20 T Common Coil End Design Concepts

Ramesh Gupta

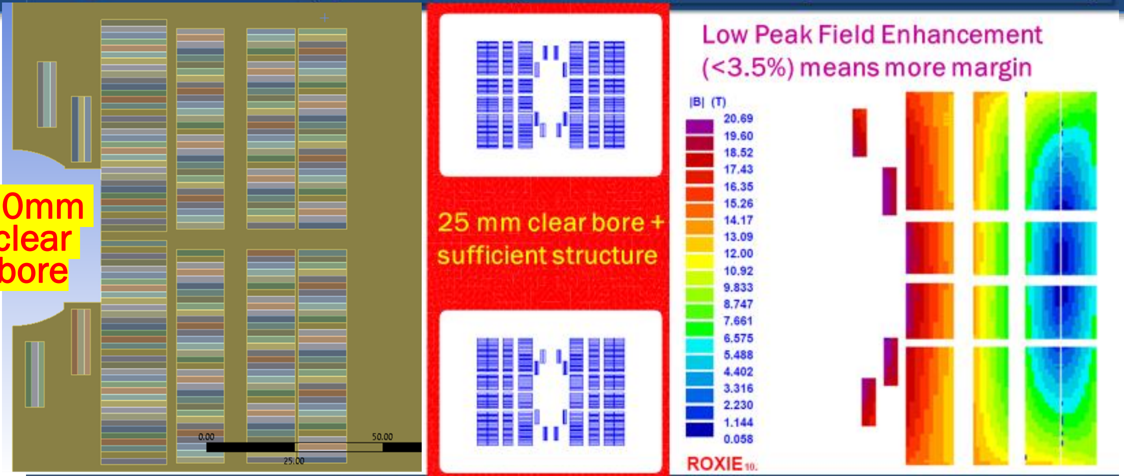
Companion Presentation

Overview

- During the last review, 2-d magnetic and mechanical analysis of 20 T HTS/LTS hybrid designs common coil were presented. Magnetic designs met the field quality and margin requirements. Only modest work in 2-d magnetic design.
- Several mechanical analysis were presented (John Cozzolino). They either met the requirements of the maximum stresses on LTS but not on HTS (fixed contacts) or met on LTS but not on HTS (sliding contacts), but not for both.
- Goals for this year were: (a) initial 3-d magnetic design and (b) progress on the mechanical analysis to meet the stress requirements for both HTS and LTS
- Progress was limited by the resources available. Shared with other projects (EIC^{+}); and other MDP tasks (test^{+}: see presentation by Mithlesh Kumar)
- Initial evaluation of 3-d end design to be presented here.
- Progress on the mechanical analysis to be presented by Mike Anerella.

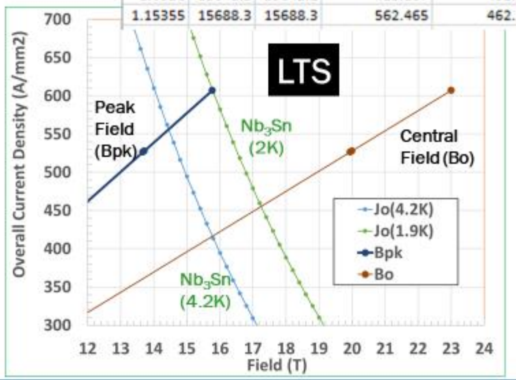
Progress in 2-d Design (Aug 2022)

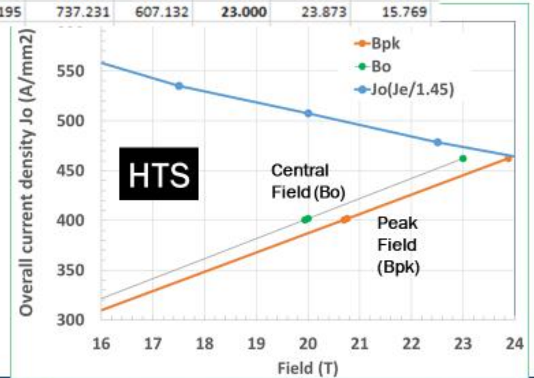
New 20 T HTS/LTS Hybrid Design (May 2022)
(spacers in magnetic design takes input from mechanical)



Magnetic Design (May 2022) with 15% Margin

	I(HTS), A	I(Nb3Sn)	Je(HTS), A/mm^2	Jo(HTS), A/mm^2	Je(Nb3Sn)	Jo(Nb3Sn)	Bo (T)	Bpk(HTS), T	Bpk(Nb3Sn)
	0	0	0	0	0	0	**0**	0	0
	13600	13600	487.60	400.672	639.10	526.316	**19.938**	20.695	13.670
1.0031	13642.2	13642.2	489.107	401.914	641.079	527.947	20.000	20.759	13.712
1.15355	15688.3	15688.3	562.465	462.195	737.231	607.132	**23.000**	23.873	15.769





