REBCO: Fermilab Status Report

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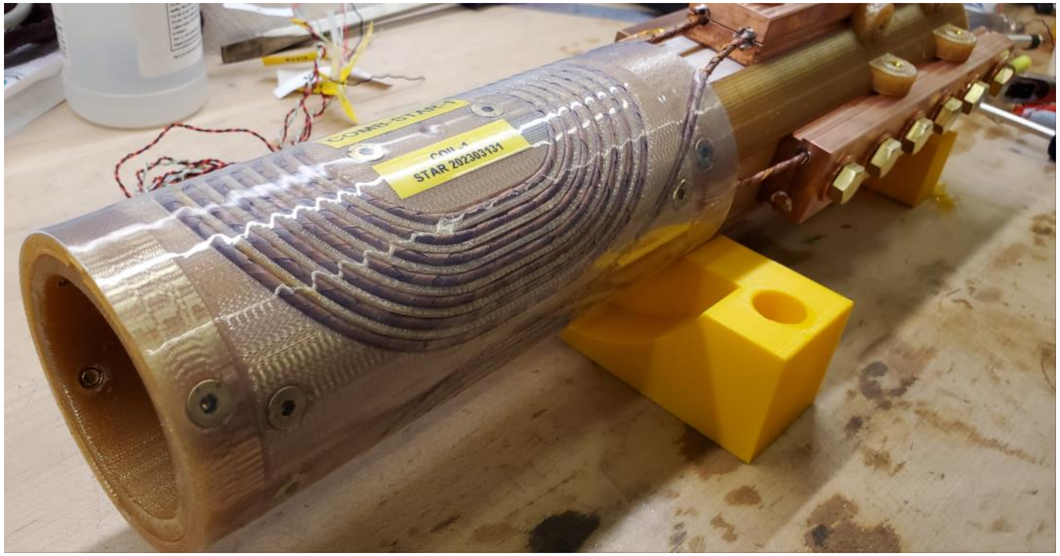
General MDP Meeting

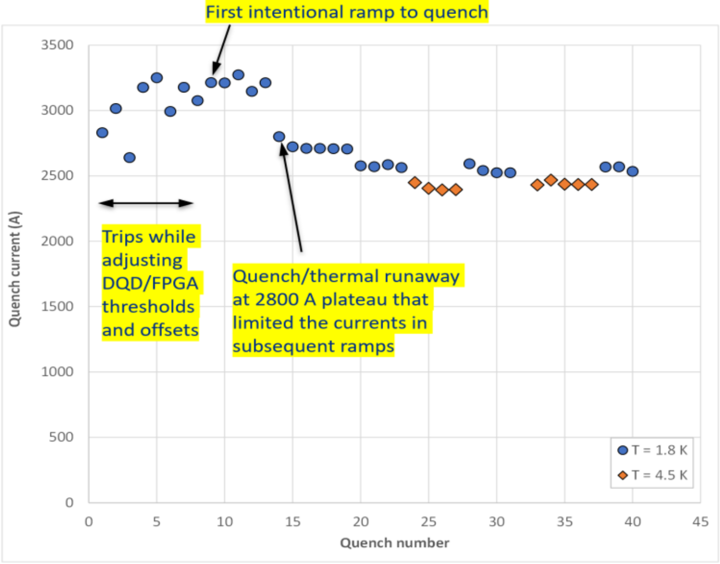
21 August 2024

REBCO magnet development activities at FNAL

- Conductor-dominated (high-field) magnets
  - Benefit from high critical field of REBCO for operation at 2-20 K
  - Conductor On Molded Barrel (COMB) design with round conductors
    - STAR wire
    - CORC cable
  - Design based on Twisted Stack (TST) cable
- Iron-dominated (low-field) magnets
  - Benefit from high critical temperature of REBCO for operation at 77 K
- Technology studies
  - Bifilar coils for quench protection
  - Exfoliated/soldered tapes to improve bending performance
  - Alternative cable designs
  - Cable stacks for fusion applications
  - Racetrack/solenoid coils for material testing

