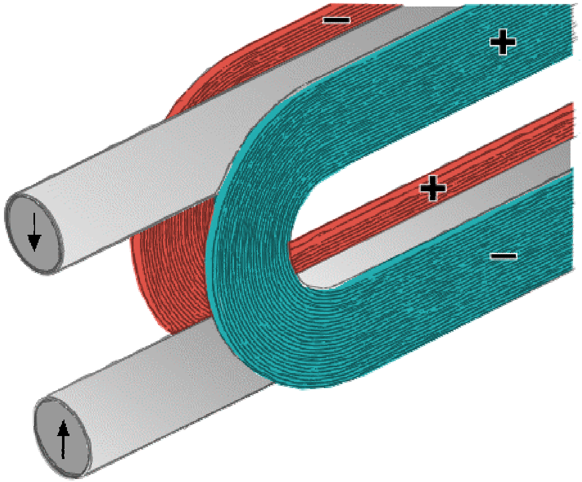


Common Coil Magnet Program at BNL

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

Ramesh Gupta
Superconducting Magnet Division
Brookhaven National Laboratory
Upton, NY 11973 USA

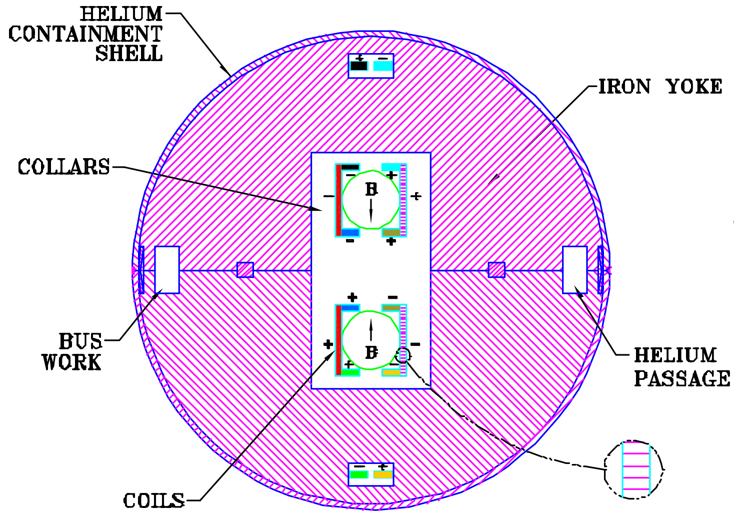
gupta@bnl.gov
http://magnets.rhic.bnl.gov/gupta/commoncoil

Outline of the Presentation

- High Field Magnet R&D Program at BNL
- Cost-effective Mini R&D Program with Rapid Turn-around
- Test Results of First Nb_3Sn "React &Wind" Mini-magnet
  - Could change the way we have been dealing with brittle conductors

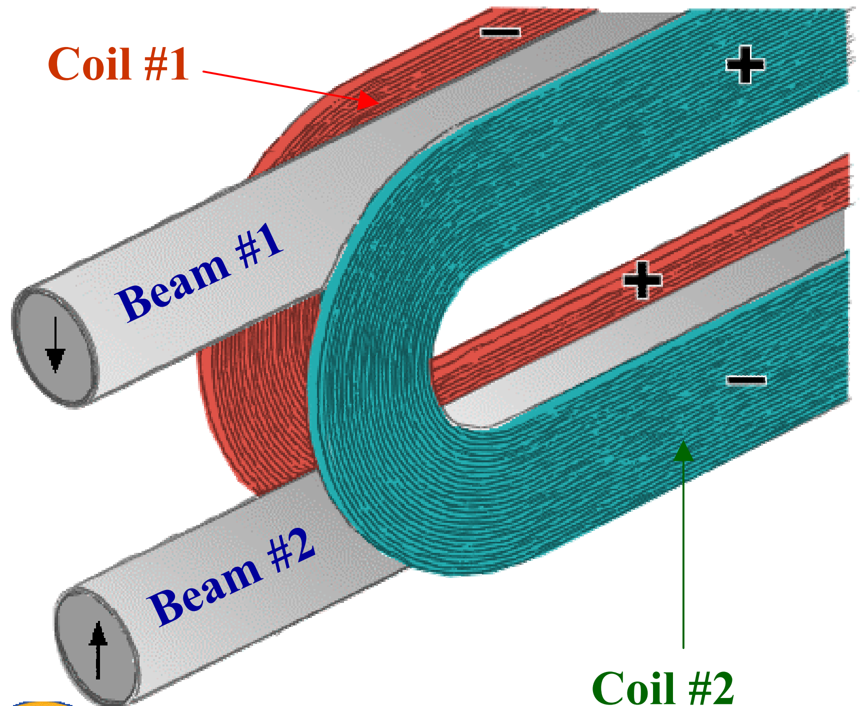
And if time permits

- Field Quality in Common Coil Design
  - End harmonics: 10^{-5} unit-meters
  - Geometric: 10^{-5} units or less
  - Saturation-induced harmonics: 10^{-4} with single power supply



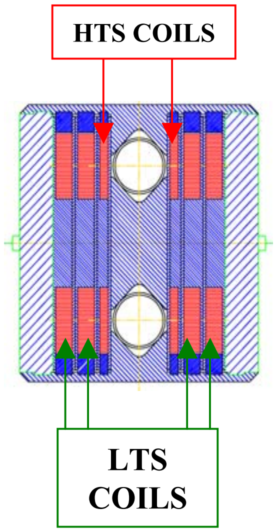
Common Coil Design
(The Basic Concept)

- **Simple 2-d geometry with large bend radius ()**
- **Conductor friendly (no complex 3-d ends, suitable for brittle materials - most for H.F. are - Nb_3Sn and HTS)**
- **Compact (compared to single aperture LBL's D20 magnet, half the yoke size for two apertures)**
- **Block design (for handling large Lorentz forces at high fields)**
- **Combined function magnets possible**
- **Efficient and methodical R&D due to simple & modular design**
- **Minimum requirements on big expensive tooling and labor**
- **Lower cost magnets expected**



Main Coils of the *Common Coil Design*

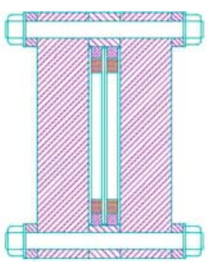
Common Coil Magnet R&D at BNL



Primary Goal of the Program:

Design and build a ~12.5 Tesla, "React & Wind" Common Coil Magnet with HTS playing a major role.

R&D Plan to Develop Technology:



A "*mini 10-turn magnet R&D program*" to systematically develop and test new ideas, designs and technologies (React & Wind HTS) in a time and cost effective manner.

At this price, we can afford to built many coils and afford to see some destroyed in an attempt to understand and develop new technology and find a limit of others.

That philosophy is in-built in the "Program Design"!

"React & Wind" Approach at Brookhaven

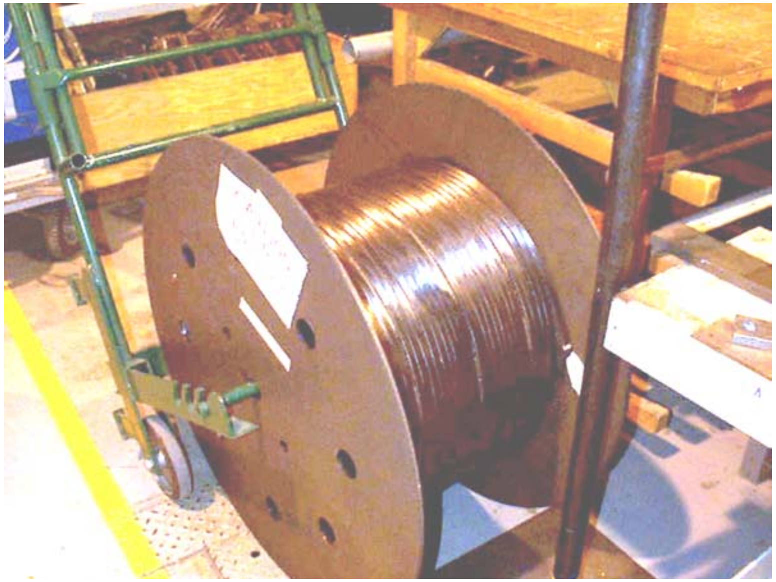
- Find out if we can adopt most of the NbTi tools, facilities and procedure in building coils and magnets with brittle materials
- Payoffs are significant, it gives a big jump start
  - NbTi Magnet Technology has matured, adopting and scaling it up should be easier, faster and relatively less expensive
  - Since the coil does not to go through the "reaction cycle", there is much more choice in selection of associated components

Must for HTS

Nb_3Sn Reaction Facility at BNL

Large (1.5 m^3) reaction furnace at BNL.

It was used for making full length Nb_3Sn magnets.



Nb_3Sn cable after reaction.

