Conductors, Cables, and Magnets for High Energy Physics: Transport, Magnetization, and Modelling

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Department of Materials Science and Engineering

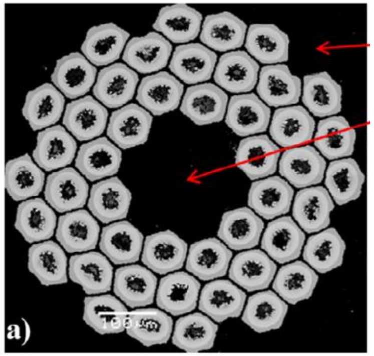
Collaborations and Collaborators

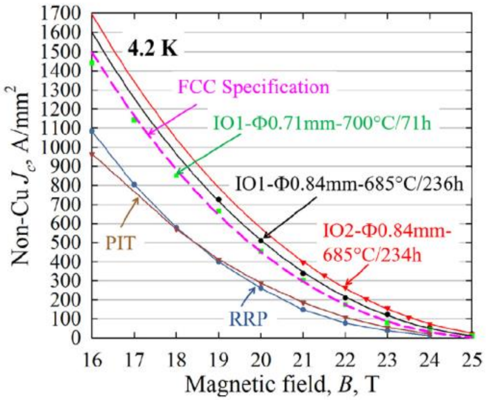
- Xingchen Xu, FNAL, Nb_3Sn APC
- Advanced Conductor Technologies, CORC Conductor
- FNAL: High Current Cable, quench (Barzi)

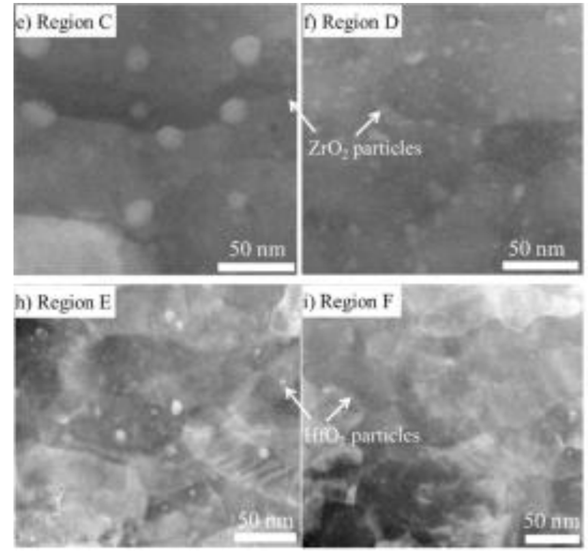
X. Wang, S. Prestemon, G.L. Sabbi, T. Shen, ATAP division, Lawrence Berkeley National Laboratory, Berkeley, CA, USA

Collaboration with the U.S. Magnet Development Program (MDP)

Nb_3Sn Results (collaboration with FNAL and HTR)

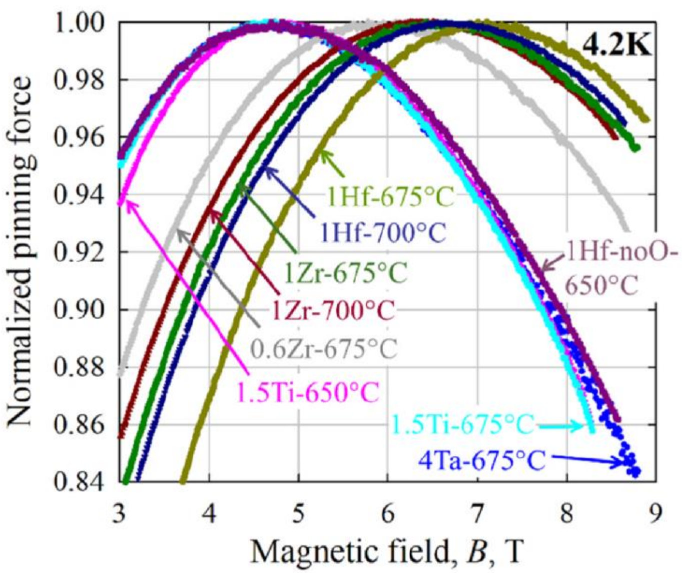


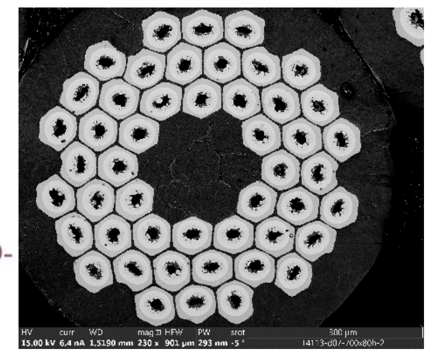


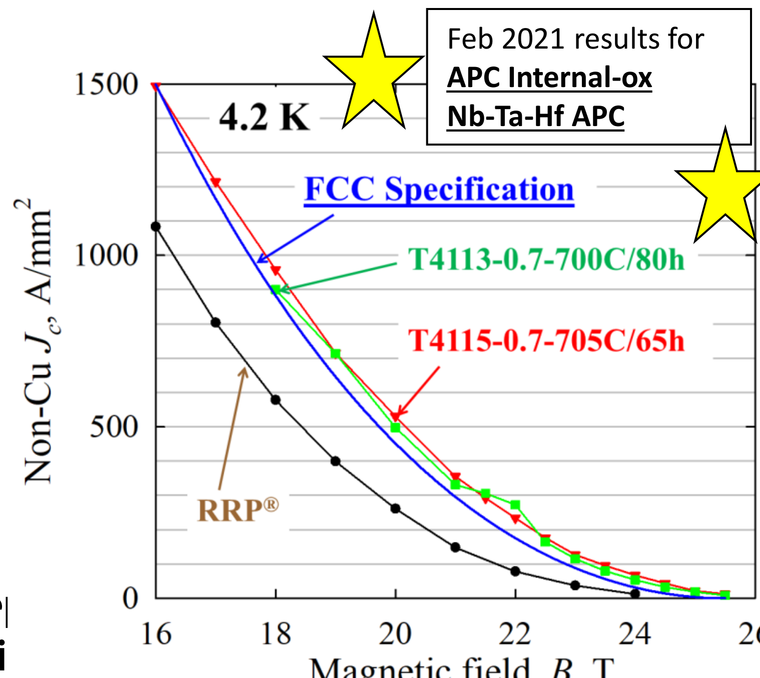


Internal Oxidation APC Nb_3Sn Nb-Ta-Zr based

X. Xu, X. Peng and J. Rochester et al. / Scripta Materialia 186 (2020) 317–320







Outline of the program (Revised Scope)

1. Cable and Conductor Magnetization, Field Error, and Drift

1.1 Measurement of Conductor and Cable Magnetization: Experimental Input for Field Error Calculation

1.2 Magnetization Modelling

1.3 Magnetization, Field Error Decay, and Snap-Back

2. Transport Measurements on Cables; Stability, Current Sharing, and Quench

2.1 <u>Measurement</u> of Current Sharing, Stability, and Quench in Cables with Full Current Excitation

2.2 <u>Modelling</u> of Stability, Current Sharing, and Quench in Cables

3. Modelling of Magnets and Coils

3.1 Calculation of Field Error and its Decay in HTS Prototype Magnets

3.1.1 Calculation of b_3 and b_3 Decay

3.1.2 Cables and Magnets for Measurement

3.2. Modelling HTS Magnets and Inserts: Contact Resistances, Quench, Strand Breakage

3.2.1 Modelling of Current Redistribution Following Strand Breakage

3.2.2 Modelling of Temperature Rise Time, Current Distribution

3.2.3 Cable-to-Cable Interface Resistance, R_{IC}, in Response to Surface Condition:

3.2.3 Thermal Diffusion in a Cable Stack

Driving Questions for OSU-GARD Program

Magnetization:

Q1: What is the size and influence of HTS and Nb_3Sn cable magnetization on field error in accelerator magnets?

Q2: Is it possible to develop precise analytic expressions for HTS cable magnetization that can provide direct input to magnet field error calculation?

Q3: How does field cycling and the associated local field-in-the-windings influence HTS magnetization and drift at injection?

Current Transport:

Q4: What is the present level of current sharing and stability in HTS cables?

Q5: How does current sharing and stability of HTS cables respond to (i) changes in surface condition, (ii) changes in cooling mode, (iii) expected increases in conductor performance (increases in J_c and reductions in Cu/SC ratio)?

Q6: How does Lorentz-force loading influence HTS cable deformation and current sharing?

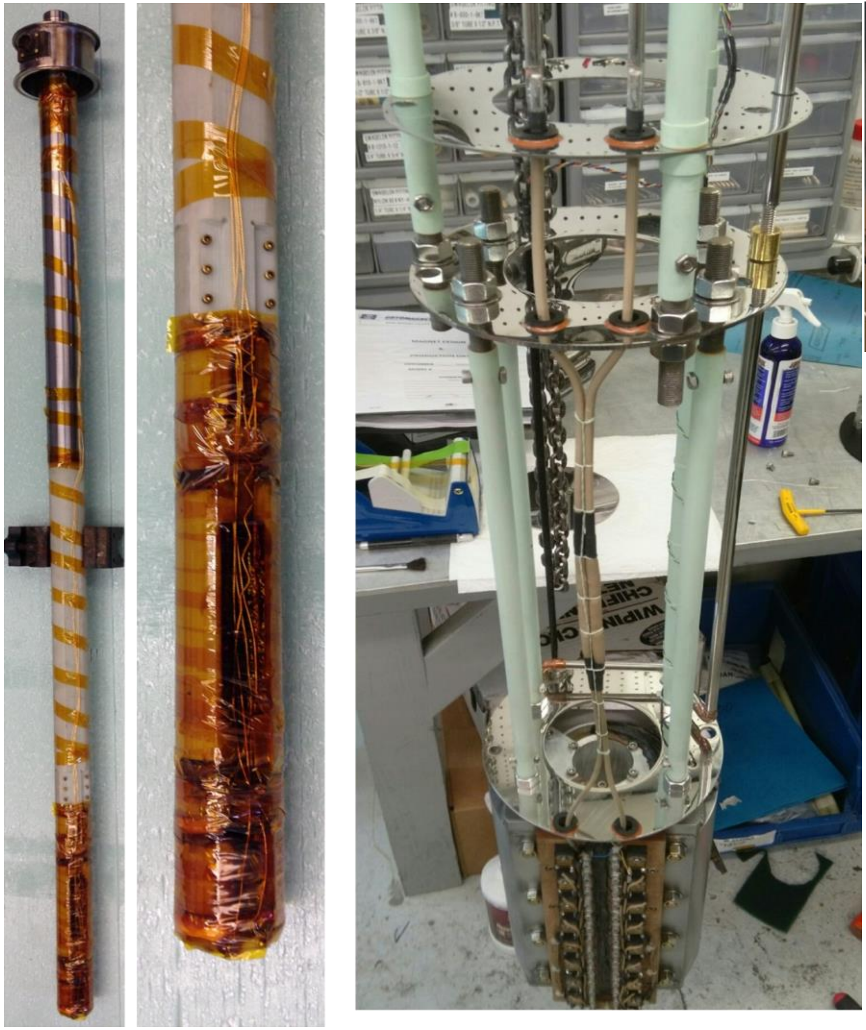
Magnet Properties:

Q7: How is the protectability of HTS cables and magnets impacted by: (i) changes in conductor surface condition, (ii) changes in cooling mode, (iii) expected increases in conductor performance (increases in J_c and reductions in Cu/SC ratio)?