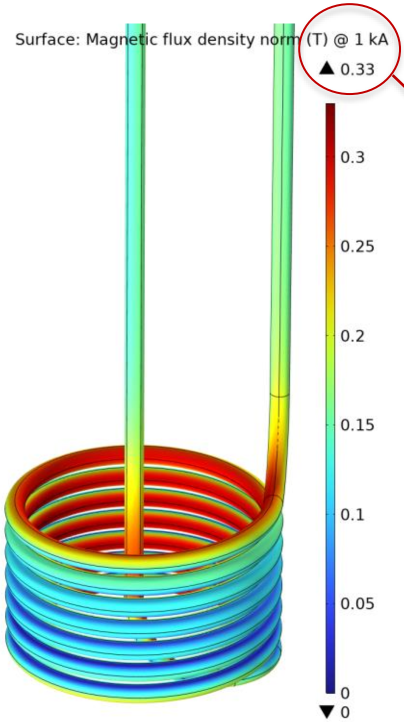
Magnet development with STAR wires

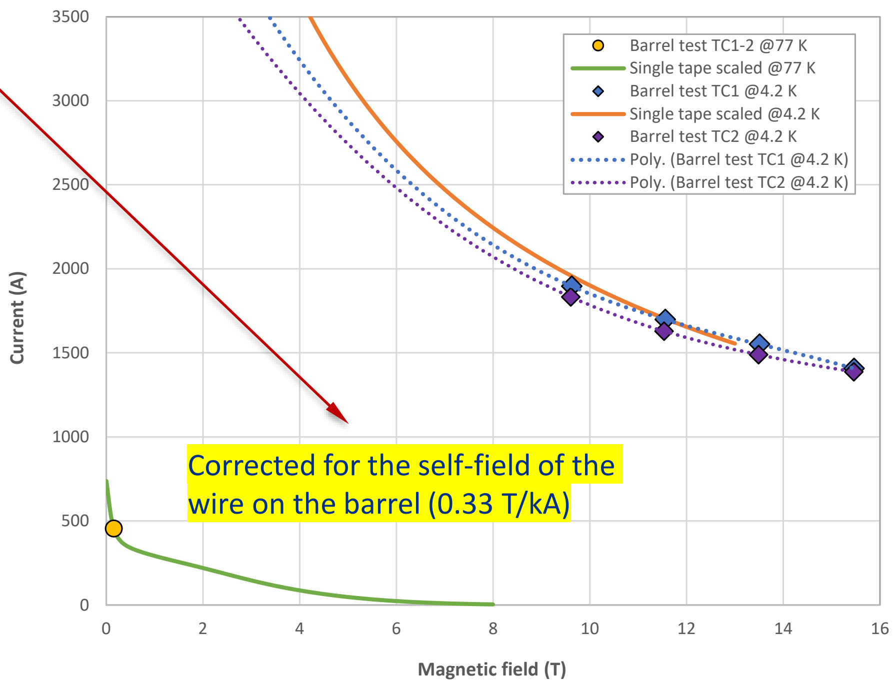




- COMB-STAR-1 magnet (2023-24)
  - Achieved 1.5 T bore field @ 3.3 kA in LHe
    - Performance limited by one half-coil
  - The coil, which limited the magnet performance is at UH for micro-CT scan
    - No obvious damage from the whole-coil (low-res) scan
    - Doing a high-res scan (slow) to check for possible damage inside of the conductor
- COMB-STAR-2 magnet (2025)
  - 100 m of STAR wire will be delivered later this or early next calendar year
  - 2 x 1-m samples are being tested
  - The magnet will have
    - 60 mm clear bore
    - 4-6 layers of STAR wire
    - target bore field ~5 T