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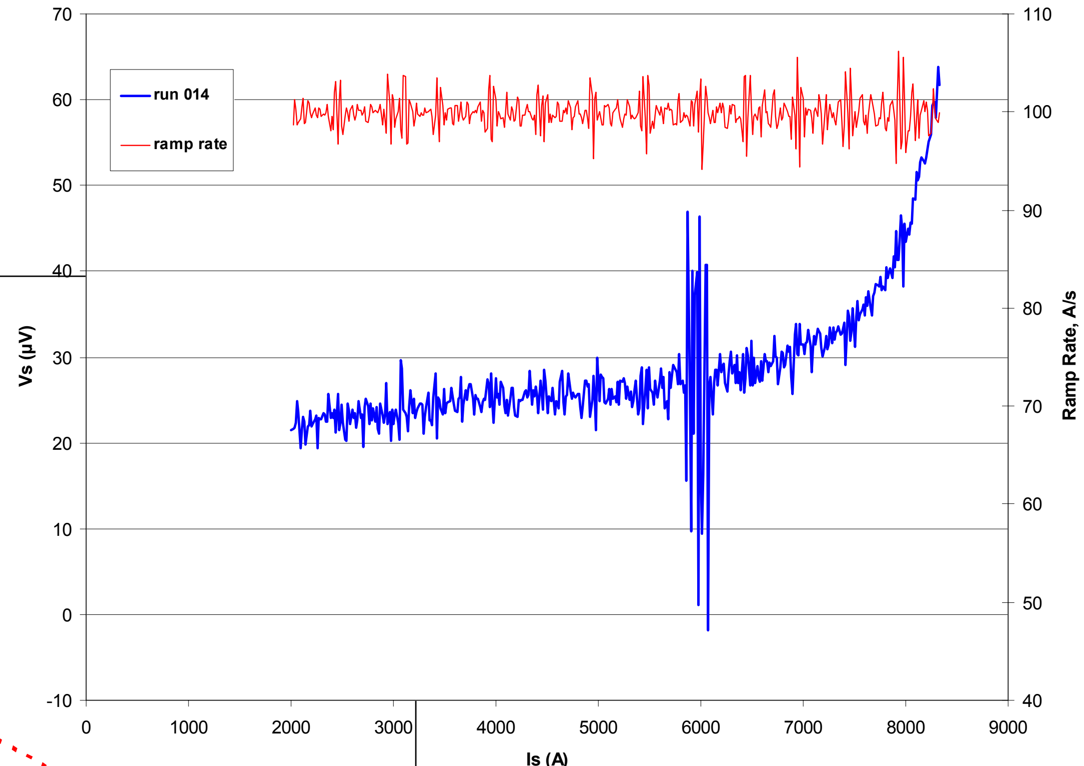
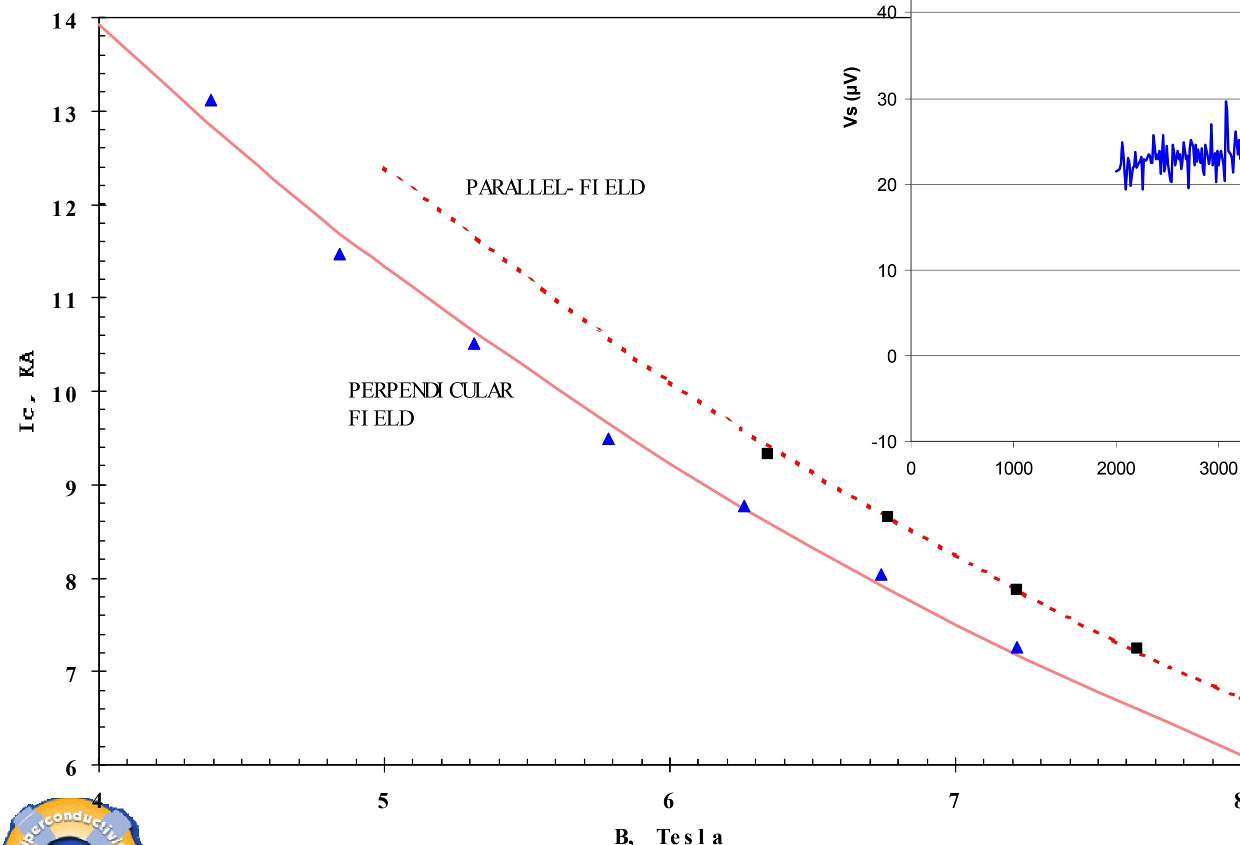
Nb_3Sn Cable Short Sample Test at BNL (Arup Ghosh)

Question:

Do we have to be super-careful in handling reacted Nb_3Sn cable?





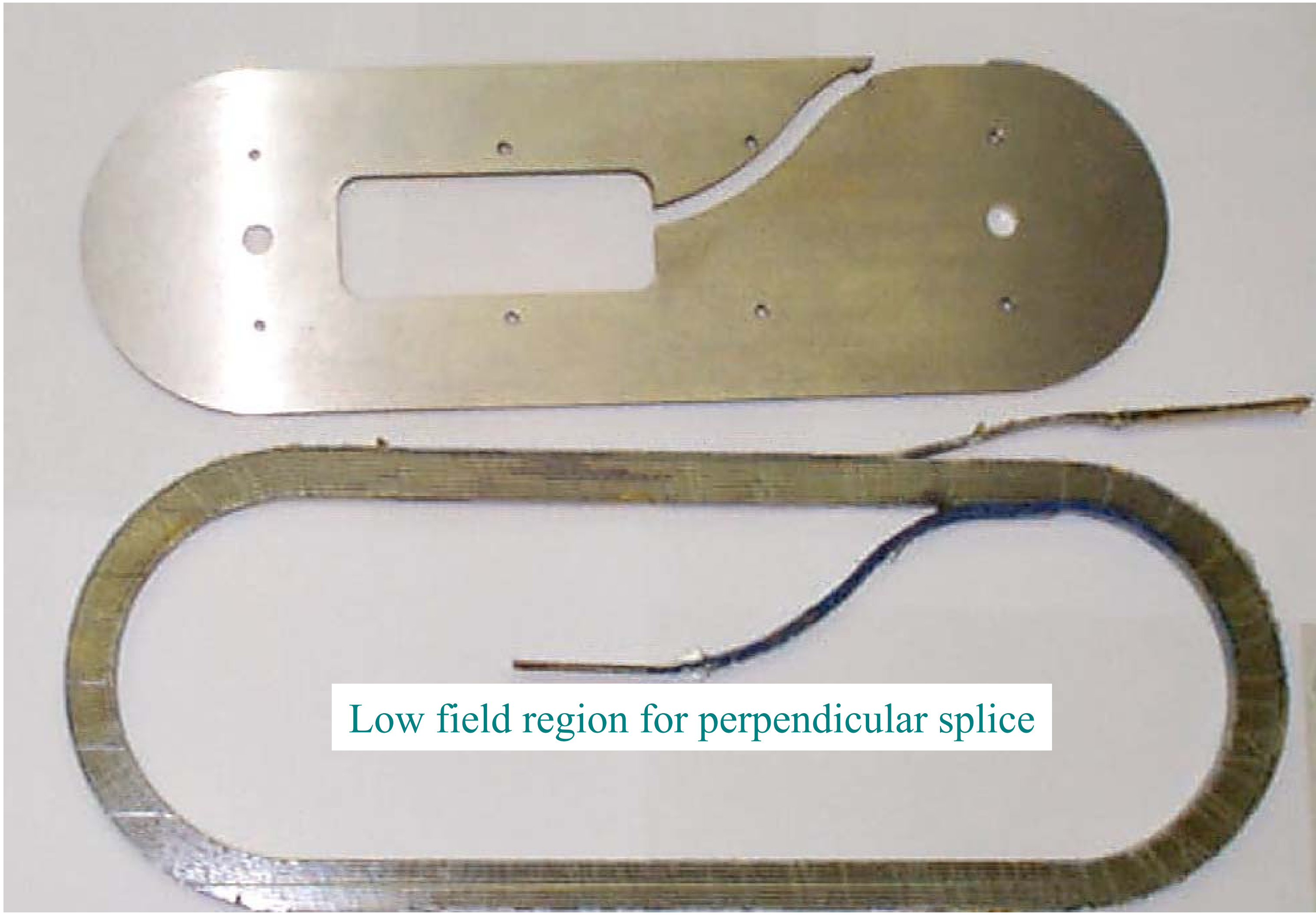
Observation:

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.

The Bobbin and the 10-turn Coil

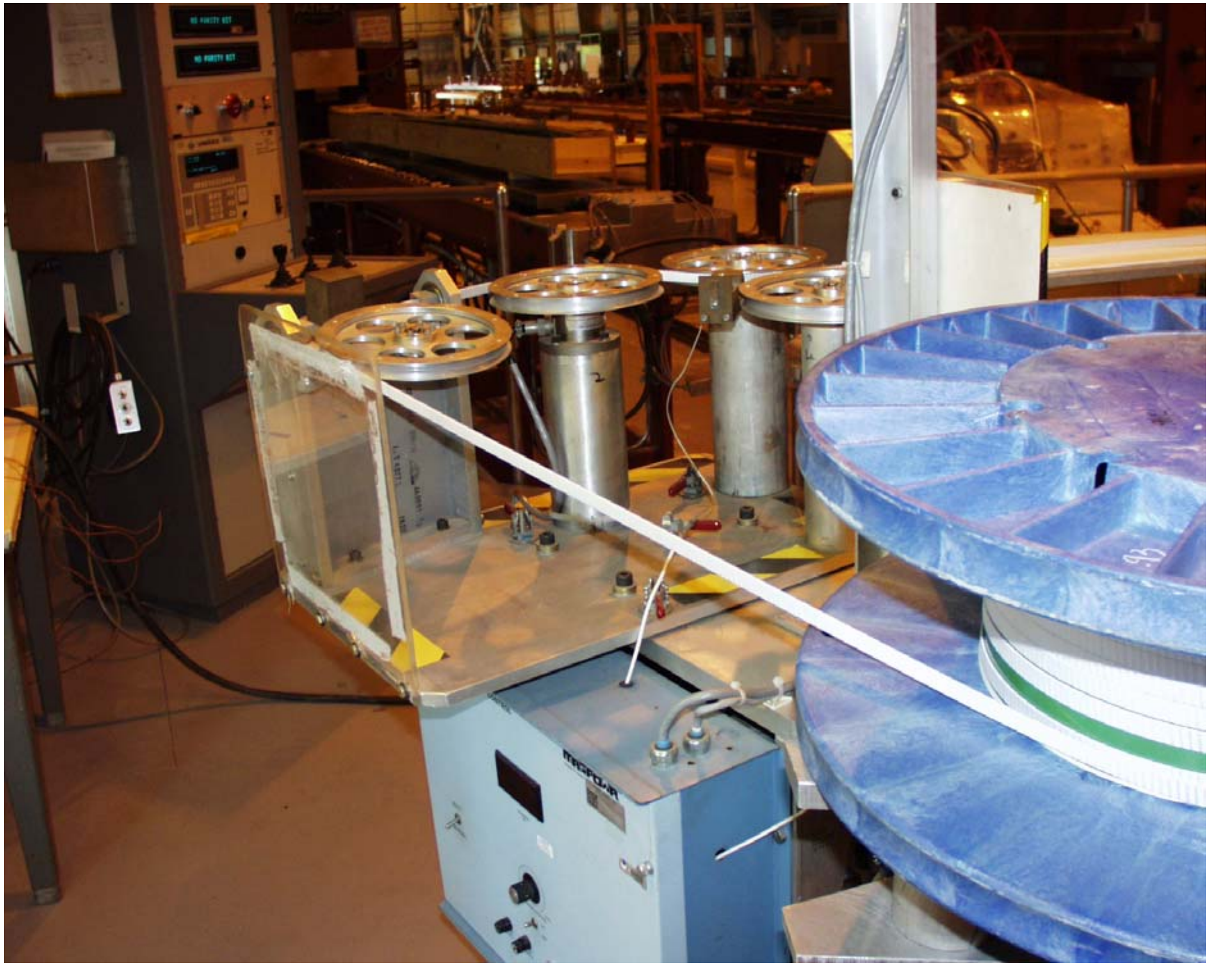
The bobbin on which the 10-turn coil is wound

