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Superconducting Magnet Division

Magnet Note

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Topic: Common Coil Design

Title: BNL Phase II Common Coil Magnet Program
http://magnets.rhicbnl.gov/staff/gupta/talks/gupta-vlhc-mt-2k/

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BNL Phase II
Common Coil Magnet Program

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This talk can be found at:
http://magnets.rhic.bnl.gov/Staff/gupta/talks/gupta-vlhc-mt-2k

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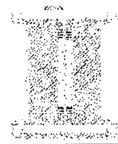
Outline of Common Coil Magnet R&D

Two parallel and complimentary aspects of the program:

1. Design and build a 12.5 Tesla, "React & Wind" Common Coil Magnet.
2. Design and operate a "mini magnet R&D program" that allows new ideas, designs and technologies to be tested in a time and cost effective manner.



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Magnet Program Design Philosophy

- It takes well over a year to build and test a product, we tend to become conservative. We tend to stay with the proven technology since so much rides on each test.
- Since significant cost reduction is unlikely to come with "the comfort zone technology", the magnet program must be designed for rapid throughput. This will scientifically evaluate old "comfort zone" issues and test feasibility and profitability of new ideas.
- In an atmosphere of limited funding, "*designing a magnet program*" is just as important as designing a magnet.

It sets the tone and nature of magnet R&D.

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Phase II Common Coil Magnet Program

- **Develop and test a series of compact 10-turn common coil configurations using reasonable engineering resources**
  - A pair of 10-turn coils in a common coil geometry made with 50 meters of Nb_3Sn cable from Berkeley generates ~8 Tesla.
- **While time is being taken in designing and building a well engineered 12.5 T magnet, continue with 10-turn coil program**
  - A positive use of time with parallel resources to address magnet engineering issues. Each test requires only a small additional investment after the first one. Each coil uses only ~11 meter of cable. We can even afford to lose a few coils.

* Good approach for HTS magnet development also.

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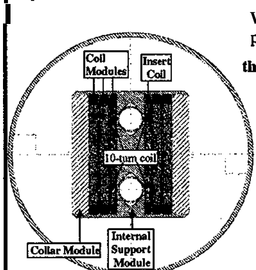
Life of 10-turn Coil Program After 12.5 T Magnet



While we optimize the 12.5 T design for cost, performance and large scale production,

the 10-turn coil program continues in parallel!

12.5 T magnet becomes a part of "magnet R&D test factory"

The 12.5 T magnet provides a significant background field facility for testing coil modules with large Lorentz forces on them -- try to simulate high field magnet situation.

Can test insert/auxiliary coil for field quality configuration also.

☺ Good approach for HTS magnet development as well.

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An Experimental Program with a Modular Approach

A few examples of systematic studies in a modular approach

- Different technologies
  - Wind & React Vs. React & Wind
- Different conductors
  - Nb_3Al, HTS, etc.
- Different insulation
- Different geometry
  - Tape, cable
- Stress management/High stress configuration
- Coil winding and Splicing

... and a variety of other things that are not included (especially those that are not included)

* **A Dynamic Program with fast turn-around time for exploring new frontiers/ideas** *

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The Team for Phase II Program

M. Anerella	R. Gupta
J. Cozzolino	M. Harrison
J. Escallier	G. Morgan
	B. Parker
G. Ganetis	W. Sampson
A. Ghosh	P. Wanderer

And the experienced designers and technicians.

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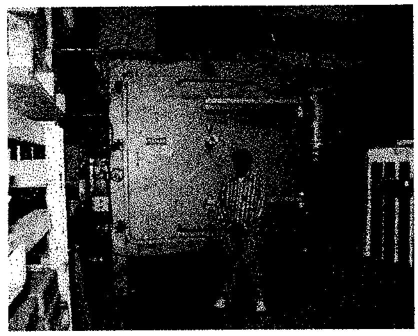
Nb_3Sn Reaction Furnace (Large)



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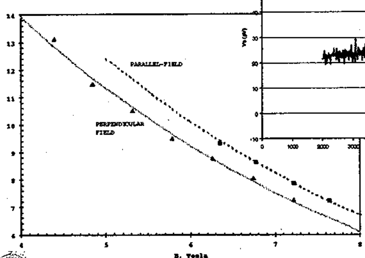
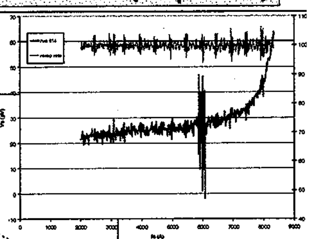
Nb_3Sn Cable Short Sample Test at BNL (Arup Ghosh)

Question:
Do we ha e to be super-careful in handling reacted Nb_3Sn cable?





