Inductively Coupled Pulsed Energy Extraction System for 2G Wire-Based Magnets

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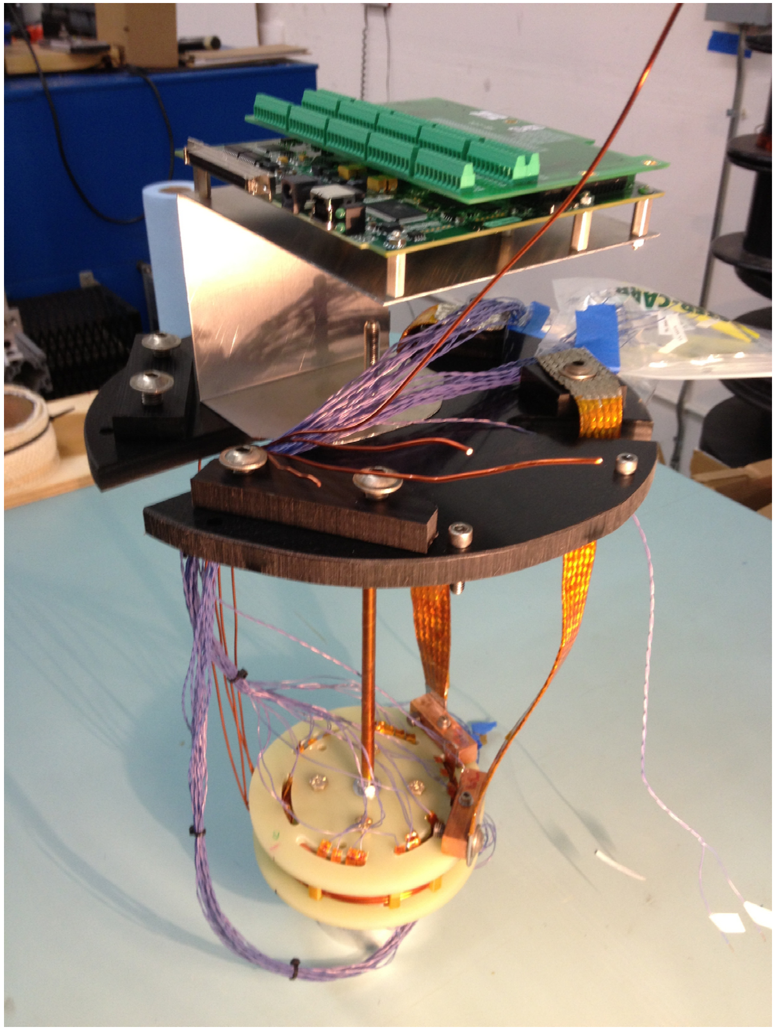
Overview

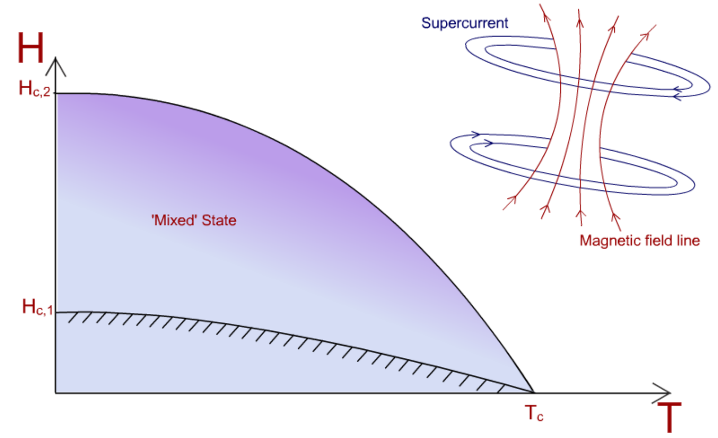
- Background
  - 2G HTS
  - Existing HTS Quench Schemes
  - Normal Zone Propagation
- Foundation
  - Formulation
  - Simulation
  - Experiment
- Execution
  - System Details
  - Fabrication
  - Data to Date
  - Future Plans



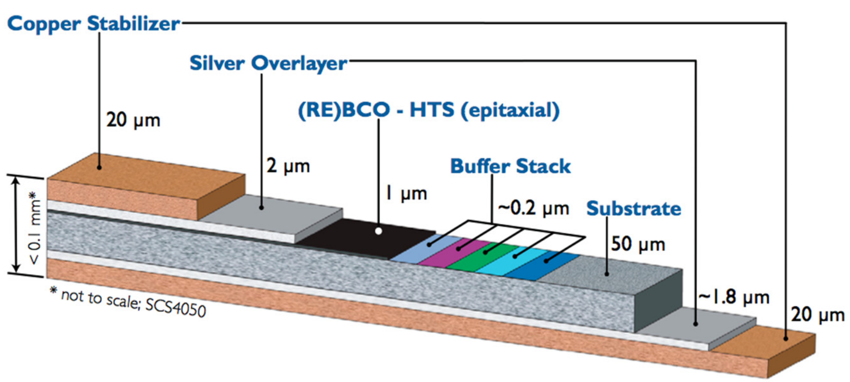
2G High Temperature Superconductor

- Type II Superconductor
  - Lower Critical Field - H_{c1}
  - Upper Critical Field – H_{c2}
  - Mixed state
  - screening current vortices
  - *Permits partial flux bundle penetration*
- 1G
  - Bismuth Strontium Calcium Copper Oxide – BSCCO
    - Powder in tube
- 2G
  - RE-Barium-Copper-Oxide *ReBCO*
    - Yttrium-BCO – *YBCO*

