Kick-off Meeting

IBS/BNL 100 mm, 25 T HTS Solenoid

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BROOKHAVEN NATIONAL LABORATORY

a passion for discovery

Office of Science
U.S. DEPARTMENT OF ENERGY

Overview

- Major Purpose of this Meeting
- BNL Roles and Responsibilities
- Schedule and Reviews
- Overall Design (including design updates)
- Conductor Requirements
- Feedback from Conductor and other Vendors
- Possible Collaborations
- Summary (with decision points)

Major Purpose of this Meeting

- **Get to know each other**
  - **This meeting is being attended by most of the key players from IBS and BNL**
- **Summarize and discuss all aspects of the project to make sure that everyone is and remains on the same page**
- **Provide update on the progress made so far**
- **BNL proposal to IBS is based on the HTS SMES solenoid**
  - **Discuss and "*approve*" if any modification in that design is required to make it more robust and suitable for the IBS before a detailed design work is started**

BNL Roles & Responsibilities

Ramesh Gupta
September 10, 2016

Statement of Work

Brookhaven National Laboratory (BNL) will design, build and test a 25 Tesla, 100 mm bore HTS (high temperature superconductor) solenoid with a nominal design which will have 22 pancake windings for inner layer and 28 pancake windings of outer layers. A proposal for building HTS coil was earlier submitted for review to the Institute for Basic Science (IBS) on August 12, 2016. As a part of this project for building the HTS solenoid system, BNL will be responsible for purchasing superconductor, power-supply, cryostat and for building the operating system to protect and test this magnet. In addition, BNL will deliver the entire magnet system to the Center for Axion and Precision Physics Research (CAPP) in Daejeon, Korea and help install it and provide initial training for operating it. The design is based on the previously built similar solenoid for HTS SMES (superconducting magnetic energy storage) solenoid and a significant amount of existing tooling will be adapted to carry out various tasks. It is expected that the students and staff from CAPP will receive training in using the magnet. They are expected to participate in the testing of the individual pancake coils at 77 K and the intermediate and final testing of the magnet at high fields at 4 K.

Deliverable (items additional to SOW highlighted)

Deliverable

BNL will provide IBS a fully assembled and tested high field 100 mm aperture HTS solenoid in a support structure with a design similar to that used in the solenoid developed for SMES. In addition, BNL will purchase conductor, power supply and cryostat. BNL will build the magnet system that can be operated in a stand-alone mode. All work will be carried out on the best effort basis. BNL will provide documentation, drawings and other information that is generated with this IBS funding during the period of the work performed. CAPP staff is expected to participate in the testing of this solenoid so that they can independently operate at CAPP. In addition, BNL engineering and technical staff will visit CAPP site to support the installation and the first operation of the HTS magnet by CAPP staff. BNL will provide to CAPP a fully tested magnet system, including magnet itself, cryostat, power supply, monitor and control system, quench detection hardware with software and documentation to operate this solenoid in a user facility. BNL will electronically send quarterly progress reports to CAPP.

Deliverable includes regular progress reports, documentation, support in installation and providing initial training to CAPP staff

Schedule and Reviews

- **Kick-off Meeting: 1 month => this meeting**

  delayed due to scheduling issues. However, a significant progress has been made towards planning. Initial discussion for ordering key parts, etc. has been started.

- **Preliminary Design Review: 3 months => 3rd week of May 2017**
- **Product Readiness Review: 6 months => September 2017**
- **Annual Review: 12 months => March 2018**

The dates of the following reviews is subject to on-time delivery of the conductor:

- **Project Status and Test Planning Review: 18 months => September 2018**
- **Final Project Review: 23 months => March 2019**

> ➢ Monthly web-conference between BNL and IBS

Overall Approach

As presented at IBS last year (august 2016)

- Design of IBS solenoid will be very similar to the SMES solenoid
- Only those small and simple changes will be accepted which are necessary and/or those that clearly makes the design more robust

Major areas of concern:

- R&D nature of the conductor and quench protection

Recent results in "no-insulation" have been encouraging in providing the extra level of security. Should this be applied here?

SMES and IBS Solenoids

Similarities:

- Same high field and large aperture (25 T, 100 mm)
- Large stresses and past experience with HTS coils

Differences:

(which may permit No-Insulation consideration in IBS)

- Large charging time
- Significant energy losses

Above were not acceptable for SMES. But may be OK for IBS.

