

SMES Coil Status

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Overview of Activities

- **Status of engineering design and fabrication of parts**
- **Construction of single pancake coils**
- **Construction of fixture for testing outer double pancakes**
- **Test results of outer double pancake coils**
- **QA for detecting deviations from nominal performance and localization of defect, if any**
- **Summary**

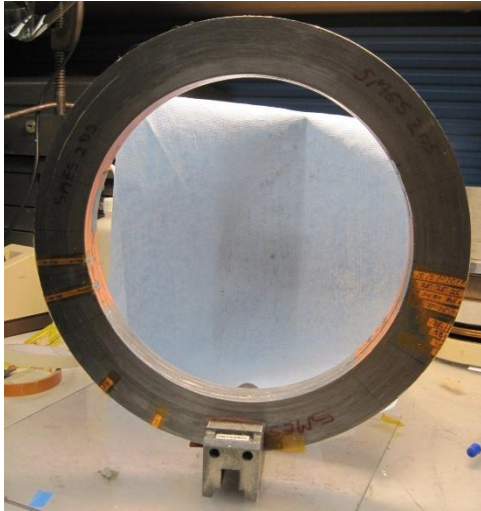
Status of Engineering Design and Fabrication of Parts

- Detailed engineering design has been carried out to extent that is common between 1.7 MJ and 2.5 MJ SMES
- We designed, ordered, fabricated or received parts that are common between 1.7 MJ and 2.5 MJ SMES. In particular support structure tubes have been received and machined

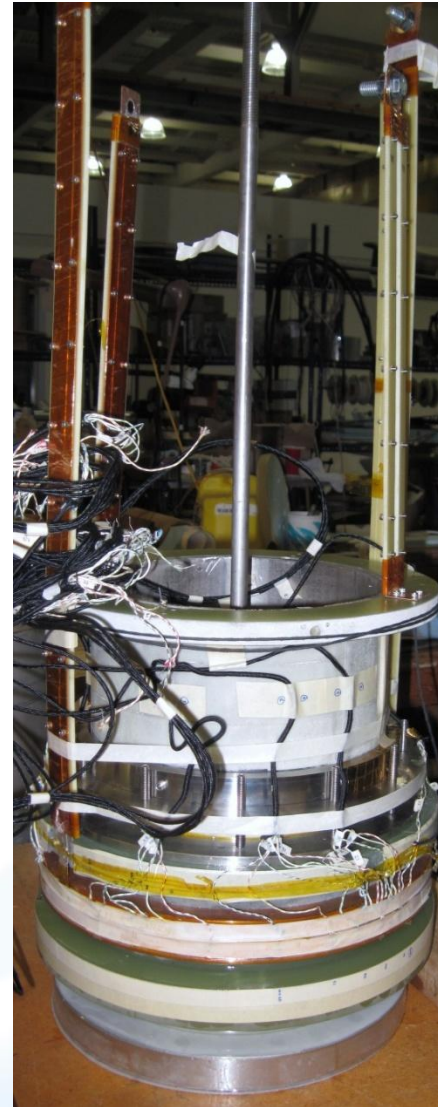
Construction of Pancake Coils

- Construction of all (28) inner pancake coils was reported in last quarter
- Construction of the required number of outer pancake coils (16) for 1.7 MJ has now been completed
- Construction of additional outer pancakes (12) for 2.5 MJ will start only after receiving confirmation of plus-up funding

Construction of Fixture for Testing Outer Double Pancake Coils at 77 K Test



Each outer pancake uses
~200 m of conductor

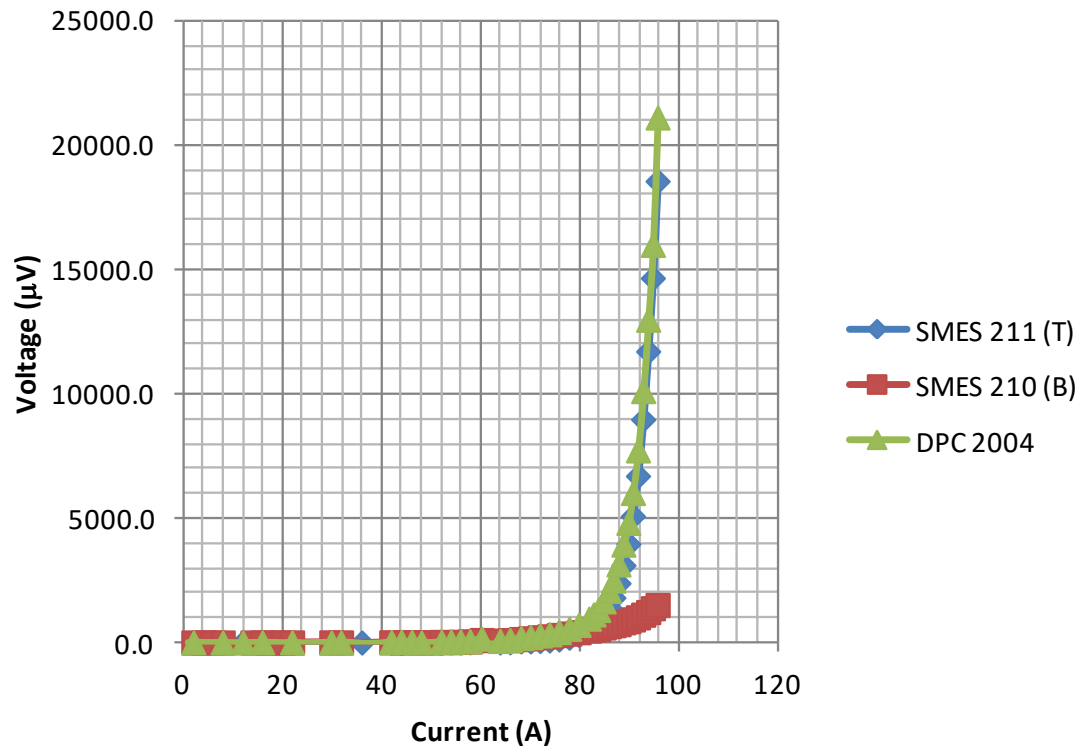


Fixture has four
leads to allow
testing of the two
coils and splice
separately

Test Results of Outer Double Pancake Coil DPC2004

(2 pancakes powered in series)

Double Pancake Coil DPC2004 consisting of SMES210 and SMES211 is good



I_c for $1\mu\text{V}/\text{cm}$ criteria

SMES210: Beyond the range ($>96\text{ A}$)

SMES211: 95 A, $N=23$

Double pancake coil: $>96\text{ A}$

I_c for $0.1\mu\text{V}/\text{cm}$ criteria

SMES210: Beyond the range ($>96\text{ A}$)

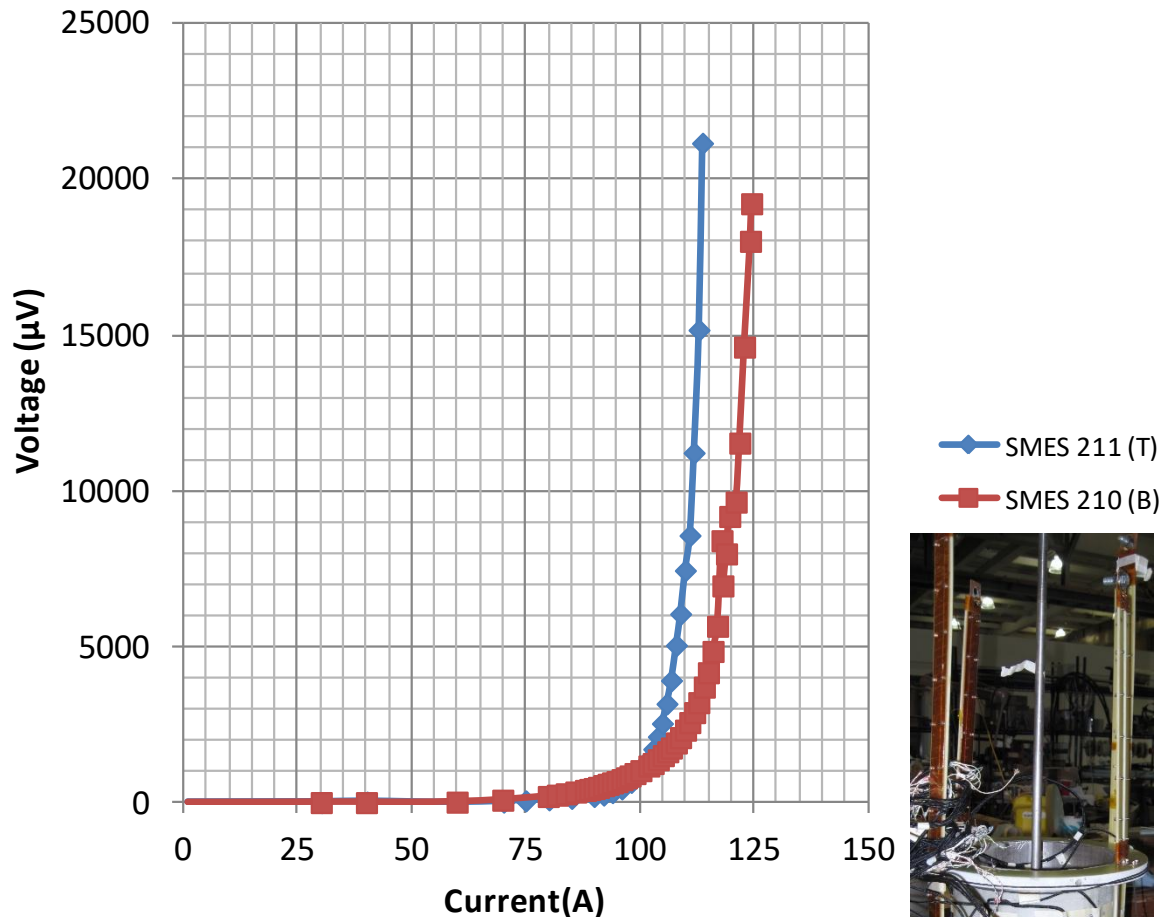
SMES211: 86.8 A, $N=23$

Pancake coil SMES210 carries significantly higher critical current than coil SMES211 @77K