Type II



Courtesy of www.doitpoms.ac.uk

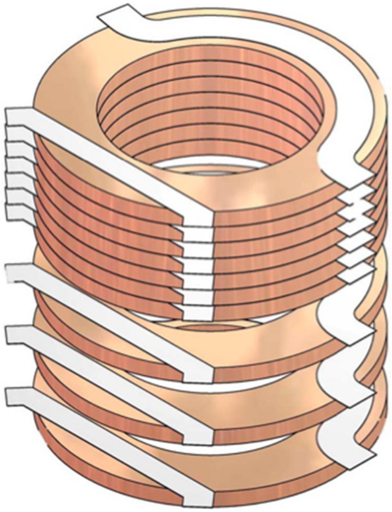


Courtesy of SuperPower Inc

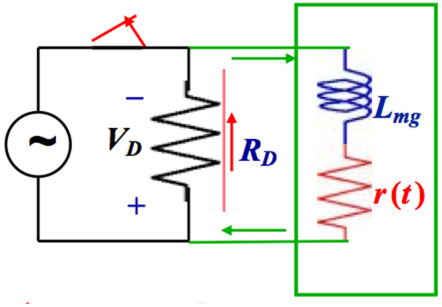
HTS Quench Protection

- Need to Protect the Coils!
- Active
  - Resistive Heating
    - Thermal conductivity of insulators
    - Slow
    - Aging
  - Dump Resistor, Diodes and Semiconductor Switches
    - Can create challenges with electronics
    - Challenges with current source
  - CERN – CLIQ
    - Coupling Loss Induced Quench Protection

E. Ravaioli, New, Coupling Loss Induced, Quench Protection System for Superconducting Accelerator Magnets



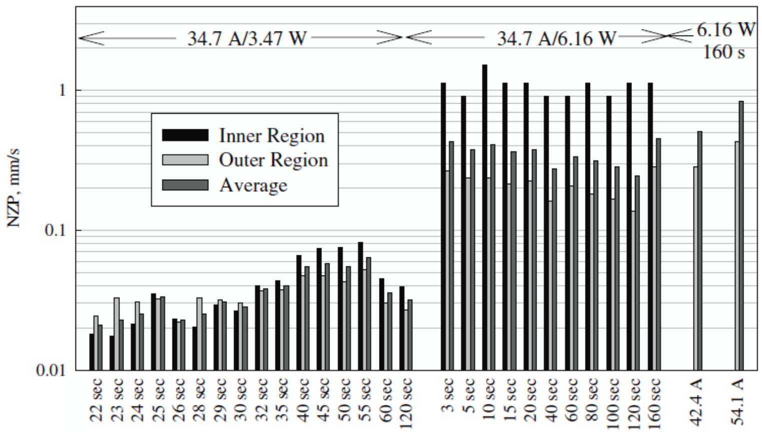
W. Denis Markiewicz, IEEE TRANSACTIONS ON APPLIED SUPERCONDUCTIVITY, VOL. 18, NO. 2, JUNE 2008



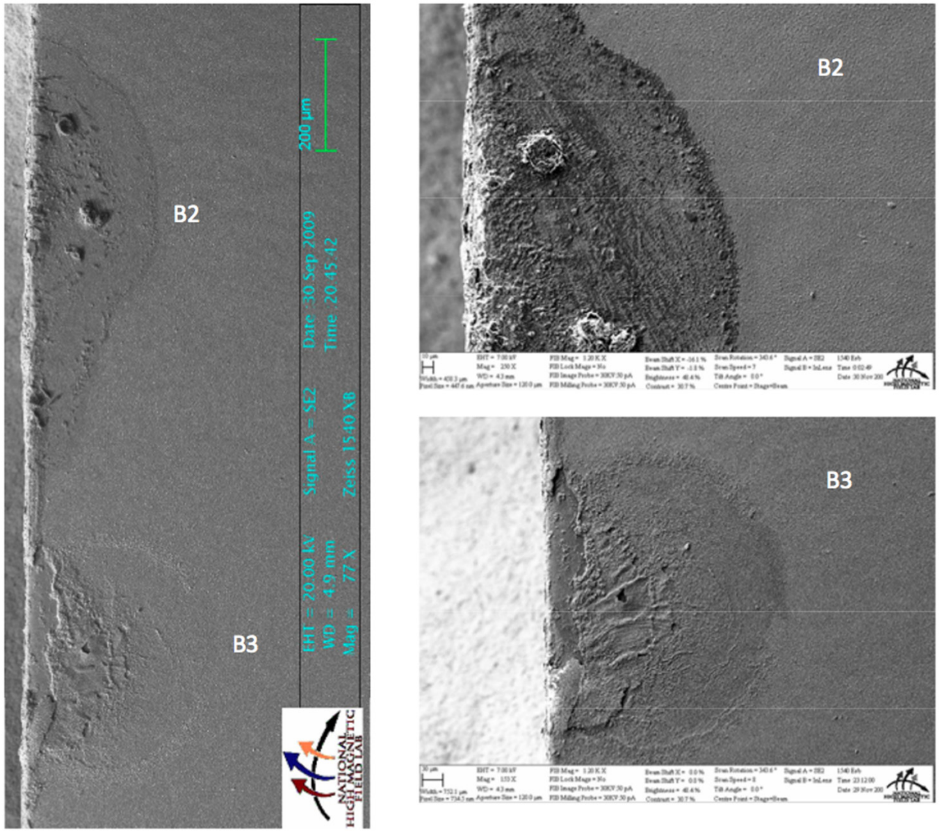
Charles Oberly, Quench Protection of Magnets at Elevated Temperature, DOE Wire Workshop 19 - 20 Jan 2005 St. Petersburg, FL