Magnetic Design (May 2022) Good Field Quality

MODEL	mdp_may2022-v2
BI2212R	Bi2212
Bare w	1.52
Bare h	18.35
Insulation	0.15
Ins w	1.82
Ins h	18.65
Ins Area	33.943
Current	13600
Je (A/mm^2)	487.60
Jo (A/mm^2)	400.67
Bpeak (T)	20.6951
MDPH2	Nb_3Sn
Bare w	1.6
Bare h	13.3
Insulation	0.15
Ins w	1.9
Ins h	13.6
Ins Area	25.840
Current	13600
Je (A/mm^2)	639.10
Jo (A/mm^2)	526.32
Bpeak (T)	13.6701
Bo	19.9382

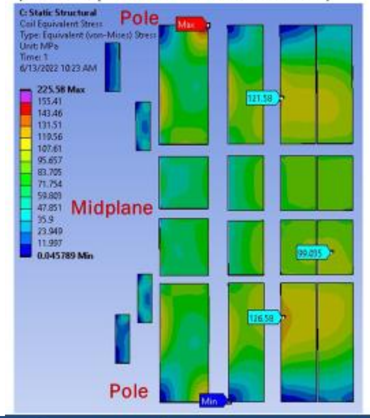
```
NORMAL RELATIVE MULTIPOLES (1.D-4):
b 1:  10000.00000  b 2:     -0.00000  b 3:      0.05059
b 4:     -0.00000  b 5:      0.09440  b 6:      0.00000
b 7:     -0.78244  b 8:      0.00000  b 9:     -0.92602
b10:      0.00000  b11:     -0.18313  b12:     -0.00000
b13:     -0.02800  b14:      0.00000  b15:     -0.01273
b16:      0.00000  b17:     -0.00410  b18:     -0.00000
b19:     -0.00094  b20:      0.00000

SKEW RELATIVE MULTIPOLES (1.D-4):
a 1:      0.00000  a 2:     -0.00405  a 3:      0.00000
a 4:     -0.02333  a 5:     -0.00000  a 6:     -0.15914
a 7:      0.00000  a 8:      0.20675  a 9:      0.00000
a10:      0.08678  a11:     -0.00000  a12:      0.00779
a13:      0.00000  a14:      0.00593  a15:     -0.00000
a16:      0.00258  a17:      0.00000  a18:      0.00056
a19:     -0.00000  a20:      0.00019  a
```

All harmonics < 1 unit

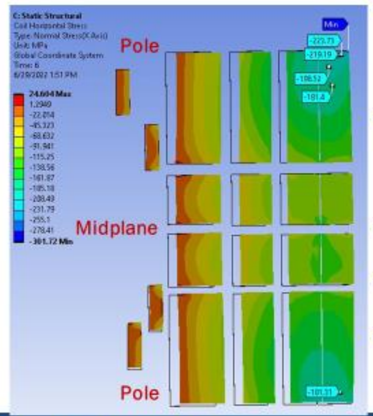
Developing Mechanical Structure

John Cozzolino

Original Case (vertical spacers bonded to the collar)



SST vertical separators are allowed to slide relative to the collar



- Stresses and Strain are within acceptable limits at most places See John Cozzolino's presentation
- However, at pole the exceed the limit either in HTS or in LTS, depending on the contact (bonded or sliding)
- Attempt to make things better for decreasing the local peak
- Enhanced peaks are because of the bending of the coil layer.
- The two cases show that it can be balanced out

