Neutron radiation damage to organic insulation in the coil winding pack is a critical issue for the next step fusion reactors where orders of magnitude higher neutron fluence than that in ITER are expected. On the other hand, slow current charging time is an issue in a fully non-insulation coils for fusion. We present design, construction, and cryogenic testing of mid-level field PPPL in-house built Nb₃Sn solenoid coils with a new design of significantly reduced organic insulation in the coil winding pack. Coil performance and behavior during current charging and discharging is investigated for magnetic flux swing needed from the FNSF CS magnet design.

Objectives

- New simplified construction of radiation tolerant superconducting solenoid coils with ITER wire, and reduced insulation but better structural reinforcement.
- Investigate coils of simplified fabrication (without VPI) to improve winding pack current density while subsequent lower cost and enhance radiation resistance.

Coil Design

Coil insulation scheme:
- Large coil = 120 mm diameter and 250 mm height (5 layers) – no turn to turn insulation for high WP density
- Mini coil = 55 mm diameter and 50-60 mm height (3 layers, ~10 turns)
- Large coils without turn to turn insulation but small coils with various insulation schemes were fabricated and tested.

Coil Winding

Winding approach:
- Coils are wound by a hand winder on a steel coil form under 5 pounds winding tension using bare Nb₃Sn wire (US ITER TF conductor wire from Lutaloy) no glass sleeve on wire as in conventional process
- Coil insulation:
  - No turn to turn insulation but one layer of 5-glass cloth was applied between layers.
  - Tension control: Uniform tension during winding applied by weight

Methods

PPPL is currently leading the design studies for the next-step fusion devices based on the most promising magnetic configurations. Superconducting fusion magnets with high current density are particularly beneficial for low aspect ratio "spherical" tokamaks and the compact stellarators.

To integrate magnet design with burning plasma physics for fusion energy beyond ITER, a clear strategy with focused effort on targeted R&D activities is needed.

Coil Performance in Current Ramp Test

Coils went through standard heat treatment from ITER specification in the PPPL vacuum brazing furnace. Tie-wax leak was found in one of the small coils.

Structural reinforcement (clamping rings) is applied on exterior of coil winding pack (remove the VPI process) to ensure compactness and structural integrity of winding pack while improving overall winding pack current density.

Further tests of the no-insulation coils at University of Geneva with better control of current ramp rate (~1 A/s) showed excellent coil performance.

No-insulation coil reached ~700 A in current ramp and generated ~3 T field at coil-central bore.