- SMES was initially started out as high-risk, high rewarded R&D (later became a project). Not so for IBS.
- SMES solenoid had no margin. IBS solenoid must.

Guiding Principles for the IBS Solenoid

- IBS solenoid is a key part of an important facility. The magnet must be as reliable as possible and it must remain as protected as possible.
- Use the advanced quench detection/protection system at BNL. However, evaluate the extra level of safety provided by "No-Insulation" against local issues.

➢ As compared to the HTS accelerator magnets, in IBS:
  - ✓ Field quality is much relaxed: few percent OK
  - ✓ Long ramping time tolerable: 1 day or so OK

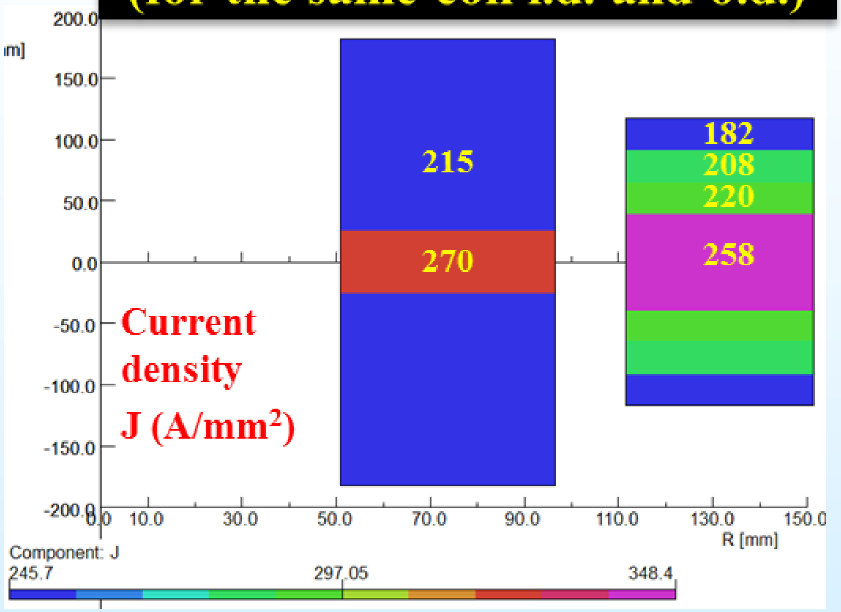
This means No-Insulation coils may be considered.

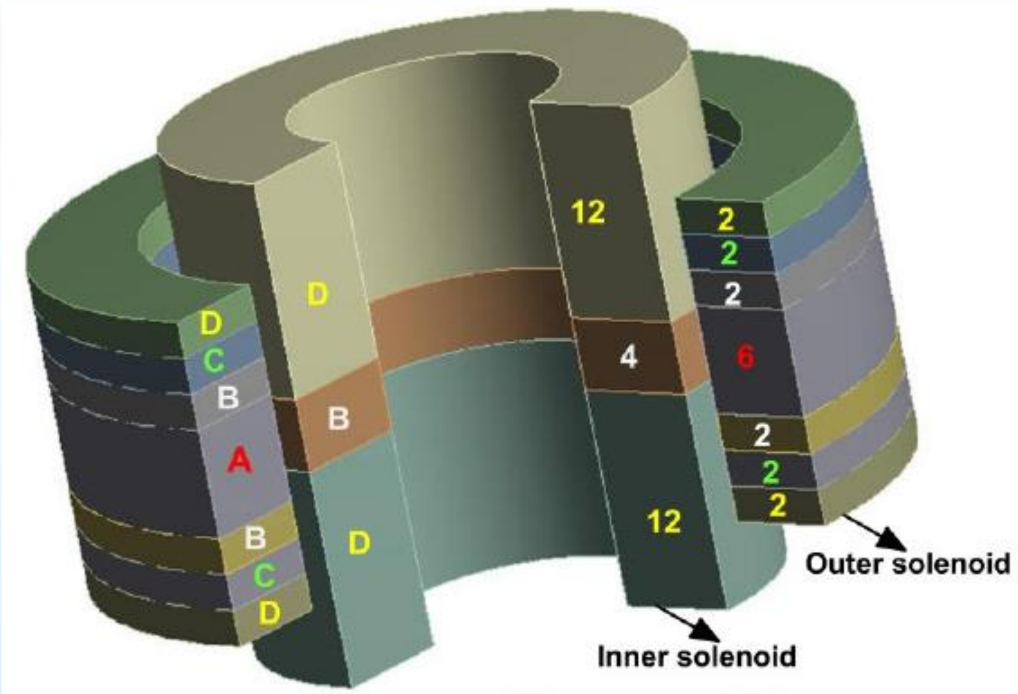
Impact of Changing from SS-tape Insulation to No-Insulation