Resistance of the diagonal splice: $4.2\text{ n}\Omega$

Outer Coil SMES210 and SMES211 Used in DPC2004

(each pancake powered separately)



Based on $1\mu\text{V}/\text{cm}$ criteria

SMES 210: 124A, N=18

SMES 211: 113.8 A, N= 23

Based on $0.1\mu\text{V}/\text{cm}$ criteria

SMES 210: 109.2A, N=18

SMES 211: 103.1 A, N= 23



Double Pancake Coil DPC2004 and coils SMES210 and SMES211 used in making them are good

Additional leads in the center of the outer fixture allowed us to determine the performances both coils despite a significant difference in their critical currents (improvement over inner fixture).

Quality Assurance (QA) Steps in Place

1. Check surface of the conductor critically during the winding:

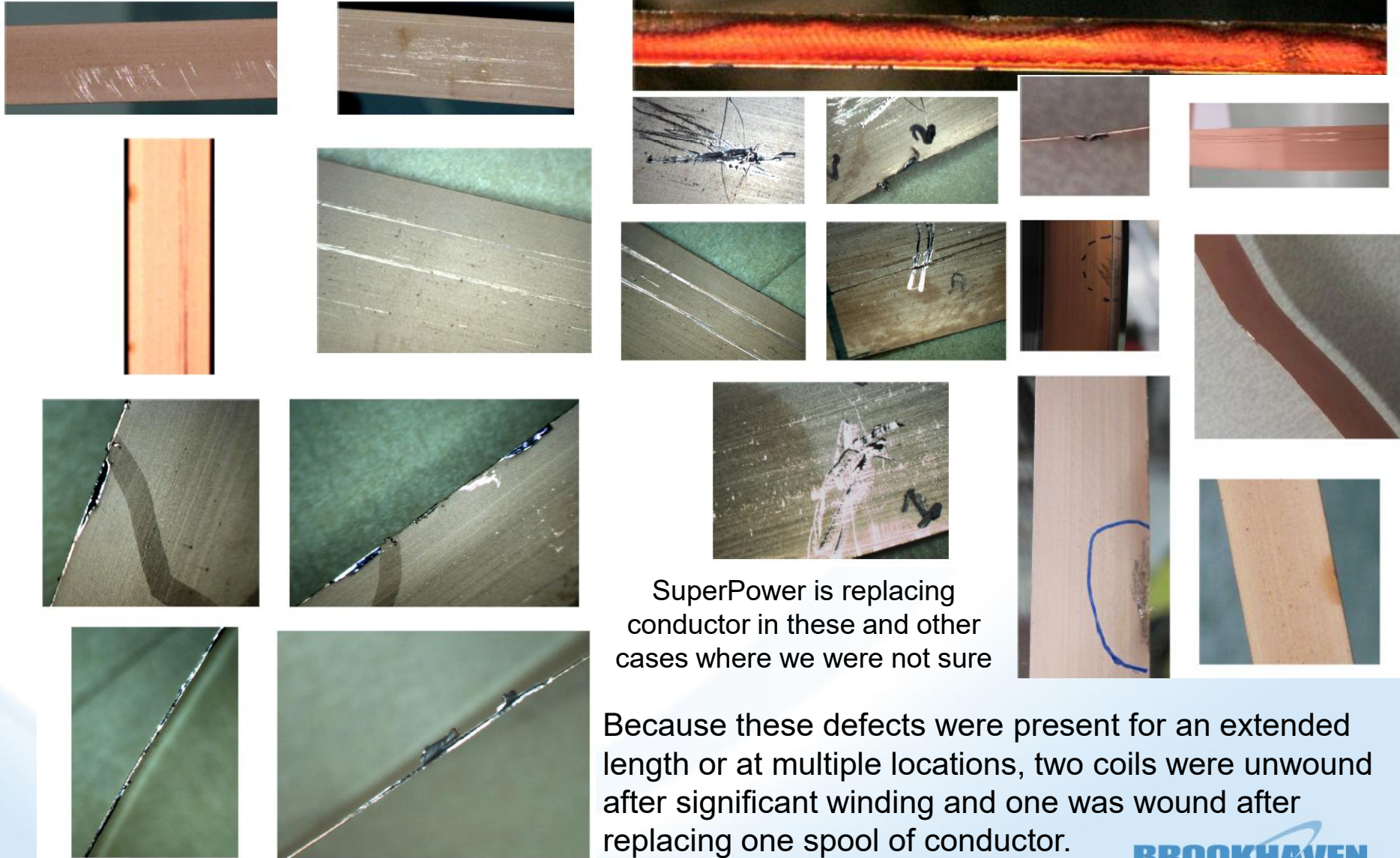
- Any concern are immediately notified to manufacturer (SuperPower)
- In particular, we inspect splices, delamination in copper or any scratches, etc. as they may limit the coil performance
- If the issues is serious, the coil is unwound and conductor is sent back to manufacturer for further inspection
- Having conductor manufacturer as a collaborator is a major benefit

2. Perform 77 K test of the double pancake coil assembly:

- HTS offers a unique opportunity of carrying out a relatively inexpensive test of the performance of superconducting coil in liquid nitrogen
- We install several voltage taps to examine the performance of internal splices and of a group of turns (0, 10, 25, 50, 75, ..., ~200). Number of these voltage taps will get reduced/eliminated as the technology matures
- Any deviation from nominal is critically examined. Most of the time we are able use a relatively weaker coil in an area where we have large margin. So far only one coil (out of 33 tested) could not be used

Visual Inspection of Conductor and Splices

During Coil Winding (first line of defense in QA)



SuperPower is replacing conductor in these and other cases where we were not sure

Because these defects were present for an extended length or at multiple locations, two coils were unwound after significant winding and one was wound after replacing one spool of conductor.

QA and Localization of Defect in Coil

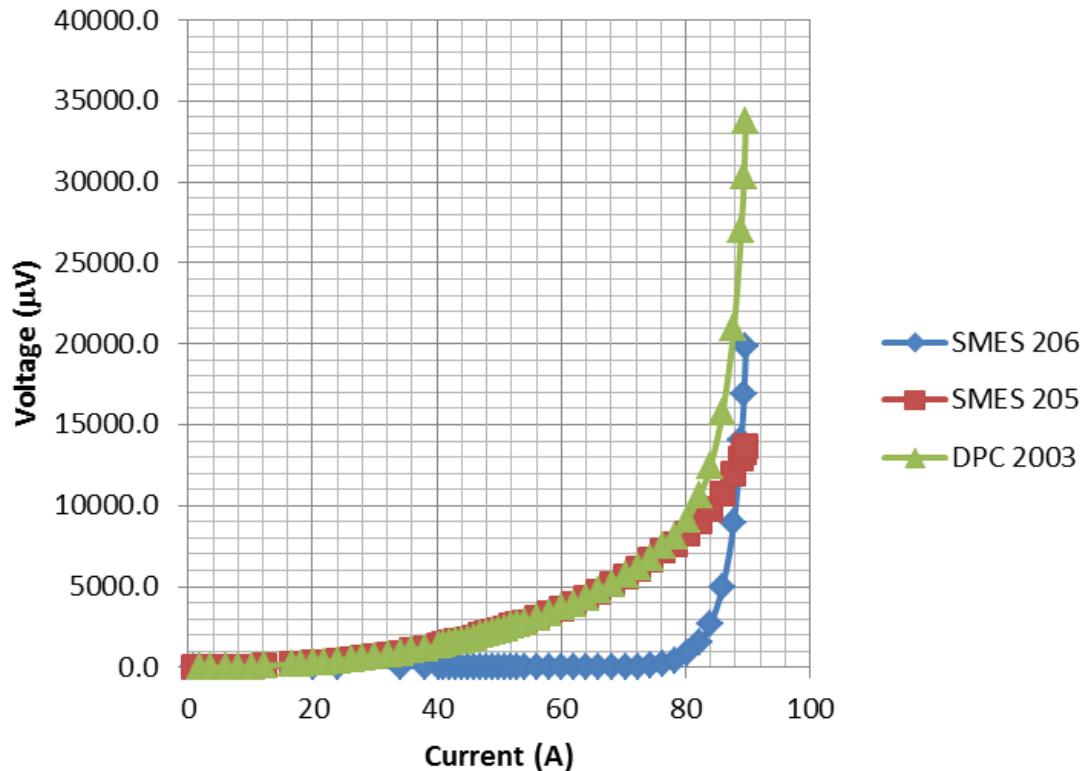
Next four slides show a powerful method in operation:

1. Perform and analyze 77 K measurement of double pancake coil. If there is a defect, isolate the major part in double pancake assembly (splice between two coils or one or both coils).
2. If in splice between two coils, measure the performance of splice joint again with two extra leads incorporated in the new fixture. If in coil, energize the good coil alone to observe detailed performance to certify the coil good.
3. Measure the performance of bad coil. Determine the approximate location of the defect with the help of number of voltage-taps put between the turns.
4. MAP the location of turns to 5-m critical current measurements performed by vendor (SuperPower). Communicate all details to vendor which has a variety of data and extensive measurements to possibly determine the cause. Also go through the internal detailed log (traveler) at BNL to make sure that there was no unusual event or observation.

Test Results of Outer Double Pancake 2003

(2 pancakes powered in series)

DPC 2003- SMES 205 and SMES 206



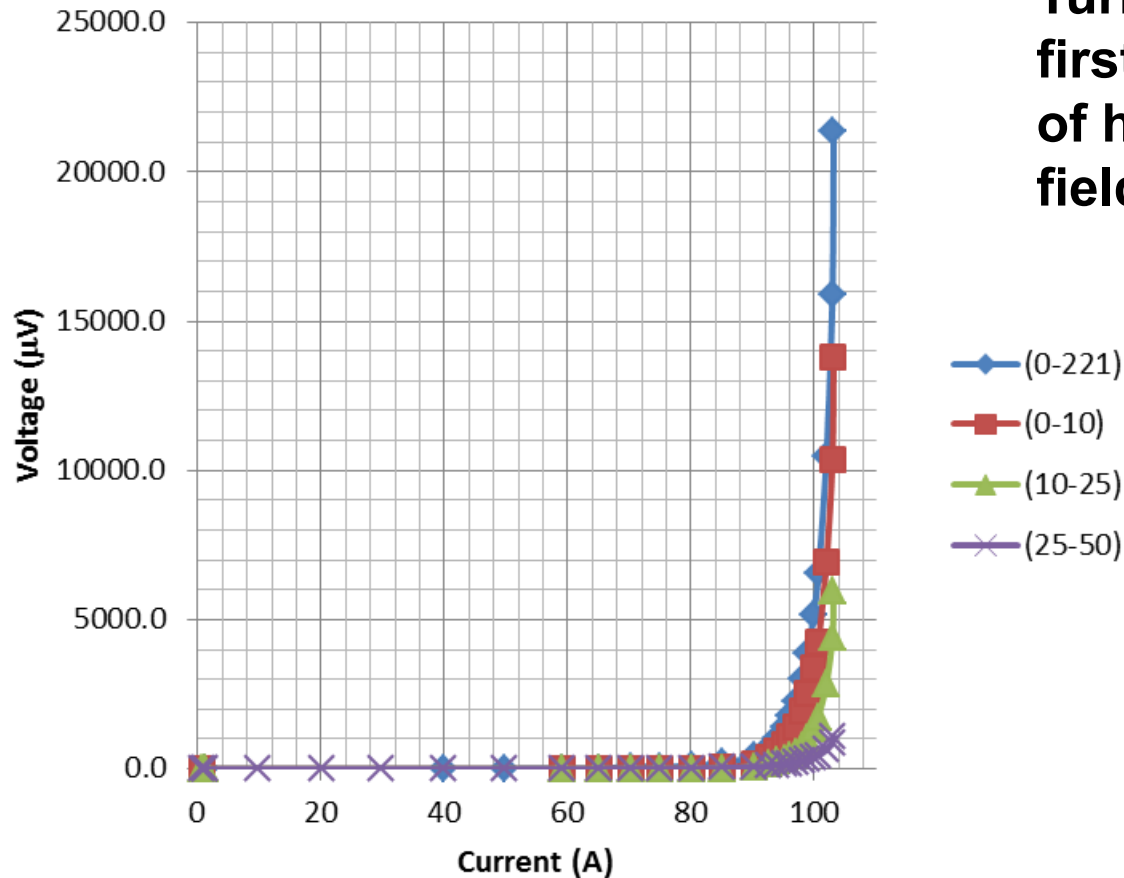
Pancake SMES206 is good but coil SMES205 develops resistive voltage early on.

SMES205 can't be used in the device.

Extra leads in the middle (new in the outer coil setup) allows test of good coil individually when there is an issue with one coil (such as here)

Outer Pancake Coil SMES 206 (good) Powered Alone

SMES 206

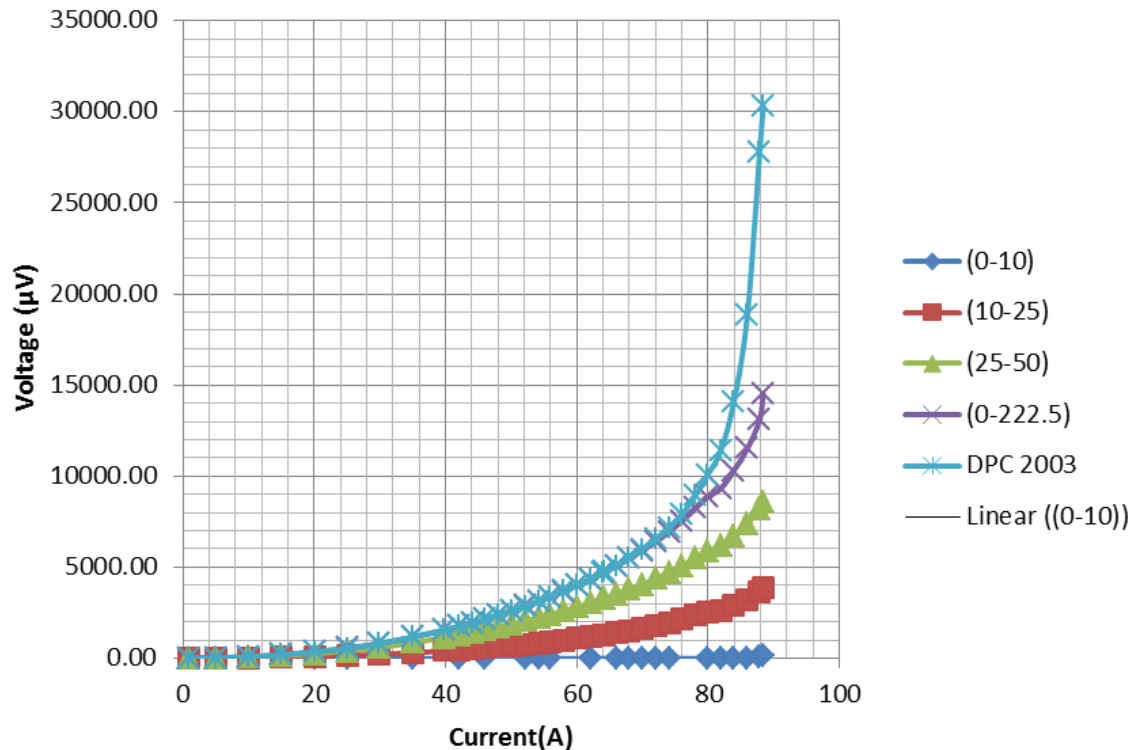


Turn #0-10 turns normal first, as expected, because of higher perpendicular field component.

Outer Pancake Coil SMES 205 (with defects) Powered Alone

(Measurement of voltage on the coil and on the group of turns)

SMES 205 AT 77 K,



Early onset of indicates that there is a significant problem in this coil.