The first 10-turn practice coil knocked out of bobbin after impregnation. Coil #2 and #3 were used for test

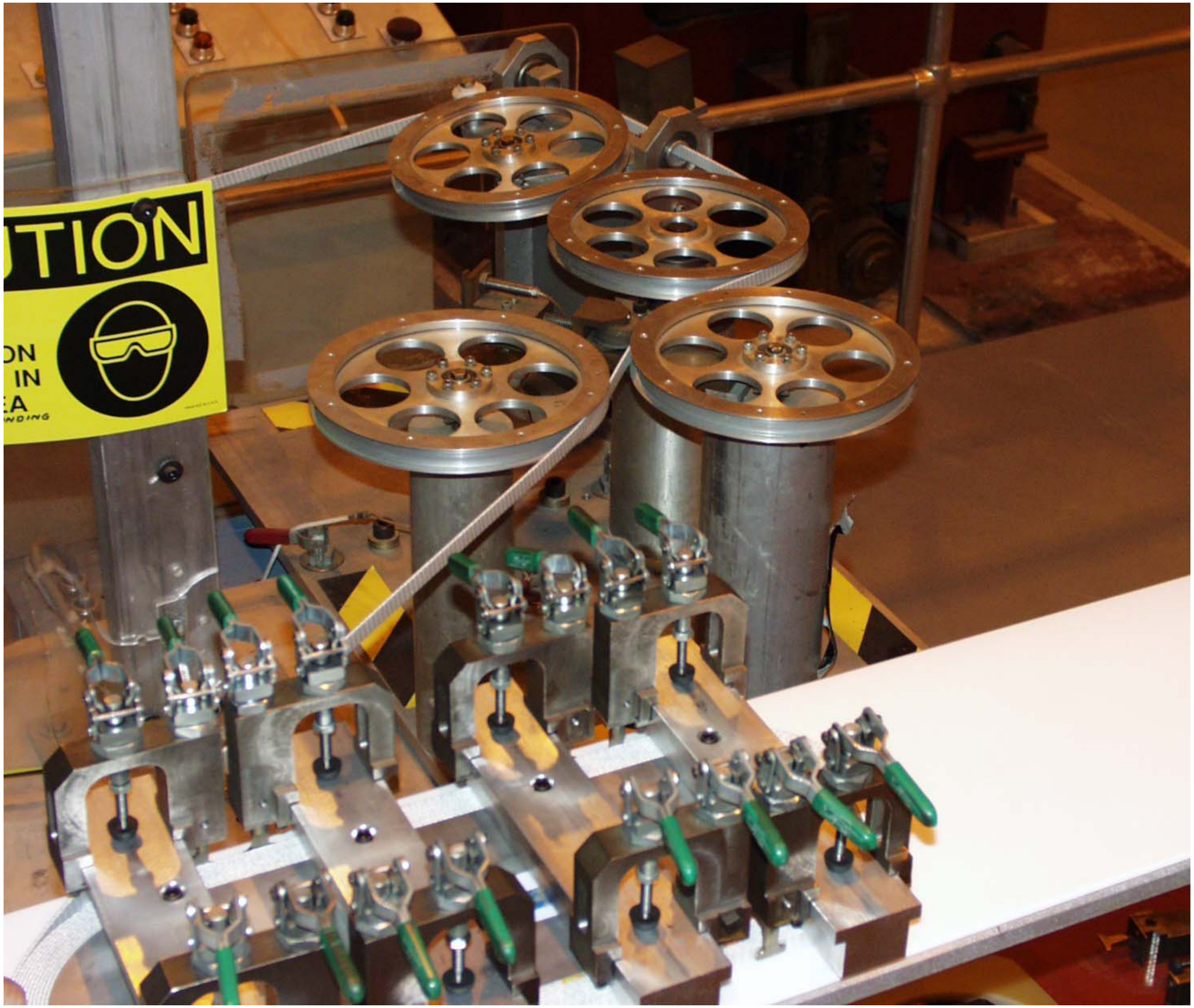


Nb_3Sn Cable Coming Out of Spool

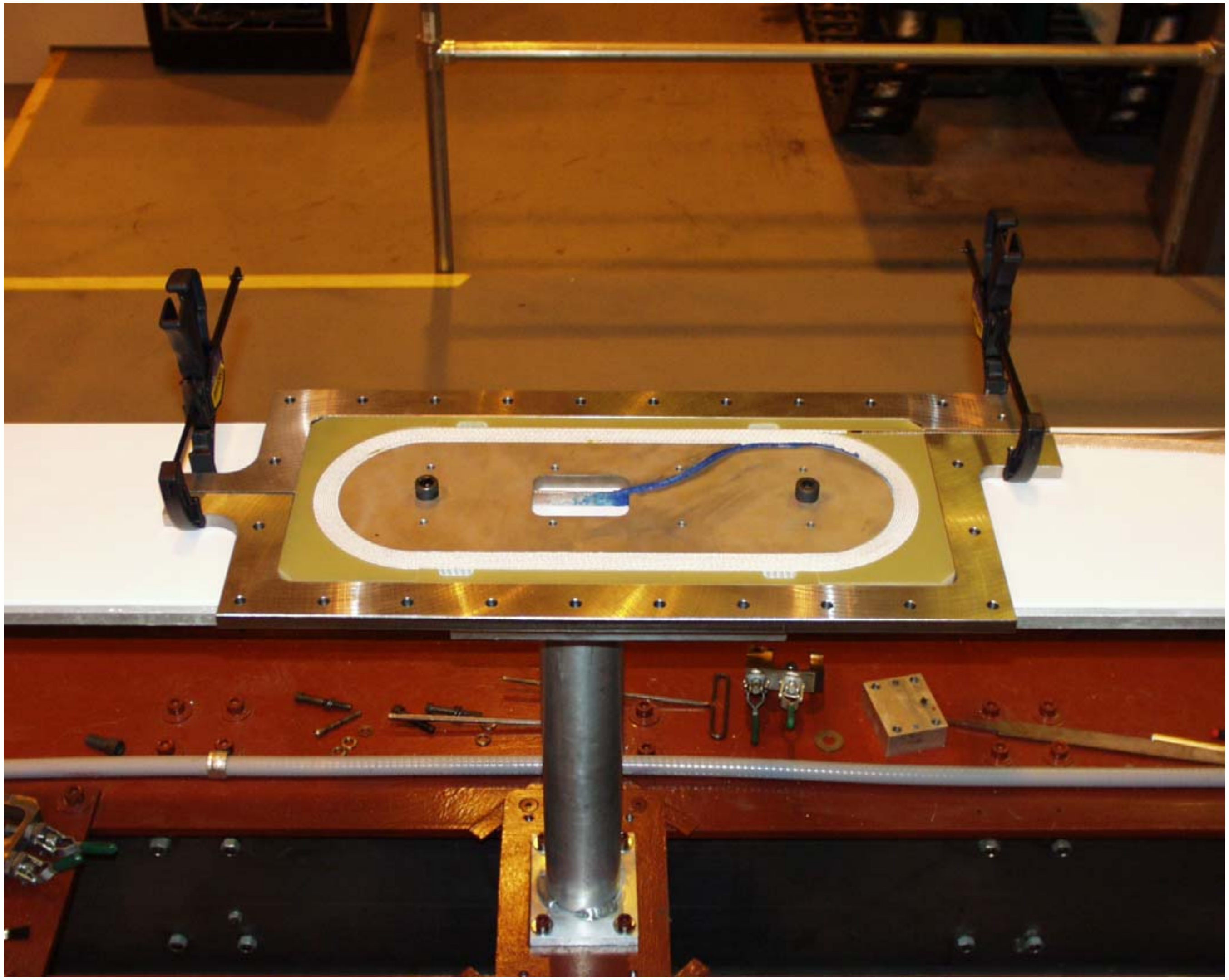
The coil is wound like a regular NbTi coil, of course with proper care (e.g., lower tension). This should help establish procedure, care (cost) required for Nb_3Sn magnets.