- **Even-though the "No-Insulation" provides the desired robustness, it has a large impact on the design.**
- **Stainless steel tape was also helping in the structure in dealing with large stresses. Removing that changes the structure element, including the coil modulus.**
- **With insulation missing, the current density (J) goes up significantly. This is generally desired in most cases; but in large aperture, high field magnet, the design is also limited by hoop stresses which is proportional to: J, B, R.**
- **Larger J creates larger stress. We need to review it carefully.**

Magnetic & Mechanical Design of SMES (more SS in the middle, more Cu in the ends)

Number of turns per pancake (for the same coil i.d. and o.d.)





Coil type		A	B	C	D
Thickness of HTS tape	µm	120	120	160	160
Thickness of the surround copper stabilizer layer	µm	65	65	100	100
Thickness of SS ribbon	µm	25	50	25	50

SMES and Options for IBS

- **Turn-to-turn spacing in SMES: 0.145 mm to 0.21 mm**
  - **(Hastelloy+SS)/Cu goes from 0.100/0.065 to 0.075/0.100 (in mm)**

- **Turn-to-turn spacing in options for IBS (Hastelloy/Cu, in mm)**
  - **0.08 mm (0.05/0.02)**
  - **0.10 mm (0.05/0.04)**
  - **0.13 mm (0.10/0.02)**
  - **0.15 mm (0.10/0.04)**

Reduction in turn-to-turn spacing increases Je
In No-Insulation IBS solenoid it could be over 2.6 less (J_e 2.6 more)
- **Structure consideration become very important**
- **Figure of merit for hoop stress : J x B x R**

Stress was kept to 400 MPa in SMES. It will become larger in IBS.

Reducing Cu may Permit Higher Stresses (Rule of Mixture)

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Stress–Strain Relationship, Critical Strain (Stress) and Irreversible Strain (Stress) of IBAD-MOCVD-Based 2G HTS Wires Under Uniaxial Tension

Y. Zhang, D. W. Hazelton, R. Kelley, M. Kasahara, R. Nakasaki, H. Sakamoto, and A. Polyanskii

$$\sigma = \frac{F}{A} = \frac{F_1 + F_2}{A} = \frac{(\sigma_1 A_1 + \sigma_2 A_2)}{A_1 + A_2}$$