Normal Zone Propagation

- Thin YBCO layer
- Slow rate of NZP ~1mm/s
- Concentrated energy deposition
- Poor thermal conductivity
- Low thermal mass



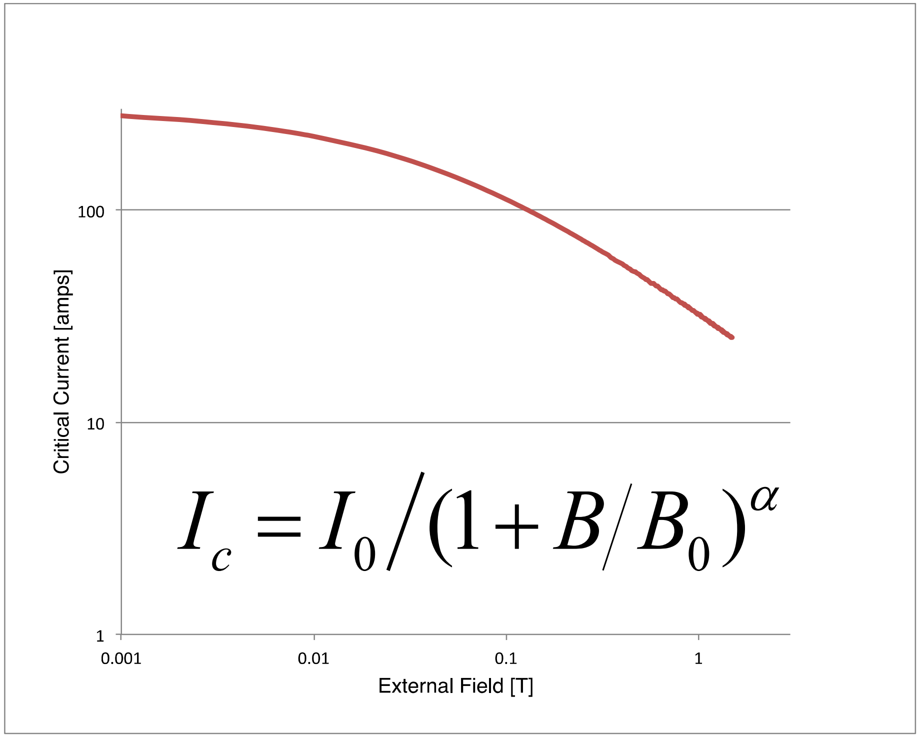
Sumption et al. Superconductor Science and Technology (2010) vol. 23 (7) pp. 075004



Song. *Microscopic observations of quenching and the underlying causes of degradation in YBCO coated conductor*, Thesis

Formulation

- Need faster NZF
- Inductive Pulsed Energy Extraction
  - Why 'pulsed energy extraction'?
  - Ring coil with an AC signal
  - Induce AC currents in HTS
  - Raise current above I_c
  - Target <10ms, >50% NZF
- Brandt Model
  - Penetration



$$I_c = I_0 / (1 + B/B_0)^{\alpha}$$

I_0=295A (self field=0T, 77k)
B_0= 0.05 T, individual pinning field
α=.7, pinning exponent