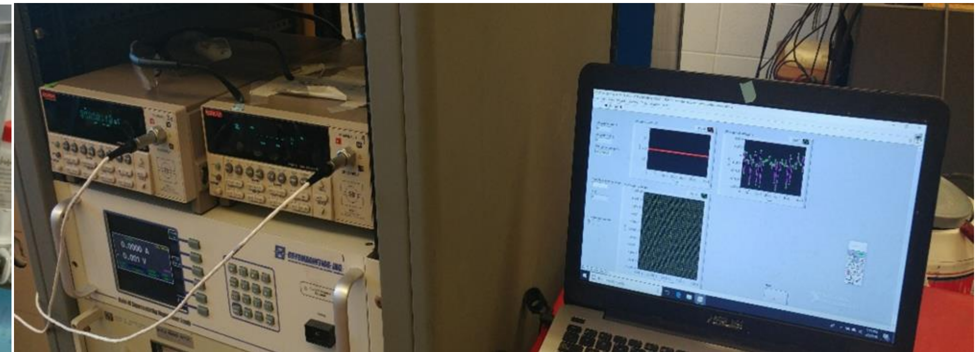
Section I: Magnetization of Conductors, Conductors in Cables

- Data for use in Modelling of field errors
- Models of magnetization to use for modelling of field errors

3 T Dipole Magnet Cable Magnetization System

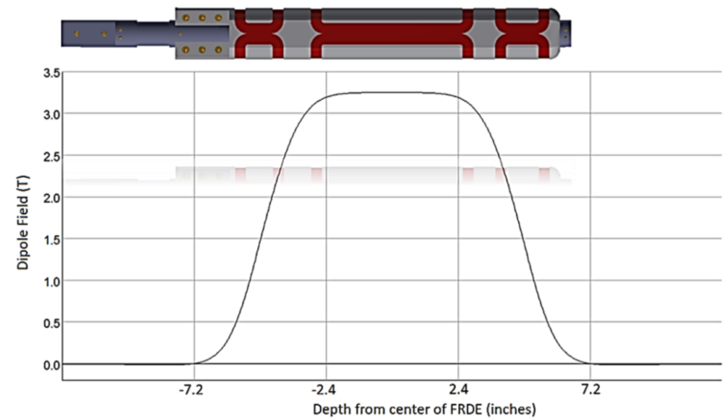


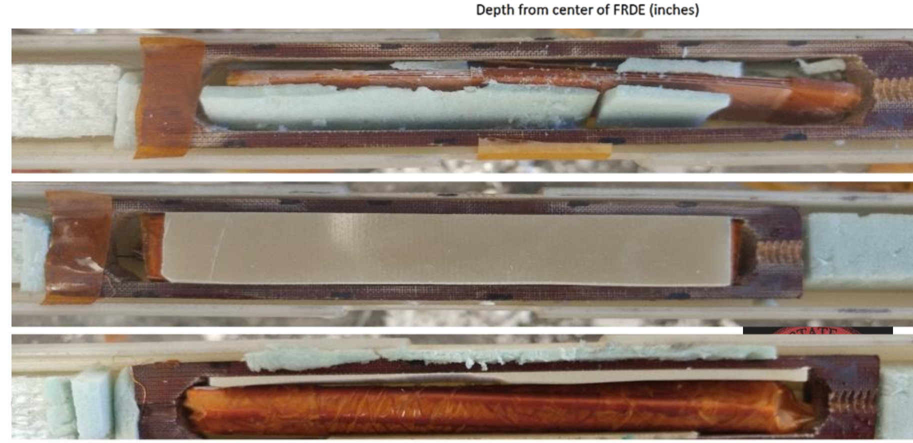
Sample holder, Pickup Coils, Dipole Magnet



Data Acquisition, Magnet Supply, Control Computer

B = ± 3 T

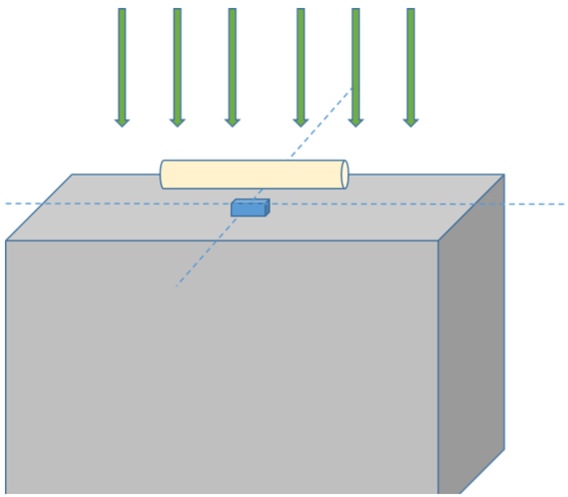


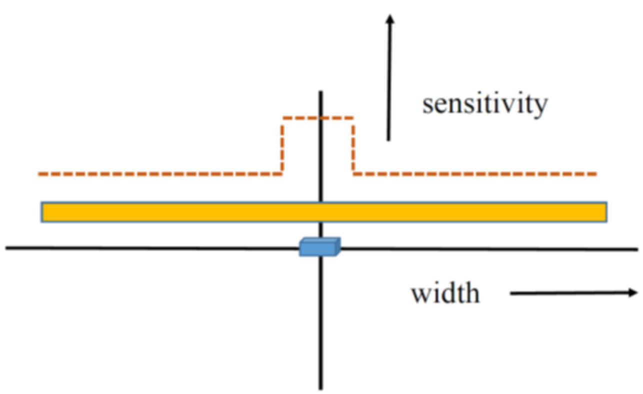


Samples in pick-up coils

12 T Hall Probe Cable Magnetometer

- Measurement made by ΔB between sample and no sample
- Field generated by 12 T, liquid cryogen free, RT bore magnet
- Cooling provided by varitemp dewar





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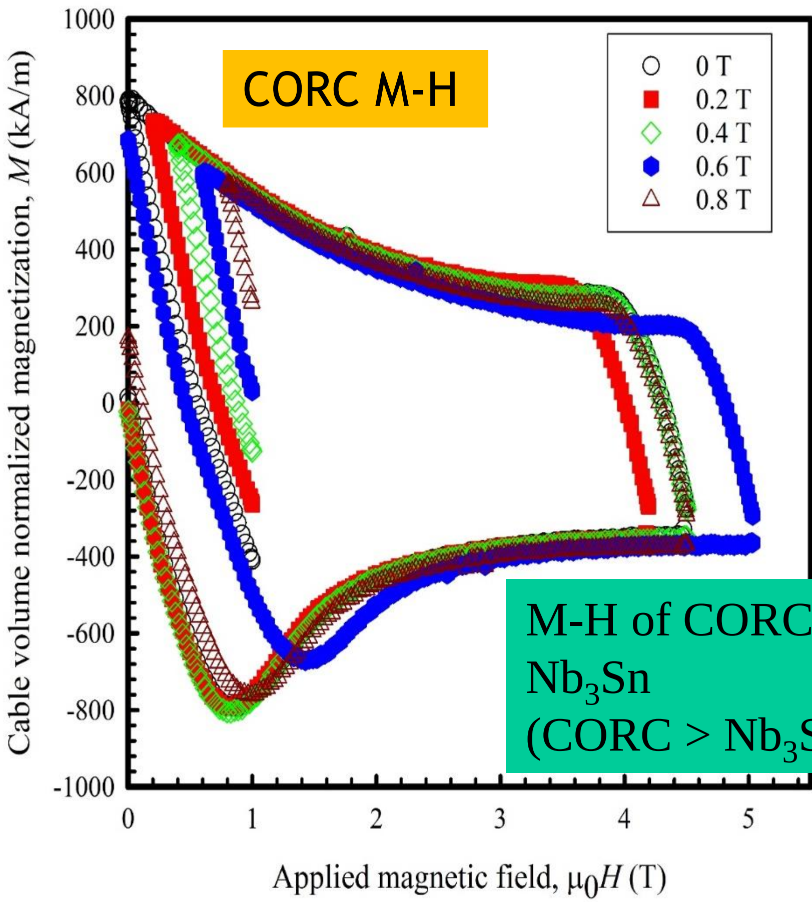
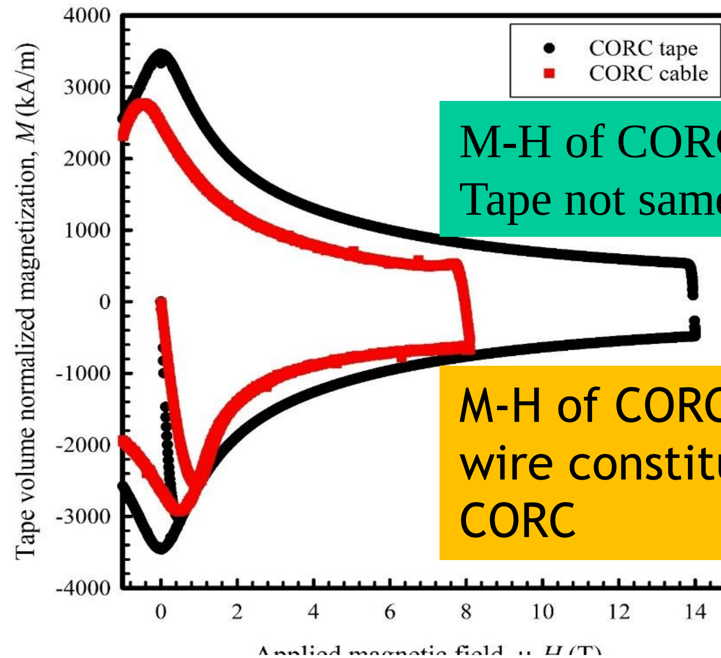
M-H of CORC cable Comparison to YBCO tape and Nb_3Sn



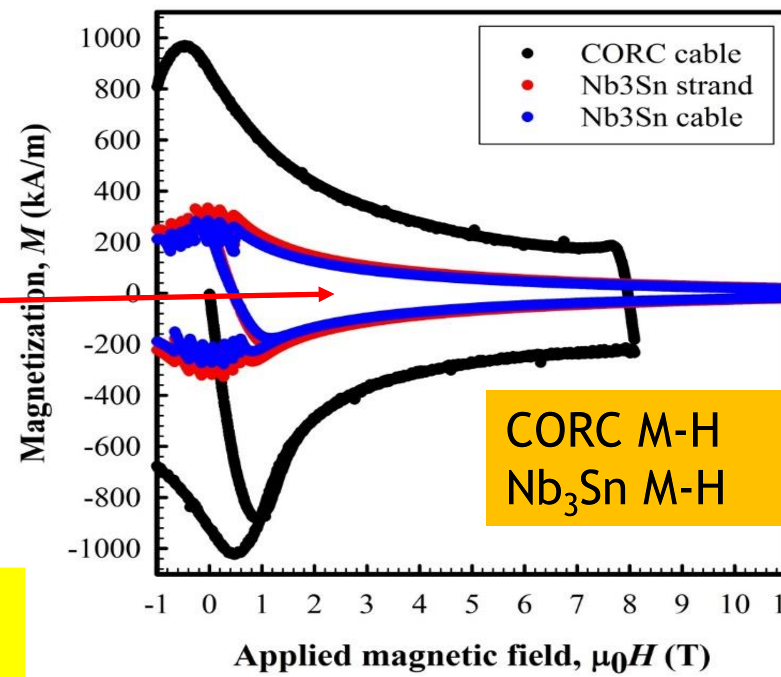
CORC M-H

M-H of CORC vs Nb_3Sn
(CORC > Nb_3Sn)



M-H of CORC and Tape not same

M-H of CORC and wire constituting CORC



CORC M-H
Nb_3Sn M-H

Takeaway: CORC Cable Mag Characterized Compared to Nb_3Sn

Magnetization of Bi:2212 Cables

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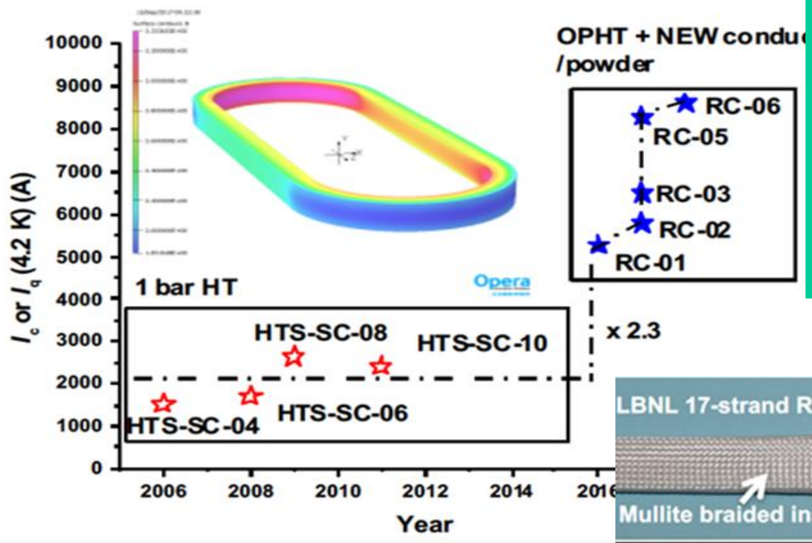
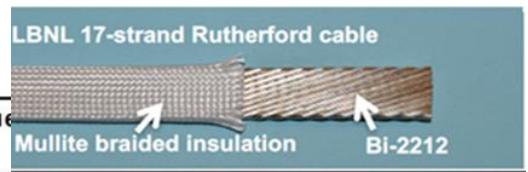
LBNL HTS (2212) subscale r... topped with new RC-06 resu...