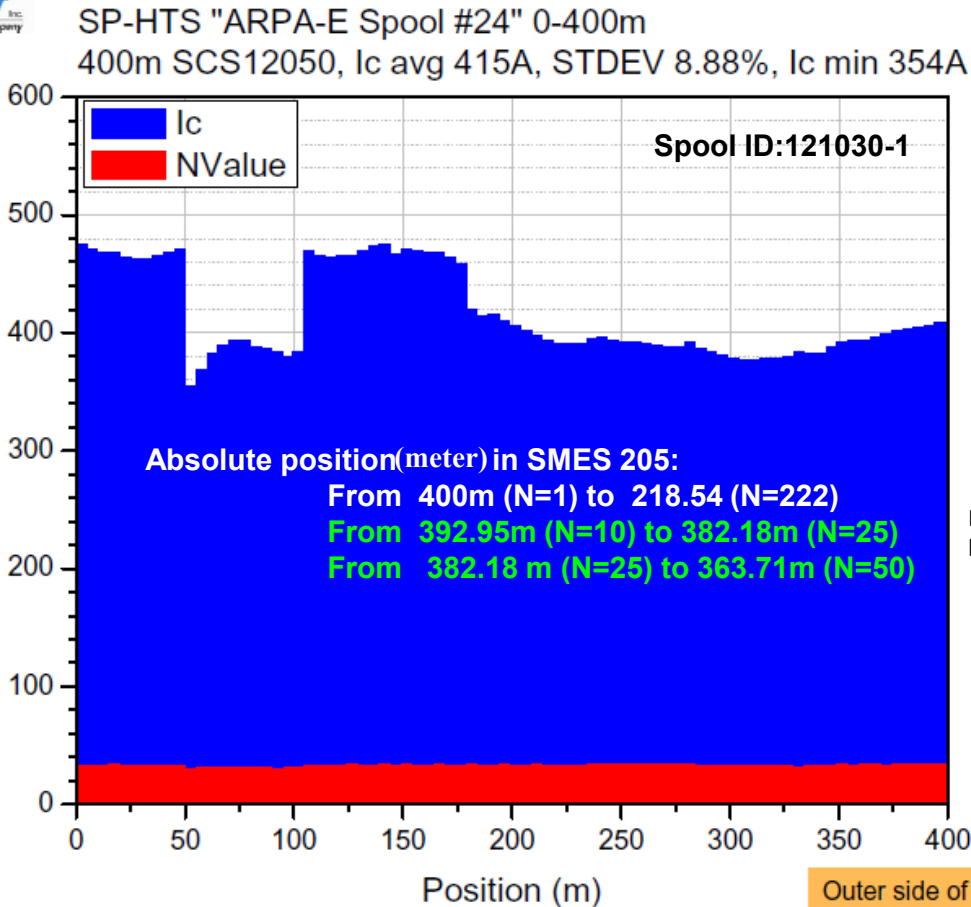
Turn #10-25 and #25-50 see significant voltage before turn #0-10.

A new outer pancake coil has already been wound which will be used instead of this coil.

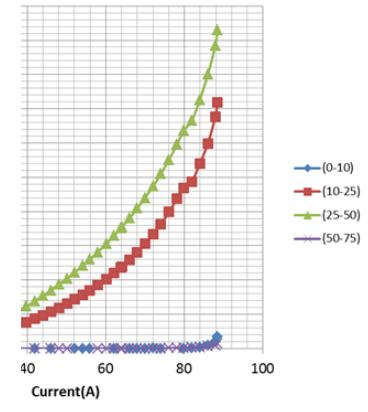
SuperPower has offered a replacement conductor.

Detailed Investigation of the Conductor Used in SMES205

Absolute position of conductor in the coil turns of SMES 205



ibution in SMES 205



N(10-25) and N(25-50) have lower I_c and poor N value.

#1) started from here

Conductor critical current in self-field is significantly higher than that in the coil where the field is much larger.

Summary

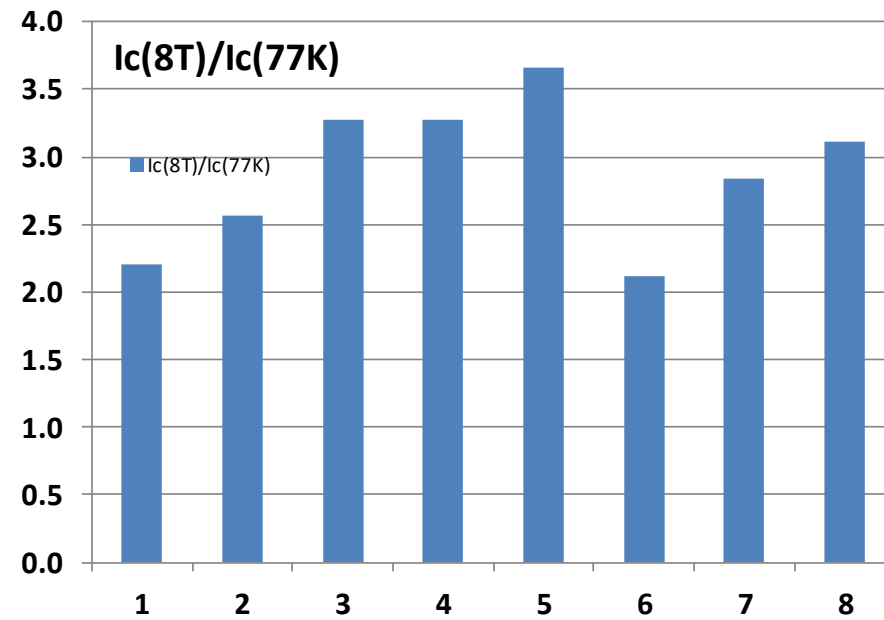
- Construction of all inner pancakes and all outer pancakes for 1.7 MJ has been completed.
- Fabrication of fixture for testing outer double pancake at 77 K has been completed and successfully used. It allows testing of both pancakes even when they have significantly different critical currents.
- All inner pancakes and five outer pancakes have been tested at 77 K.
- QA in place has been effectively used. We continue to monitor all parts and construction carefully. Successful construction and test of 10 T coil in Q6 gives us a degree of confidence.

Backup Slides

Opportunity to Increase High Field Performance of REBCO

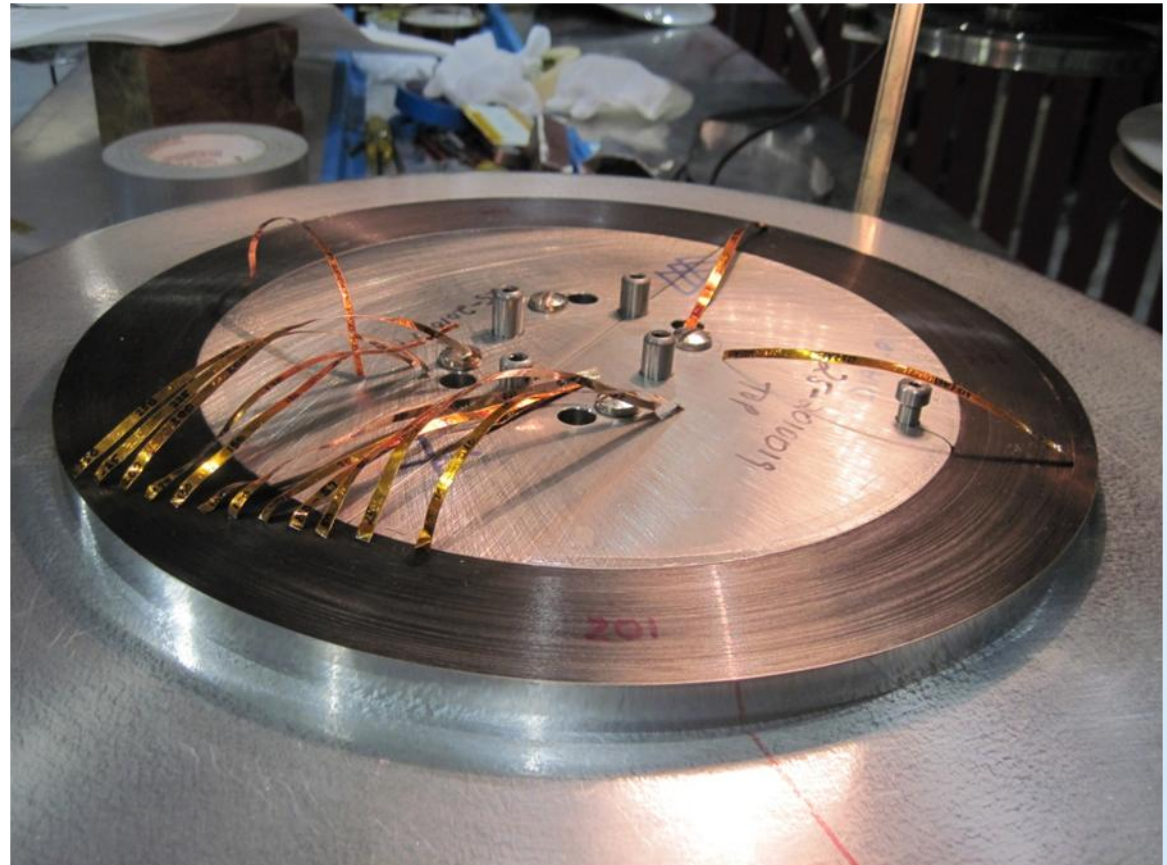
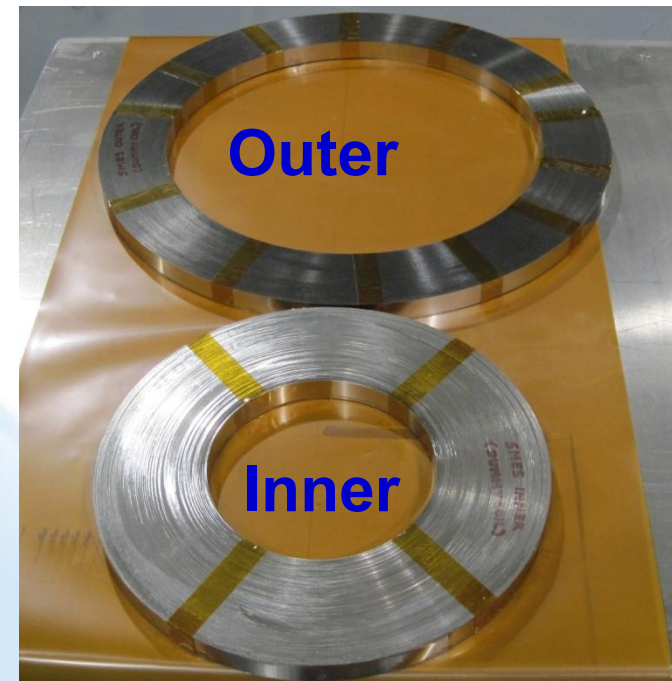
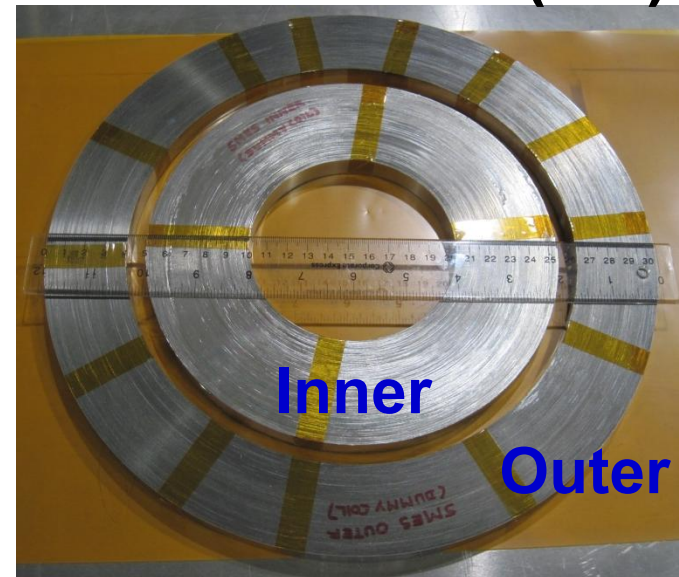
- Critical current of HTS tape is highly anisotropic. Coil performance is limited primarily by its field perpendicular value (or within 20° of this angle)
- BNL measurements of the wire used in coil show that 4K perpendicular field I_c varies as much as ~2X (726A to 1401A)
- Once we understand the sources, we may be able to apply them in production
- See earlier presentations by Selva
- Here is an opportunity for increasing high field I_c by a factor of two or more
- ARPA-E SMES is driving this R&D
- BNL will receive the improved wire from Houston as a part this program

