand
Quadrupole	155	52.9	0.80	NbTi Std. MRI	1.65 mm x 2 mm
Quadrupole	44	82	0.80	NbTi Std. MRI	1.65 mm x 2mm
Sextupole	125	528.7	0.50	NbTi Strand	.508 mm

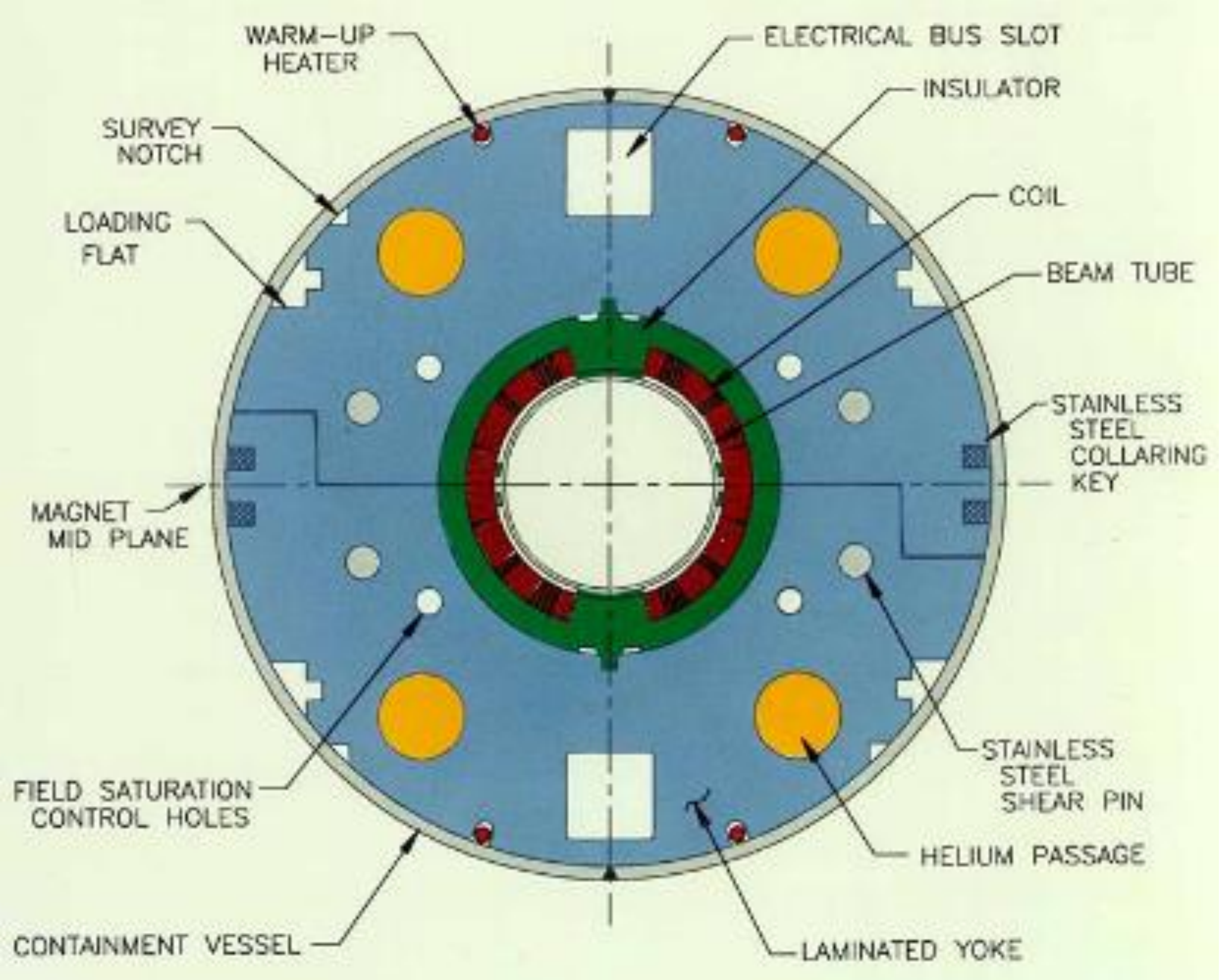
Booster Ring SC Magnets

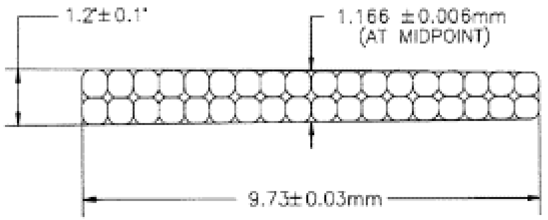
- All ***Magnets are Straight*** and have a ***Coil Aperture of 10 cm diameter***
- Fast Ramping Magnets – ***Dipoles ramped at 1 T/s***, others follow suit
- 2 Dipoles and 1 Quadrupole are contained within a single cryostat
- Cryostat Diameter: 0.61m
- Operating Temperature: ***4.5 K***