$$P = \nu\mu_0 \oint M(H_a)dH_a = 4\nu\mu_0 a^2 J_c H_0 g(H_0/H_c)$$

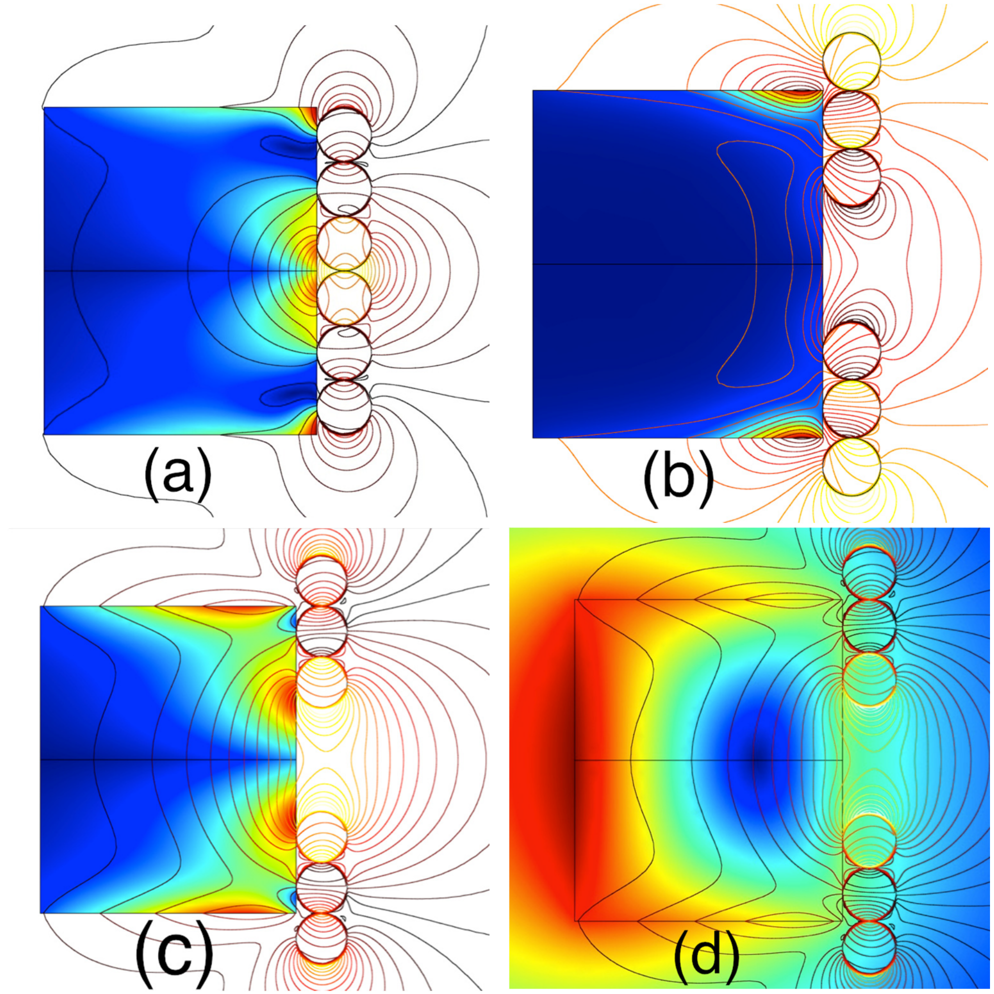
$$P = (2\pi\nu\mu_0 a^2 / 3H_c^2)H_0^4, \qquad H_0 << H_c a$$