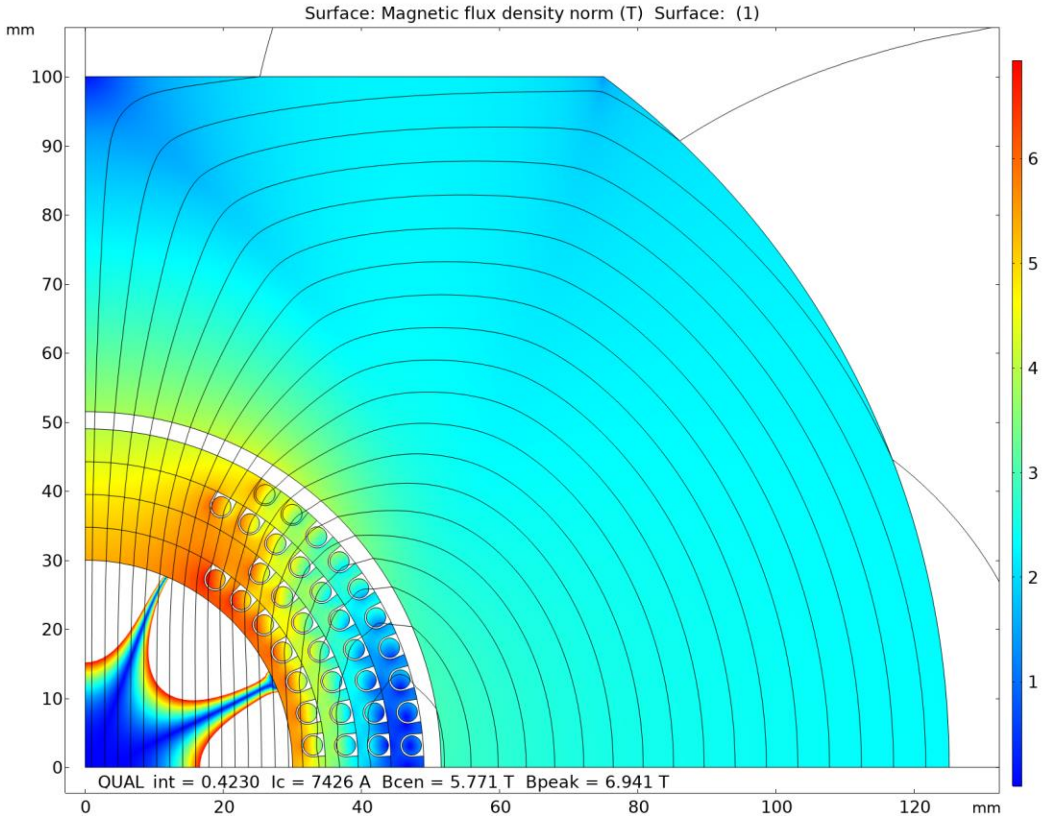
STAR wire testing for COMB-STAR-2 magnet





- The 12-tape STAR wire was tested on a Ti barrel (32 mm OD – slightly conservative vs. the magnet pole width of 34.9 mm)
  - The wire was bare in TC1 and wrapped with glass tape, heat-shrink tubing and Stycast in TC2
- The barrel data at 77 K (Ic = 456 A, n-value = 23) are consistent with the straight wire tests at the vendor (Ic = 745 A, n-value = 22) after the self-field correction – good Ic retention after bending
- The barrel data at 4.2 K show a reduced lift factor and a lower field dependence in 9-16 T range vs. the vendor data (on slightly different tapes)
  - Small (3%) Ic reduction between TC1 and TC2 (can be an effect or Stycast)
  - We will test a single tape of the type used in the wire in the full field range to see if it has the same field dependence

COMB-STAR-2 magnet



- The coil will consist of at least four layers of STAR wire with each turn placed into a channel in a dedicated COMB structure
  - Six layers are also being considered
  - Coil OD is ~100 mm for the 4-layer design and ~120 mm for the 6-layer design
- Can fit as an insert into a Nb_3Sn coil
  - currently there are no plans for such a test
- Each half-coil may be wound from a single piece of cable without inner joints
  - Depends on the maximum continuous conductor length the vendor can deliver