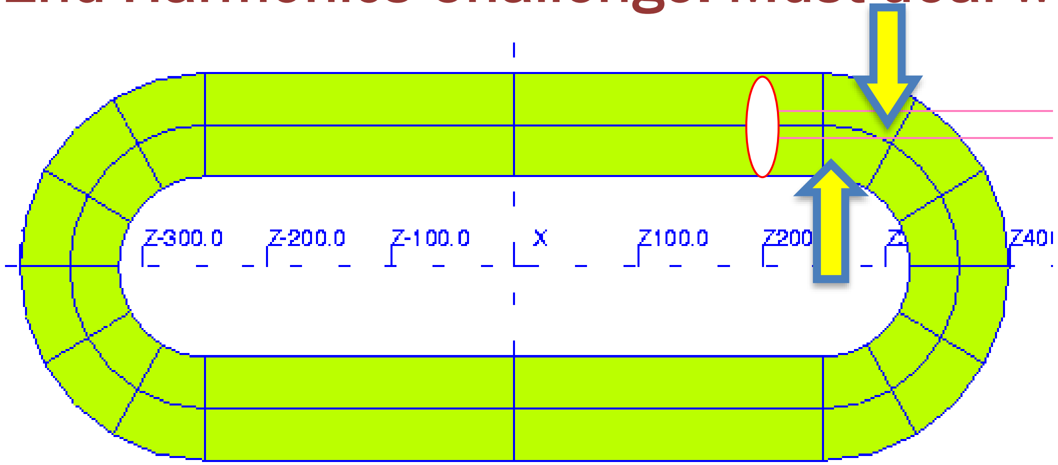
Recent Progress by Mike Anerella

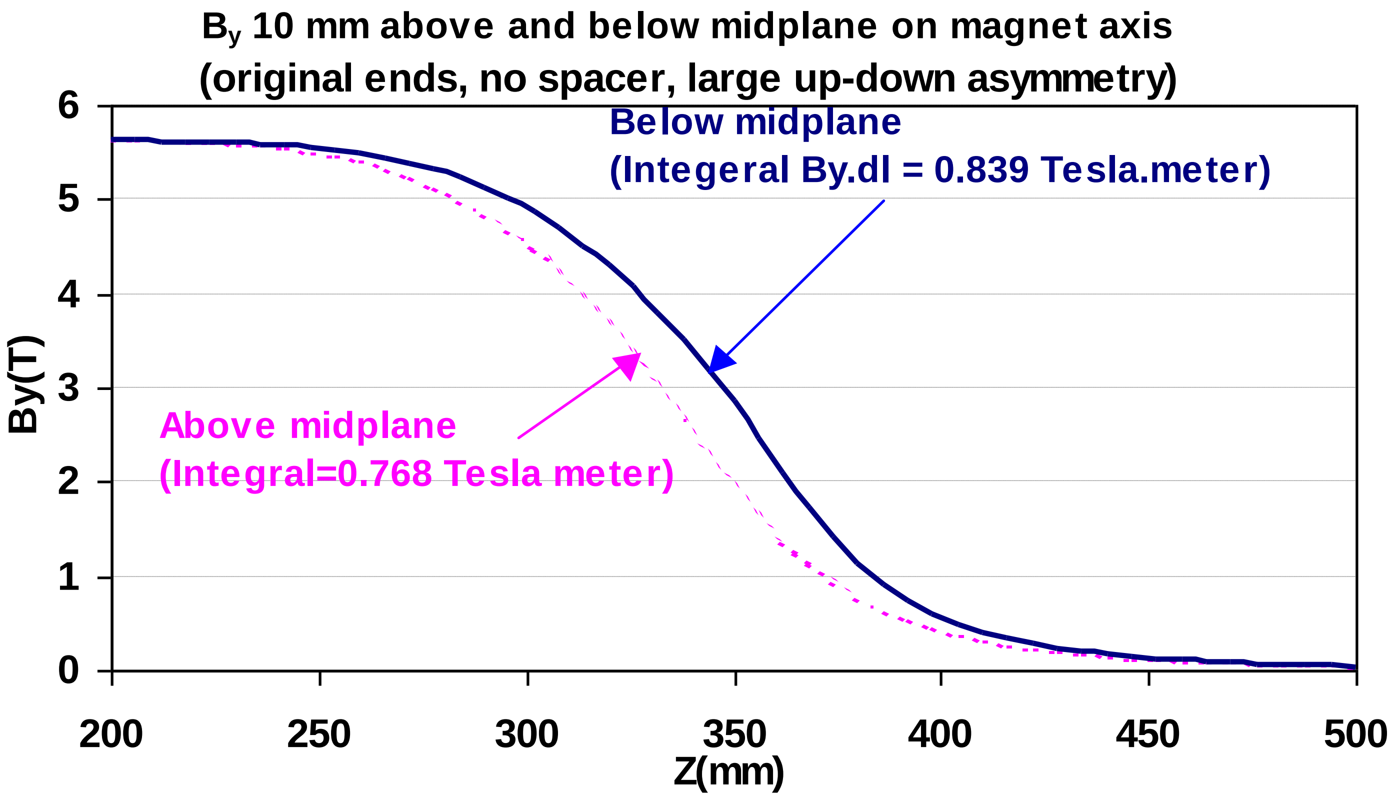
Issues/Challenges Specific to the Common Coil End Design and How they are Tackled

Challenges in Optimizing End Harmonics Specific to the Common Coil Design

U.S. MAGNET DEVELOPMENT PROGRAM

End Harmonics Challenge: Must deal with the missing up-down symmetry (skew harmonics)

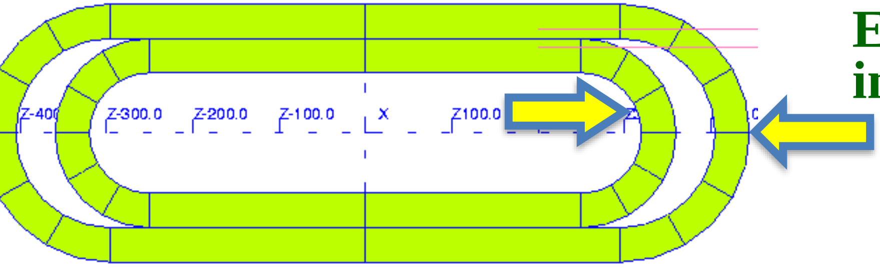




- A proof-of-principle model of good field in the ends is shown in the next slide
- Minimization of end harmonics needs to be performed with codes like ROXIE.