Observation:
ITER cable (obtained from LBL) was reacted at BNL. Went through some handling (including show and tell pass in conference room). However, J_c remained in line with expectations.

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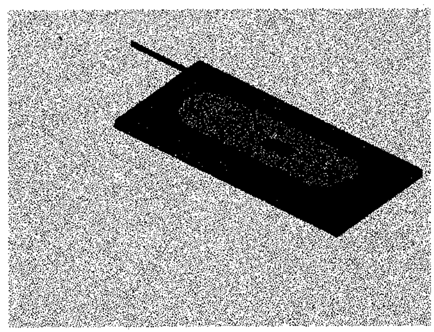
Drawing of 10-turn Coil Showing Inner and Outer Lead (all 2d)



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Nb_3Sn Cable Coming Out of Spool

The coil is wound like a regular NbTi coil, of course with proper care (e.g., lower tension). This should help establish procedure, care (cost) required for Nb_3Sn magnets.

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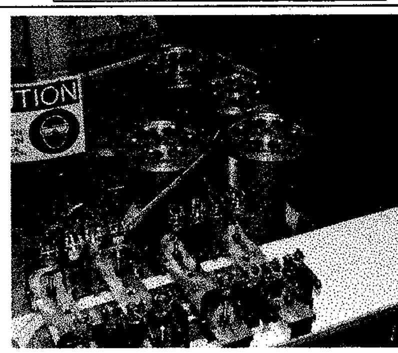
Coil Tensioner with 10-turn coil on the Winding Table



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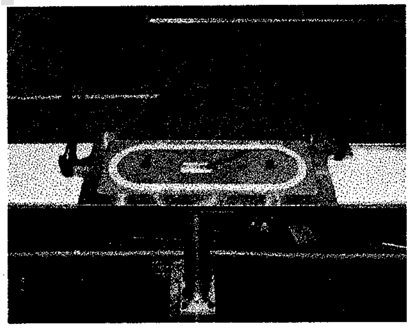
10-turn Coil Being Prepared for Vacuum Impregnation



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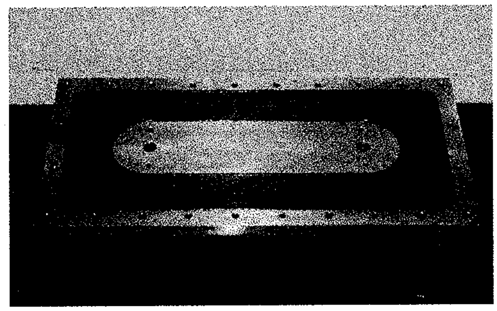
Side Plate for Vacuum Impregnation



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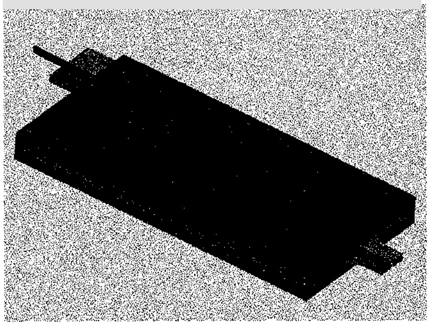
Drawing of *One* Coil Module (ready for vacuum impregnation)



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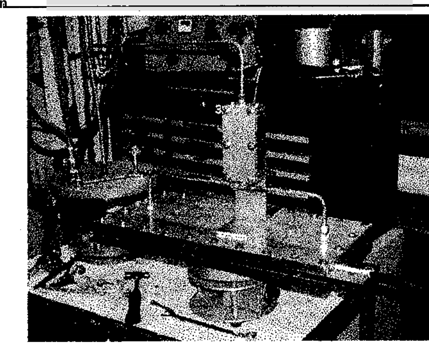
Vacuum Impregnation Setup