Sample Num	Comments	Tape Width, mm	$I_{c_Perp}(8T)$	$I_c(77K)$	$I_c(8T)/I_c(77K)$
1	PERP TEST	12	726	330	2.200
2	PERP TEST	12	800	312	2.564
3	PERP TEST	12	1119	341	3.282
4	PERP TEST	12	1324	404	3.277
5	PERP TEST	12	1401	383	3.658
6	PERP TEST	12	773	365	2.118
7	PERP TEST	12	956	337	2.837
8	PERP TEST	12	1369	439	3.118



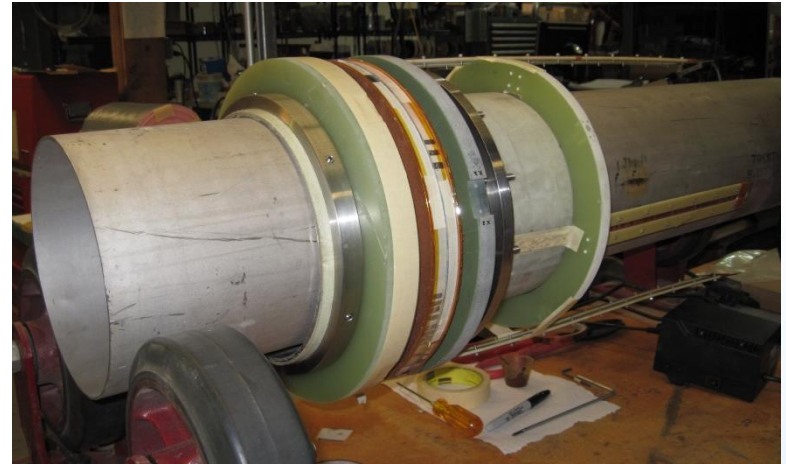
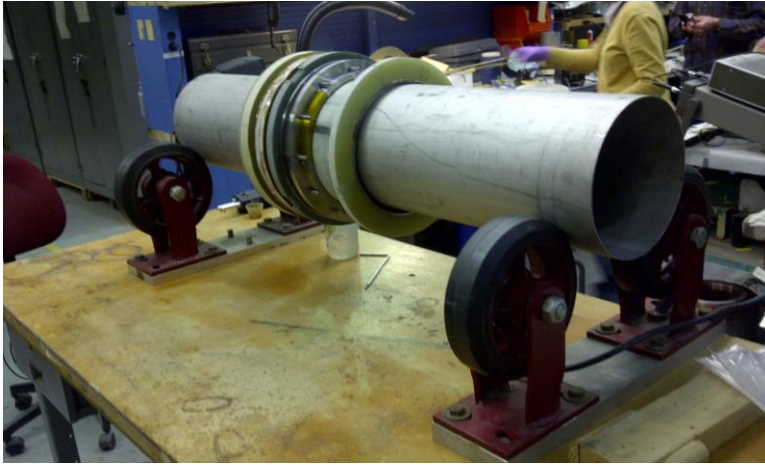
Practice coils (SS)

Outer Pancake #1



Made with ~210 meter of 12 mm tape with 65 micron copper.
25 micron of SS tape between turns (No. of turns = 258).