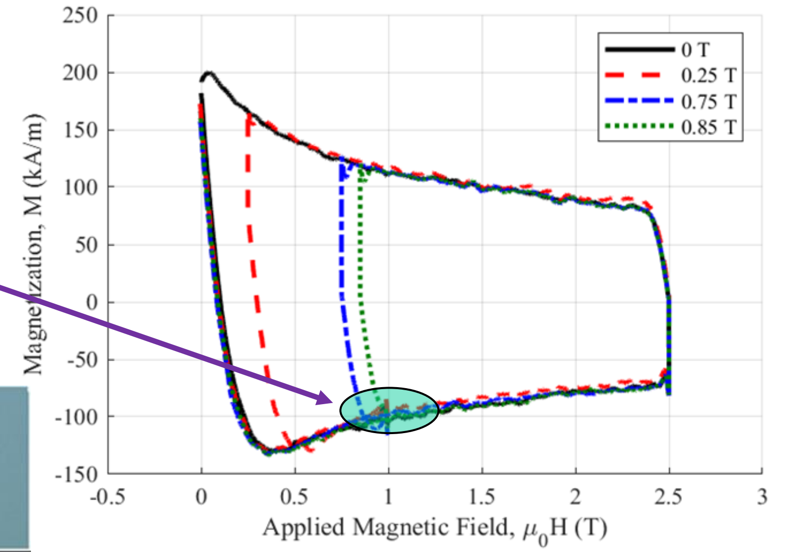
Subscale coils allow fast-turnaround test of cable and magnet-relevant technologies.





≅ Nb_3Sn, but not scaled for Amp-turns

≅ (i.e., Jc)



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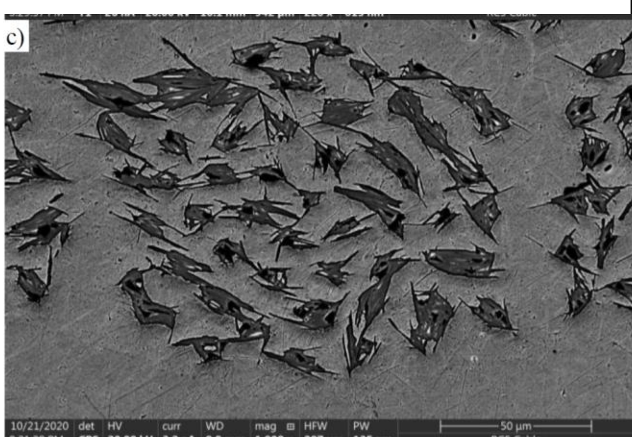
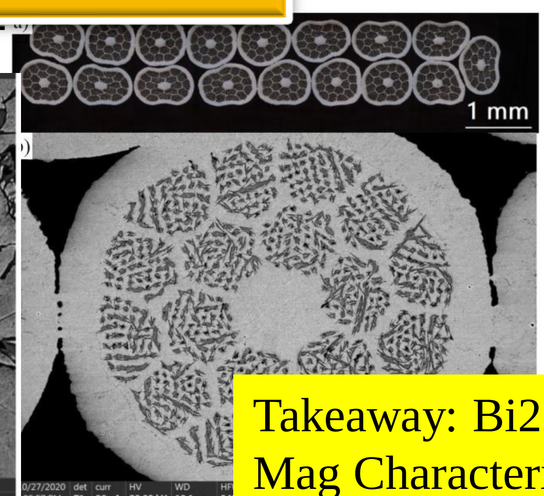
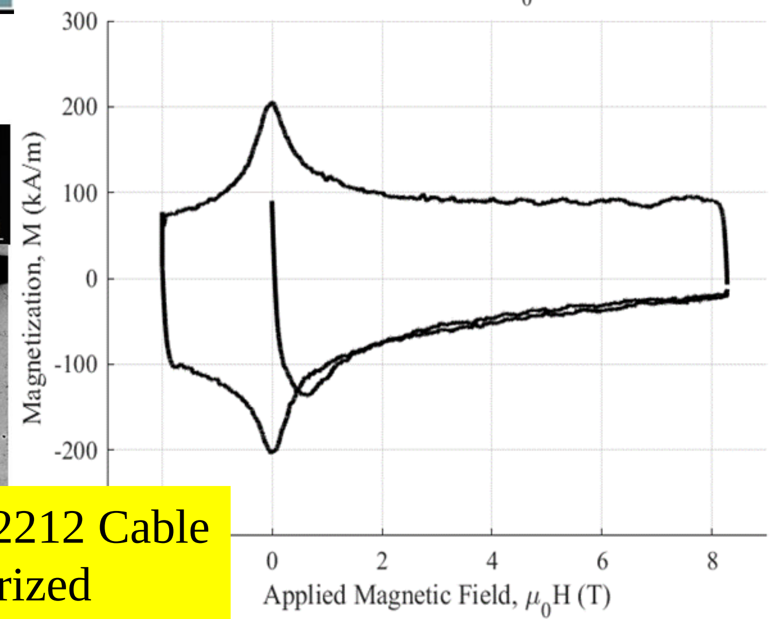
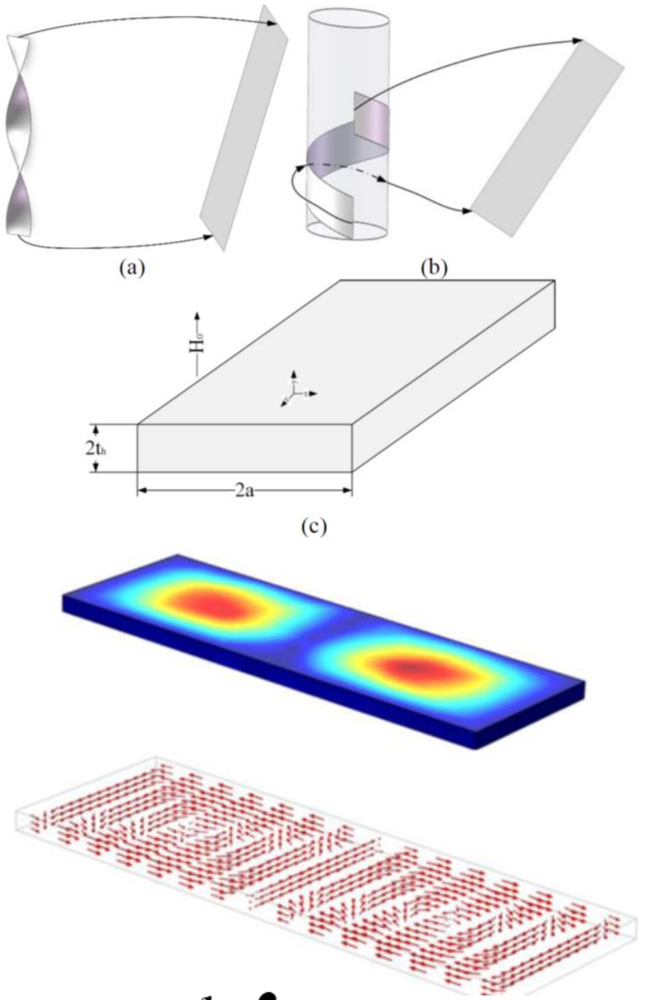


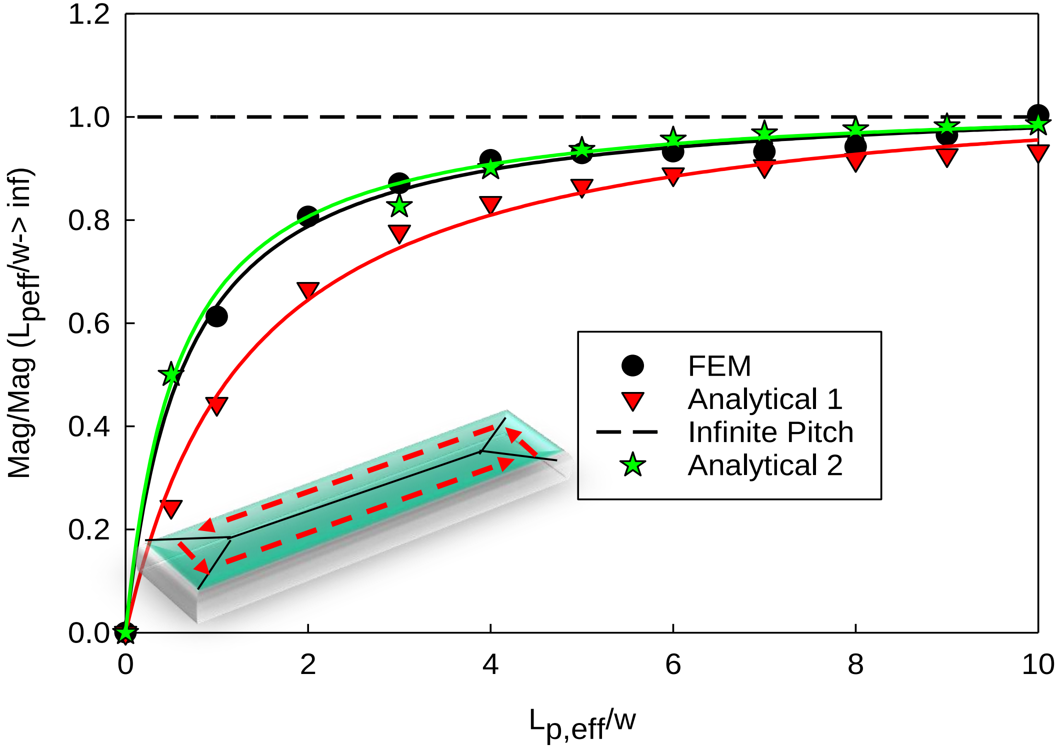




Takeaway: Bi2212 Cable Mag Characterized

Model- Magnetization of CORC





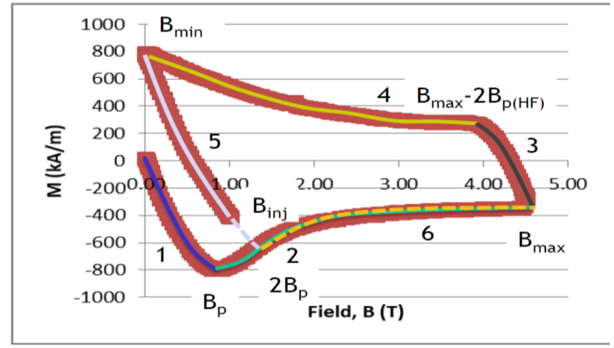
$$M = \left(\frac{1}{V}\int_V H_{local}\, dV - H_{applied} \right)$$

- Dashed line gives infinite pitch
- Shorter L_{peff}/w ratios give lower mag
- Agreement between FEM and analytic OK with Analytic 1 (even better when WF included – Analytic 2)

Analytic 1

$$\Delta M = \Delta M_0 \frac{2}{\pi}\left(1 - \frac{2y_m}{3L}\right) = \Delta M_0 \frac{2}{\pi}\left(1 - \frac{w}{3\frac{L_p}{2}}\right) = \Delta M_0 \frac{2}{\pi}\left(1 - \frac{2w}{3L_p}\right)$$