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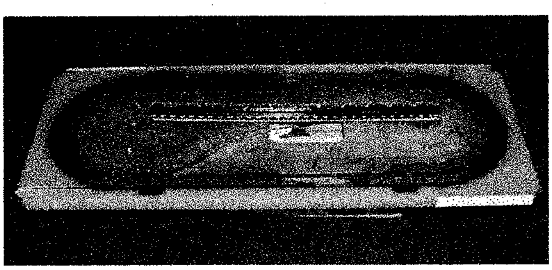
Vacuum Impregnated Coil



Vacuum impregnated coil made after "react and wind" technique

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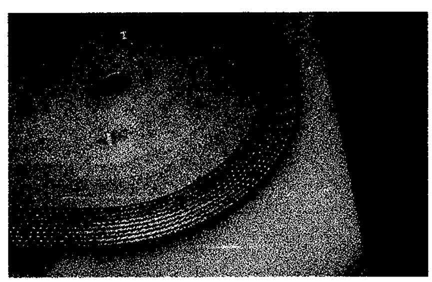
Vacuum Impregnated Coil



Non-lead end view of the vacuum impregnated coil

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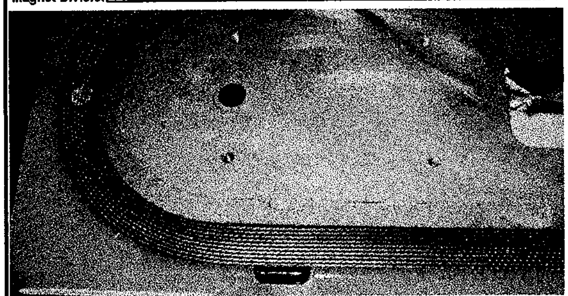
Vacuum Impregnated Coil



Lead-end view of the vacuum impregnated coil

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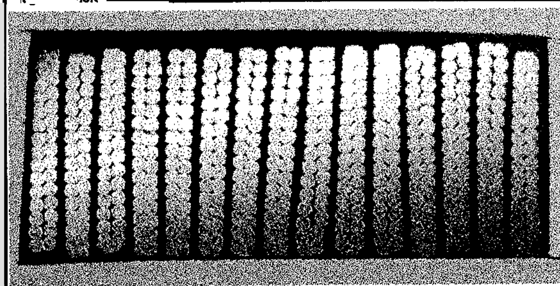
10-turn Vacuum Impregnated Cable sample



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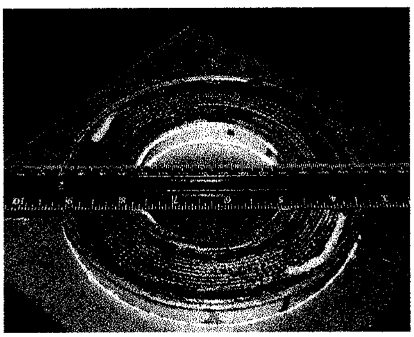
Cable Insulation Test Setup



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Field Quality in a Common Coil Design

From other speakers/experts:

PAST

One of the challenge in the common coil design is to demonstrate good field quality

Demonstrated here:

PRESENT

Common coil design can produce as good field quality as cosine theta design with similar amount of conductor

Significant progress since last meeting!

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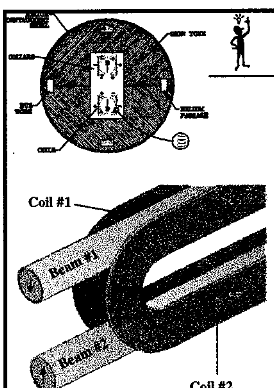
Common Coil Design (The Basic Concept)



Main Coils of the *Common Coil Design*

- ...ple 2-d ... with large bend radius (no ... 3-d ends)
- Conductor friendly (suitable for britt... ...als - most are - Nb_3Sn, HTS tapes and HTS ...)
- Compact (compared to single aperture LBL's D20 magnet, half the yoke size for t... aperture...)
- Block design (for large Lorentz forces at high fields)
- ...at and ... R&D due to simple & ... design
- Minimum requirements on big expensive tooling and labor
- Lower cost magnets expected