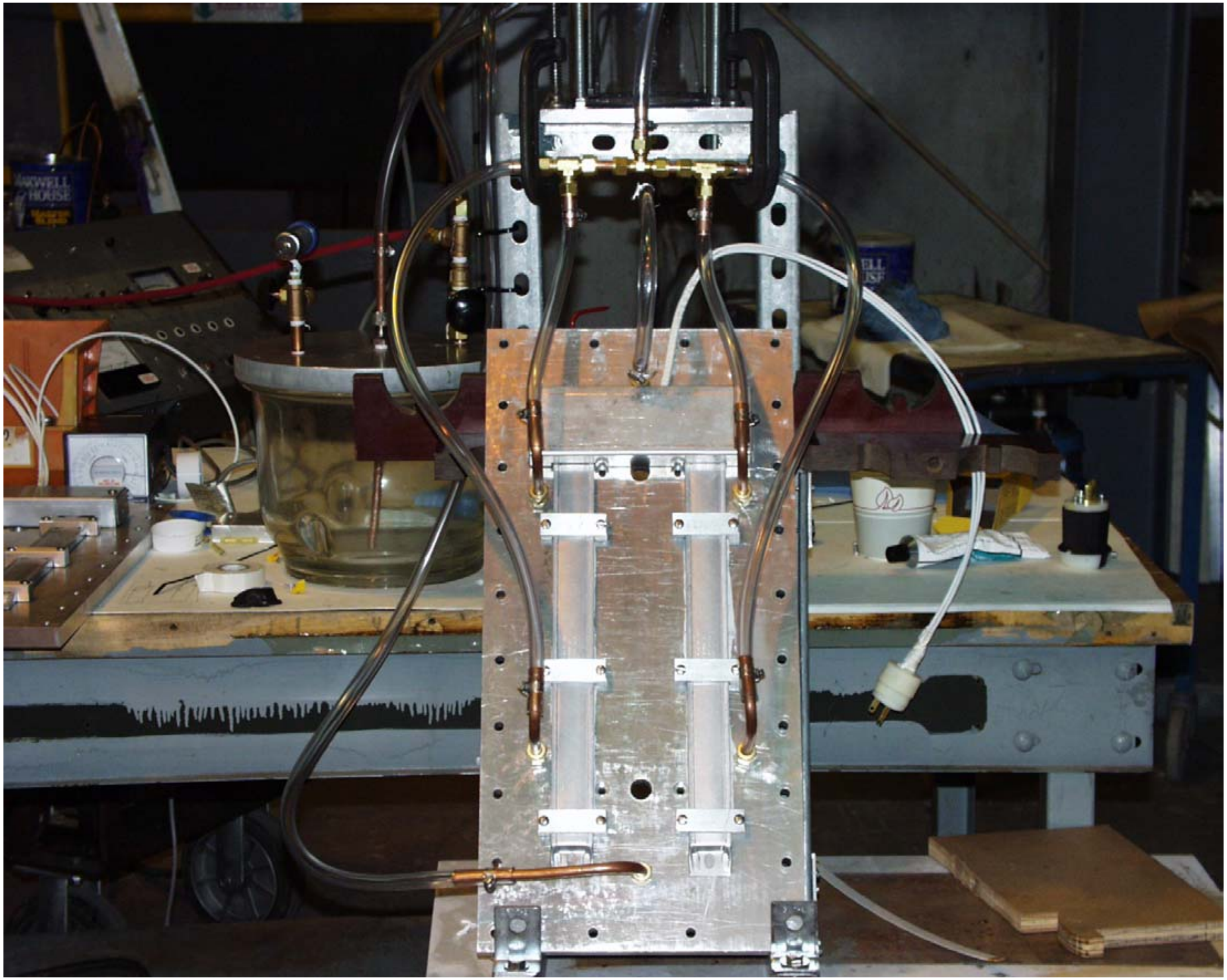
Coil Tensioner with 10-turn coil on the Winding Table



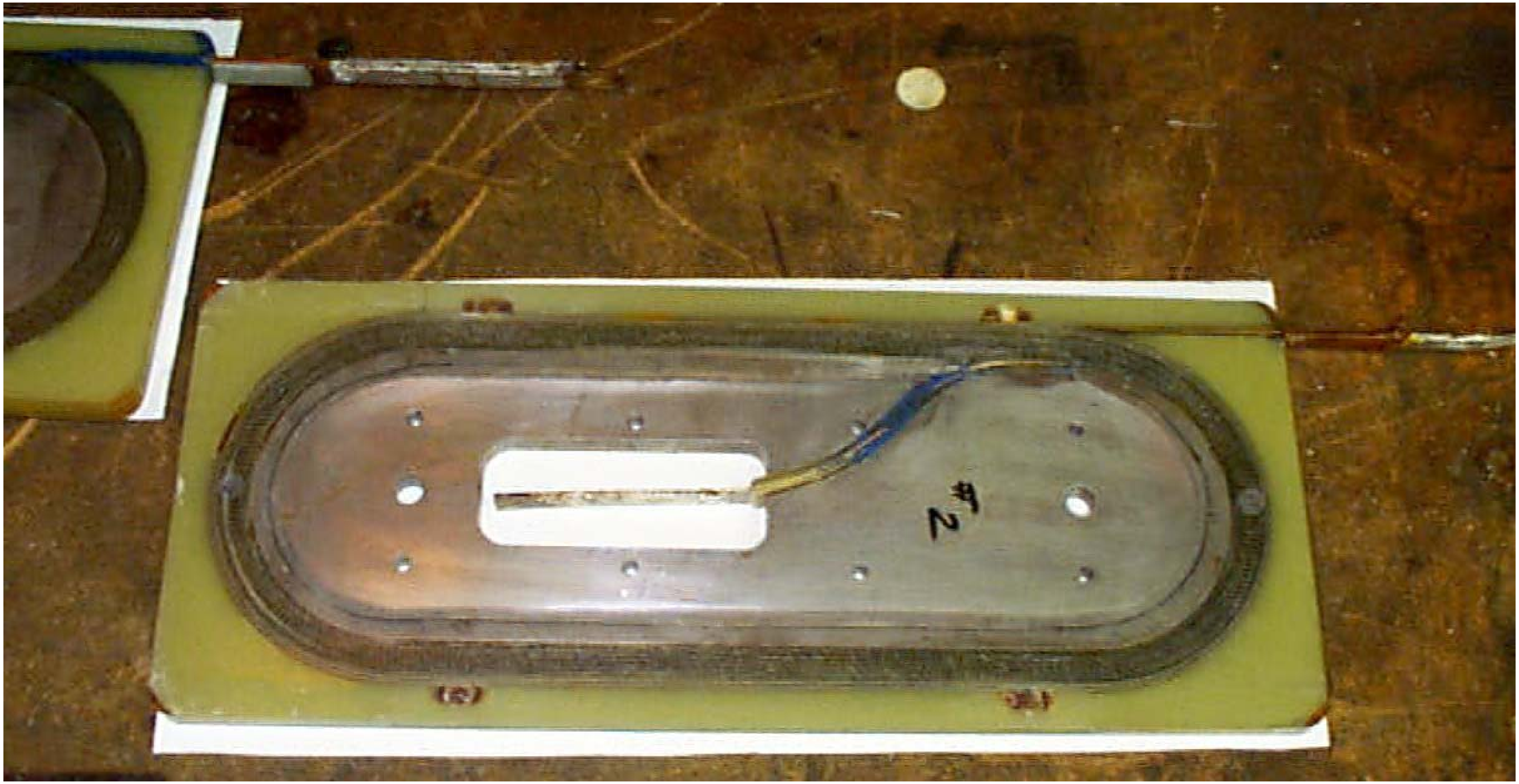
10-turn Coil Being Prepared for Vacuum Impregnation



Vacuum Impregnation Setup



Vacuum Impregnated Coils



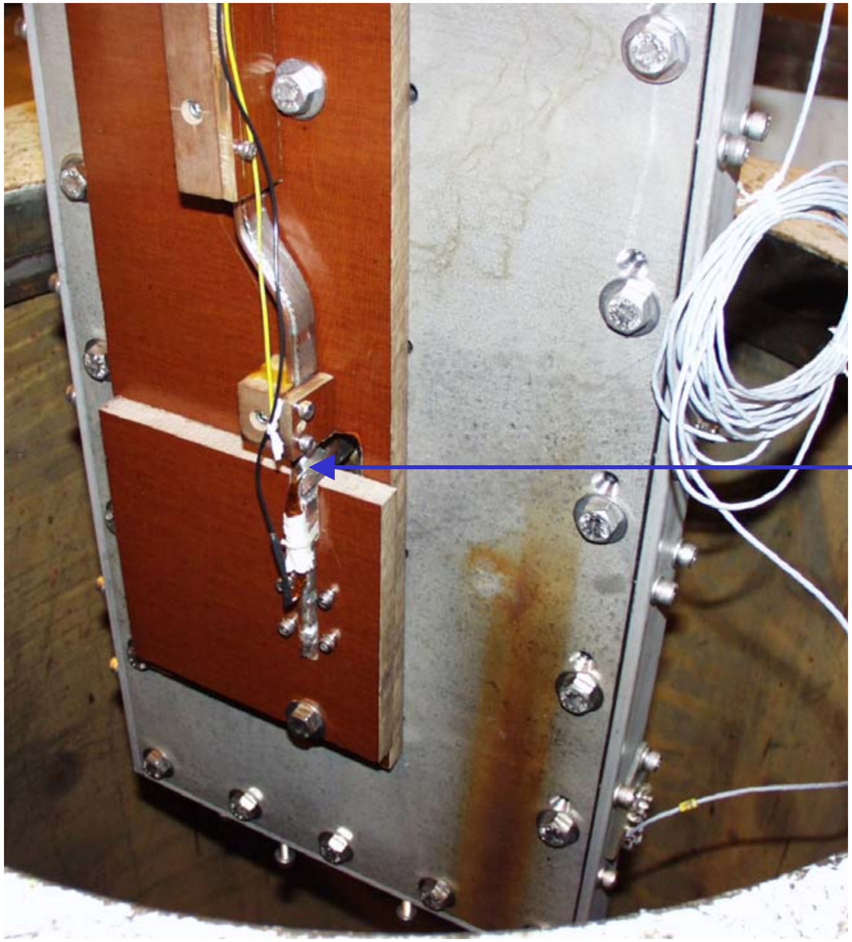
Vacuum impregnated coils made after "react and wind" technique.

This picture was taken after the coils were tested and removed from the support structure.