Modelling CORC for accelerator cycles II



1-virgin initial permeability, 0->B_p

$$M = \frac{-M_0}{\left[A + \left({}^{B}/_{B^*}\right)\right]}\left(\frac{B}{B_p}\right)$$

2-1st shielding, B_p->B_{max}

$$M = \frac{-M_0}{\left[A + \left({}^{B}/_{B^*}\right)\right]}$$

3-init reversal, B_{max}->B_{max}-2$B_{p(HF)}$

$$M = \frac{-M_0\left(1 - \left(\frac{[B_{max} - B]}{B_{p,HF}}\right)\right)}{\left[A + \left({}^{B}/_{B^*}\right)\right]}$$

$$M0 = M_{max} = \frac{2}{\pi}\frac{J_c a}{2}FF\left[1 - \frac{w}{3L_{p,eff}}\right]$$

4-trapping, 0-> B_{max}-2$B_{p(HF)}$->B_{min}

$$M = \frac{M_0}{\left[A + \left({}^{B}/_{B^*}\right)\right]}$$

5-2nd initial permeability, B_{min}->2B_p

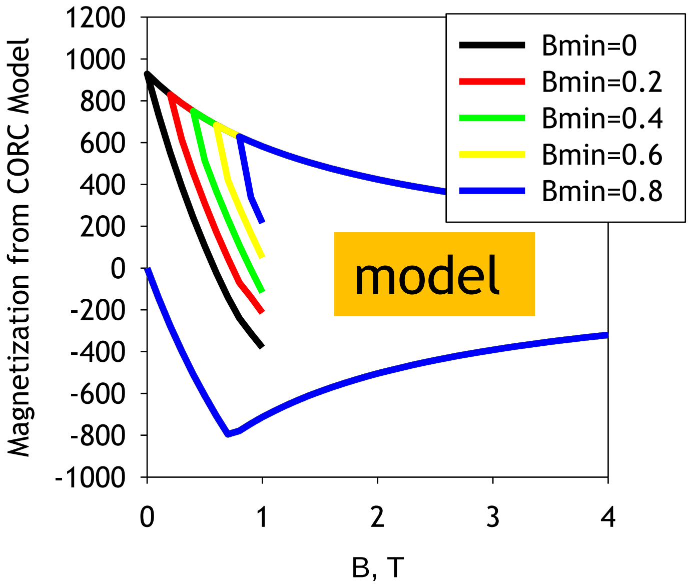
5i-2nd init perm, B_{min}->B_{inj}

$$M = \frac{M_0\left(1 - \left(\frac{[B - B_{min}]}{B_p}\right)\right)}{\left[A + \left({}^{B}/_{B^*}\right)\right]}$$

6-2nd shielding, 2B_p->B_{max}

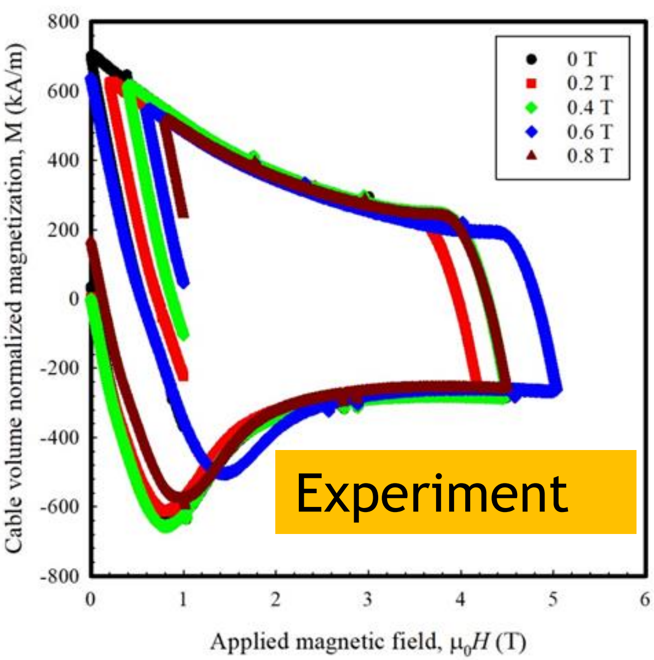
$$M = \frac{-M_0}{\left[A + \left({}^{B}/_{B^*}\right)\right]}$$

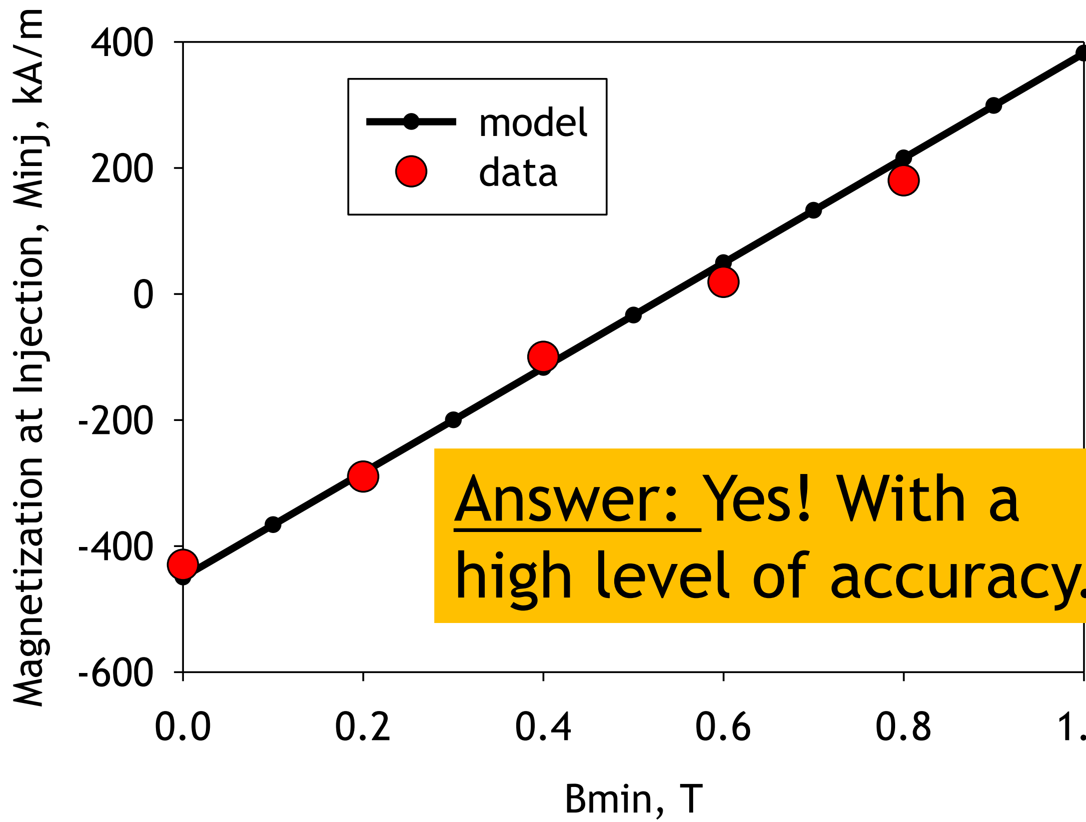
Ques: So, can we make a model, predict magnetization for various arbitrary cycles?



Now, can we use this model as a feed into the FEM model to make b3 predictions?

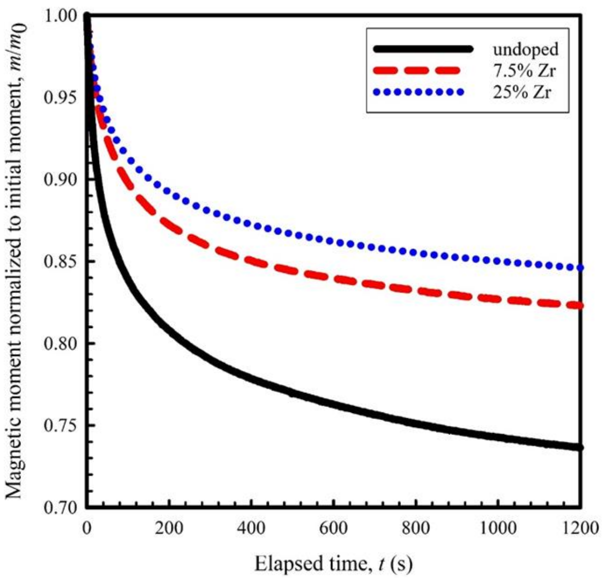
Sample type and hold field	M_0 (kA/m)
CORC 0 T	-430
CORC 0.2 T	-280
CORC 0.6 T	19
CORC 0.8 T	180

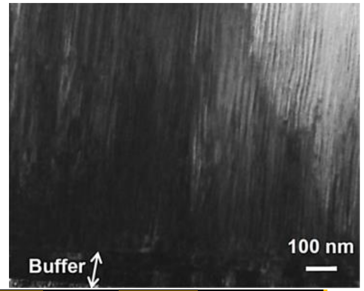




Answer: Yes! With a high level of accuracy.

Creep in YBCO tape

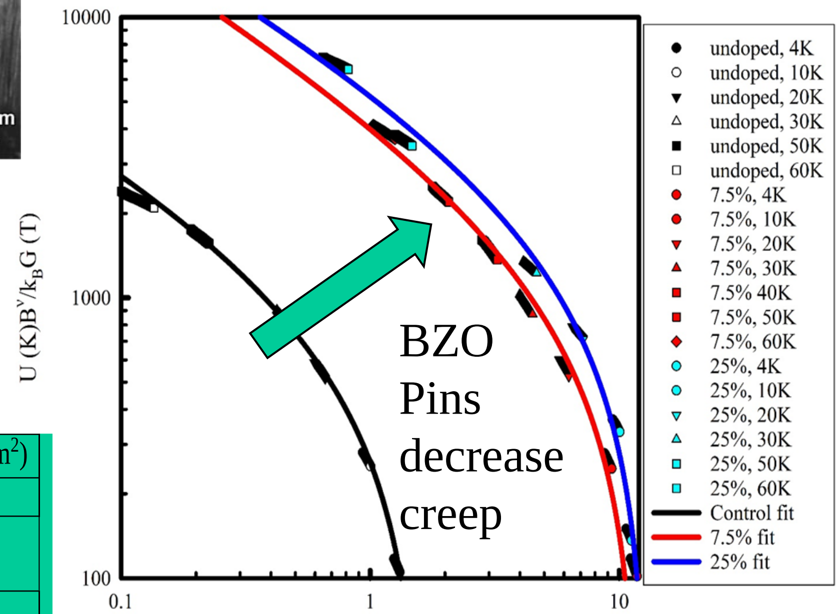




Sample	U_0	μ	J_c MA/cm^2
Control	625	0.65	35
5% (211)	650	0.7	40
10% (211)	650	0.72	40
2% (BZO)	650	0.25	25

Sample	U_0	μ	J_c (MA/cm^2)
Control	480	0.46	1.62
7.5 % (BZ0)	525	0.72	14
25% (BZO)	1000	0.5	13