- Work to continue to show it for a 20 T ends with good mechanical and engineering design

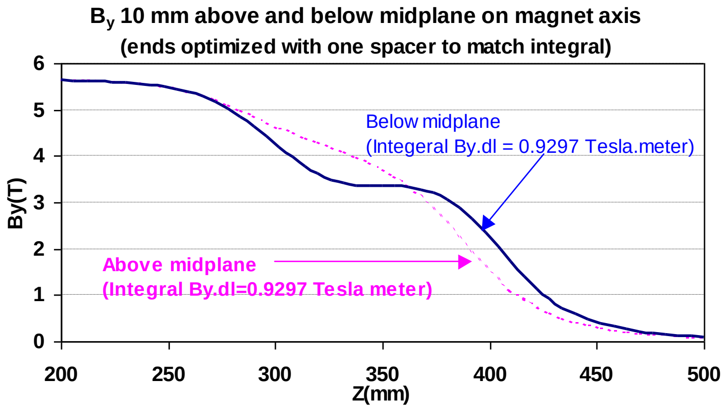
Good Field Quality in Common Coil Ends (as demonstrated in an earlier design)



End harmonics can be made small in a common coil design.

Missing up-down symmetry can be partially restored with the end spacers.

Integral By.dl 10 mm above & 10 mm below midplane.

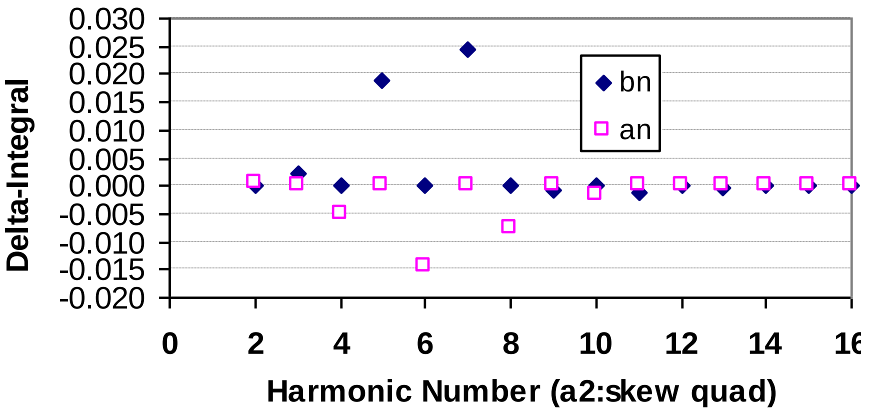


End harmonics in Unit-m
(Very small)

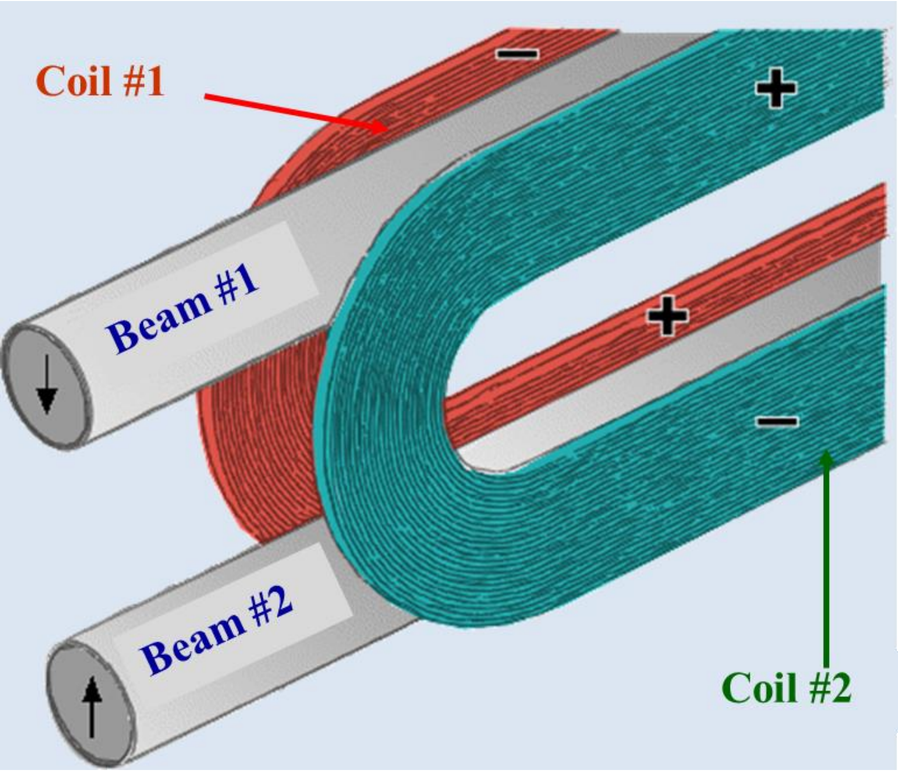
n	Bn	An
2	0.00	0.00
3	0.01	0.00
4	0.00	-0.03
5	0.13	0.00
6	0.00	-0.10
7	0.17	0.00
8	0.00	-0.05
9	0.00	0.00
10	0.00	-0.01
11	-0.01	0.00
12	0.00	0.00
13	0.00	0.00
14	0.00	0.00
15	0.00	0.00
16	0.00	0.00
17	0.00	0.00
18	0.00	0.00

Contribution to integral (a_n,b_n) in a 14 m long dipole ($<10^{-6}$)

n	bn	an
2	0.000	0.001
3	0.002	0.000
4	0.000	-0.005
5	0.019	0.000
6	0.000	-0.014
7	0.025	0.000
8	0.000	-0.008
9	-0.001	0.000
10	0.000	-0.001
11	-0.001	0.000
12	0.000	0.000

