Fatigue Behavior of No-Insulation Coils with and without Reinforcing Co-Wind


The National High Magnetic Field Laboratory is supported by the National Science Foundation through NSF DMR-1644779 and the state of Florida.

Abstract

The National High Magnetic Field Laboratory has commenced the development of an all-superconducting 40 T magnet that will be installed in its DF-Field User Facility. At present various high temperature superconductor technologies are being investigated as candidates for the magnet construction. It is the objective of this early development stage to address questions regarding the application of a type of superconductor to magnet technology through model coil testing and properties measurements. No-insulation (Ni) REBCO is a viable conductor and coil configuration for the 40 T magnet but needs further studies to reduce risk and to better understand its ability to perform reliably through long term user operations. The research presented here is focused on the fatigue effects of small Ni test coils (4 kJ) with and without reinforcing stainless steel coil wind. The coils contain six double pancakes with an inner diameter of 100 mm and will be operated to stress levels up to 0.45% in a background field of 6.9 T. The impact of electromagnetic cycling on the REBCO is evaluated using Yatestar which is a device that provides a full-length image of the REBCO’s superconducting state via magnetization and transport measurements. The contact resistivity is measured periodically and is observed to decrease with load cycling.

Test Coil and Test Bed Configurations

- **Objective**:
  - Observe effects of cycling on REBCO coils with electromagnetic loads, including screening currents, up to ~0.4% - 0.45% axial strain
  - Test Bed: NbTi magnet, 170 mm cold bore, 6.9 T
  - Insert Coils:
    - IR = 50 mm
    - GR = 55 mm
    - Six Double Pancakes (4 mm wide)

- **Test Coil #1**
  - REBCO: 94 µm thick (50 µm substrate), 53 turns per pancake
  - REBCO oxidized via Ebonol-C
  - No co-wind, no reinforcement
  - Inductance = 32 mH
  - Termination: stiff ring

- **Test Coil #2**
  - REBCO: 51 stainless coil (30 µm substrate), 61 turns per pancake
  - 30 µm thick stainless co-wind
  - Inductance = 39.1 mH
  - Termination: stiff ring

- **Test Coil #3**
  - REBCO: 94 µm thick (50 µm substrate), 40 turns per pancake
  - 30 µm thick stainless co-wind
  - Inductance = 24.8 mH
  - Termination: flexible

- **All conductor is scanned through Yatestar before and after cycling for damage comparison and location identification**

- Screening currents computed using a T-A formulation [1] in COMSOL and input into an ANSYS structural finite element model which utilizes contact elements between neighboring conductor turns [2]

- Characteristic resistivity, $R_c$, measured before and after cycling

- **Test Conditions**
  - Current: 330 A (6.4 T - 330 A, SF)
  - Max / Min Central Field: 8 T - 9 T
  - Peak Strain: 0.50% (0.45% with $R_c$)

- **Test Results**
  - The conductor was oxidized to increase the turn resistivity.
  - At room temperature and 77 K, the measured resistivity was 62.5 µΩ cm² / 77.5 µΩ cm² respectively.
  - Peak strain: 0.59% (0.54% with $R_c$)
  - Prior to cycling the NbTi quenched at 6.4 T causing damage to DP3 (1.2 m substrate, 53 turns)
  - 110 ramp cycles were applied to the coil, primarily at 20 A/s
  - No additional degradation to DP after cycling
  - Yatestar scan shows no damage on REBCO
  - $R_e = 62.5 \mu \Omega cm^2 / 77.5 \mu \Omega cm^2$

- **Test Results**
  - Test Coil #1:
    - Current cycle: 110 A – 350 A (0 T – 1.65 T)
    - Background Field: 6.3 T
    - Max / Min Central Field: 6.3 T – 7.7 T
    - Peak Strain: 0.50% (0.45% with $R_c$)

- **Screening Current Strain**
  - Six strain from transport and screening currents were evaluated at 350 A and 110 A
  - During ramp down screening current reverses direction, as indicated in the current density contour plots
  - This creates hoop compression on the upper end of the pancakes (end three pancakes)

Conclusions

- REBCO has been shown to withstand at least 2000 cycles to strains in the range of 0.4% - 0.45% and with a high gradient (electro-magnetic load cycling to be continued on test coil #3)

References