Intermediate Steps in Preparation for 77 K Test

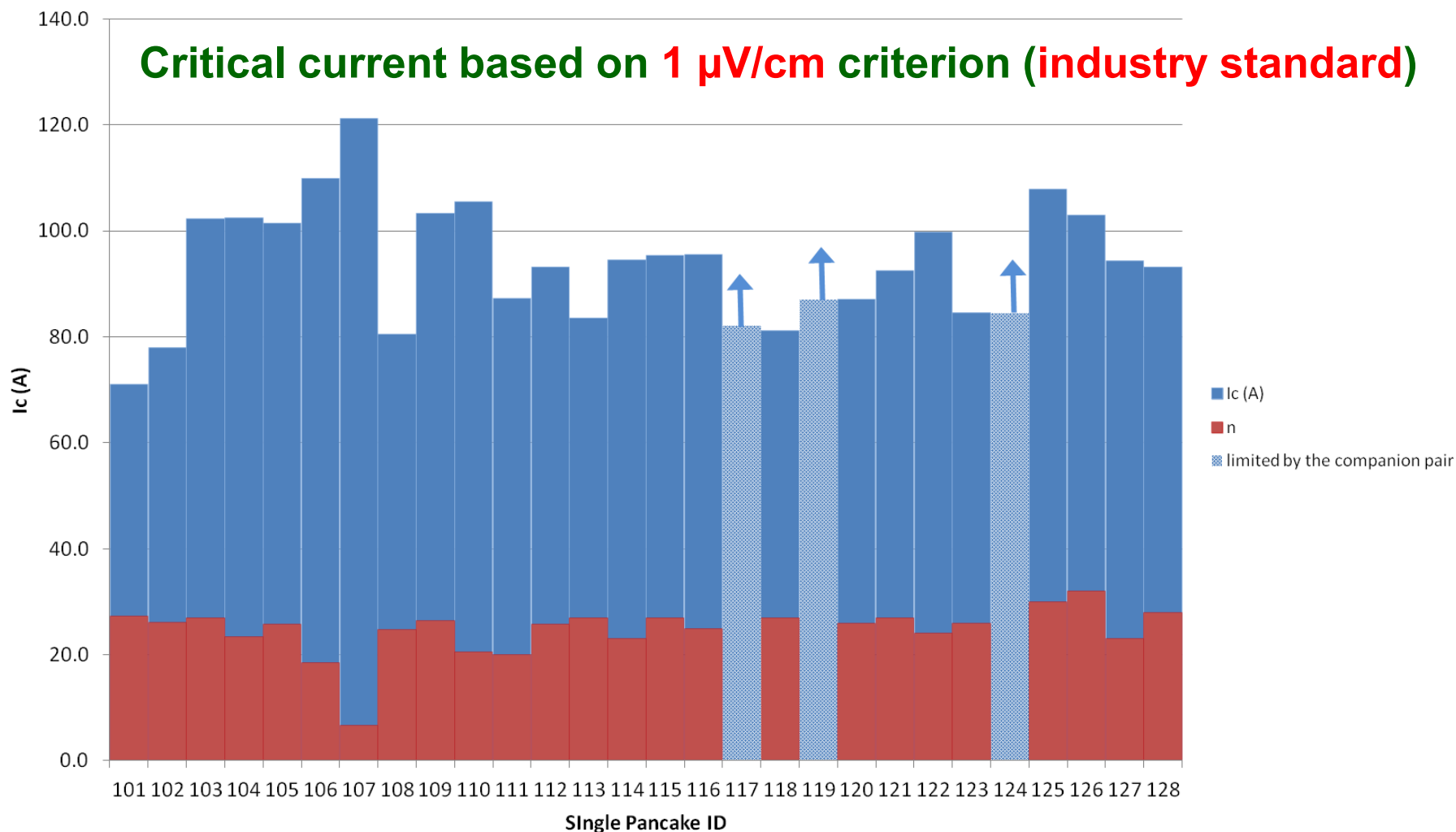


Demanding Requirement on the Conductor

- High strength, high performance conductor is one of the major enabling technology of this project
- This project uses a large quantity of the conductor : 8.4 km of 12 mm width (equivalent to over 25 km of standard 4 mm width)
- The project relies on the unique wire that SuperPower produces in large quantities with requirements never demanded by any project before: very high fields, very high strengths, very high stress/strain tolerances and good bonding with copper stabilizer
- For this reason a conductor that might be OK for other projects, may not be acceptable here. Therefore, the conductor is carefully monitored as it pays out during winding and any deviation is reported
- Variety of examples have been shown. The wire was sent to SuperPower for further inspection. All being replaced voluntarily

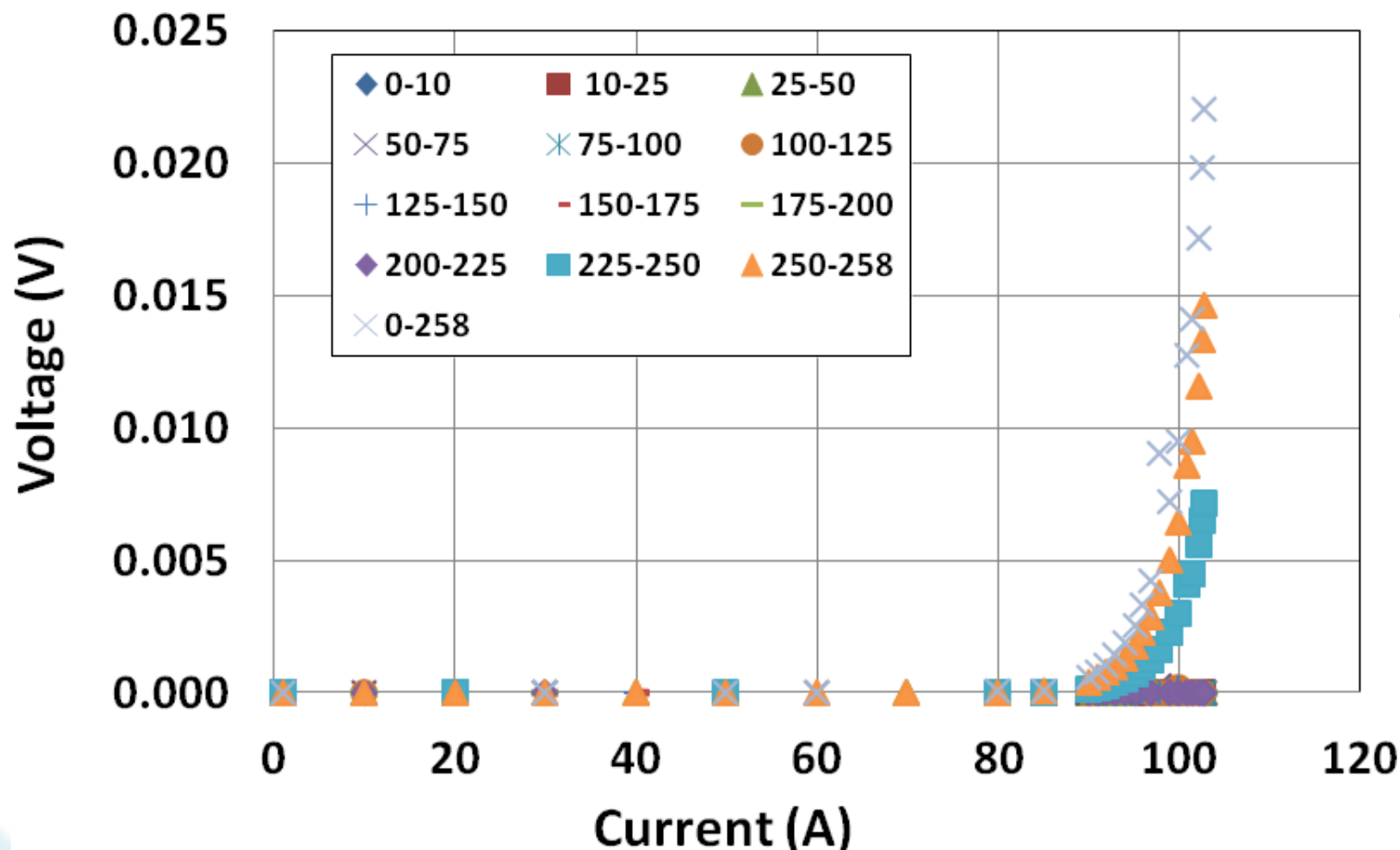
Summary of 77 K test of all inner pancakes

I_c and n value at 77 K of single pancake coils



**Tested in double pancake structure with two single pancakes powered in series.
Arrow indicates lower performing pancake limiting the I_c measurements.**

77 K Test Result of the First Outer Pancake



Legends indicate the turn numbers between the sections where the onset of resistive voltage is measured

Pancake reaches over 100 A (1 μ V/cm criterion)

➤ **Coil and winding techniques are acceptable**

✓ **OK to proceed**

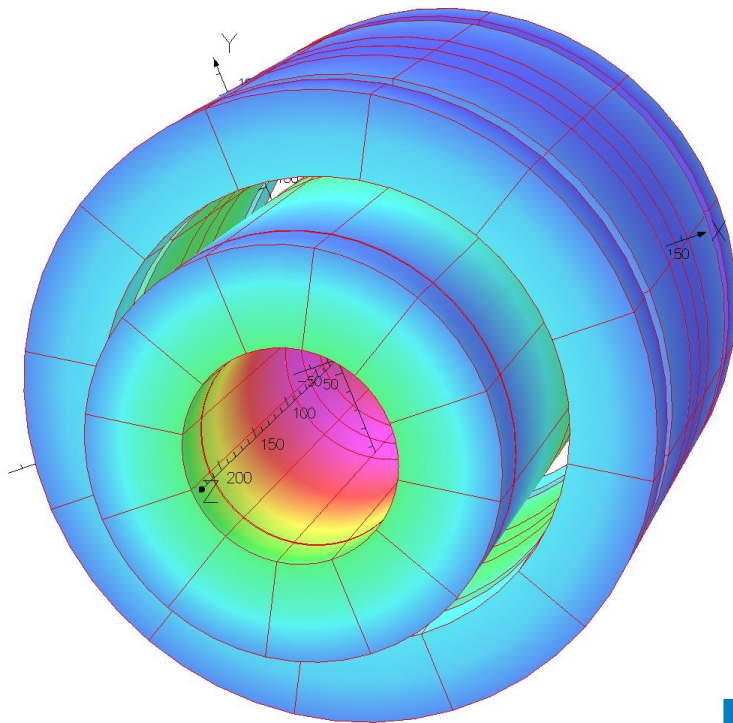
1.7 MJ SMES Coil Design

12/04/2012 16:25:06

Surface contours: BMOD

2.561830E+001
2.000000E+001
1.500000E+001
1.000000E+001
5.000000E+000
3.573412E+000

|B|

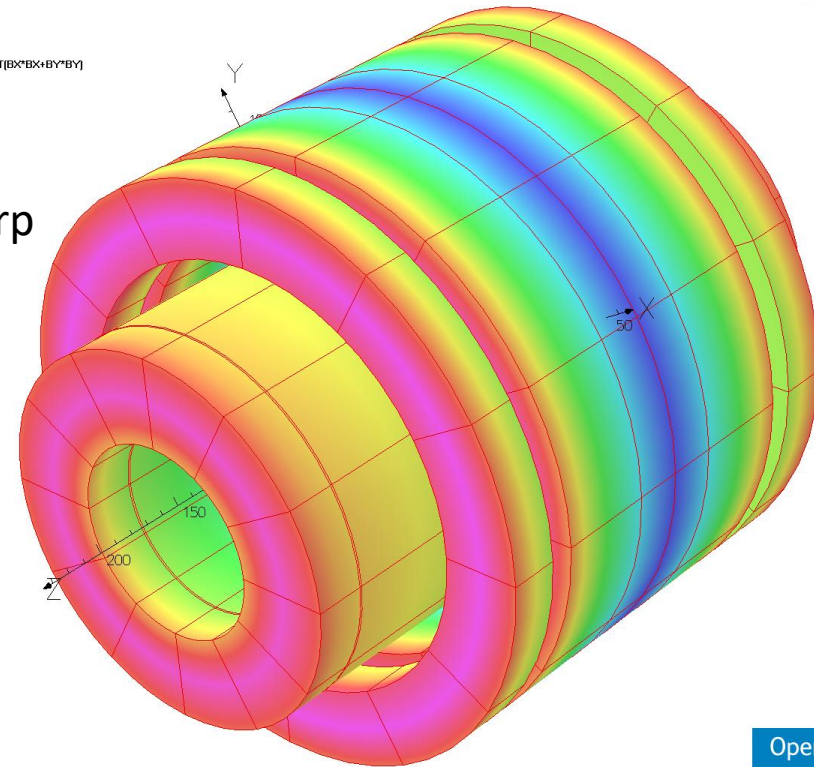


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Surface contours: SORT(BX*BX+BY*BY)