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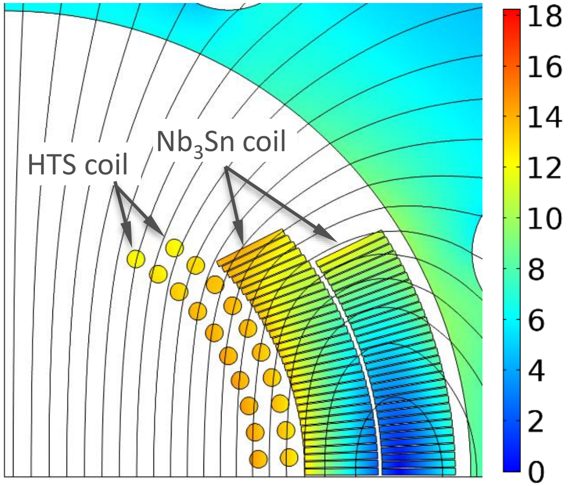
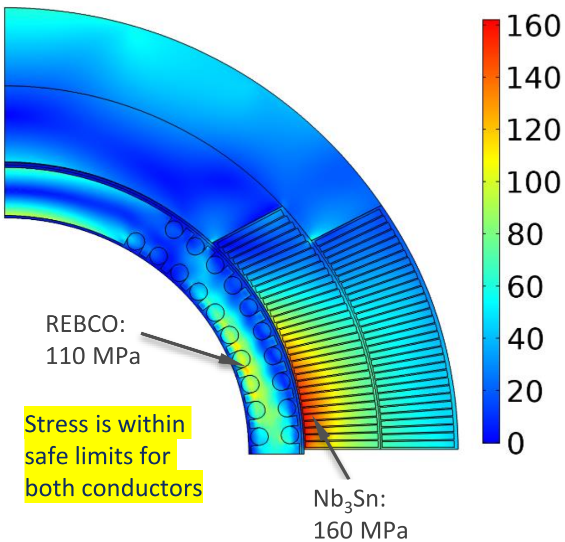
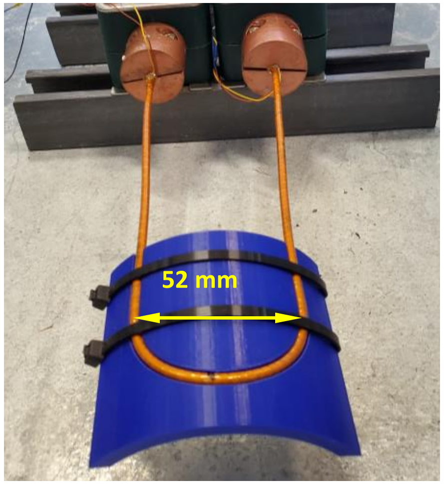
Magnet development with CORC conductors

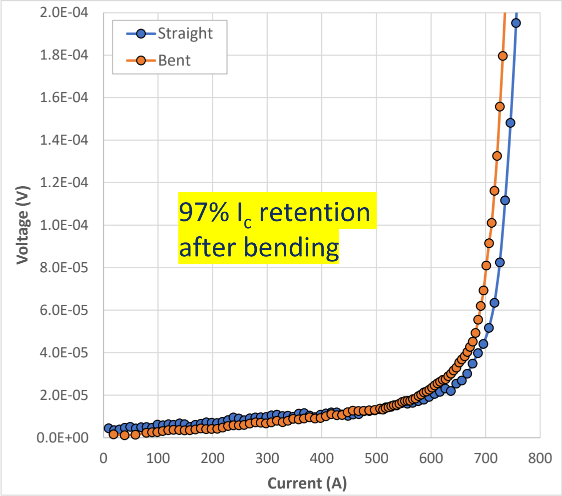
Magnetic field (T)



Equivalent stress (MPa)







- CORC cable is larger and less flexible than STAR wire
  - Had issues with the past generation of conductors that were degrading by 50% after bending
  - Bent the new conductor to 52 mm diameter (expected pole turn diameter) and measured 97% Ic retention in LN_2
- COMB-CORC-1 magnet (2024-25)
  - ~100/120-mm ID/OD and ~5 T target bore field
  - Standalone test this/next year in LN_2 and LHe
    - MDP Milestone AIIb-M7: COMB performance demonstration
  - Hybrid test (next year ?) with a Nb_3Sn coil
    - MDP Milestone AIIb-M5: Complete COMB insert test
    - Need significant test facility upgrades

REBCO coil concept based on TST cable

An HTS coil based on a Twisted Stack (TST) cable made of REBCO tapes – an alternative to round REBCO cable technology