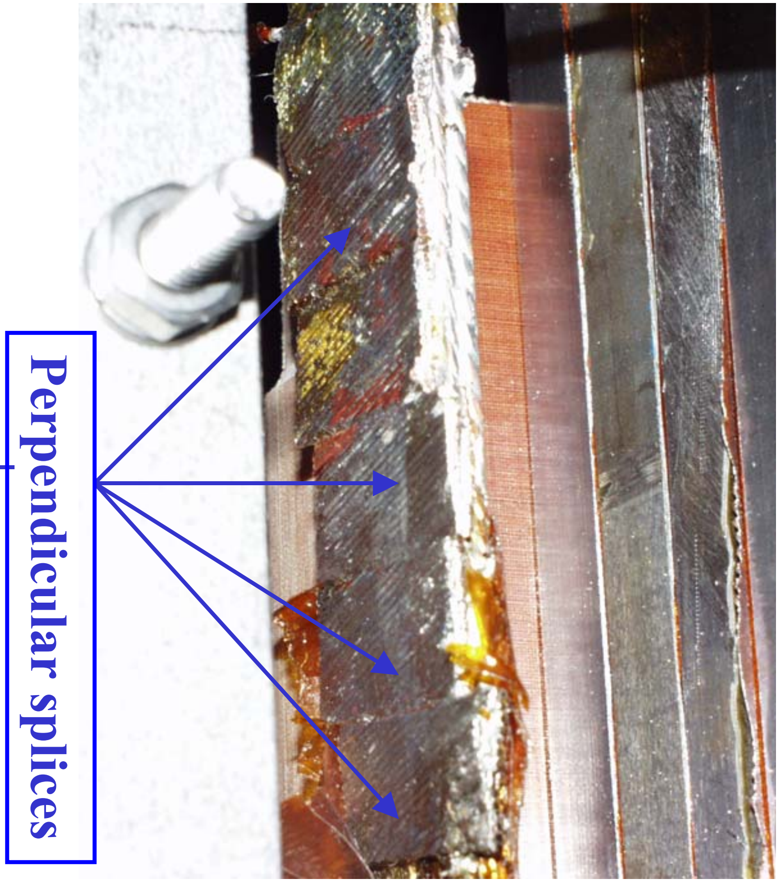
Coils in Support Structure

Two coils in a support structure

Internal Splice in Common Coil Design
(splices are perpendicular and are in low field region)

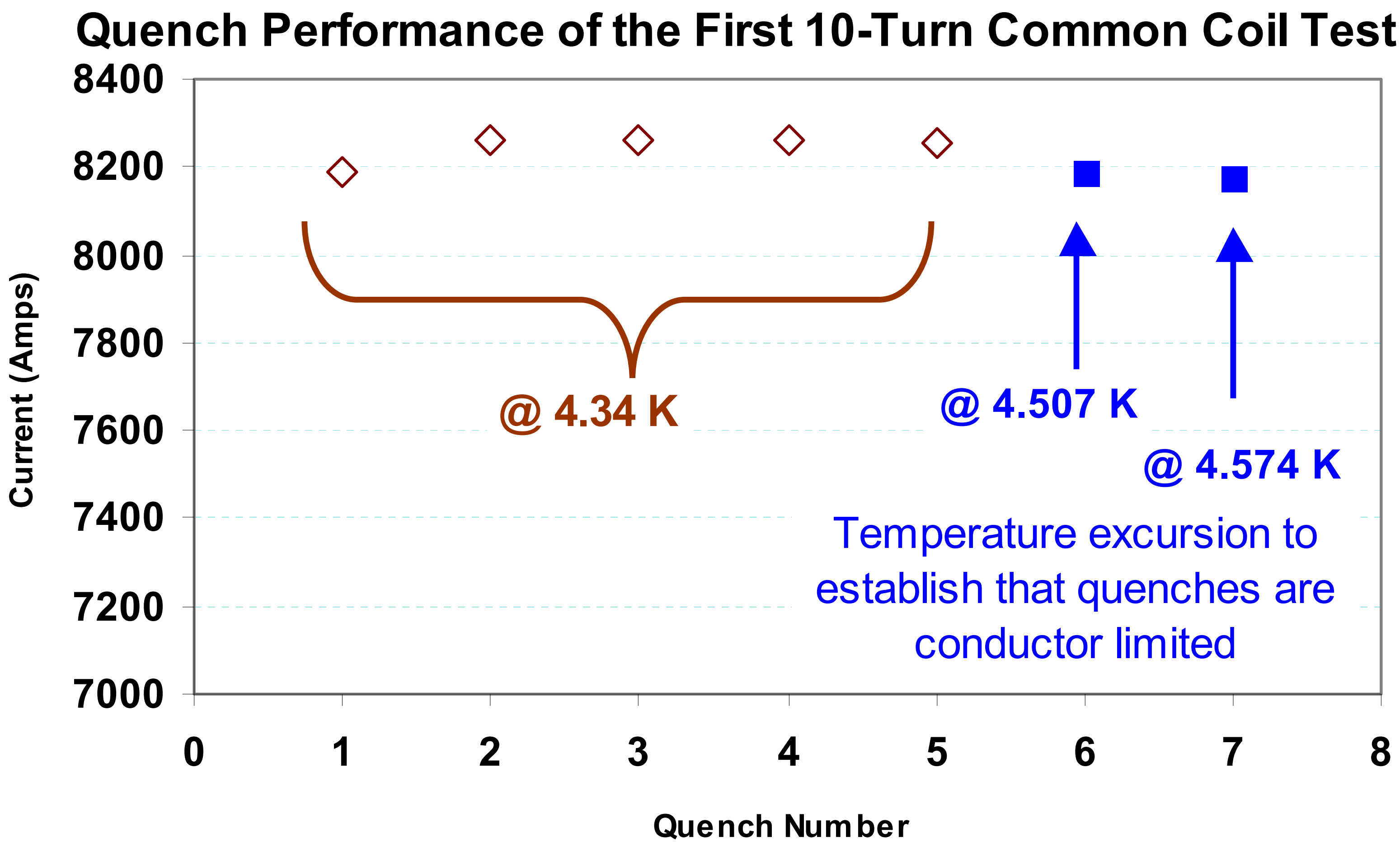


Splice for a single coil test (perpendicular splice take out the current to outside lead)



Internal splice between two coils in a common coil configuration (note several perpendicular splices)

Test Results Of 1st React & Wind Nb_3Sn Coils

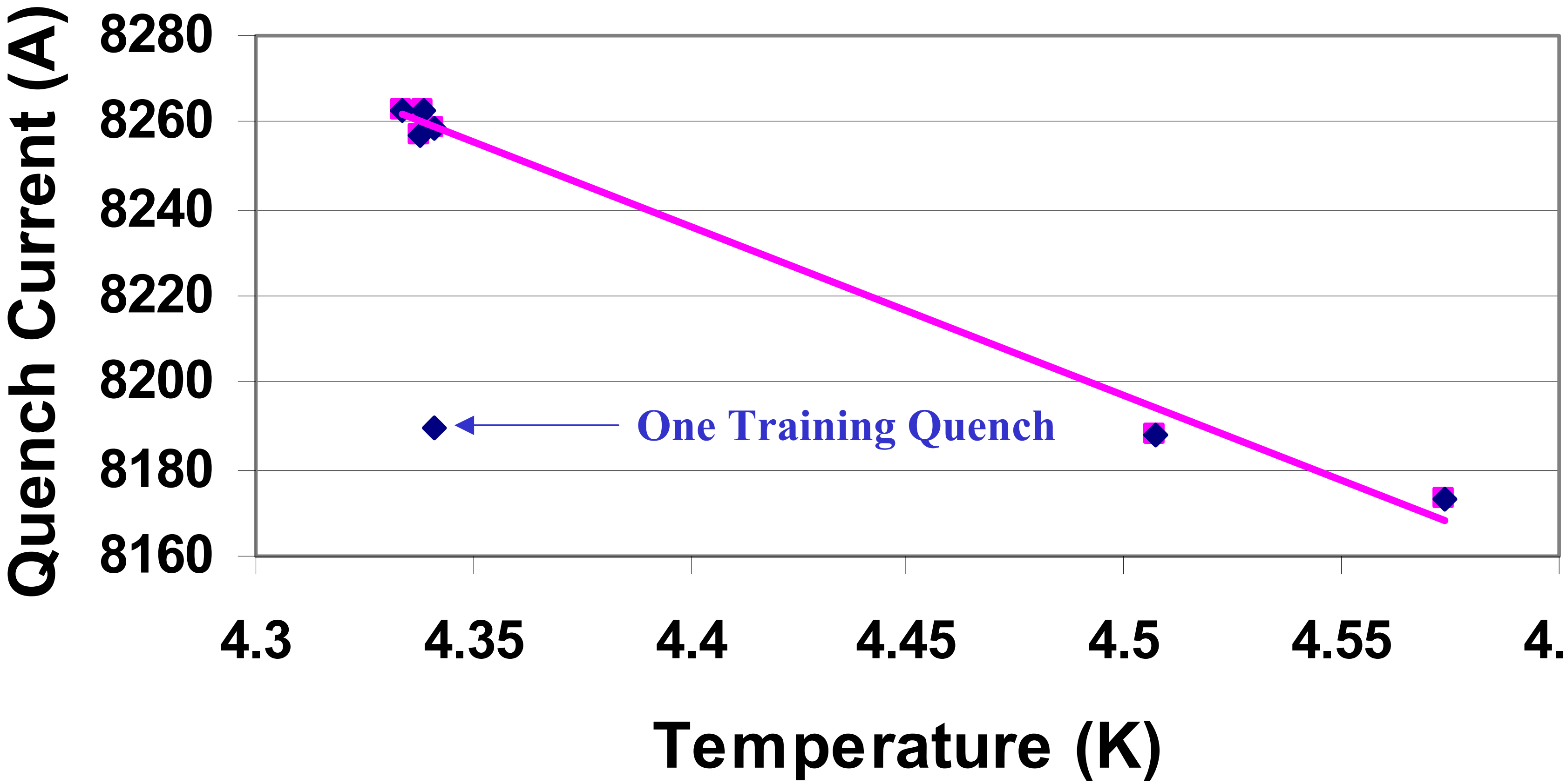


Magnet made with limited resources and by practically all technicians and engineers who were new to Nb_3Sn technology.

No problem in the splices, structure behaved well.