6.605375E+000
6.000000E+000
5.000000E+000
4.000000E+000
3.000000E+000
2.000000E+000
1.000000E+000
0.000000E+000

Bperp



No. of Pancakes: 28 inner and 16 outer (28 outer will give 2.5 MJ)

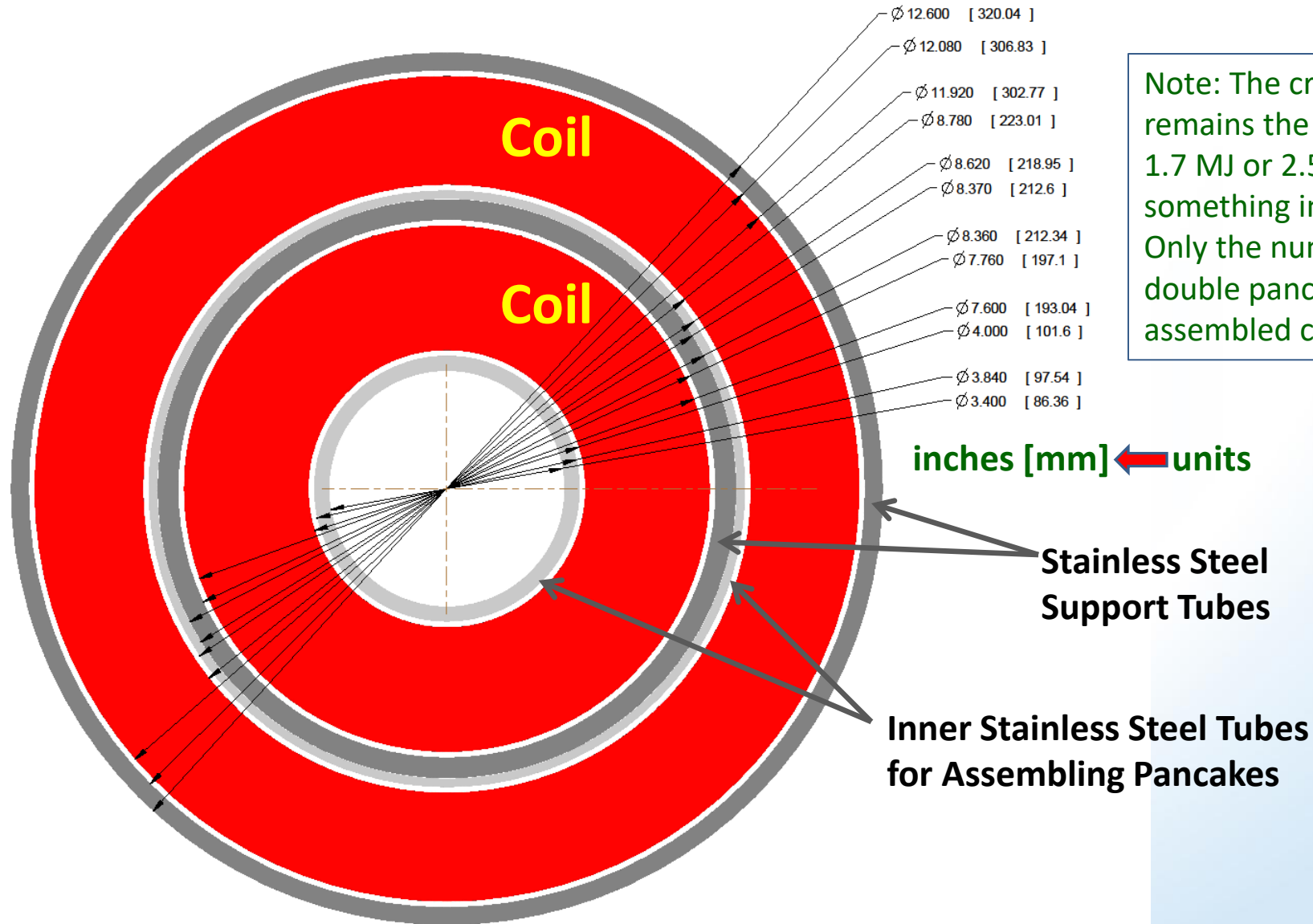
Strategy: Optimize for 1.7 MJ but do not prevent 2.5 MJ upgrade

Note: Use high strength conductor in the middle section

Nominal Parameters of 1.7 MJ SMES Coil

Stored Energy	1.7	MJ
Current	720	Amperes
Inductance	7	Henry
Maximum Field	25	Tesla
Operating Temperature	4.2	Kelvin
Overall Ramp Rate	1.2	Amp/sec
Number of Inner Pancakes	28	
Number of Outer Pancakes	16	
Total Number of Pancakes	44	
Inner dia of Inner Pancake	101	mm
Outer dia of Inner Pancake	193	mm
Inner dia of Outer Pancake	223	mm
Outer dia of Outer Pancake	303	mm
Intermediate Support	15	mm
Outer Support	7	mm
Width of Double Pancake	26	mm

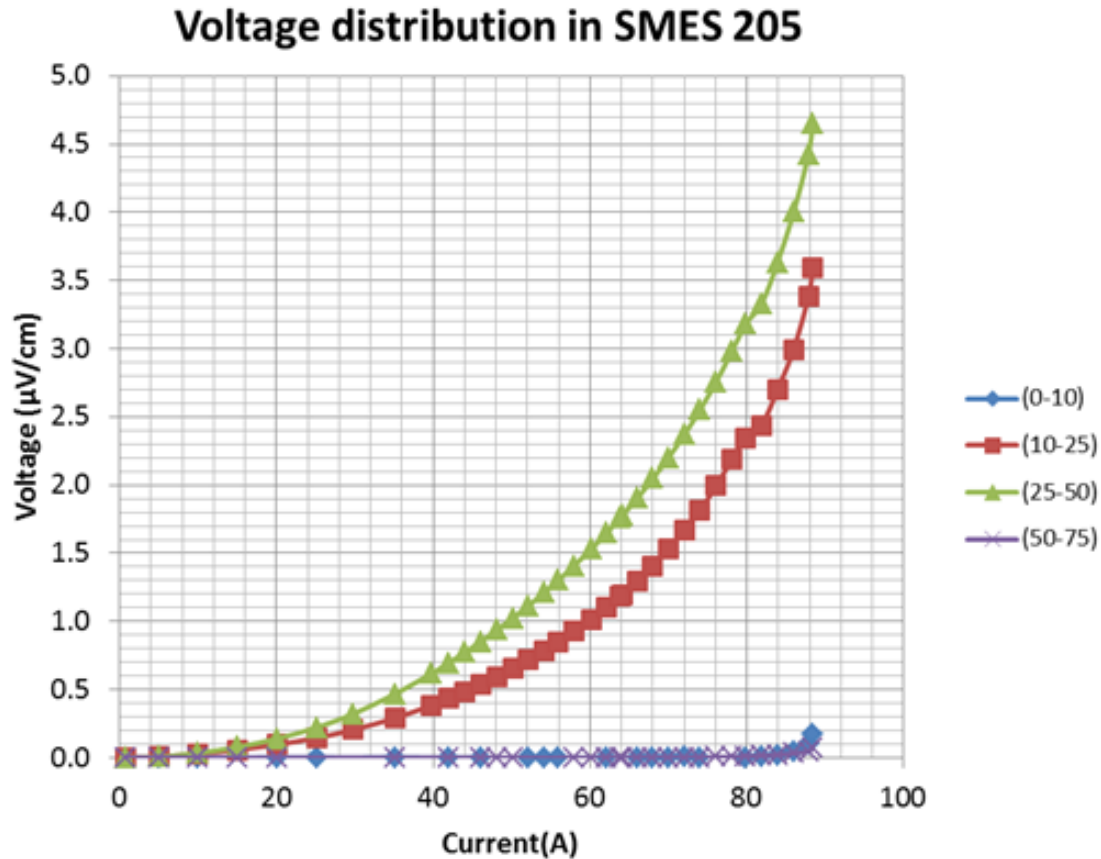
Cross-section of Coil and Support Tube Structure



Note: The cross-section remains the same for 1.7 MJ or 2.5 MJ (or something in between). Only the number of double pancakes to be assembled changes.