MOCVD + BZO



MOCVD Samples with BZO pinning provided by Selva

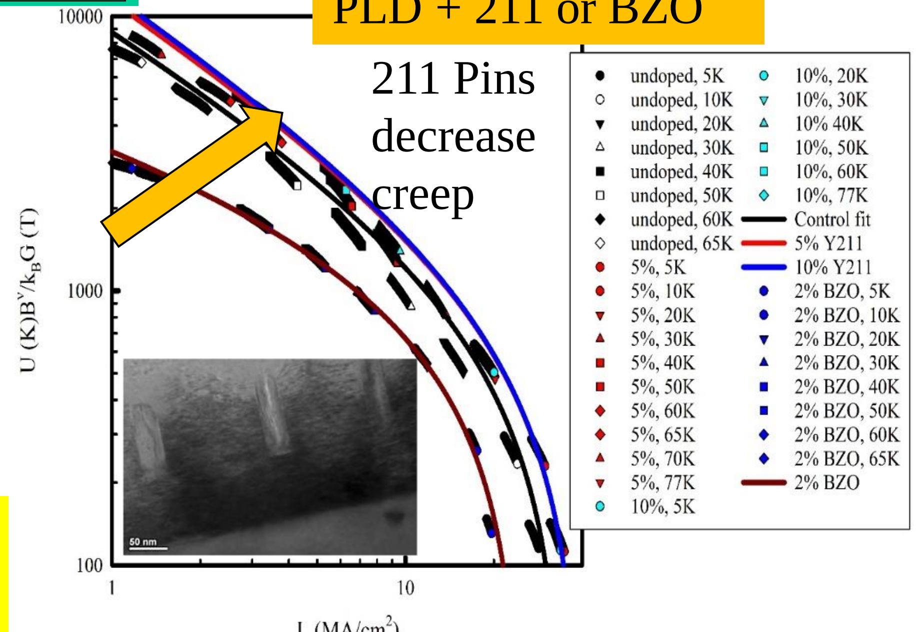
-> Simple-minded approach… U_{eff}

$$M = M_0\left[1 - \frac{k_B T}{U_0}\ln\left(\frac{t}{t_0}\right)\right].$$

-> more complete approach… true U_0

$$U(J) = \frac{U_0}{\mu}\left[\left(\frac{J_c}{J}\right)^{\mu} - 1\right],\ G(T) = \left[1 - \left(\frac{T}{T_x}\right)^{m}\right]^{n}$$

PLD + 211 or BZO



Takeaway: Pin Type Affects not only J_c, but Mag Decay

Section II: Cables: Contact Resistance, Current Sharing, Stability, Quench

- Contact Resistance
- Current Sharing
- Quench

Contact Resistance I: YBCO 10 stacks and Roebel Cables

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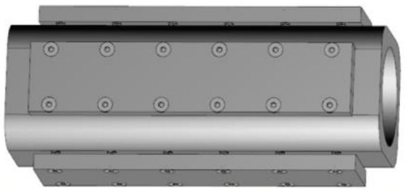
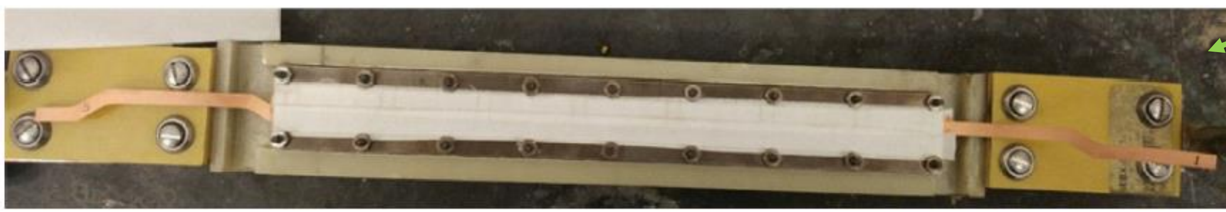


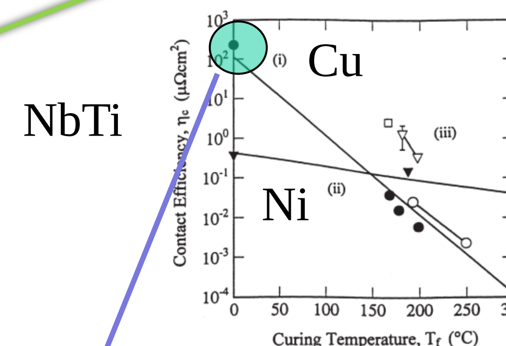
TABLE III
ICR AND PROCESSING OF COATED CONDUCTORS LAP JOINTS AT 77 K WITH 200 MPa OF TRANSVERSE PRESSURE

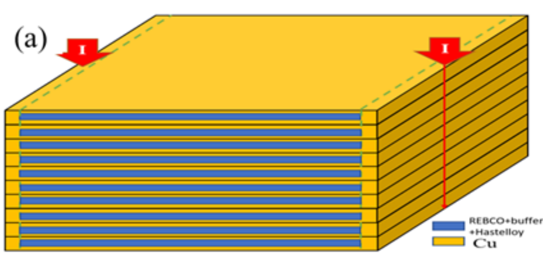
Sample Processing	Thickness (μm)	*ICR* (μΩ·cm²)
As-received	Native oxide	17076 ± 5%
Chrome ED	25 ± 5 μm	564 ± 5%
Nickel ED	25 ± 5 μm	987 ± 5%
Silver ED	50 ± 10 μm	12 ± 5%
Nicklon	125 ± 10 μm	94 ± 5%
As-received w/ CNT tape	20-60	300 ± 5%

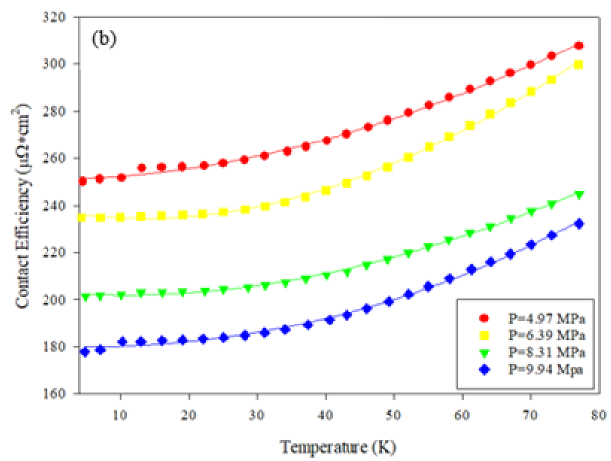
TABLE IV
ICR AND PROCESSING OF ROEBEL CABLE AT 77 K WITH 2.7 MPa OF TRANSVERSE PRESSURE

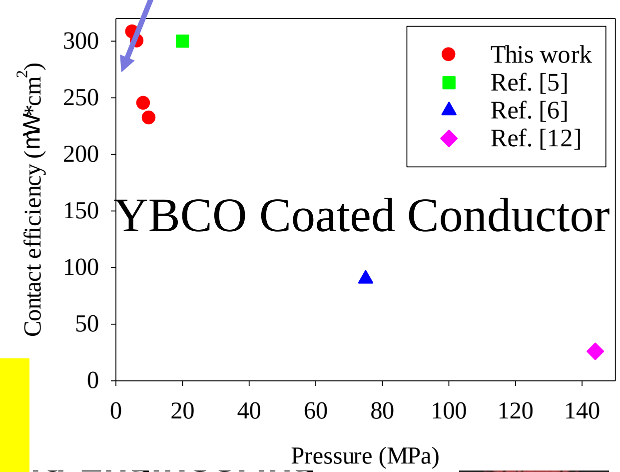
Sample Processing	Thickness (μm)	ICR_{press} (μΩ·cm²)	$ICR_{area-calc}$ (μΩ·cm²)
As-received	Native oxide	655 ± 5%	8.9 ± 5%
Chrome ED	25 ± 5 μm	7200 ± 5%	98 ± 5%
Cu–Cu 150 °C x 3 hr	n/a	425 ± 5%	5.8 ± 5%
Cu–Cu pO_2 240 °C x 6 hr	n/a	634 ± 5%	8.6 ± 5%









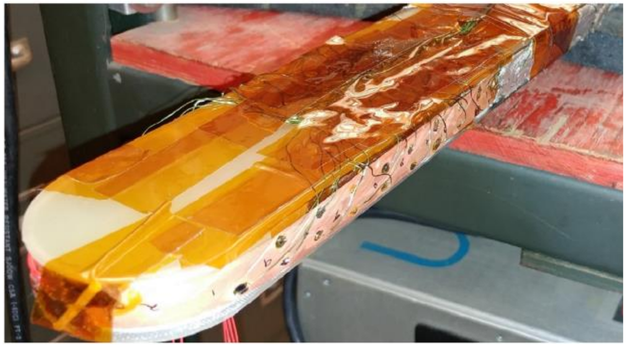


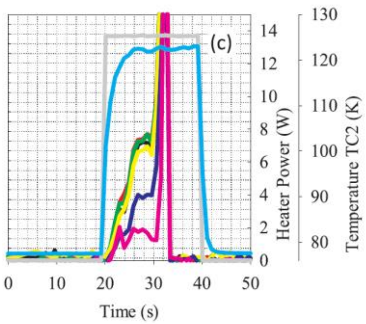
<u>Takeaway:</u> Surface condition and processing (pressure, HT) key

Stability/Cooling Conditions
Quench/Measurement/Modelling

Roebel Cables

CORC Cables





$$\Delta T = \frac{\frac{\rho I_c^2}{P A_{Cu}} + G_d}{\eta h + \frac{\sqrt{2\kappa A_{Cu} P \eta h}}{A_s}}$$

Static approach sufficient

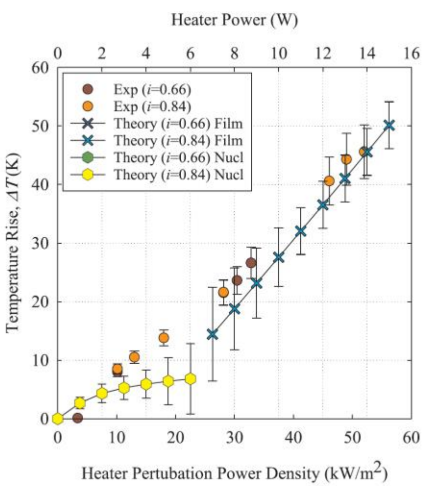
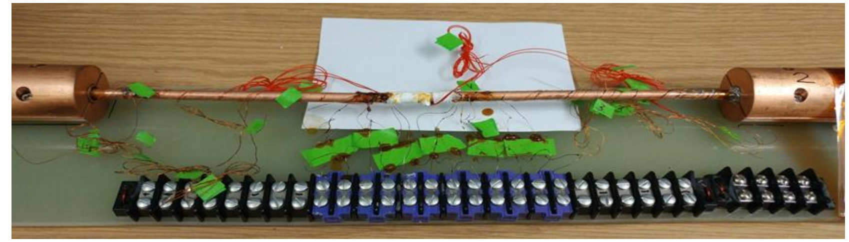
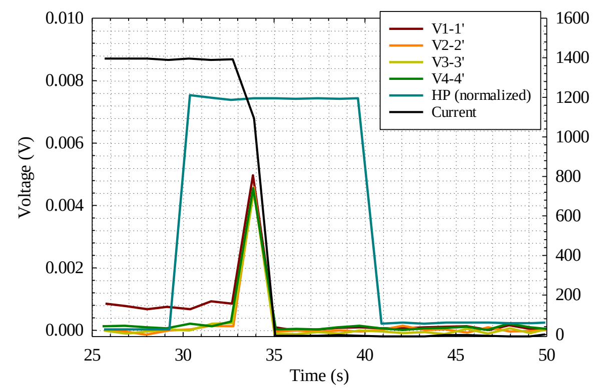


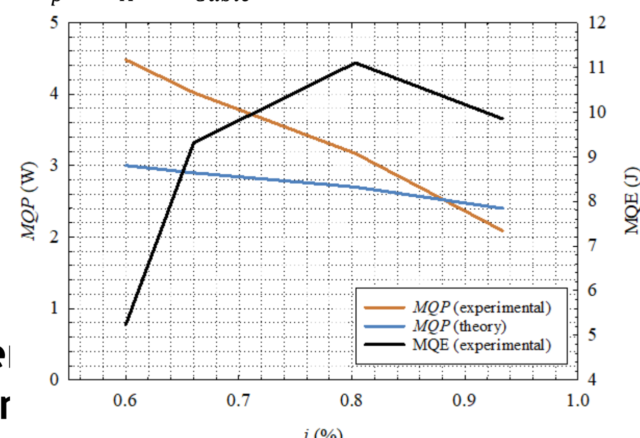
Fig. 6. ΔT as function of G_d: experimental results compared with theory, Eqs. (14, 16, 17).