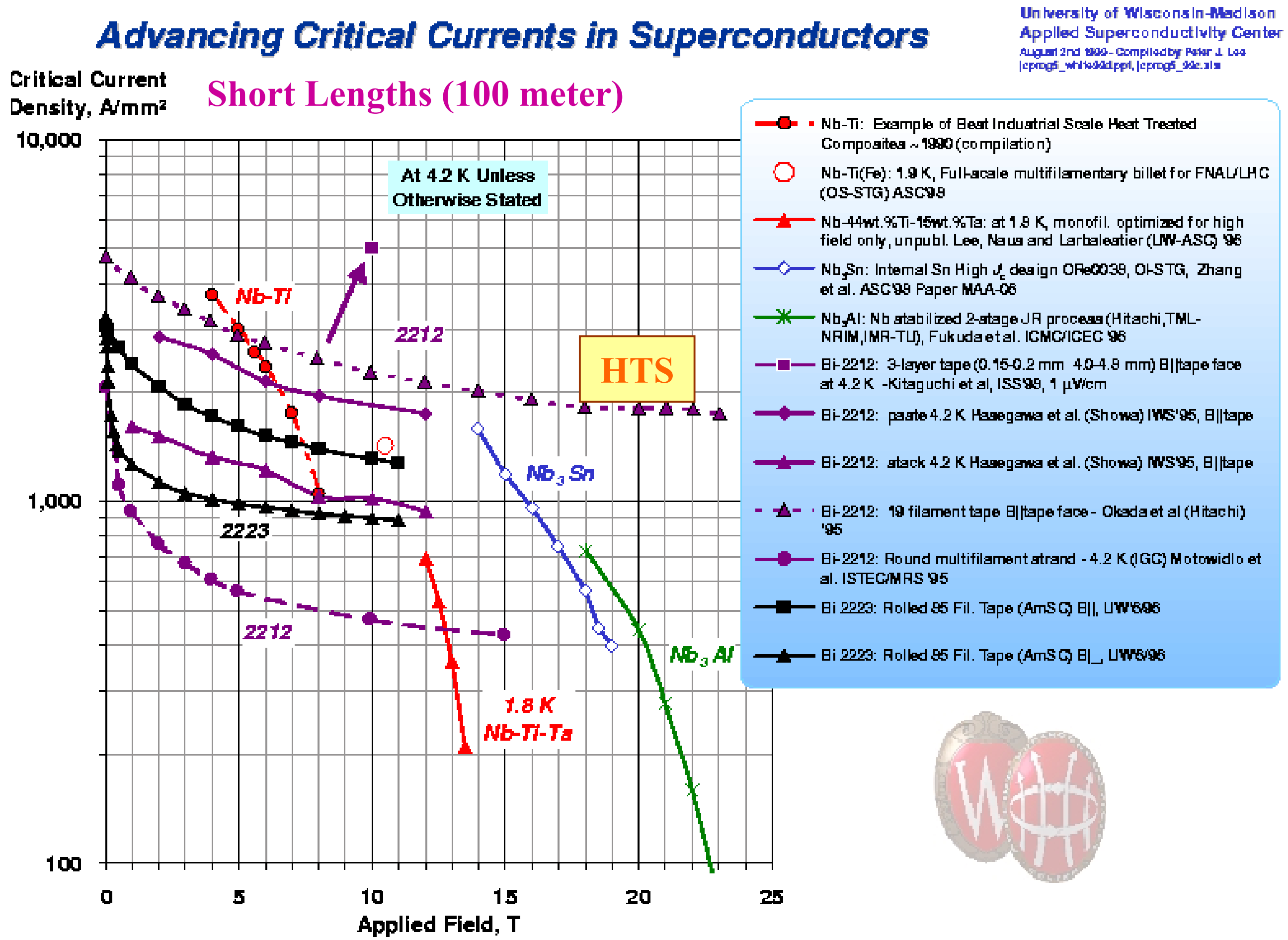
A reasonable quench performance (one training quench) and relatively small degradation(~8%), despite brittle Nb_3Sn subjected to the normal NbTi coil making process, is an encouraging sign for the future of “React & Wind” common coil magnets (including scale up process)

Temperature Dependence in Quench Current



Temperature excursion establishes that quench are conductor limited. The temperature dependence is similar to what was observed in LBL's RD2 magnet

High Field Magnets and High Temperature Superconductors (HTS)



A 30 strand cable made with recently tested wire should carry ~20 kA at zero field (4K) and ~6 kA at 15 T field.

This is ~1/3 of Nb_3Sn today.

IT'S TIME TO START HTS DIPOLE MAGNET R&D.

BNL IS PLAYING A LEADING ROLE IN THIS AREA.

BNL's Strategy on HTS Magnet Development

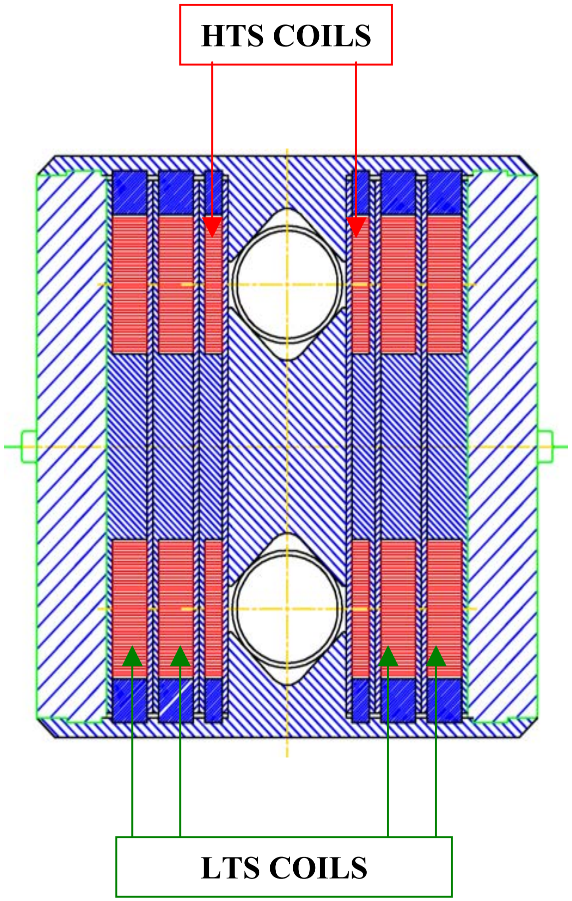
Think Long Term

- In terms of performance, HTS is knocking on the door. But it's not there yet to make a complete high field magnet HTS magnet.
- The availability of HTS cable is limited and the cost is still high.

- However, it takes a long time to do such magnet R&D!
- Start with a series of short coil 10 turn coils and quickly step in to ~50 turn coil.
- Provide high background field with Nb_3Sn using similar technology ("React & Wind") and similar design (common coil).
- Long range future is hard to see, but a high field hybrid (HTS, Nb_3Sn) magnet is a cost-effective possibility.

Immediate Program: Start with 10 turn Nb3Sn coil program to develop "React & Wind" High Field Magnet Technology and then move to HTS

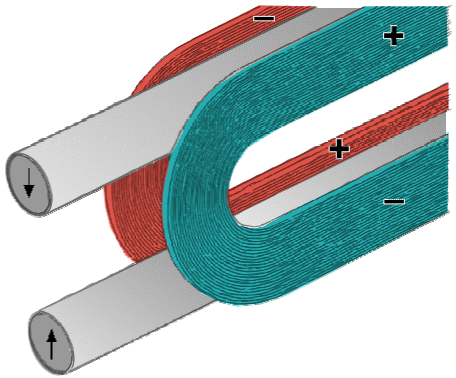
HTS in a Hybrid Magnet



- Perfect for R&D magnets now.

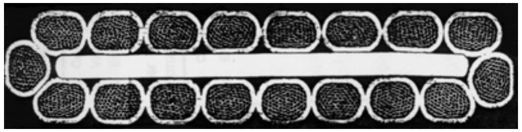
  HTS is subjected to the similar forces that would be present in an all HTS magnet. Therefore, several technical issues will be addressed.
- Also a good design for specialty magnets where the performance, not the cost is an issue. Also future possibilities for main dipoles.
- Field in outer layers is ~2/3 of that in the 1st layer. Use HTS in the 1st layer (high field region) and LTS in the other layers (low field regions).

Status of HTS Common Coil Program



HTS tape program, Bill Sampson, earlier talk.

In addition, BNL has started a program for building a series of common coil magnets using HTS (BSSCO 2212) Cable.



Over 40 meter of kA class cable (over 0.5 km of wire) has been obtained. This is enough for testing cables and to make 3 HTS coils. In addition 24 meter of high performance (a factor of 3 better) is being prepared. Also ~ 30 meter of mixed strand cable (2 BSCCO 2212 and 18 Ag) has been delivered.

Established a very good collaboration between labs (BNL, LBL) and industries (IGC, Showa). It has been very productive so far and it is being carried out in a good spirit.

Ron Scanlan (LBL)
T. Hasegawa (Showa)
R. Sokolowski (IGC)
L. Motowidlo (IGC)

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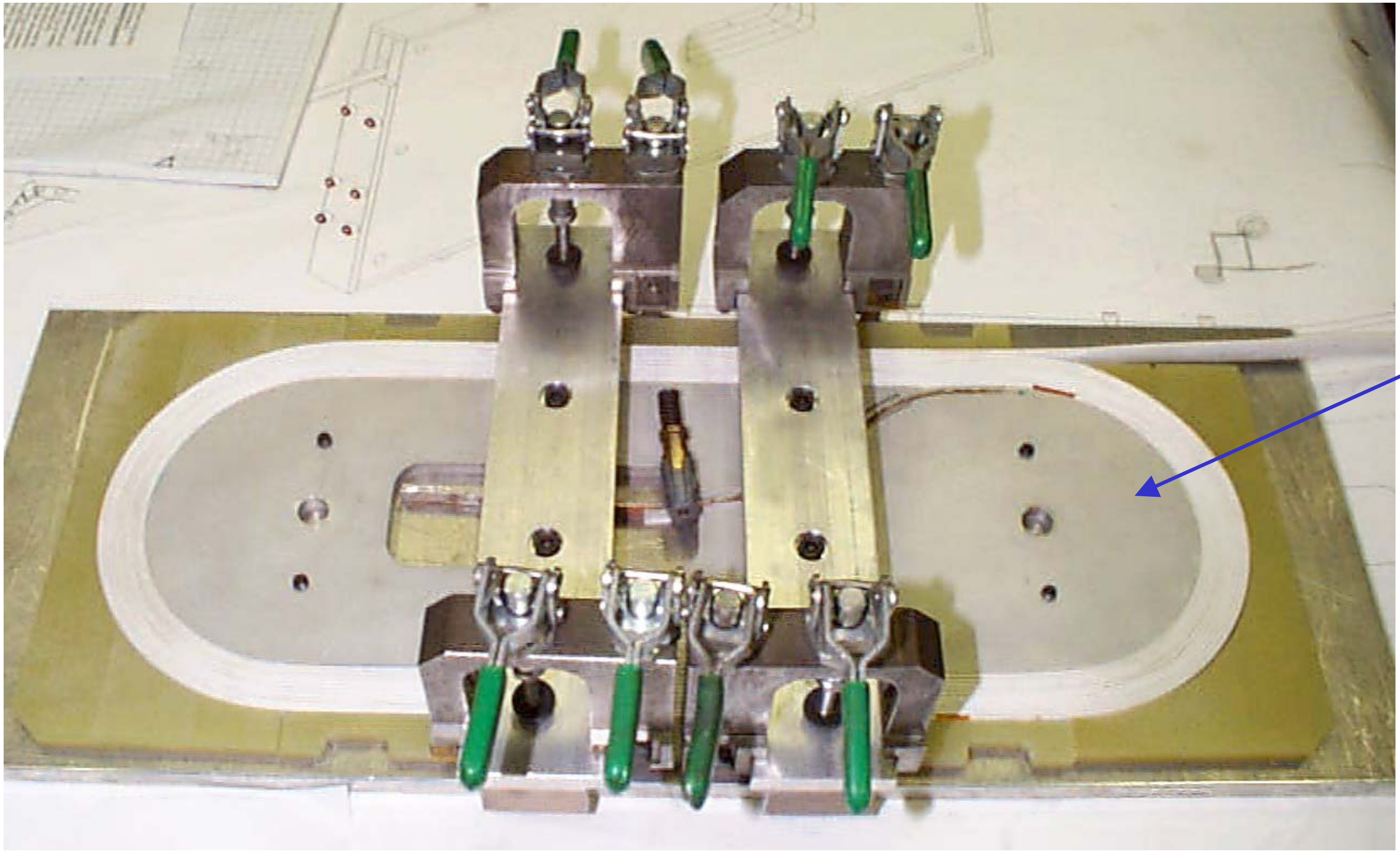
HTS Coil Wound by Hand