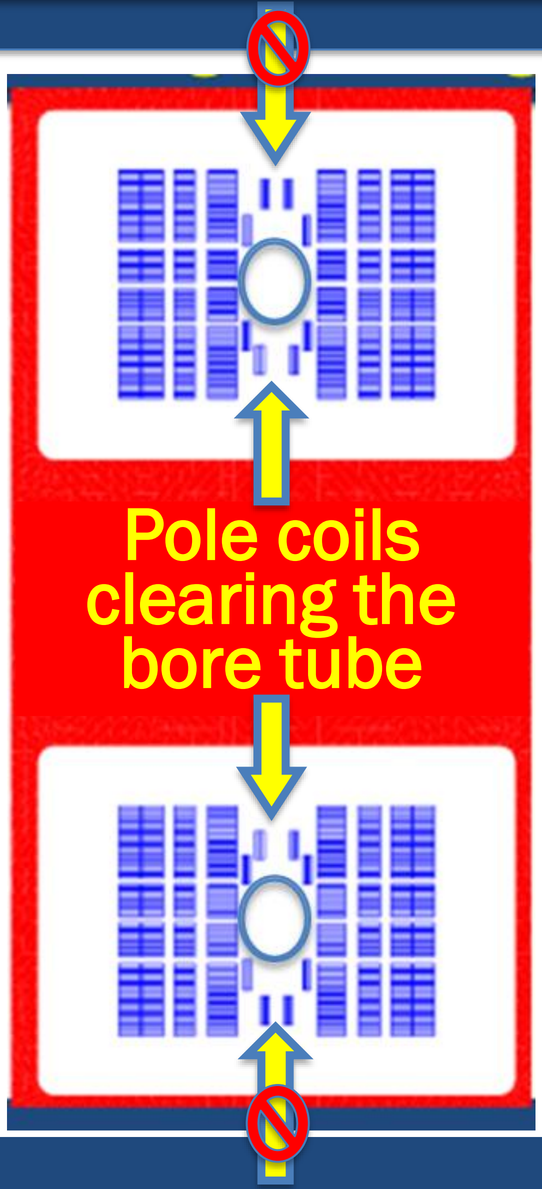


Geometric Challenge for Pole Coil Blocks

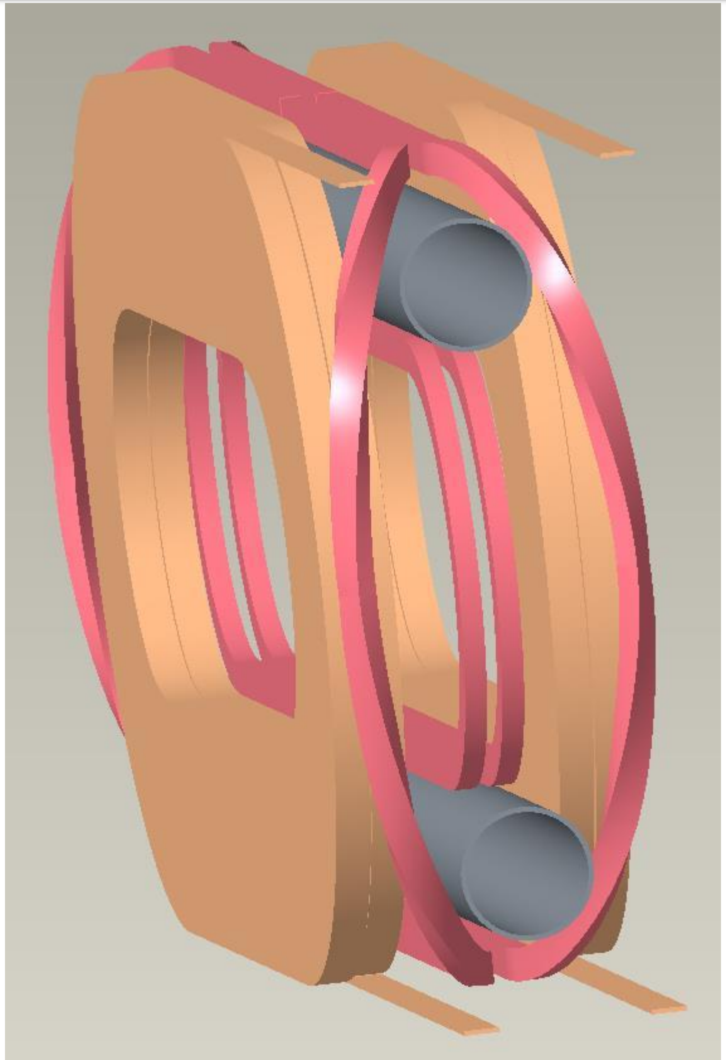


Main Coils of the
Common Coil Design

- Pole coils are used for a good field quality design (accelerator quality)
- Some pole coils (a) either ideal common coil geometry to clear the bore tube or (b) use extra conductor
- A few concepts/geometries are presented in the next few slides
- Practice windings of some done as parts of several SBIR/STTR
- Design tested for HTS coils at 77K
- None, however, yet tested at 4K or integrated with the main coils