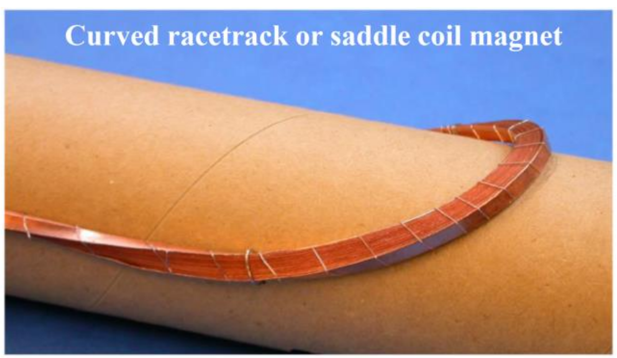
Contact person: Sasha Zlobin

M. Takayasu, MIT, PSFC
1st Workshop on Accelerator Magnets in HTS at DESY, Hamburg, Germany, 2014

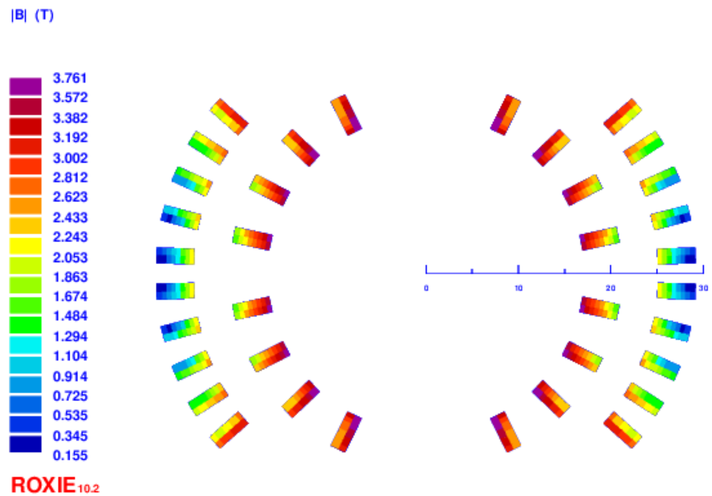
I_c degradation due to bending

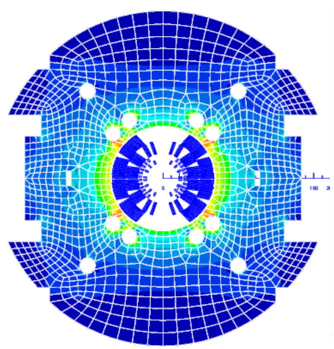
Bending Diameter	Degradation
250 mm	1.9 %
140 mm	5.4%
Straighten after bending tests	3.6%

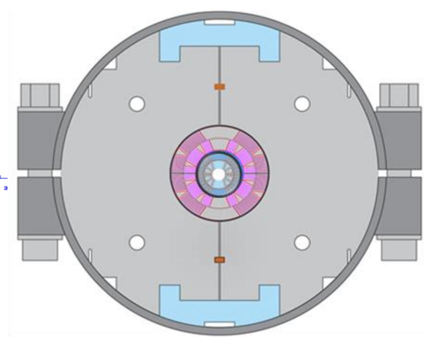
TSTC conductor is bendable.



Coil and magnet cross-section







Practice coil: 3D-printed structure and 12-stack cable made of 4x0.1 mm^2 SS tape

REBCO tape testing in LHe is in progress

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REBCO testing in LHe at FNAL

- The first REBCO magnet test at VMTF revealed several issues with the test facility
- The magnet test facility needs upgrades to test REBCO magnets standalone
  - Decrease/eliminate current spikes from the dump switch by changing SCRs to IGBTs
  - Reduce noise in the (fast) quench detection channels to preferably <0.1 mV
  - A true simultaneous (slow) multi-channel V-I measurement system with low noise
- The magnet test facility needs upgrades to test hybrid magnets
  - Separate/integrated quench detection/protection for HTS and LTS coils with different thresholds
  - The REBCO coil should be discharged in a few ms. Doable standalone, but not possible when connected in series with the Nb_3Sn coil due to its much larger inductance
    - Cold bypass diode and a cold dump resistor to protect the HTS coil
    - Separate magnet powering and protection circuits
- The SSTF in IB3A can benefit from upgrades to test REBCO cables/small coils in the background field
  - There are several cryostats and solenoid magnets that can go up to 15 T, but currents are limited by 2 kA power supplies and the leads
    - Could test the STAR wire in 9-15 T range, but larger CORC-like conductors would exceed the power supply limit
    - Existing superconducting transformer may allow powering small samples and coils up to 25 kA; the quench detection/protection of REBCO in this regime needs further analysis
  - Upgrade with a >5 kA power supply/leads would allow
    - Testing of CORC-like conductors and subscale coils at 4.2 K in 0-15 T background field
    - Much faster turn-around than the magnet test facility
  - A gas recovery line to the helium liquefier is being considered to reduce the operating cost