Al Bobbin
(Next SS Bobbin)

HTS Cable: IGC/Showa/LBNL/BNL collaboration

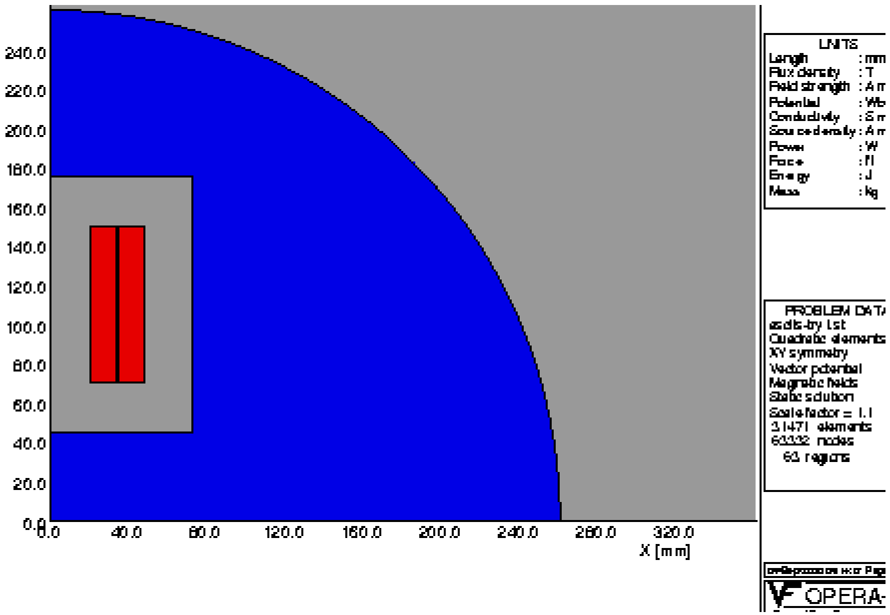
Fiberglass Sleeve from LBNL

Status and Plans with Cable (BSCCO 2212) Common Coil Program

- One 10-turn HTS coil has been wound and being prepared for test.
- Other should be wound and ready in ~one month.
- Test these two coils separately and together in the common coil configuration.
- Also test in the background field of Nb_3Sn coils.
- Test 20 turn coil with Mixed strand cable.

Then depending on the progress, continue with more 10-turn coils and/or go for full 50-turn program. (either with mixed strand cable BSCCO or with all HTS cable).

High Field Magnet Design At BNL
(Nb_3Sn, "React & Wind", in first stage)



Expected Short Sample: ~12.5 T

J_c~ 2000 A/mm^2

2 Layers Nb_3Sn Coils

No. of strand (both layers): 30

Strand diameter (both layers) 0.8 mm

Cu/Sc: 1.0 (inner); 1.86 (outer)

J_{cu}: 1400-1500 A/mm^2 (both layers)

A unique feature of this design: Variable grading with two power supplies

Allows the studies of cable behavior as it sees in the magnet.

Example: Vary current density in Cu@Quench dynamically

Perhaps first such study in real magnet situation

Important design parameter, results useful for future designs

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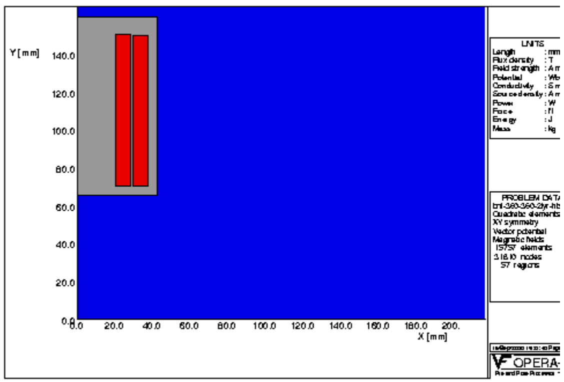
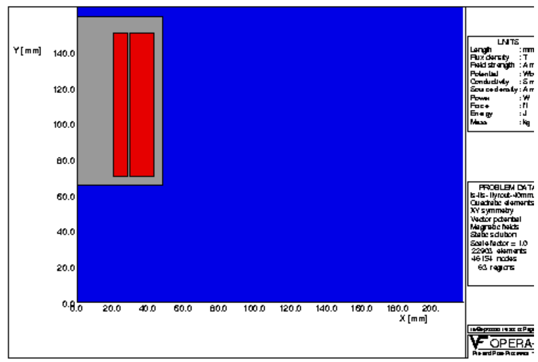
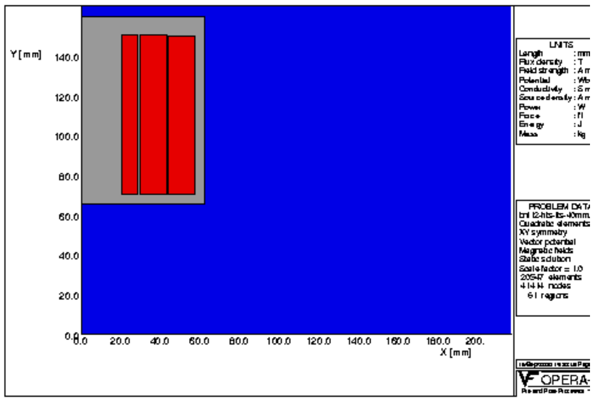
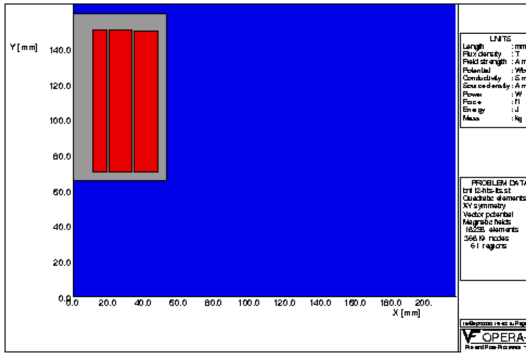
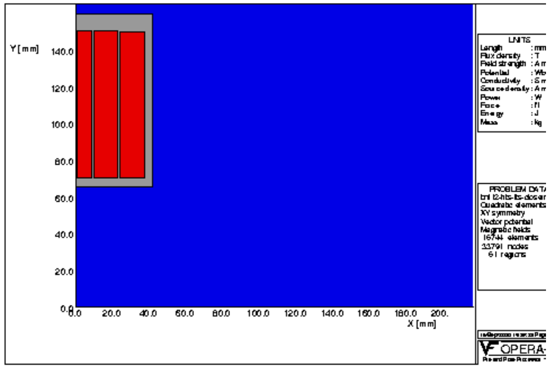
Possible HTS Hybrid Magnet designs with Nb3Sn coils of 12.5 T Design

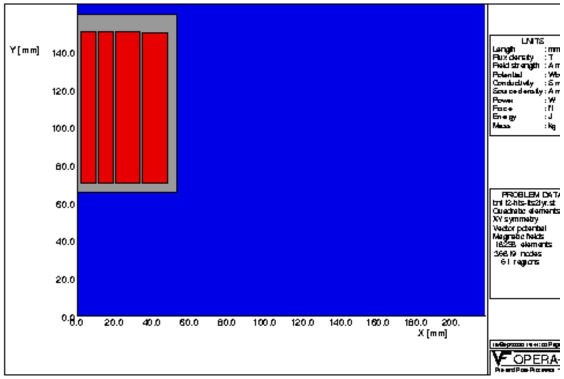










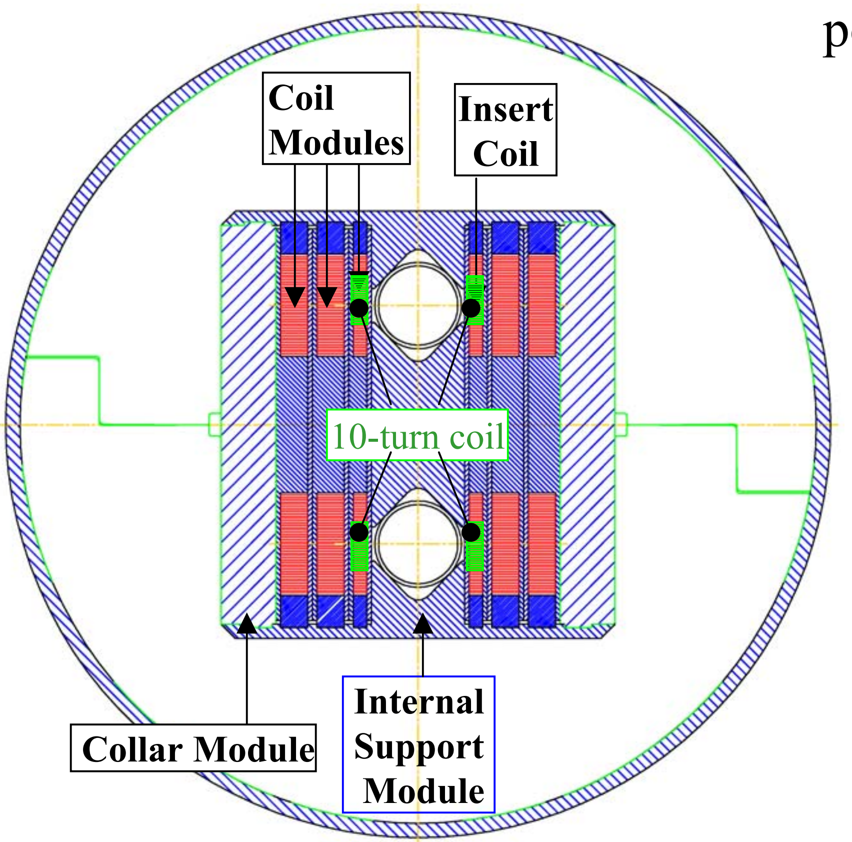


Field Test Range: 8-20 Tesla (with BSCCO 2212 wire carrying 600 A at 4K and 0T)