Addressing Pole Coil Challenge with Flared Ends (SBIR Phase I with PBL)



Phase II for integrating such coils with common coil dipole DCC017 was not funded

Earlier Design Study on 20 T Hybrid Design
(with IHEP visitor at BNL to work on the common coil)

The Optimization of SPPC 20T Superconducting Common Coil Magnet

Qing Li
Accelerator Division, Institute of High Energy Physics, Chinese Academy of Science
Ramesh Gupta
Superconducting Magnet Division, Brookhaven National Laboratory

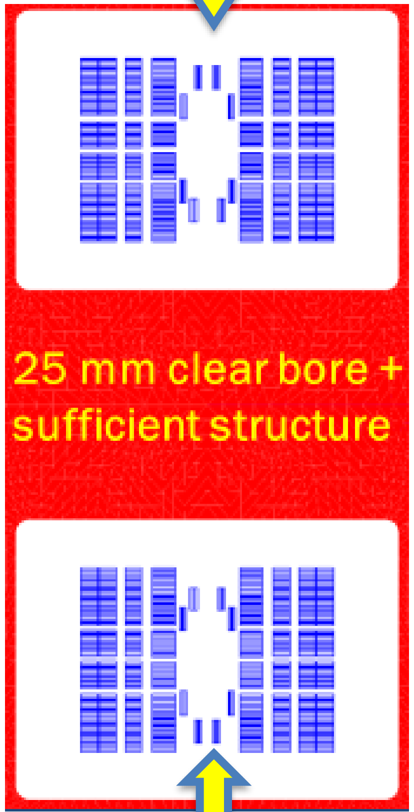
October 2016

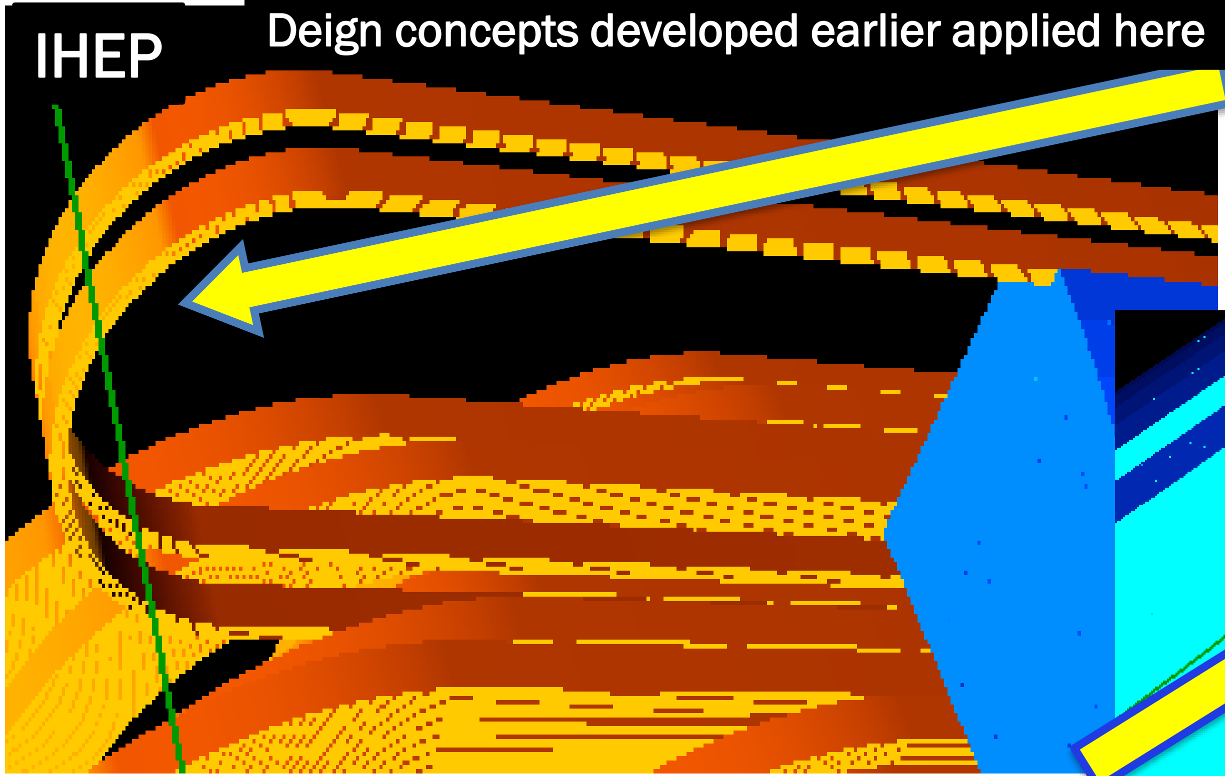
No ongoing collaboration with IHEP now

Addressing the Pole Coil Challenge (2)

(all pole coils must clear the beam tube)

