LANL Contributions to GE HTS Generator Development

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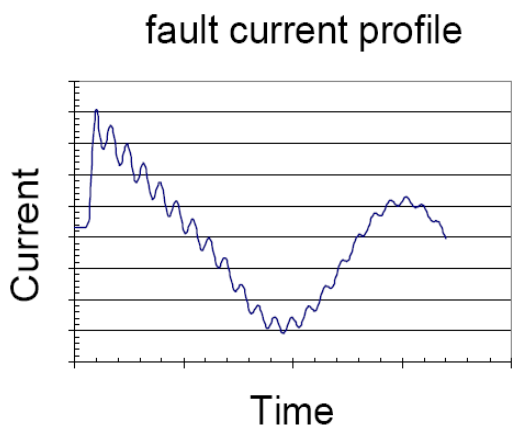
Objective was successful demonstration of 100 MVA HTS generator

- LANL entered into a CRADA with GE to provide assistance in several technology areas
- Technology areas
  - Long term vacuum maintenance
  - Alternative rotor cooling methods
  - Thermal modeling of cooling system
  - Engineering support
    - AC loss characterization
    - 2nd Generation wire impact
- CRADA ended prematurely at the end of 2nd Qtr.
- FY 2006 Funding (6 months of fiscal year):
  - $215k (LANL/DOE)
  - $215k (GE in-kind)

AC loss characterization allows GE to make reliable heat load calculations

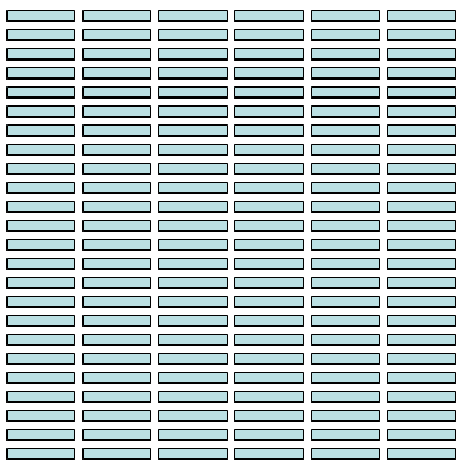
- AC fields ⇒ joule heating
  - Increased heat load on refrigeration system during normal operation
  - In Fault Current (FC) condition ⇒ quench and damage of coil ⇒ loss of capability
- First phase was to estimate the AC losses numerically in coil
  - steady state contribution from exciter harmonics
  - 60 Hz fault current scenario



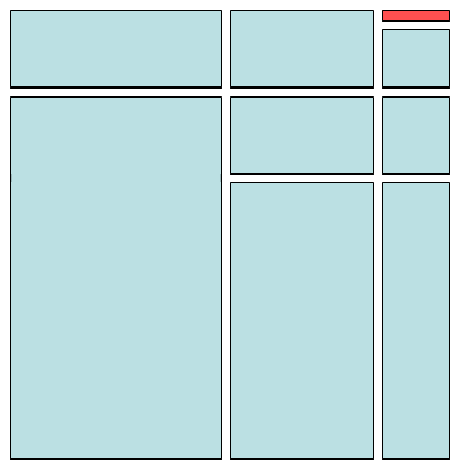
- Studied the AC loss characteristics of an individual stainless steel clad BSCCO tape
- Study AC losses in some ‘critical’ positions inside the overall coil cross-section
- Develop a heat generation profile => thermal analysis

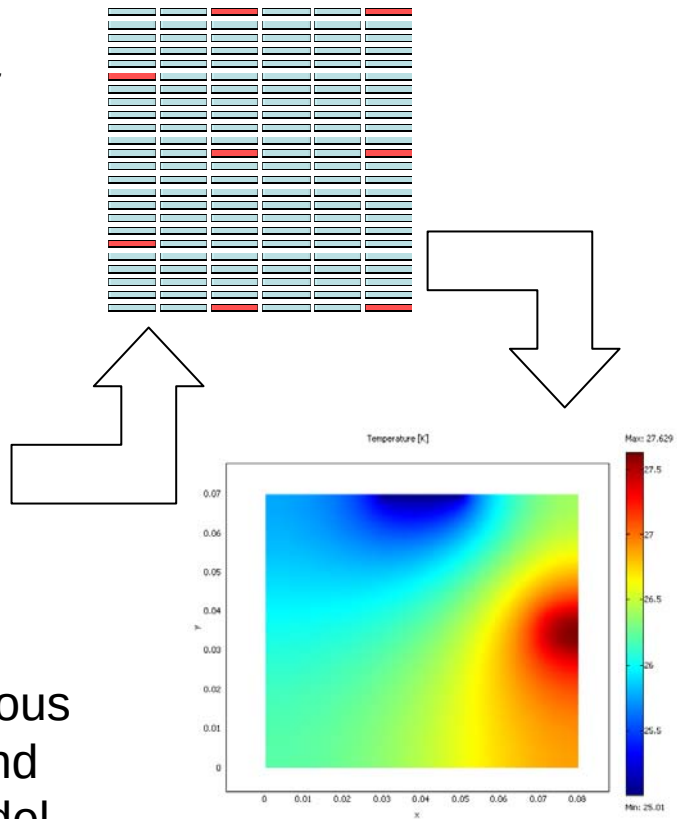
AC loss calculation method for coil used a discretized approach