Dynamic approach required



$$\frac{dT}{dt} = \frac{\left(\frac{L_A \times \rho_{stabilizer}}{A_{Cable}} \times I_{stabilizer}\right. + G_P - h\eta\Delta T(2N_{CC}A_{HP}) - \left.\Delta T\eta\sqrt{2\kappa A_{CC}Ph}\right)}{C_p \times L_A \times A_{Cable}}$$



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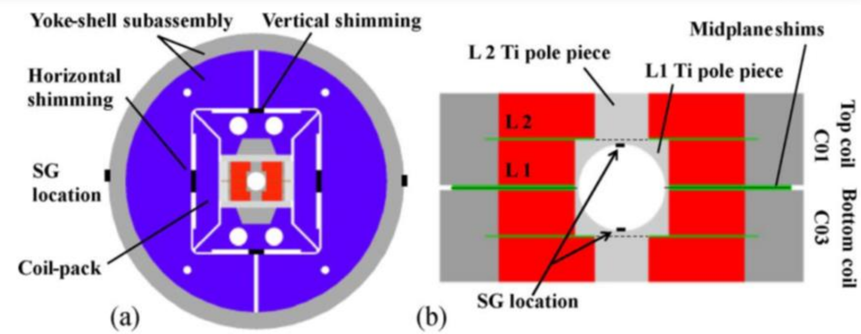
Section III: Magnet Modelling: Field Error, Current Sharing, Thermal Sharing, Quench Evolution

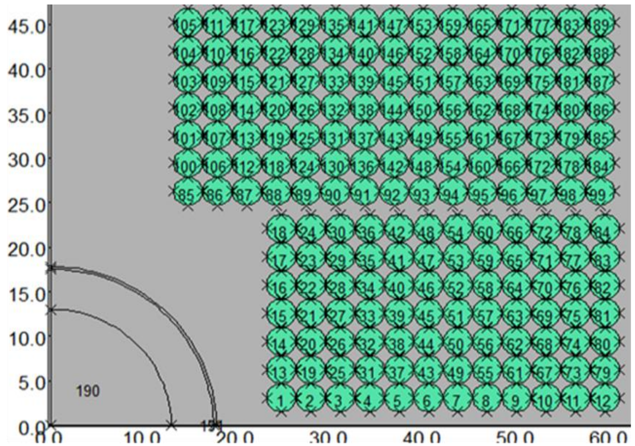
- Field Error, using data and models from Section I
- Current Sharing, integrating Models (Multi-Scale Modelling) from Section II
- Thermal Sharing and Quench Modelling

Modelling of Field Errors in Magnets I

- <u>Cory Myers (OSU), X. Wang, (LBNL)</u> (ICMC 2019 – work performed at LBNL)
- CORC *direct drop in replacement for Nb_3Sn in HD3*
- <u>Field errors are only somewhat larger than that of Nb_3Sn – reason is that Ic of CORC cables is 3 kA, that of Nb_3Sn is 30 kA.</u>

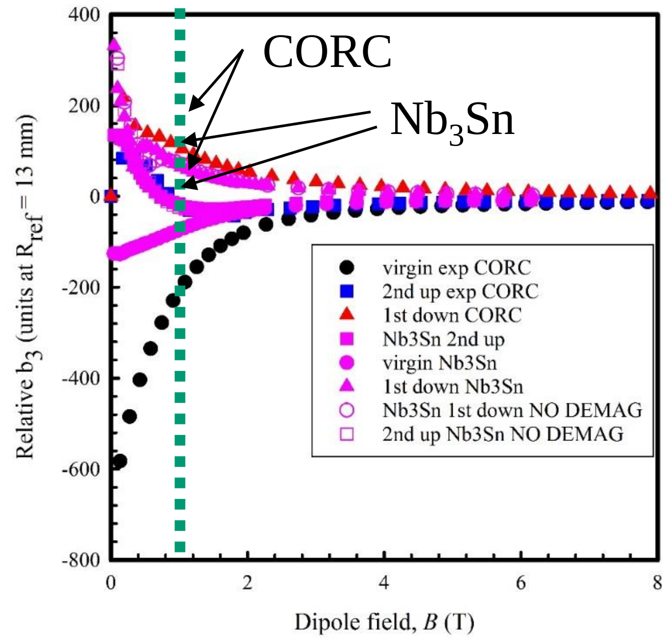
<u>X. Wang, S. Prestemon, G.L. Sabbi, T. Shen</u>, ATAP division, Lawrence Berkeley National Laboratory





HD3 block dipole layout with CORC® cable substituted. 84 turns x 105 turns

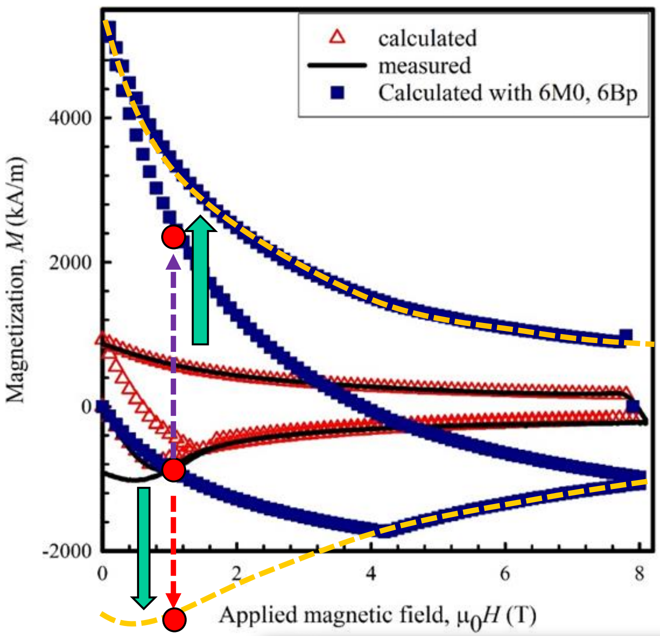
Drop in replacement CORC

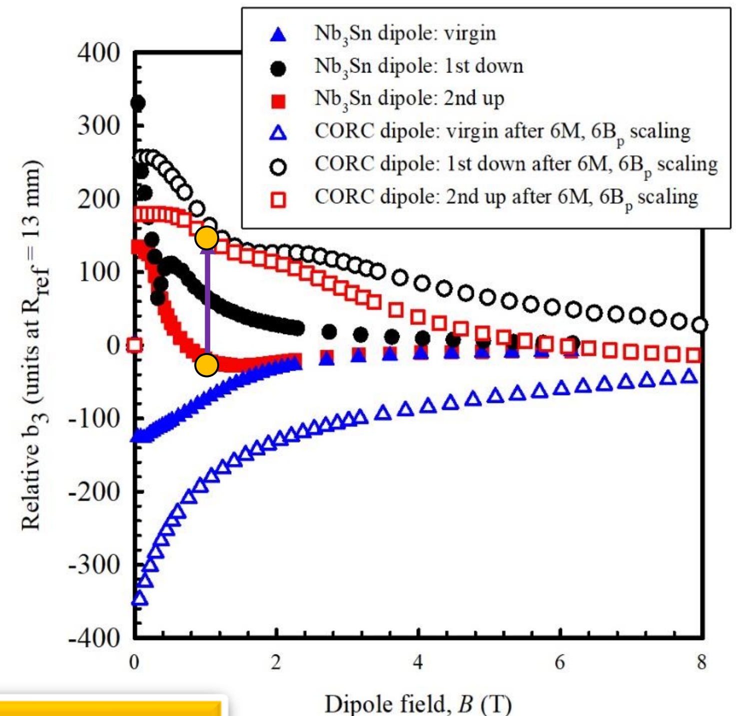


- If we make amp-turns equal at 15 T, we need 6 X higher Jc CORC cables
- Can we correct for that by just multiplying magnetization by Amp turn ratio? <u>No – now we need the analytic model we made above!</u>

Modelling of Field Errors in Magnets II

- OK, so why do we need model rather than just multiply Magnetization X 6?
- If we just multiply by 6 X, we move out from the red/black M-H curve of the existing CORC to the yellow dashed line (a Huge increase!)
- But, the penetration field is also increased (6 X), which means that the real magnetization at injection does not become large and negative, but large and positive! (in this case)





X. Wang, S. Prestemon, G.L. Sabbi, T. Shen, ATAP division, Lawrence Berkeley National Laboratory

- Is it a killer that b3 = +150 instead of -50? Probably not, but nice to know!
- Would vary with CORC Jc, strand design, and sweep parameters

Field error Results, HD3, but including time decay via analytic model

It is possible to estimate the drift of b3 with time based on the models we have developed

First, use derived expressions..

1-virgin initial permeability, 0->B_p

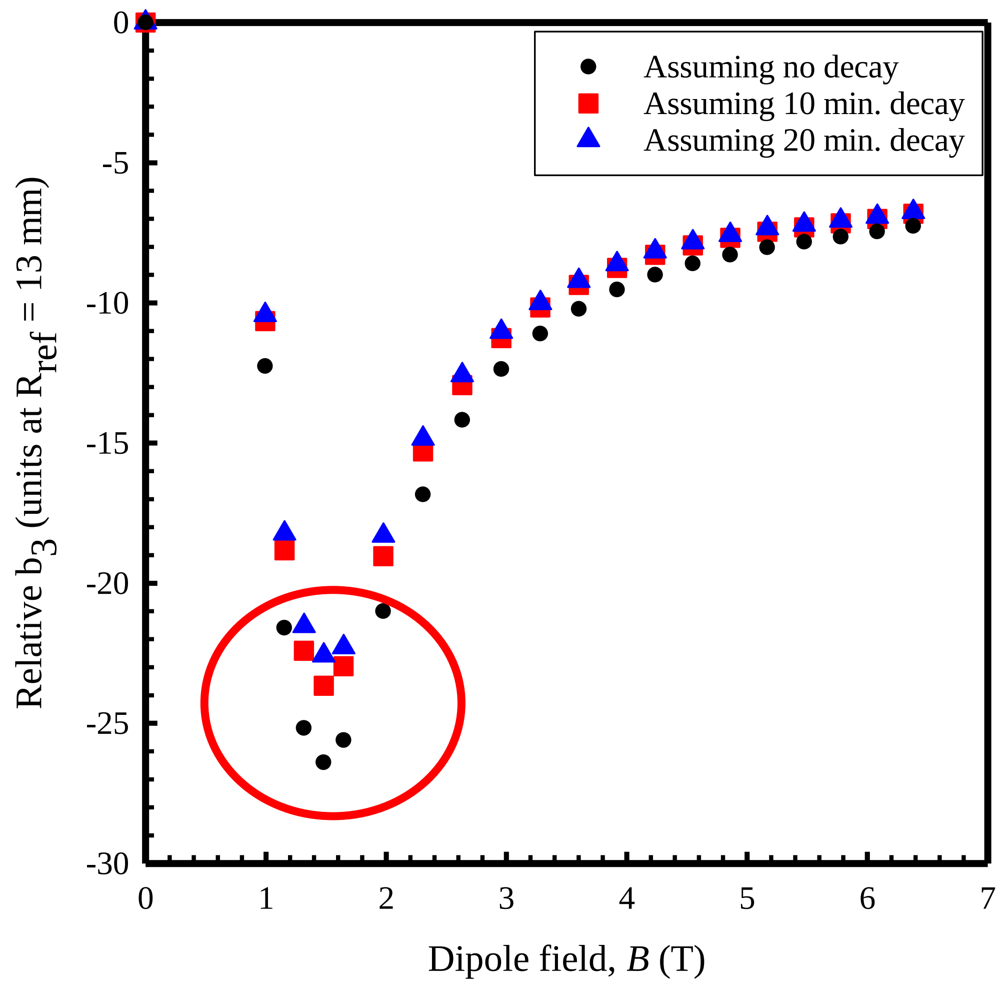
$$M = \frac{-M_0}{\left[A + \left({}^{B}/_{B^*}\right)\right]} \left(\frac{B}{B_p}\right)$$

2-1st shielding, B_p->B_{max}

$$M = \frac{-M_0}{\left[A + \left({}^{B}/_{B^*}\right)\right]}$$

Now insert $M = M_0[1\text{-}Ln(t)]$

The, insert into FEM model and compute at any given time!