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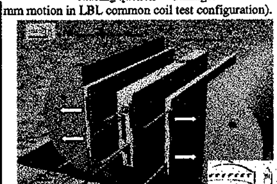
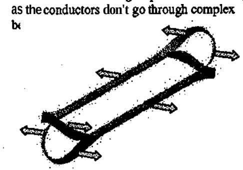
Common Coil Design in Handling Large Lorentz Forces in High Field Magnets

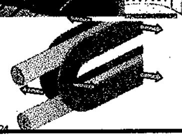
In common coil design, geometry and forces are such that the impregnated solid volume can move as a block without causing quench or damage. Ref.: over 1 mm motion in LBL common coil test configuration).



In cosine theta designs, the geometry is such that coil module cannot move as a block. These forces put strain on the conductor at the ends and may cause premature quench. The situation is somewhat better in single aperture block design, as the conductors don't go through complex b...



Horizontal forces are larger



We must check how far we can go in allowing such motions in the body and ends of the magnet. This may significantly reduce the cost of expensive support structure. Field quality optimization should include it (as was done in SSC and RHIC magnet designs).

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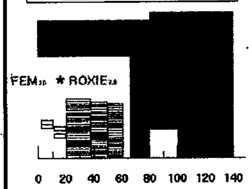
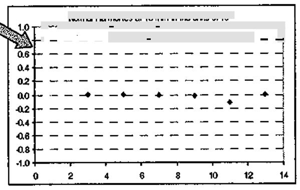
Progress in Field Quality Geometric Harmonics

Typical Requirements: ~1 in 10^4 we have part in 10^5





(from 1/4 model)

MAIN FIELD: -1.86463 (IRON AND AIR):

b 1:	10000.000	b 2:	0.00000	b 3:	0.00308
b 4:	0.00000	b 5:	0.00075	b 6:	0.00000
b 7:	-0.00099	b 8:	0.00000	b 9:	-0.01684
b10:	0.00000	b11:	-0.11428	b12:	0.00000
b13:	0.00932	b14:	0.00000	b15:	0.00140
b16:	0.00000	b17:	-0.00049	b18:	0.00000

Earlier models used slanted auxiliary coils.
The above model uses all flat coils.

BNL design uses very small spacing between modules. Above design is consistent with that.

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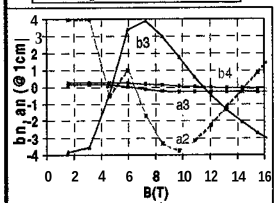
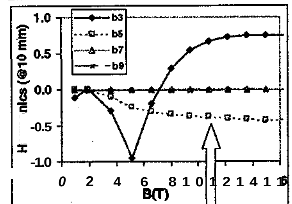
Progress in Field Quality Saturation-induced Harmonics

Use cutouts at strategic places in yoke iron to control the saturation.

Saturation in earlier designs: several parts in 10^4



New designs: ~ part in 10^4
Satisfies general accelerator requirements



Low saturation induced harmonics till 15 T with a single power supply

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An Example of End Optimization with ROXIE (iron not included)

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

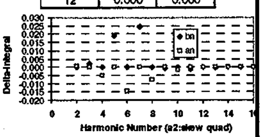
(Very small)

End harmonics in Unit-m

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



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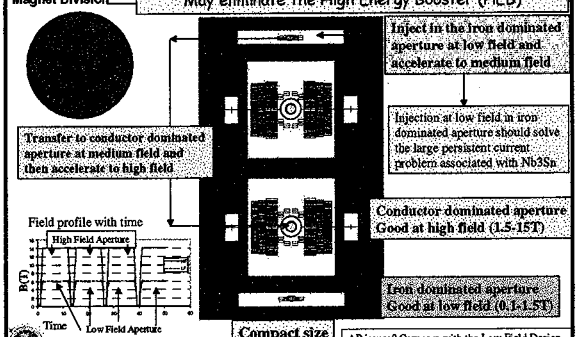
A Common Coil Magnet System for VLHC
A Solution to Persistent Current Problem
May eliminate the High Energy Booster (HEB)



Compact size

AP issues? Compare with the Low Field Design.