$$P = (2\pi\nu\mu_0 a^2 / 3H_c^2)H_0^4, \qquad H_0 >> H_c$$

$$g(x) = (2/x)\ln\cosh x - \tanh x$$

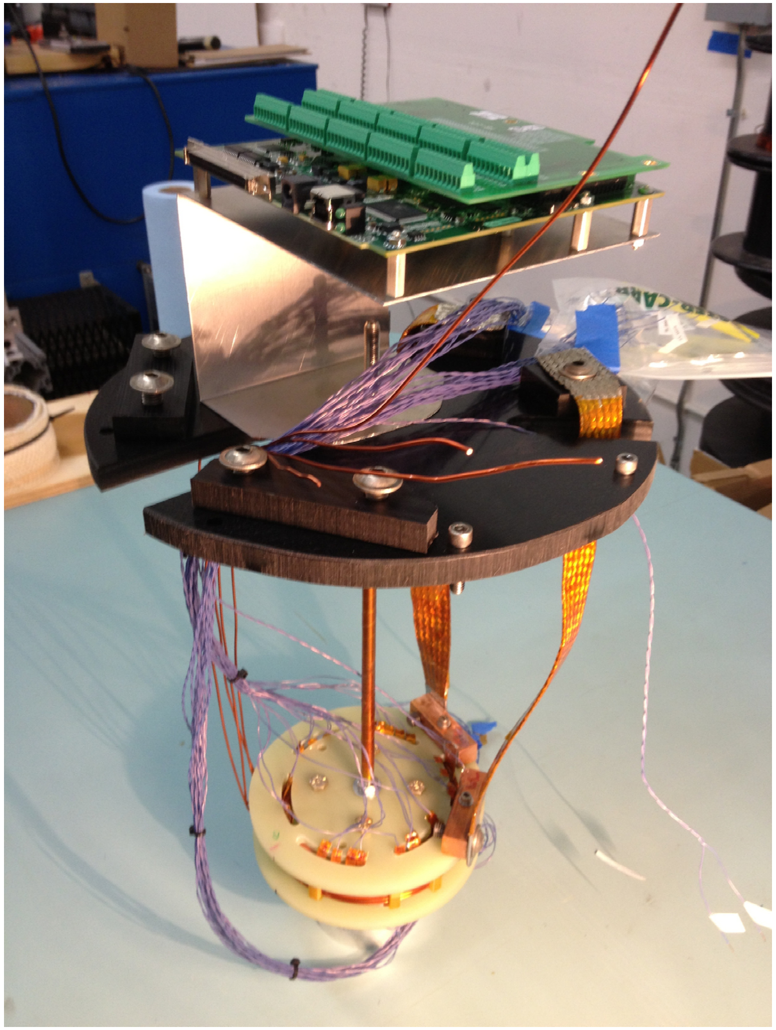
Simulations

- Brandt Equations
  - penetration
- Response Optimization
  - (a) Geometry
    - 4mm ∅ AC wire
  - (b) Frequency
    - 1000Hz
    - Skin depth
  - (c) Optimized
    - 12mm spacing
    - 150 Hz
    - 70% penetration
- (d) AC / DC Field Map



Experimental Plan

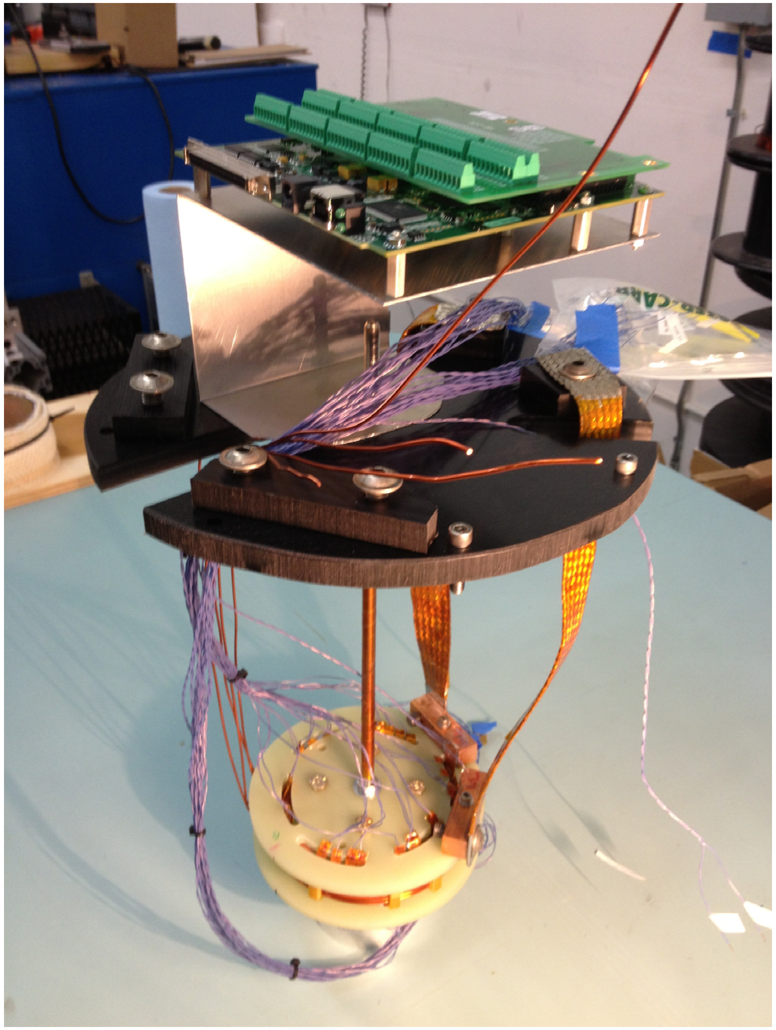
- Double pancake solenoid wrapped with resonant coil
  - 2 x 60 turns (~1m/turn)
- Include voltage taps
  - ~2.5m
- Baseline measurements
  - Warm measurement
  - Critical Current
- Ring resonant coil
  - Frequency
  - Current
  - Modify geometry
- Observe voltage response