Department of Materials Science and Engineering

Ongoing Magnet Level Modelling

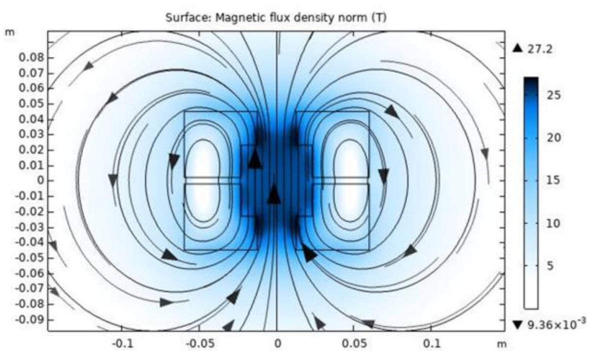
Modelling HTS Magnets and Inserts: Contact Resistances, Quench, Strand Breakage

3.2.1 Modelling of Current Redistribution Following Strand Breakage

3.2.2 Modelling of Temperature Rise Time, Current Distribution

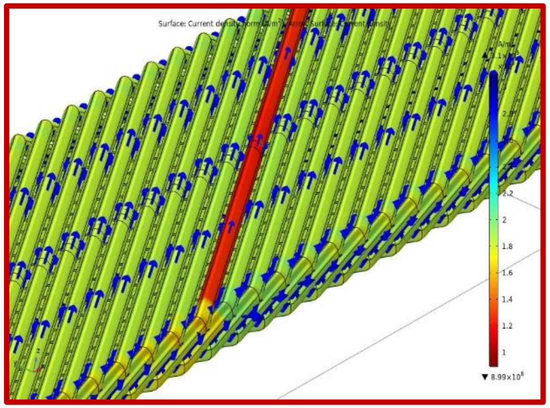
3.2.3 Cable-to-Cable Interface Resistance, R_{IC}, in Response to Surface Condition:

3.2.3 Thermal Diffusion in a Cable Stack



Multi-Scale Modelling

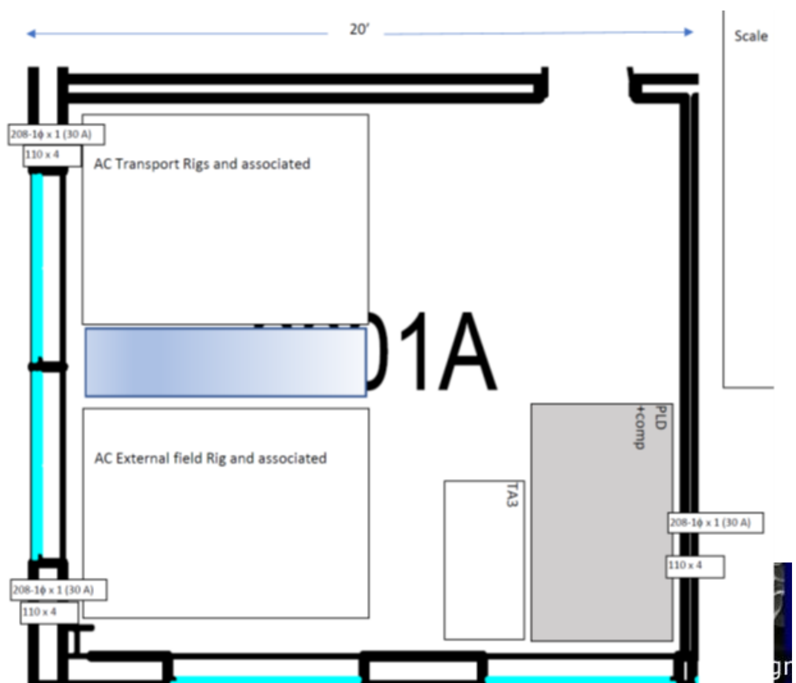
Large Scale
Fine Scale



New Planned Upgrades

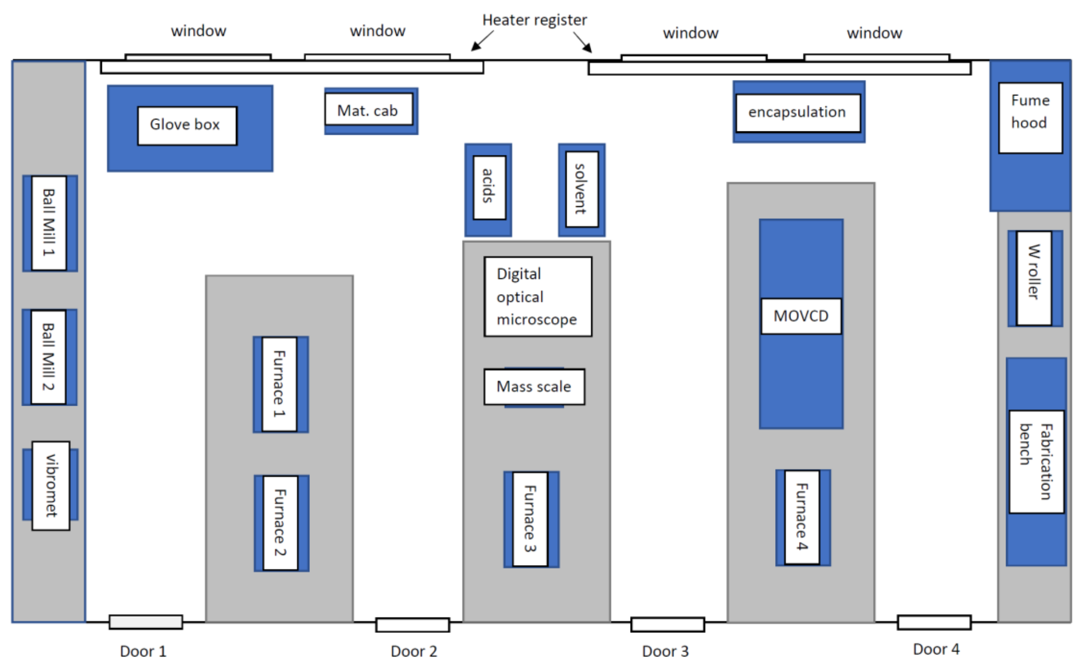
- OSU requested as part of HEP GARD Program Equipment for high current studies of Cable –
  - Support for personnel but not capital Equip
  - **<u>However, as part of New APRA-E Program starting 2021 on High Current cryogenic Cables for Electric Aircraft, OSU has new DC power supply capacity in the pipeline</u>**
- Lab facilities move and Upgrade

New AC Loss Lab

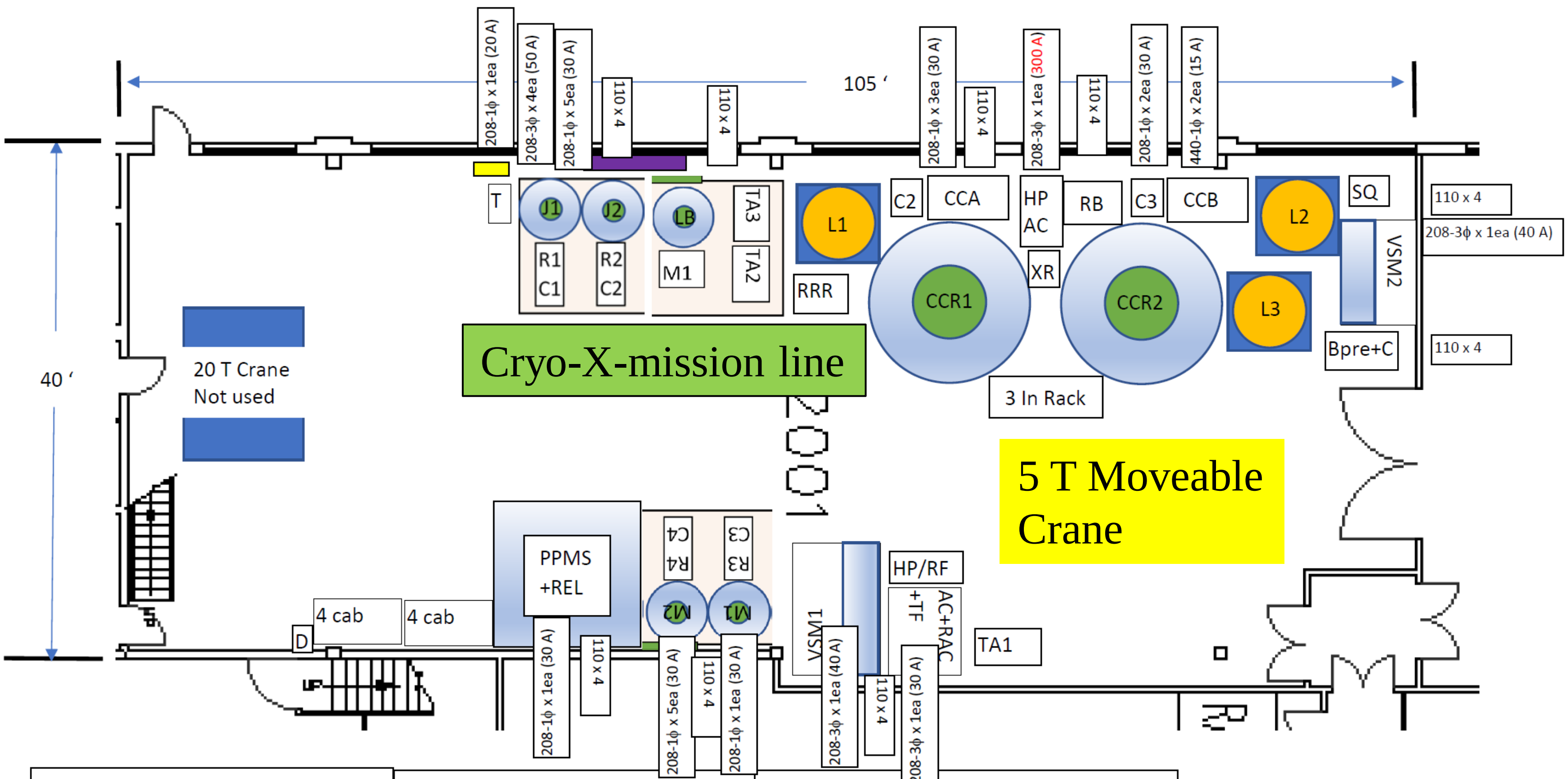


New Processing and HT lab

Sumption/Collings Evans Lab space: Shown below is only 4028. Nov 18, 2020



New Cryogenic Transport Lab



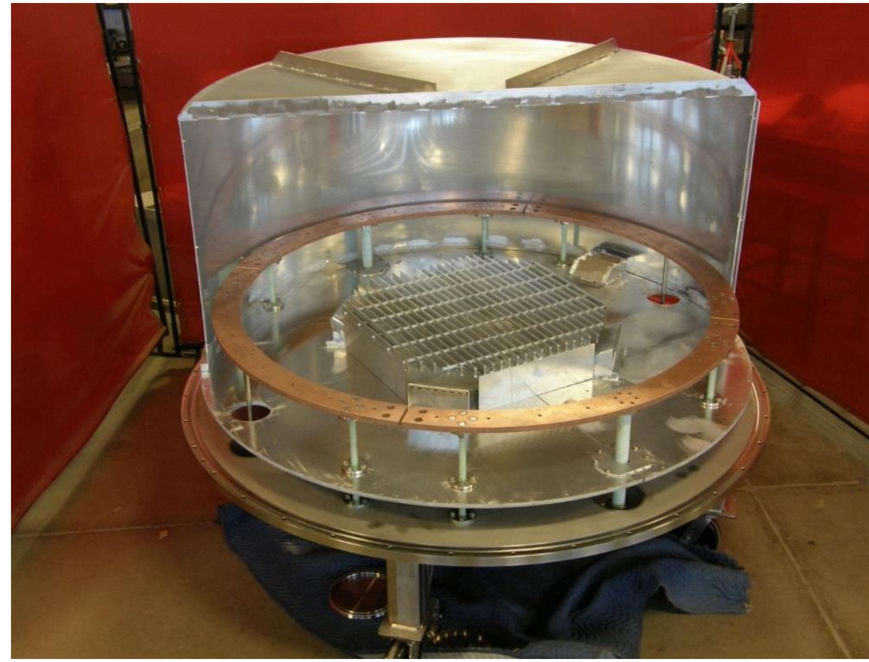
PPMS = PPMS
REL = Reliquifier
C1,2,3 = Chillers 1-3
TA1,2,3 = Table 1,2 (PPMS, LB)
CCA = Cryocoolers, pair A
CCB= Cryocoolers, pair B
XR = Transformer, high current
3 in rack = 3 instrumentations racks
J1=12 T Jc
J2 = 15 T Jc
M1 = 3 T Dipole
M2 = Hall Probe Magnetometer
Peach color = Small crane region
J1,2 = 12 and 15 T Jc rigs