Magnet Type	Number of Magnets	Magnet Strength (T, T/m, T/m^2)	Magnetic Length (m)	Conductor type	Conductor size
Dipole	64	3.0	1.42	NbTi – modified for low AC losses	15mm x 2mm, 36 strand
Quadrupole	92	29.6	0.40	NbTi – modified for low AC losses	15mm x 2mm, 36 strand
Sextupole	64	201.0	0.20	NbTi Strand	.508 mm

RHIC Dipole Magnets – Reference Design *(RHIC Configuration Manual)*

- Comparable field strength: 3.52T (D0 Insertion Dipole)
- D0 Insertion Dipole: 10cm Coil Aperture
- Cold Mass OD: 0.277 m
- Cryostat OD: 0.61m

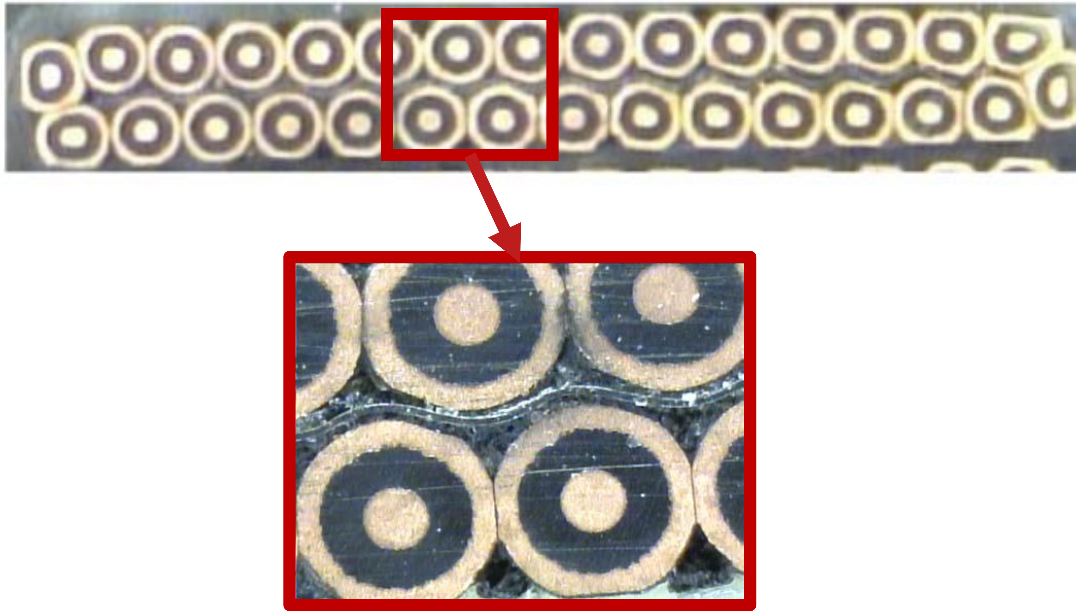




Rutherford Cable Design for High Ramp Rate

Required Changes from “Standard” Rutherford Cable to reduce AC Losses:

- Reduced Filament Size – 3.5μm to 6.0μm
- Reduced Filament Twist Pitch
- CuMn Interfilamentary Matrix vs Cu
- Stay Bright ® Strand Coating
- Thin layer of SS between cable layers



References

IEEE TRANSACTIONS ON APPLIED SUPERCONDUCTIVITY, VOL. 17, NO. 2, JUNE 2007 1437

Cable Design for FAIR SIS 300

J. Kaugerts, G. Moritz, M. N. Wilson, *Member, IEEE*, A. Ghosh, A. den Ouden, I. Bogdanov, S. Kozub, P. Shcherbakov, L. Shirshov, L. Tkachenko, D. Richter, A. Verweij, G. Willering, P. Fabbricatore, and G. Volpini