Experimental Components

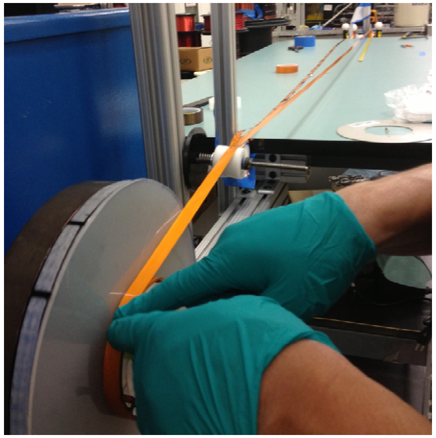
radiabeam TECHNOLOGIES

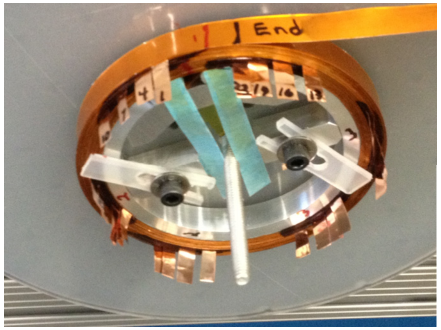
- *Janis* Model 9VSRD Cryostat
- Main Coil
  - 12mm wide
  - *Superpower* SCS12050 – AP
- Main Coil Supply
  - *TDK Lamda* Genesys 3U 30V-333A
- Main Coil Supply Protection
  - Low-Side switch
    - N-channel MOSFETw/source to ground
- Resonant Coil
  - 2 'halves'
  - Preliminary version
- Resonant Coil Supply
  - *2x Kepco* BOP 10V-100A GL
- DAQ
  - *Measurement Computing* USB-2537
  - 1MS/s
  - ~50 µs to sample all taps once
  - 64 SE measurements
- Control
  - Custom Labview VI

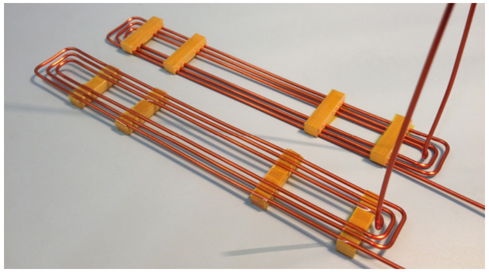


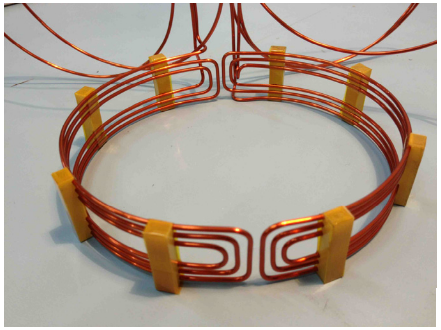
Fabrication

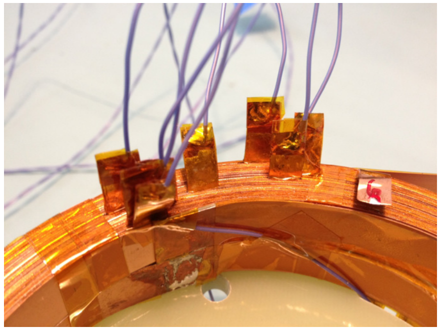
- HTS Coil Winding
  - Nearly no tension
  - Co-wound 65µm Kapton tape
- Resonant Coil
  - Form wound flat pattern
  - G10 wire spacers
  - Preliminary geometry
- Soldering
  - Pure Indium
    - 157°C melting point
  - Coil leads
  - Voltage taps
- Clamping Supports
- Warm Lead/Electronics Mount