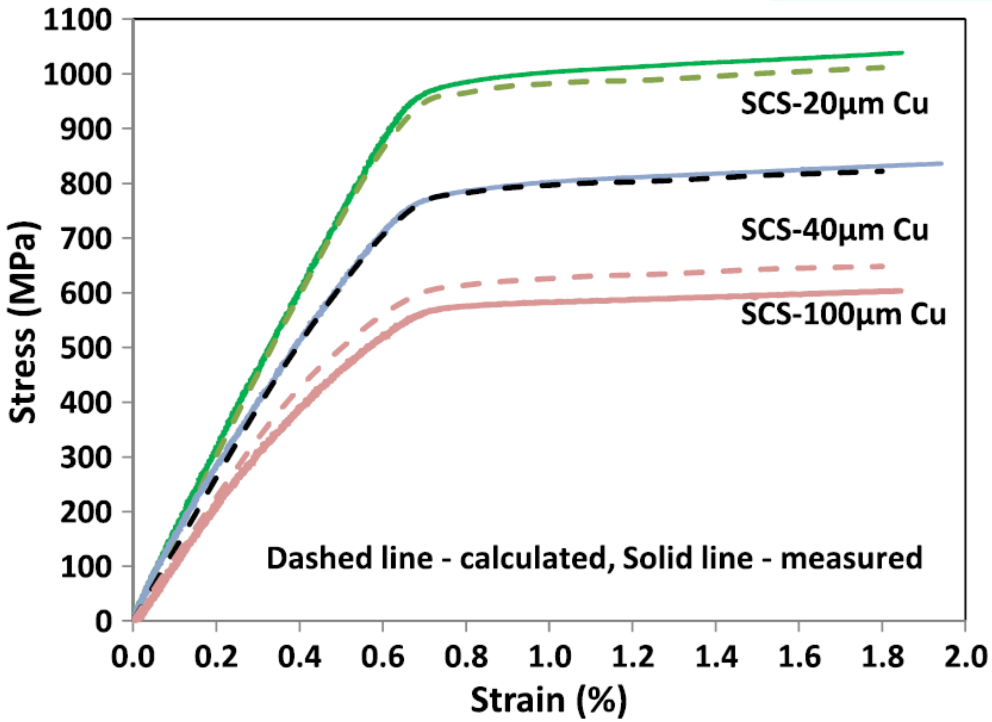

Fig. 3. Calculated (dashed line) and measured (solid line) stress–strain curves at 77 K for 2G HTS wires on 50-μm-thick Hastelloy substrate and with variation in electroplated Cu stabilizer thickness.

Simple expression can evaluate the impact.
We are considering reducing the thickness of copper stabilizer and increasing the Hastelloy substrate.

Reducing Cu and Increasing Hastelloy May Permit Higher Stresses (2)

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A widely used analytical expression of the stress–strain relationship that takes account of both linear and nonlinear deformations is the Ramberg–Osgood equation [18], Eq. (2).

$$\varepsilon = \frac{\sigma}{E} + 0.002\left(\frac{\sigma}{\sigma_{0.2}}\right)^{\alpha} \quad (2)$$