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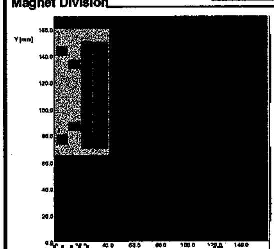
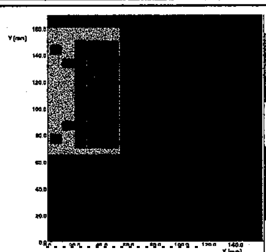
Initial Considerations of A 12.5 T Magnet Design



All Nb_3Sn Design
Cu/Sc Inner: 1.2, outer: 2.7 for Jcu ~ 1500 A/mm^2
(conductor use at 12.5 T is about 1/2 of that at ~15 T)
*** Nb_3Sn portion in outer may be reduced



Hybrid Nb_3Sn (Inner) and NbTi (outer) Design
Cu/Sc Inner 1.2, Outer: 1.5
(Inner same as in all Nb3Sn)

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Is hybrid design really a better solution for a 12.5 T magnet?

- Mixing two technologies may *create* complications. Also a larger required volume of NbTi conductor makes the support structure and magnet bigger.
- J_c of Nb_3Sn at 8 T (field in outer coil) is over 4 times that of NbTi.
- Compare the cost of the same size (*0.8* mm) wire per meter (remember much more NbTi is needed)
  - NbTi: ~$0.65/m
  - Nb_3Sn: ~$3.50-$4.00/m (W E Goal ~$1/m)
  - Copper. by weight, is about an order of magnitude cheaper. The effective cost of Nb_3Sn *can* be significantly reduced by mixing it

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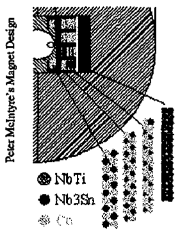
Schemes of Adding Cu to Nb_3Sn to Reduce Overall Conductor Cost

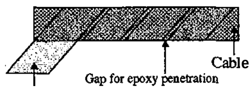
Generally discussed

Mix copper strand with Nb_3Sn strand



An alternate **proposal**

Wrap copper strip on Nb_3Sn cable



Role of epoxy between SC & Cu?

Better packing factor
Lower strand diameter
May make better cable
Better (no) matching of different strands

10-turn coil program is ideal for feasibility studies of such ideas.

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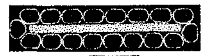
HTS Common Coil Program

BNL is embarking on a promising BSCCO 2212 common coil "cable" magnet program.



kA quality Rutherford cable. A very good collaboration between labs (BNL, LBL) and industries (IGC, Showa).

10kA type Rutherford cable may be possible in near future!

Over 80 meter of kA class cable (ova 1 5 km of wire) to be shortly available (weeks to months, in installments) to BNL for testing cables, winding coils, making short magnets, etc

Current plan:

First test a pair of 10-nun coils in common coil configuration.
Then depending an the progress, continue with more 10-turn coils and/or go for full 40-turn cable (either Ag and mix or all HTS strands) coil.
Test a pair of coils in a stand-alone mode and in a hybrid high field configuration.

More on HTS in a l a t a talk by Arup Ghosh.

*** Special thanks to Robert Sokolowski (IGC) and Ron Scanlan (LBL).

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Cost Saving Opportunities in VLHC

A multi-uronged approach:

- Lower cost magnets expected from a simpler geometry.
- Possibilities of applying new construction techniques in reducing magnet manufacturing costs.
- Possibilities of reducing aperture due to more favorable injection scenario in the proposed common mil magnet system design.
- Possibility of removing the high energy booster (the second largest machine) in the proposed system.
- Possibility of removing main quadrupoles (the second most expensive magnet order) in the proposed combined function magnet design.

Need to examine the viability of these proposals further; need to continue the process of exploring more *new ideas and* re-examine old *ones* (they may be attractive now due to advances in technology, etc.): need to keep focus on the bigger picture...

VLHC cost reduction may also come from otha advances: cheaper tunneling. development of superconductor technology, etc.

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SUMMARY

- Set on a path for carrying out dynamic and innovative magnet R&D.
- This is expected to significantly reduce the cost of building VLHC.