Coil SMES 205 Powered Alone

(Voltage gradient on the coil and on group of turns)



Pancake SMES205 is suspected because the turn #10-25 and turn #25-50 see an early onset of resistive voltage.

This could be either due to a mishap during winding or a weak portion of the conductor was not caught by visual inspection.

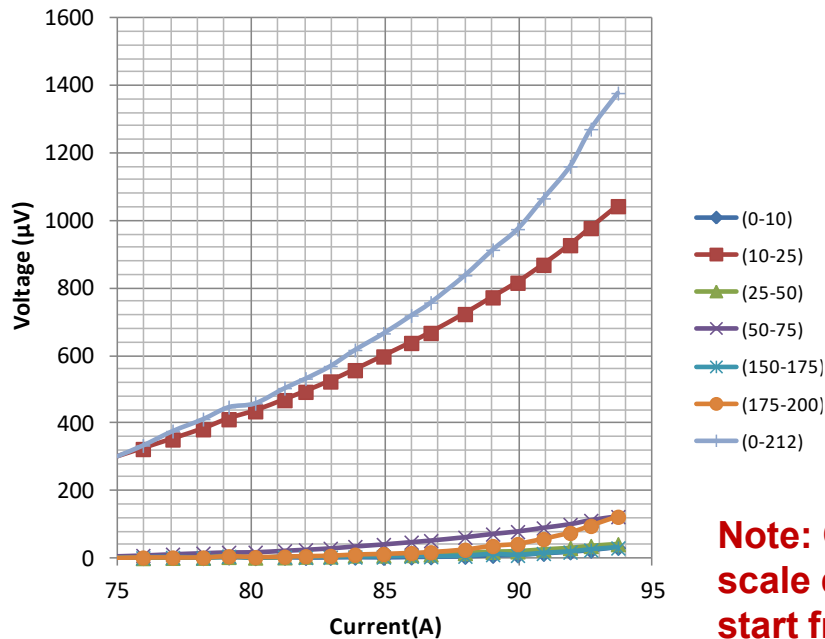
Critical current is usually defined at 1 $\mu\text{V}/\text{cm}$ but that definition is relevant here.

Test Results of Double Pancake 2004

(2 pancakes powered in series)

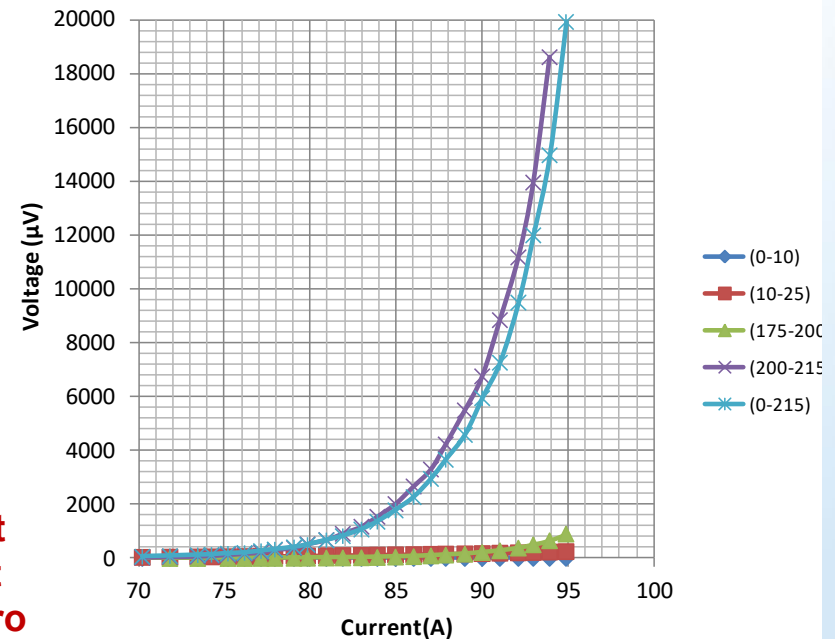
Note: In both coils the onset of voltage doesn't start in turn#1-10. However, there is no defect in the coil. This has been seen before and is likely due to variation in in-field performance due to variation in doping.

Voltage distribution in SMES 210



Note: Current scale doesn't start from zero

Voltage distribution in SMES 211

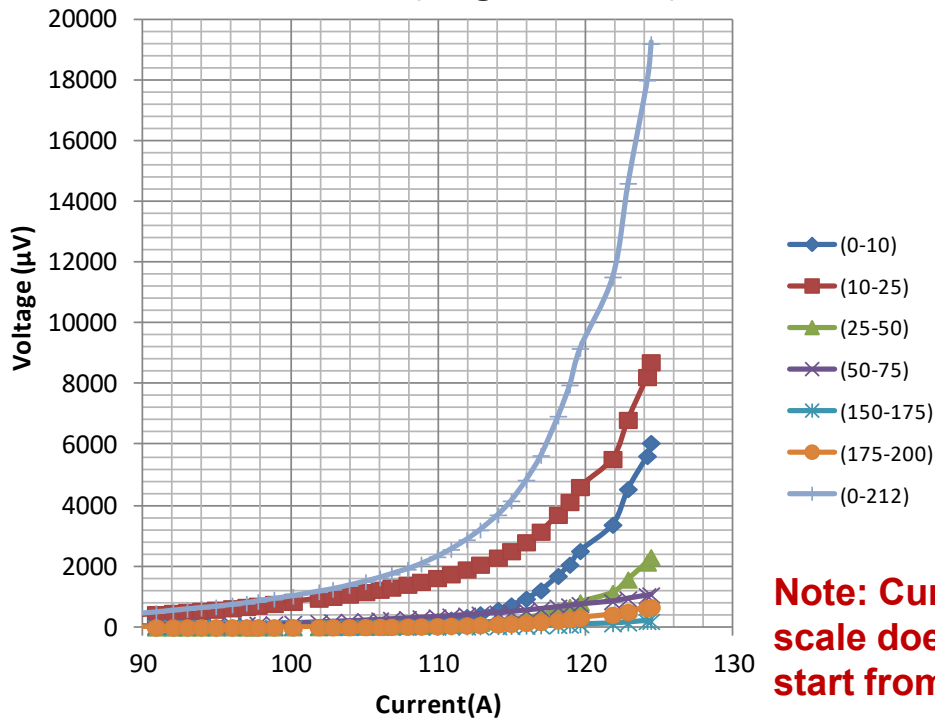


Extra leads in the middle (new in the outer coil setup) allows detailed test of individual coil separately when there is a significant difference in performance (such as here).

Coil SMES210 and SMES211 Powered Alone

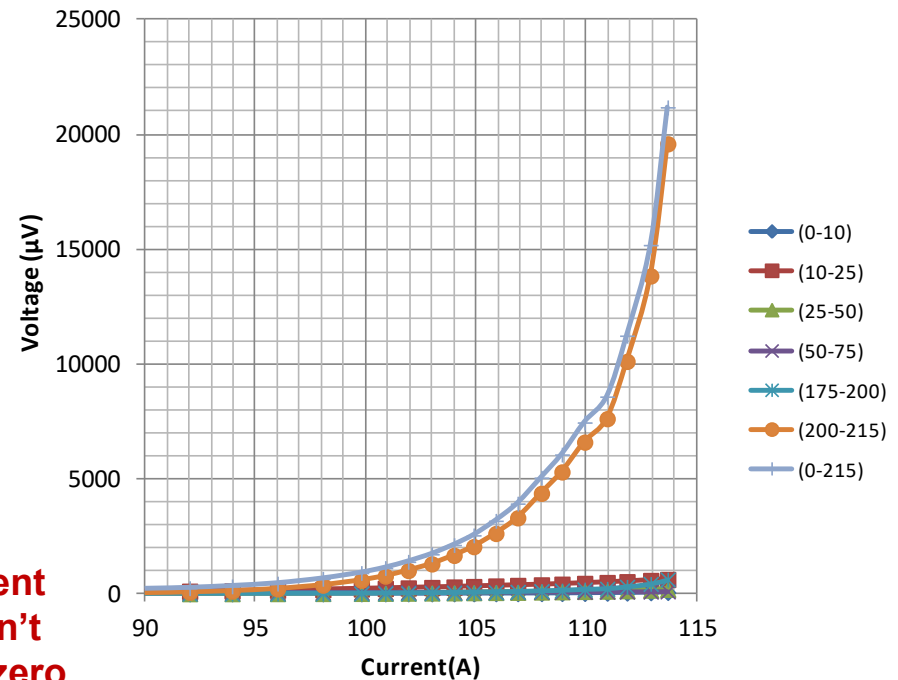
(Measured voltage on the coil and on group of turns)

SMES 210 (single coil test)



Note: Current scale doesn't start from zero

SMES 211 (single coil test)



Note: In both coils the onset of voltage doesn't start in turn#1-10. However, there is no defect in the coil. This has been seen before and is likely due to variation in in-field performance due to variation in doping.