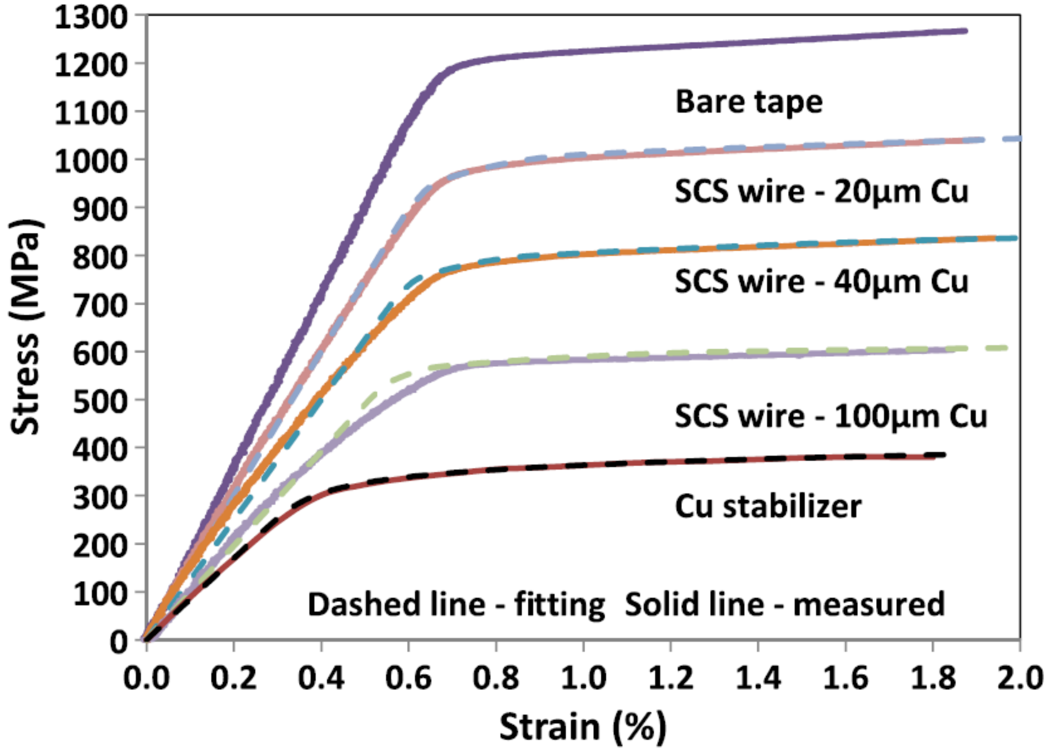
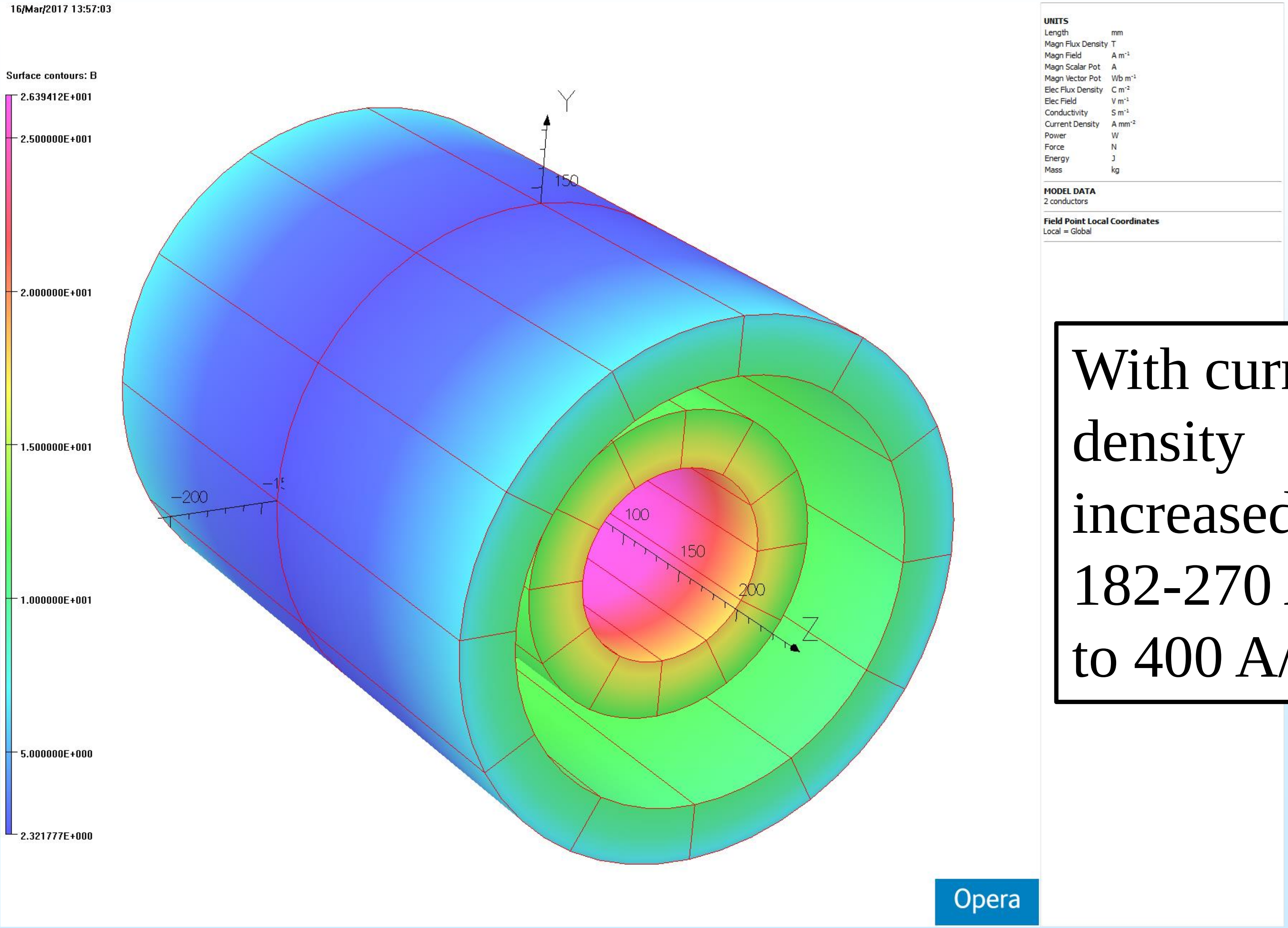


Fig. 4. Fitting of the measured stress–strain curves of different wires using the Ramberg–Osgood equation.