WAMSDO PROCEEDINGS

LOW LOSS WIRE DESIGN FOR THE DISCORAP DIPOLE*

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P. Fabbricatore, S. Farinon, R. Musenich, INFN Genova, Italy
U. Gambardella, INFN LNF, Italy
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SIS300 IHEP Dipole – 6T Dipole Reference Design

SIS 300, a fast-ramping heavy ion synchrotron with a rigidity of 300 T-m, with 6 T, 100 mm coil aperture 2.6 m long superconducting dipoles. A two layer cos-theta magnet design, using a cored Rutherford cable, has been chosen.

- Cold Mass OD: ~0.52 m
- Cryostat OD: 1.0 m

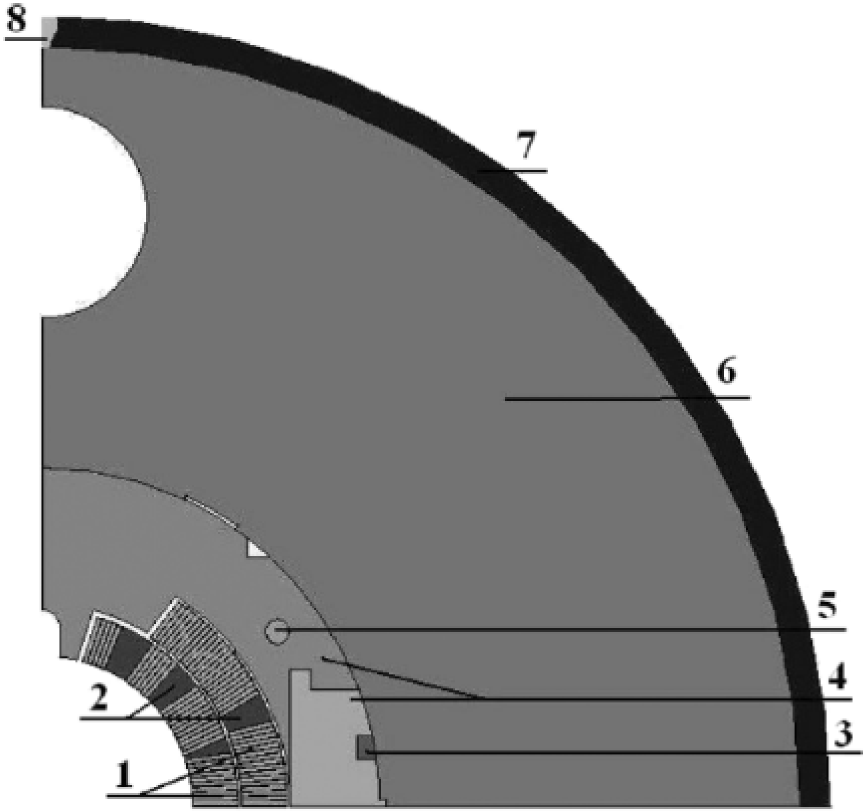

Fig. 1.   Cross-section of the dipole (one quadrant is shown). 1-coil, 2-inter-turn spacers (wedges), 3-key, 4-collars, 5-pin, 6-yoke, 7-outer cylinder, 8-weld.

Reference

1LF08

Design of a 6 T, 1T/s Fast-Ramping Synchrotron Magnet for GSI's Planned SIS 300 Accelerator

J. E. Kaugerts, G. Moritz, C. Muehle, A. Ageev, I. Bogdanov, S. Kozub, P. Shcherbakov, V. Sytnik, L. Tkachenko, V. Zubko, D. Tommasini, M. N. Wilson, W. Hassenzahl

TABLE I
MAIN CHARACTERISTICS OF DIPOLE

Central magnetic field, T	6
Magnetic field ramp rate, T/s	1
Operating current, A	6720
Stored energy, kJ	260
Inductance, mH	11.7
Number of layers	2
Inner layer turn number	64
Outer layer turn number	76
Coil inner diameter, mm	100
Length of coil straight part, mm	580
Coil length, mm	1020
Collar thickness, mm	30
Thickness of iron yoke, mm	140
Thickness of outer cylinder, mm	10
Outer diameter of outer cylinder, mm	520
Length of outer cylinder, mm	1292
Weight of dipole cold mass, kg	1800