individual tapes of actual coil



discretized bulk coil current sources and single tape of interest

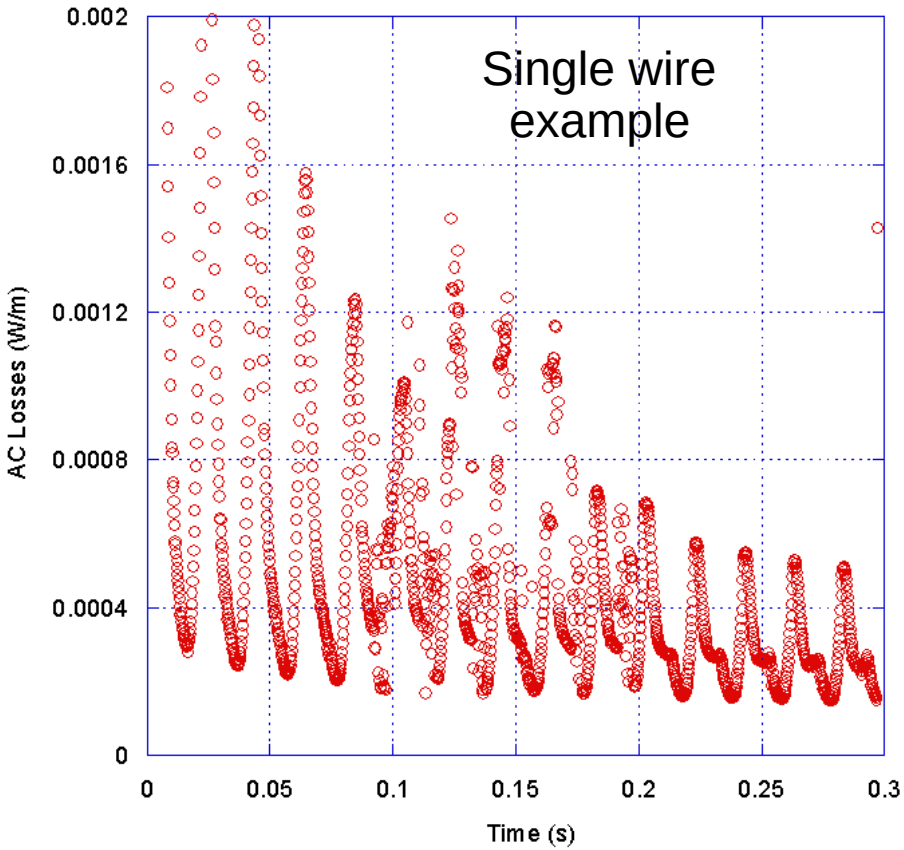




Repeat calculation for various discrete locations in coil and interpolate for thermal model

Preliminary AC loss numerical results were completed in support of planned tests

- Results for numerical analysis were completed for single wire and method for coil determined
- Experimental apparatus was completed in FY05
- Measurements scheduled to follow were not performed due to premature end of CRADA

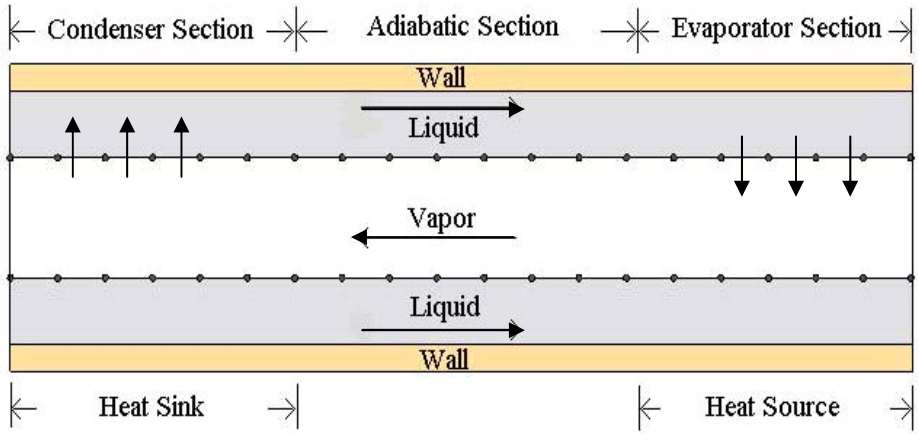


LANL provided thermal modeling of the baseline He coolant loop

- Transient analysis of rotor was deemed unnecessary and was not performed
- LANL assisted GE with steady state analysis of rotor cooling and baseline refrigeration system
  - Performed CFD analysis of the coolant path
  - Investigated affect of rotation on heat load
- Completed initial simulations of coolant loop to verify heat due to flow work on helium