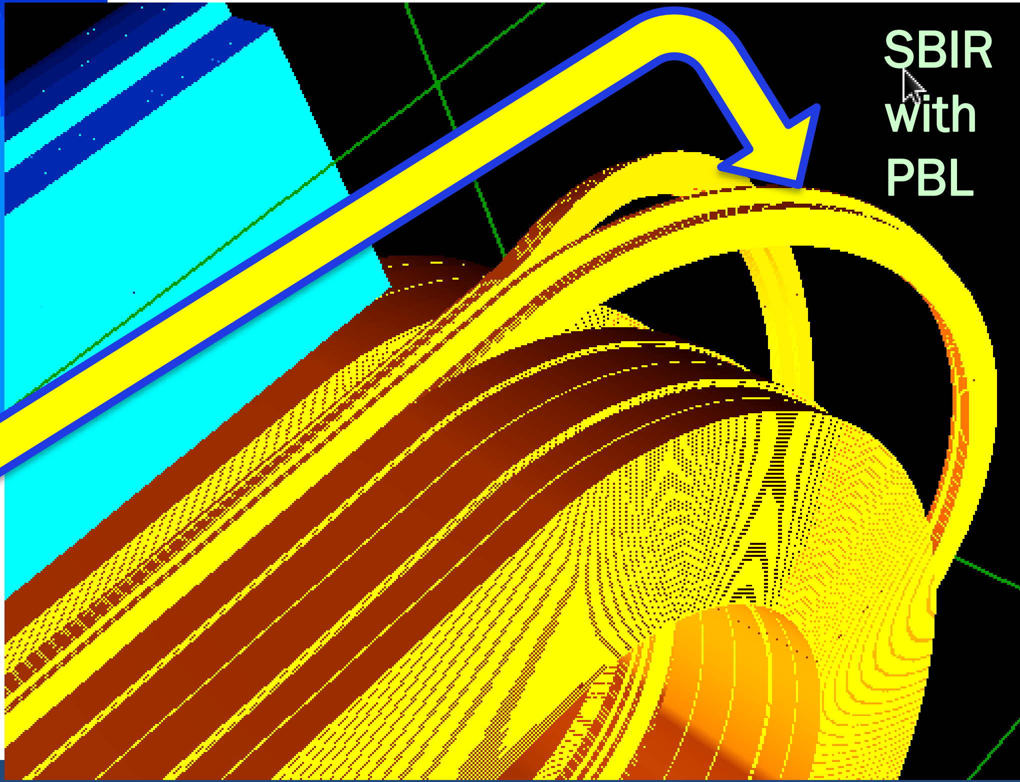
MDP





Deign concepts developed earlier applied here

Solution #1: offending pole coils return away from the aperture
Plus: simple racetrack maintained
Minus: Extra conductor

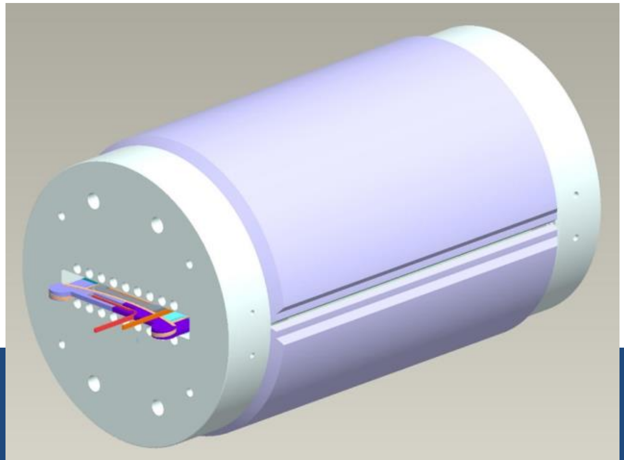


Solution #2: offending pole coils with flared ends to clear the aperture

- Plus: No extra coils
- Minus: No longer a simple racetrack coils

Addressing the Pole Coil Challenge with New Designs (overpass/underpass: Proposed in 2002, TWO SBIRs)

Two STTRs: (a) with e2P; (b) with PBL.
Phase I - two coils wound; one tested.
Phase II- PoP proposed, not funded.
Demo can now be pursued with MDP.