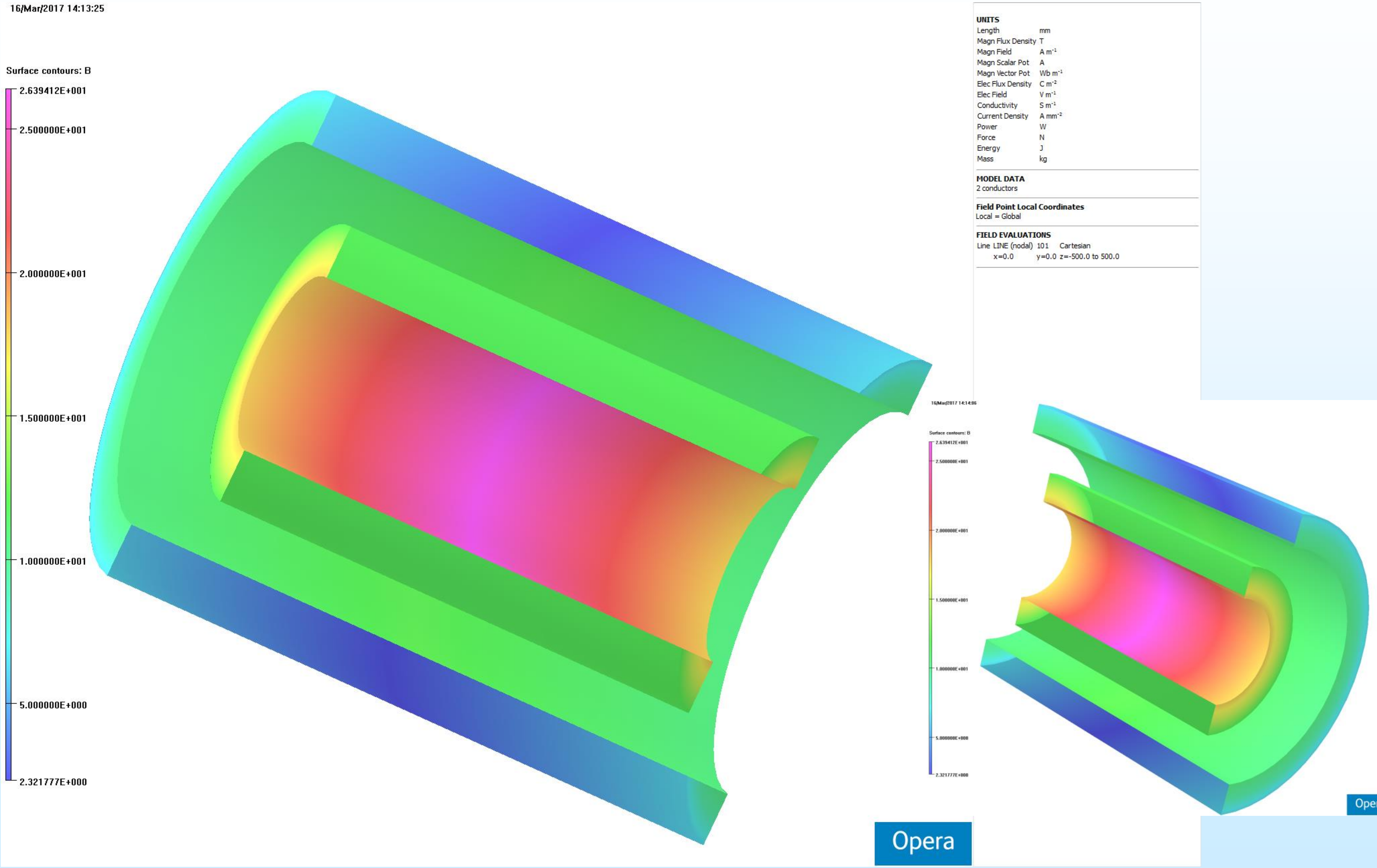
Design iterations needs to be carried out to make sure that we work within the magnetic and mechanical limit of the conductor

Initial Design Evaluation



With current density increased from 182-270 A/mm^2 to 400 A/mm^2.