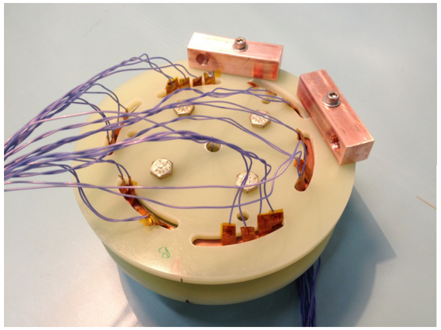






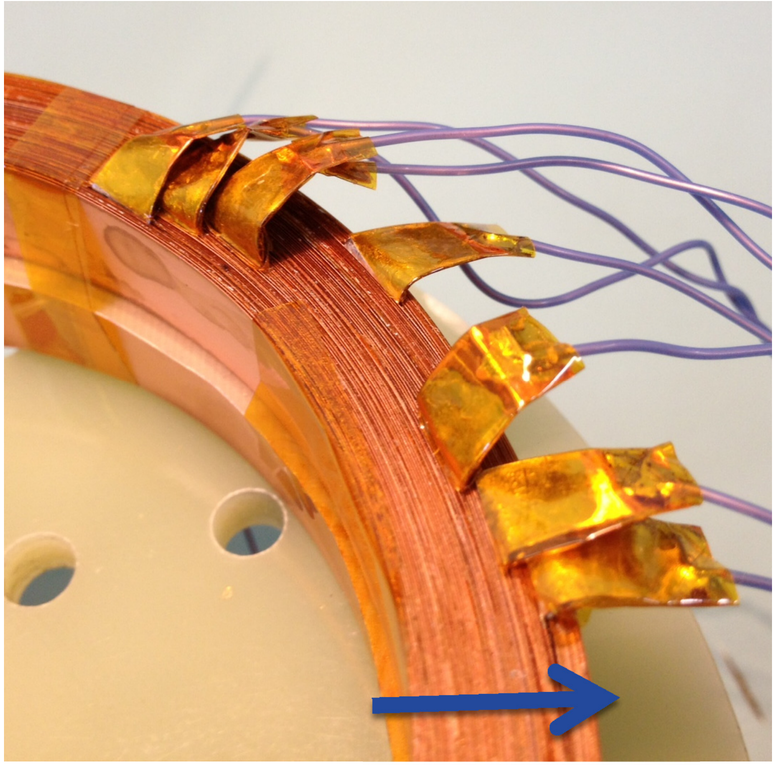


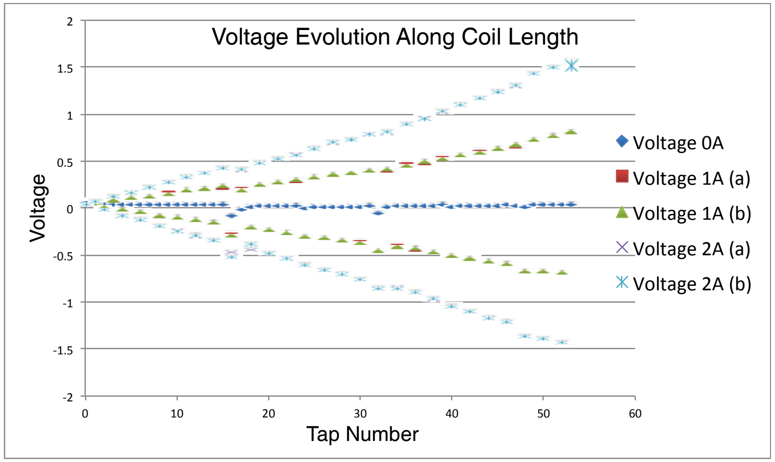


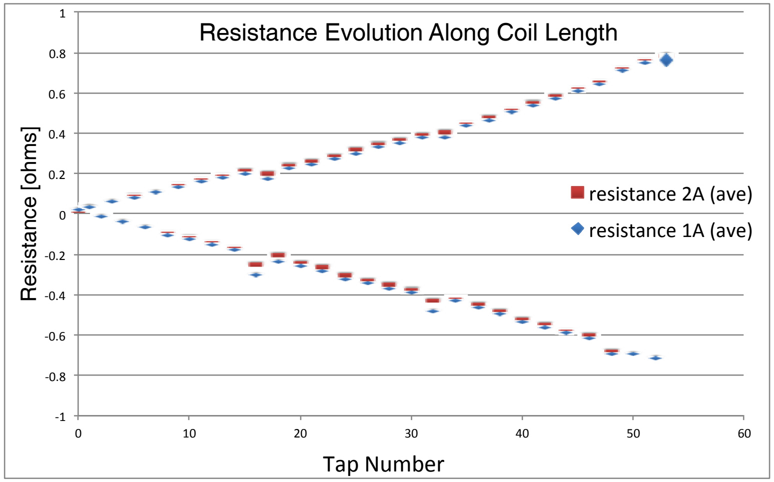


Experimental Data To Date

- Warm Measurement for Validation
  - 1A / 2A
  - Tap #16 & #32 issue

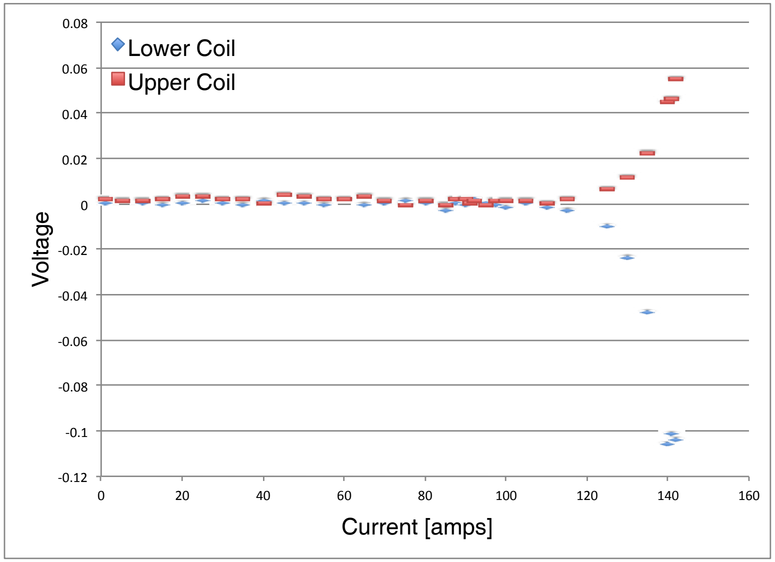


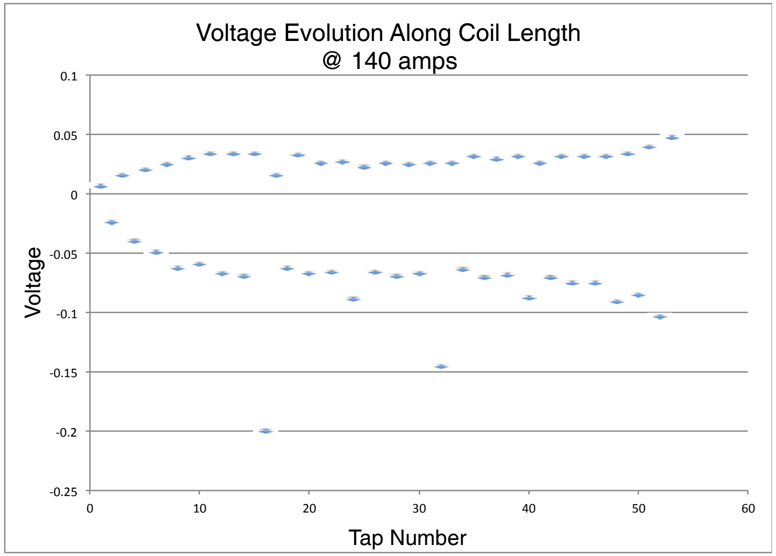


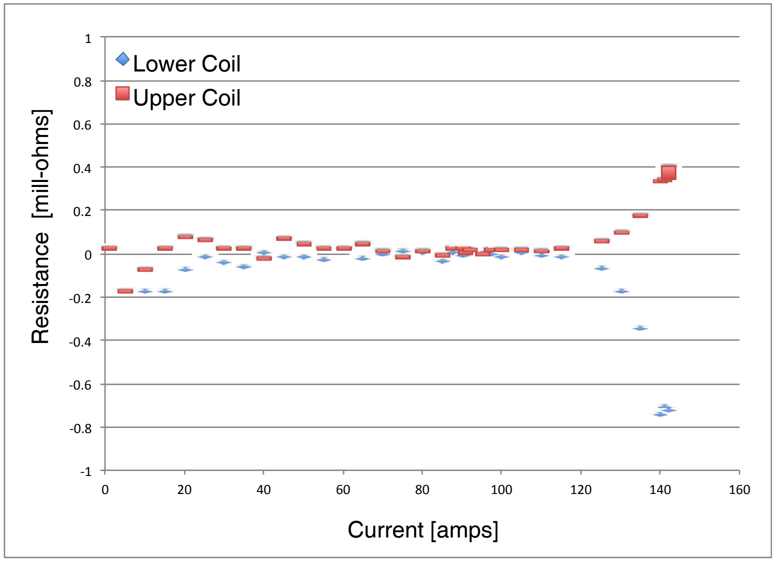


Experimental Data To Date

- Cold Measurements
  - LN_2
  - 0 -142 amps
  - Onset of transition ~115 amps
  - Indications of normal zone formation

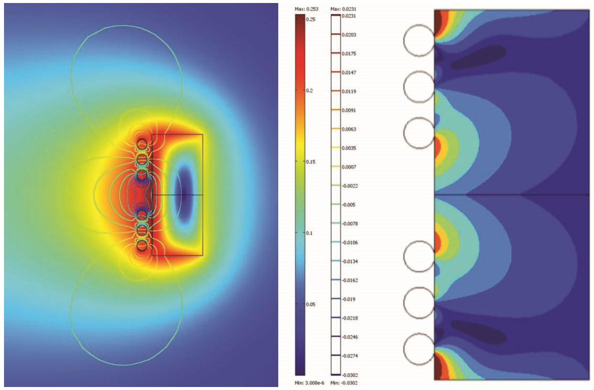


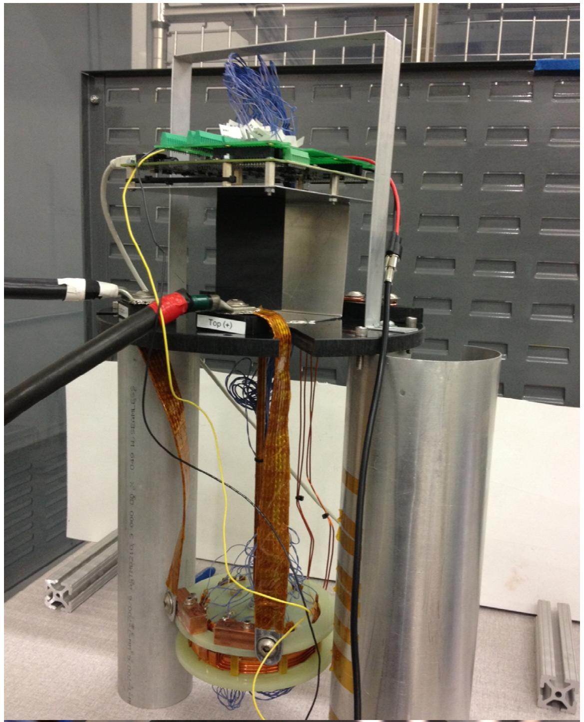




Future Work

- Initialize Resonant Coil
  - Establish baseline
    - Noise reduction
    - Sampling frequency
- Correct manufacturing imperfections
  - Leads
  - Taps
  - Coil spacer
- Examine Resonant Coil Variations
  - Implement simulation geometry
  - Interior placement
- Parametric Studies
    - Frequency
    - Amplitude
    - I_c Sensitivity





Acknowledgements

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  - Josiah Hartzell
  - Scott Storms
  - Yung Chen
- DOE SBIR Program
  - Work executed under Phase I contact #DE-SC0009547

Conclusion

Interested in Phase II Collaboration?

Come visit us on your way to the beach in Santa Monica.

Thank you for your attention!