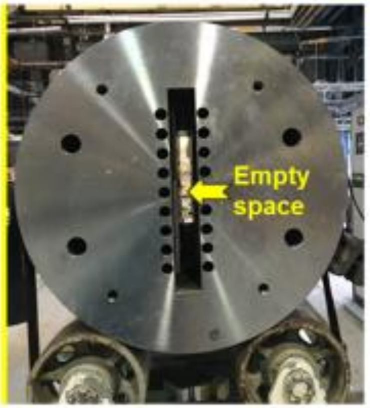


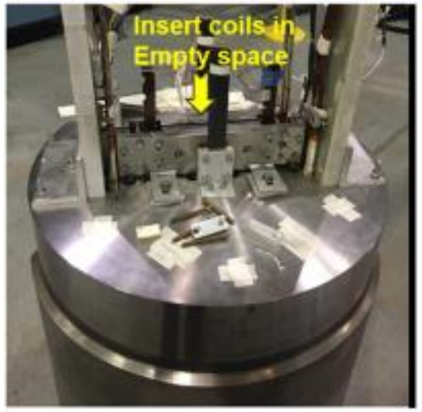
STTR with PBL

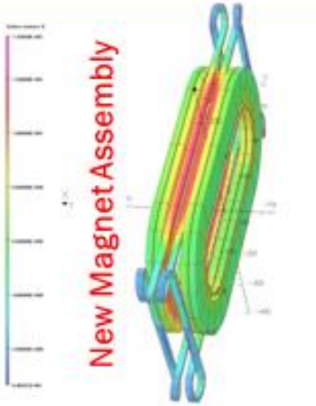
Goal of Phase II, if funded

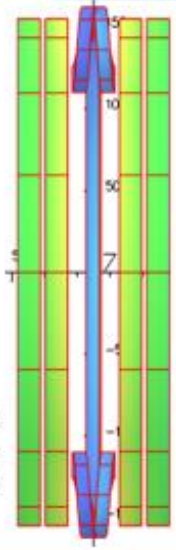
Insert coil test in BNL DCC017 for a "Proof-of-Principle" demonstration of (a) overpass underpass end design (b) Field quality common coil design

Design developed during Phase I for Phase II









OP/UP coil ends must remain in the opening of DCC017. The cable at hand allows only three cable width. This makes the PoP design more challenging than that of a new magnet.

Figure 12: BNL common coil dipole with a large open space (left), with insert coil for another PBL/BNL STTR (middle), and the magnetic model of the proof-of-principle test (right). Similar to the design of the pole blocks of a high field common coil dipole, the overpass/underpass ends of the proof-of-principle design will be in a relatively lower field region, pointing to another advantage of the design.

U.S. DEPARTMENT OF ENERGY | Office of Science   Overpass/UnderPass (Clover-leaf) End Design for Block Coil Dipoles – Ron Scanlan for PBL/BNL   USMDP, March 5, 2021

R. Gupta et al., "Proof-of-Principle Design of a High-Field Overpass/Underpass Nb3Sn Dipole," in IEEE Transactions on Applied Superconductivity, vol. 32, no. 6, pp. 1-5, Sept. 2022, Art no. 4005005, doi: 10.1109/TASC.2022.3159300. (Poster)

U.S. MAGNET DEVELOPMENT PROGRAM

Historical Documents are Back

https://wpw.bnl.gov/rgupta/

HomePage | Talks/Presentations + | Publications + | Magnet Development Program +

Resources on Superconducting Magnets

- Proceedings of the 1968 Summer Study on Superconducting Devices and Accelerators
- Selected Cryogenic Data Notebook
- Material Properties Important to the Design of A Large Superconducting Magnet

BROOKHAVEN NATIONAL LABORATORY
SELECTED CRYOGENIC
DATA NOTEBOOK

VOLUME I
SECTIONS I-IX

Compiled and Edited by
J.E. Jensen[1] W.A. Tuttle[1]
R.B. Stewart[1] H. Brechna[2]
A.G. Prodell

1. Worcester Polytechnic Inst. and National Bureau of Standards, Cryogenic Division
2. Institute of Technology, Rapperswil, Switzerland

Revised August 1980

1. SUPERCONDUCTING RF CAVITIES AND LINACS (**First Week**)
2. CRYOGENICS (**Second Week**)
3. SUPERCONDUCTING MATERIALS (**Third Week**)
4. AC EFFECTS AND FLUX PUMPS (**Fourth Week**)
5. SUPERCONDUCTING MAGNETS (**Fifth Week**)
6. ACCELERATORS AND STORAGE RINGS USING SUPERCONDUCTING OR CRYOGENIC MAGNETS (**Sixth Week**)

PICTURES TAKEN AT

THE 1968 BROOKHAVEN SUMMER STUDY

FIFTH WEEK – SUPERCONDUCTING MAGNETS

Chairman: W.B. SAMPSON, Brookhaven National Laboratory

Bill Sampson's week on superconducting magnets was the most popular of the Summer Study. Superconducting magnets were described, from the huge affairs under construction for large bubble chambers to miniature units suitable for transport of particle beams. It was during this week that Peter Smith of the Rutherford Laboratory brought forward his suggestions for stabilizing superconducting magnets and for reducing ac losses. These ideas already have inspired programs in a number of laboratories; thus far Smith appears to have been correct in all of his predictions.

Bill Sampson

LEFT: Chairman W.B. Sampson with P.F. Smith of the Rutherford Laboratory. RIGHT: M. Morpurgo of CERN discusses a point with D. Bruce Montgomery of the Francis Bitter National Magnet Laboratory.

U.S. MAGNET DEVELOPMENT PROGRAM

Summary

- Common coil design offers several advantages because of the conductor friendly geometry and the way Lorentz forces gets applied to the coil. It seems to be particularly attractive for high field HTS/LTS hybrid collider dipoles.
- The simple design, however, gets a bit more involved due to (a) lack of up-down symmetry in coil ends impacting the field quality, and (b) some pole blocks deviating from the ideal common coil 2-d simplicity to clear the bore tubes.
- Several design options have been examined over the years which proves that solutions exist. However, they are yet to be demonstrated in a real magnet.
- Initial work on the end design specific to MDP 20 T design has been started.
- Progress in the mechanical analysis (next presentation) shows that a structure should be possible which meets the guidelines of the 20 T design study.