M1 = 3 T Dipole rig
M2 = Hall Probe Magnetometer
R1-4 = Racks 1-4
C1-4 = Computers 1-4
L1-3 = Laydowns 1-3
CCR1 = Cryomagnetics cryo
CCR2 = Eden Cryostat
LB = Large Bucket dewar
M1 = Mounting space 1
PLD = Pulsed laser deposition
D = Laser gas cabinet
SQ = Splat quench
4 cab = 4 cabinets
VSM1,2 = VSMs 1 and 2

T = Toolbox
HP/RF = High Pressure Furnace+RF
Bpre+C = biaxial press+controller
VSM1=Bat VSM
VSM2 = New VSM
Purple = Wall mount dewar
Green = Transfer lines holder
TA3 = Jc prep
Yellow = large pump
AC+RAC+TF=AC+Roll around CC+Thin Film
HPAC = High Power AC
Scale 133 inches per inch

New Machines for Magnetization

- Installation of "Burst Magnetization" Set up
- Using Present Coil set Approach
- Retrofit with Cryogenic Hyperconductor Al Coils
- Measurements 4-20 K
- Field Amplitudes 100-300 mT
- Ramp rates 1-50 Hz



Papers from Last few years of Program

2019

1. C. Kovacs, M. D. Sumption, E. Barzi, A. V. Zlobin, and M. Majoros, "A Tear-Drop Bifilar Sample Holder for Full Excitation and Stability Studies of HTS Cables at 4.2 K Using a Superconducting Transformer", to be published in *IEEE Trans. Appl. Supercond*. **29** (2019) 4801305, DOI 10.1109/TASC.2019.2898227
2. X Xu, J Rochester, X Peng, M Sumption, and M Tomsic, "Ternary Nb_3Sn superconductors with artificial pinning centers and high upper critical fields", *Supercond. Sci. Technol*. **32** (2019) 02LT01 https://doi.org/10.1088/1361-6668/aaf7ca
3. C.S. Myers, M.D. Sumption, and E.W. Collings, "Magnetization and Creep in YBCO Tape and CORC® Cables for Particle Accelerators: Value and Modification via Pre-injection Cycle", to be published in *IEEE Trans. Appl. Supercond*. **29** (2019) 8201405, DOI 10.1109/TASC.2019.2898119
4. C. Kovacs, M. Majoros, M. D. Sumption, and E.W. Collings, "Magnetization Measurements of CORC and Roebel Type YBCO Cables for Accelerators using a ± 3 T Dipole Magnetometer", *IEEE Trans. Appl. Supercond*. **29** (2019) 8200905, DOI 10.1109/TASC.2019.2898119
5. C. S. Myers, M.D. Sumption, and E. W. Collings, "Magnetization and Flux Penetration of YBCO CORC Cable Segments at the Injection Fields of Accelerator Magnets", *IEEE Trans. Appl. Supercond*. **29** (2019) 4701105, DOI 10.1109/TASC.2019.2896625
6. M. Majoros, M. D. Sumption, D. Zhang, and E. W. Collings, "Quench Measurements in a YBCO Pancake Coil at 77 K and 4.2 K in Magnetic Fields up to 10 Tesla", *IEEE Trans. Appl. Supercond*. **29** (2019) 4600805, DOI 10.1109/TASC.2019.2899245.

2020

7. C. J. Kovacs, M. D. Sumption, M.Majoros, and E.W. Collings, "Modified Interconductor Contact Resistivity in Coated Conductor Stacks and Roebel Cables", *IEEE Trans. Appl. Supercond*. **30** (2020) 6600505, DOI 10.1109/TASC.2020.2966461
8. X. Xu, X. Peng, J. Rochester, J. Lee, M. Sumption, and M. Tomsic, "High Critical Current Density in Internally-oxidized Nb_3Sn Superconductors and Its Origin", *Scripta Materiala* **186**, September 2020, Pages 317-320
9. X. Xu, X. Peng, J. Rochester, M.D. Sumption, J. Lee, G.A. Calderon Ortiz, J. Hwang, The strong influence of Ti, Zr, Hf solutes and their oxidation on microstructure and performance of Nb_3Sn superconductors, *Journal of Alloys and Compounds* **857**, 15 March 2021, 158270
10. X. Xu, M.D. Sumption, J. Lee, J. Rochester, X. Peng, "Persistent compositions of non-stoichiometric compounds with low bulk diffusivity: A theory and application to Nb_3Sn superconductors", *Journal of Alloys and Compounds* **845,** 10 December 2020, 156182
11. J. Rochester, M. Ortino, X. Xu, X. Peng, and M. Sumption, "The Roles of Grain Boundary Refinement and Nano-Precipitates in Flux Pinning of APC Nb_3Sn", to be published in *IEEE Trans Appl Supercond*. 2021
12. J. Rochester, C. Myers, M. Sumption, T. Shen, M. Majoros, and E.W. Collings, "The Magnetization of Bi:1121 Rutherford Cables for Particle Accelerator Applications", to be published in *IEEE Trans Appl Supercond*. 2021
13. YBCO Coated Conductor Interlayer Electrical S. Xue, M.D. Sumption, and E.W. Collings, "Contact Resistance Measured from 77 K to 4 K under Applied Pressures up to 9.4 Mpa", Submitted to *IEEE Trans. Appl. Supercond*. 2020.

2021 and in draft

14. M Ortino, S Pfeiffer, T Baumgartner, M Sumption, J Bernardi, X Xu, M Eisterer, "Evolution of the superconducting properties from binary to ternary APC-Nb_3Sn wires", *Supercond. Sci. and Technol*. 34 (2021) 20210301
15. M Majoros, C Kovacs, C Myers, M D Sumption, E W Collings, "Self-field CORC cable stability, current sharing, and quench measurements in liquid nitrogen bath at 77 K", manuscript in draft
16. M.D. Sumption, C. Myers, E.W. Collings, Influence of Magnetization Decay on field Errors in Accelerator Magnets, Manuscript in Draft
17. C. Myers, M.D. Sumption, E.W. Collings, S. Prestemon, G. Sabbi, and X. Wang, "Modeling of Field Error of CORC®-based Prototype Accelerator Magnets", manuscript in draft

Presentations (2019-present)

1. Invited: M. Sumption, C. Myers, C. Kovacs, D. Kun, M. Majoros, and E.W. Collings, “Studies of the Magnetization of HTS cables Relevant to Particle Accelerator Applications”, Presented at EUCAS 2019, Glasgow, UK, Sept 2019
2. M. Sumption, D. Kun, M. Majoros, C. Kovacs, C. Myers, and E.W. Collings, “Measurements and Modelling of YBCO Cable for various HTS cables”, Presented at the ICMC, Hartford CT, July 2019.
3. M. Sumption, C. Kovacs, C. Myers, M. Majoros, and E.W. Collings, “Magnetization of HTS Cables for Accelerator Applications”, USMDP, FNAL, 16-18”, Jan 2019
4. M.D. Sumption, Magnetization of HTS Cables, LTSW Jan 2019
5. C. Myers, M. Sumption, E.W. Collings, J. DiMarco, S. Prestemon, G. Sabbi, T. Shen LG Fajardo, X. Wang, “Field Quality Measurements of High-Temperature Superconducting Canted Cosine Theta Accelerator Magnets”, Presented at MT 26, Vancouver, Canada, Sept 2019
6. C. Kovacs, M.D. Sumption, M. Majoros, and E.W. Collings, “Direct Measurement of Modified Interconductor Contact Resistance Values in Coated Conductor Stacks and Roebel Cables, Presented at MT 26, Vancouver, Canada, Sept 2019
7. M. Majoros, M.D. Sumption, and E.W. Collings, “FEM modeling of stability and current sharing in Nb3Sn Rutherford cables”, Presented at MT 26, Vancouver, Canada, Sept 2019
8. Invited: M.D. Sumption, C. Myers, C. Kovacs, and E.W. Collings, “Magnetization, Flux Penetration, and Drift of YBCO Cable Segments Models and Measurements for Accelerator Magnet Applications”, Presented at MT 26, Vancouver, Canada, Sept 2019
9. M. Majoros, M.D. Sumption, and E.W. Collings, “Numerical modeling of stability and current sharing in Nb3Sn Rutherford cables”, Presented at the ICMC, Hartford CT, July 2019.
10. C. Myers, M.D. Sumption, and E.W. Collings, “Suppression of Magnetization and Creep in High-temperature Superconducting Cable by Magnetic Field Cycling”, Presented at the ICMC, Hartford CT, July 2019.
11. M. Majoros, C. Kovacs, M.D. Sumption, and E.W. Collings, “Modeling current sharing and protection in a coated conductor-wound racetrack coil with various interlayer contact resistance values”, Presented at the ICMC, Hartford CT, July 2019.
12. C. Kovacs, M. Majoros, M.D. Sumption, and E.W. Collings, “Direct Measurement of Modified Interconductor Contact Resistance Values in Coated Conductor Stacks and Roebel Cables”, Presented at the ICMC, Hartford CT, July 2019
13. C. Kovacs, M.D. Sumption, E. Barzi, S. Zlobin, “Assessment of current-sharing of fully-excited Nb3Sn Rutherford cable with modified ICR at 4.2 K using a superconducting transformer”, Presented at the ICMC, Hartford CT, July 2019
14. C. Myers, S. Prestemon, G. Sabbi, X. Wang, M.D. Sumption, and E.W. Collings, “Modelling of Field Error and Field Error Drift of CORC®-based Prototype Accelerator Magnets”, Presented at the ICMC, Hartford CT, July 2019
15. M.D. Sumption, “Magnetization and Field Error Measurement and Modelling for HTS Accelerator Magnets”, LTSW 2020
16. Feb 26-28, 2020, Berkeley CA

Recent Theses from this program and Students Moving to Labs and in the Pipeline

- Xingchen Xu (2016): Prospects to Improve the Critical Current Density of Superconducting Nb_3Sn strands → Now FNAL
- Cory Myers (2020): The Influence of Microstructure and Nanostructure on Magnetization and its Temporal Decay in Bi:2212 and YBCO Superconductors at Low Temperatures → now LBNL
- Chris Kovacs (2019): Influence of Material Properties and Processing on Stability and Protectability in Superconducting Cables and Composites → to AFRL
- Fang Wan (2020): → ?
- Shengchen Xue – *Taking over role of Kovacs*
- Jacob Rochester – *Portions of Role of Myers*

Expected Outcomes

(1) Measurements of cable magnetization and creep, improved understanding/control of drift and field error in HTS-HEP magnets ✓

(2) Analytic expressions for HTS cable magnetization giving direct input to magnet field error calculations ✓

(3) Determine the Influence of Field Cycling and Local fields on Magnetization for HTS Cables ✓

(4) Quantification of Contact Resistance and Current Sharing in Present HTS cables ✓

(5) Determination of Current Sharing and Quench Response to Surface Condition, Cooling Mode, and Performance Increases — ongoing

(6) Modelling of Lorentz force Loading on Cable Mechanical Deformation (local) and Electrical Response — ongoing

(7) Exploration of Surface Condition, Cooling Mode, and Performance Increases on Cable and Magnet Protectibility — ongoing