Initial Design Evaluation



Conductor

Conductor Requirements

Need a significant quantity of ReBCO tape in just 1 year

10-13 mm wide for high field applications (Hastelloy substrate)

- ❑ **All HTS wire suppliers welcome**
- ❑ **Likely to use 2 conductor vendors (but not necessarily supplying the equal quantities)**

Ic (8T,4K) > 800 A@4K (in any direction)

- ➢ **Better performance is likely to increase the chances of getting the order; and the larger amount of order**

Since field is parallel in most of the solenoid, several vendors should be able to meet this requirement for some pancakes.

✓ **Higher than required speciation on Ic to provide margin**

Progress towards Procuring HTS

As such the purchase order for HTS can only be placed by BNL after the "Preliminary Design Review". However, in the interest of time all eligible wire manufacture have been contacted. Here is the status:

- **SuperPower, US**
  Quote received (SuperPower team visited BNL last month)
- **SuNAM, South Korea**
  Quote requested (currently not focusing on Hastelloy substrate)
- **SuperOx, Russia**
  Quote received (interested in supplying)
- **SST, China**
  Quote received (interested in supplying, 10-m samples coming)
- **THEVA, Europe**
  Quote requested (interested in supplying)
- **Brucker, Europe**
  Quote requested (may not be interested in supplying)

Possible Collaboration

Reviews and collaborations increase the chances of success as one can avoid oversight and benefit from the key development elsewhere.

A specific area of specific interest is "No-Insulation" coils where BNL has limited experience (Bill Sampson has been working on it for some time but only with one small coil).

Person/institution contacted:

- **Seungyong Hahn (champion of "No-insulation)**
- **Magnet Lab in Florida (for conductor testing and general collaboration)**
- **SuNAM (for possibly supplying "No-Insulation 26 T HTS solenoid" to BNL for more testing and experience and to see how it works with the BNL advanced quench system). Budget impact to be evaluated.**

Cryostat

- **Initial discussion started on procuring cryostat**
- **The actual order can only be placed after the "Preliminary Design Review"**
- **SMES solenoid is being tested elsewhere in its own cryostat. Information has been sought on that cryostat.**
- **Oxford Instruments (OI) has also been contacted. Discussion on the way if the same cryostat which OI is using for the IBS Nb_3Sn solenoid can be adapted for this HTS solenoid as well. This may simplify integrating future 3-40 T HTS/LTS hybrid solenoid, if needed.**