Aperture (coil spacing) Range: 0 to 40 mm

Above design use 1 or 2 layes of HTS coils with 0 to 2 layes of Ns3Sn coils

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,

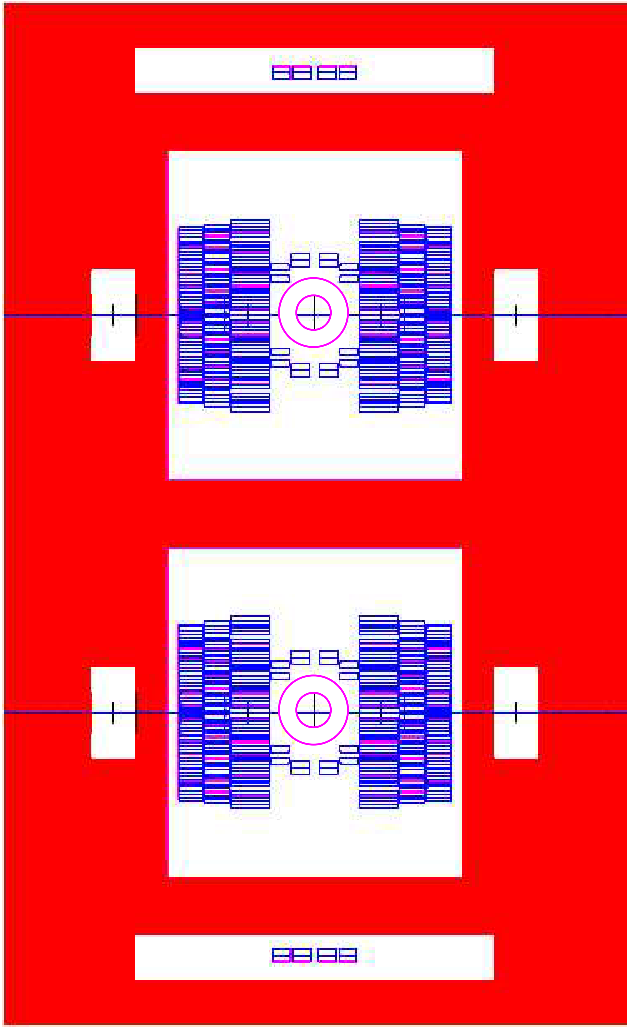
the 10-turn coil technology development program continues in parallel!

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 (HTS, Nb_3Sn) with large Lorentz forces on them -- try to simulate high field magnet situation.

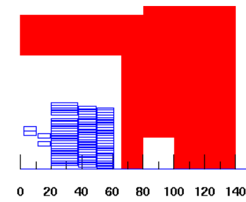
☺ Ideal approach for HTS/Hybrid magnet development !

Progress in Field Quality
Geometric Harmonics

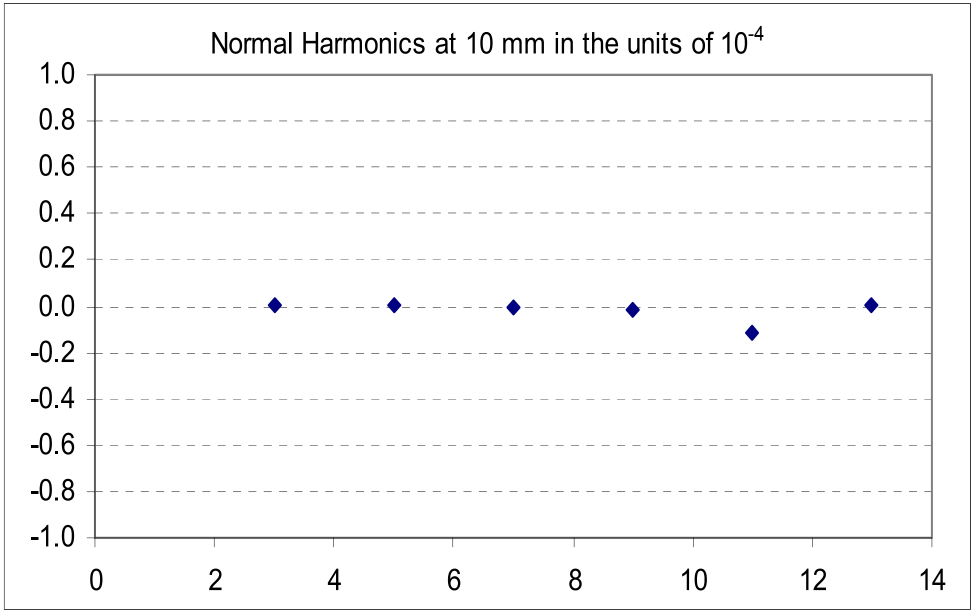


Earlier models used slanted auxiliary coils.
This model has all flat coils.

(from 1/4 model)



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



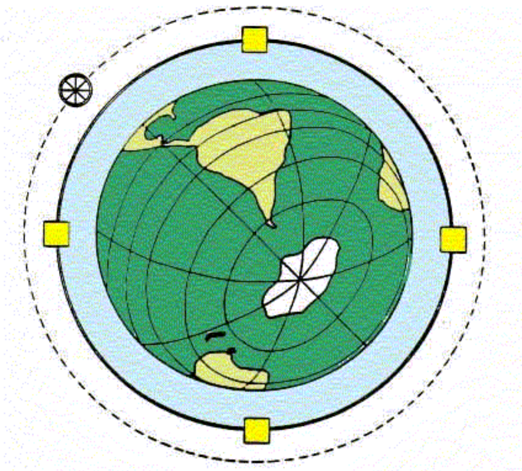
Coil Aperture = 40 mm

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

FEM 2D * ROXIE 7.0

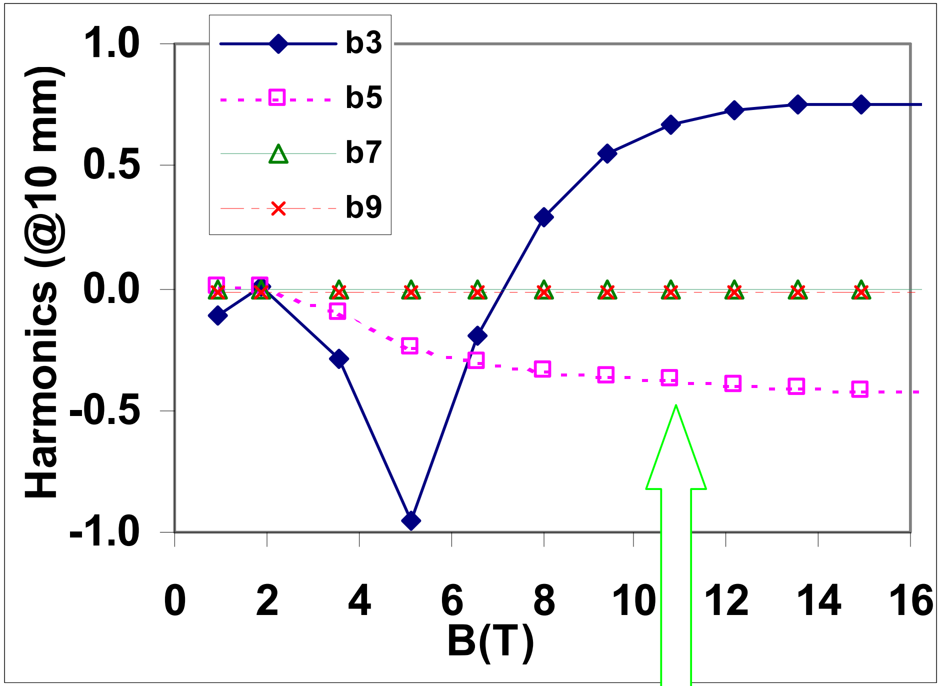
Progress in Field Quality
Saturation-induced Harmonics

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



A magnetic design for VLHC (Very Large Hadron Collider)

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



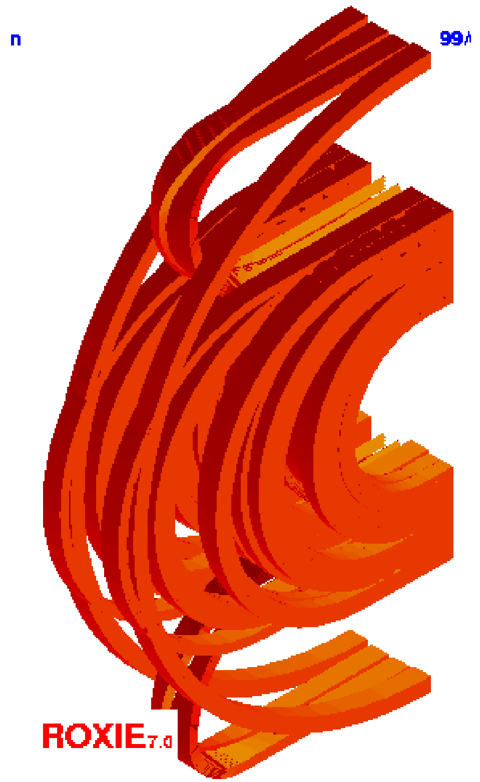
Low saturation induced harmonics till 15 T with a single power supply

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

Proof:

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

(Very small)

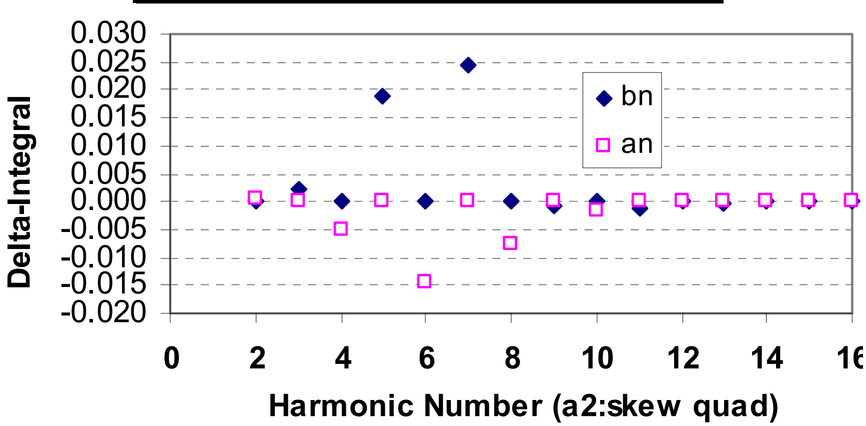


End harmonics in Unit-m

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



SUMMARY

- Set on a path of carrying out dynamic and innovative magnet R&D.
- Early success are heartening. It should change our views on "React & Wind" magnet technology.
- But more than a few success, we are banking on our R&D approach and the program is designed to deal with a few setbacks.
- The ultimate goal: significantly reduce the cost of building next colliders and to change it significantly we need to look for new approaches.