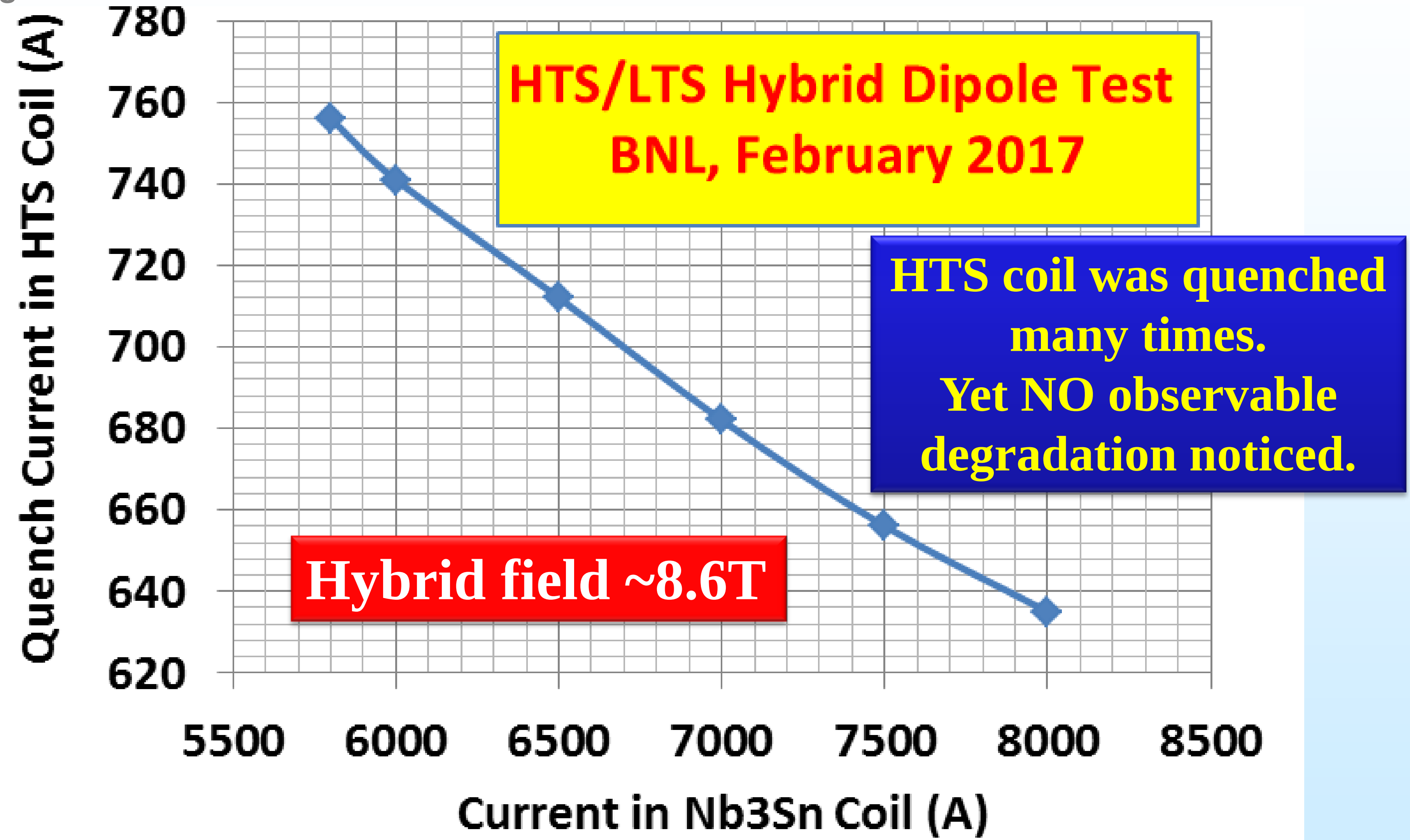
Power Supply

- Discussion on the way on coming up with specification towards procuring power supply
- Order will be placed only after the “Preliminary Design Review”

Related Topics: Looking Ahead HTS/LTS Solenoid

- **BNL has recently successfully tested a HTS/LTS dipole magnet (worlds first significant hybrid dipole).**
- **HTS/LTS coils working together should be of interest to future IBS program. In fact, HTS/LTS 35-40 T solenoid was part of the earlier proposal. However, the HTS and LTS solenoids were decoupled as no such experience or results were available.**
- **In the recent BNL hybrid magnet test, HTS and LTS coils were operated with two different power supplies (as will be in the IBS hybrid solenoid)**
- **HTS coils was quenched many times. No damage or degradation in HTS coil observed**
- **These test results are encouraging for the future IBS program.**

Recent Test Results on HTS Coils



Other Topics for Discussion

- **Progress report – how and how often (web-meeting monthly, written report quarterly)**
- **CAPP/IBS participation in the project**
- **Any other topic not covered?**

Summary

- This Kick-off meeting marks the important milestone in starting and planning of BNL work on IBS solenoid.
- Significant and detailed design work will start only after this meeting.
- However, a significant progress has already been made with the initial inquiries on key and long lead items such as conductor, power supply and cryostat. Possibilities of collaboration have also been explored.
- The actual order can only be placed after the "Preliminary Design Review" by BNL "Purchasing Dept." as per its terms and conditions.
- Key question for this meeting – to investigate "No-Insulation" or NOT
- If investigated, then the final decision has to be made in about a month (next web-meeting) if that will be presented in the "Preliminary Design Review (PDR)" or not. Only one design will presented in PDR.

Extra Slides

BNL List of Tasks

- **Magnet design update from SMES coil to IBS coil**
- **Superconductor purchase**
- **Electrical and quench protection for initial tests at BNL**
- **Design and engineering update for the final design**
- **Coil winding (inner and outer)**
- **Coil sub-assembly & preparation for 77 K test**
- **Double pancake testing at 77 K, including analysis and reports**
- **Magnet assembly**
- **Preparation for 4K testing**
- **4 K testing (4 tests), including analysis and reports**
- **Purchase power supply, build quench protection and control system**
- **Magnet system shipment, final report and documentation**
- **Training and installation of the solenoid system at CAPP site**