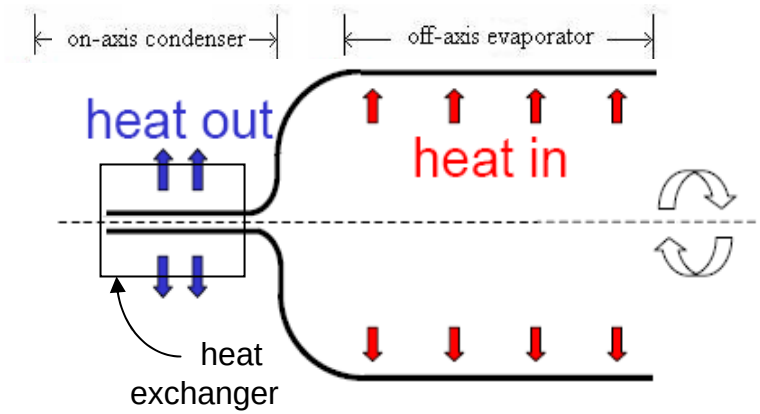
Heat pipe integration offers high payoff rotor cooling alternative

- Heat pipe has a two-phase fluid making device nearly isothermal
- Sealed device that is simple and operates passively
- Self regulates “hot spots” by providing cooling locally



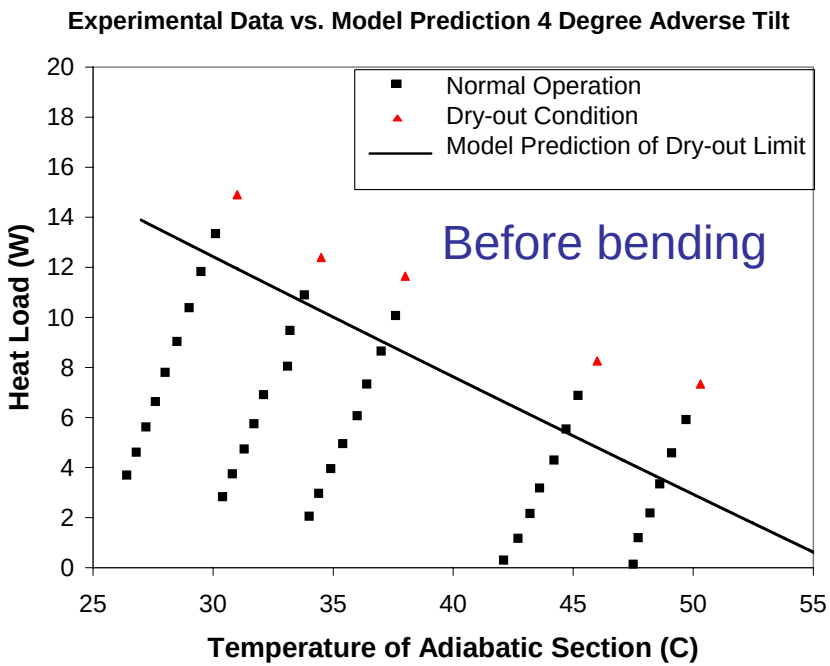
Rotating heat pipe configuration has unique operating characteristics

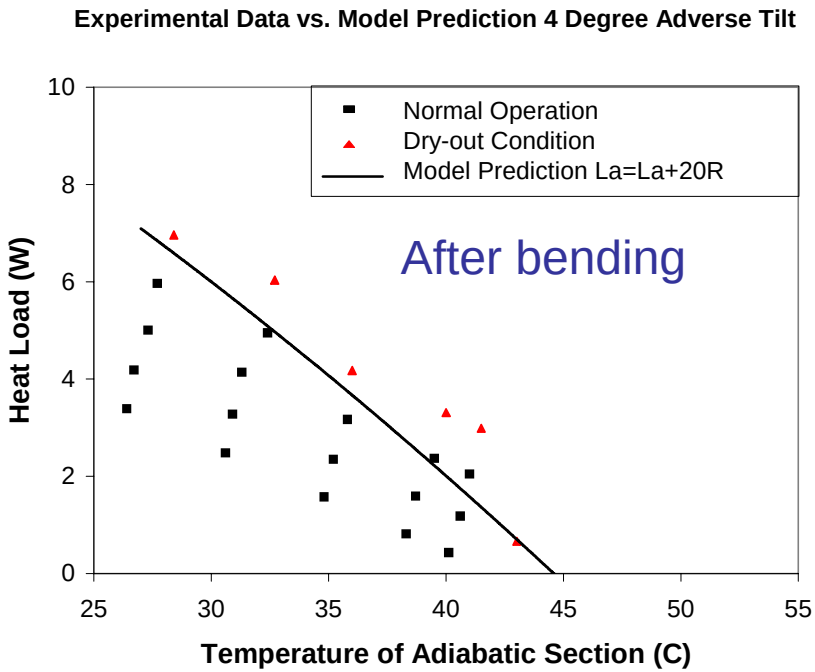
- Bent heat pipe
  - On-axis condenser coupled to refrigeration system
  - Off-axis evaporator attached to HTS windings
- Unique design of wick structure allows operation in stationary and rotating modes
  - Stationary operation return of liquid to evaporator is main challenge
    - Porous wick
    - Capillary forces
  - Rotating operation return of vapor to condenser is main challenge
    - Centrifugal Body force (gravity)



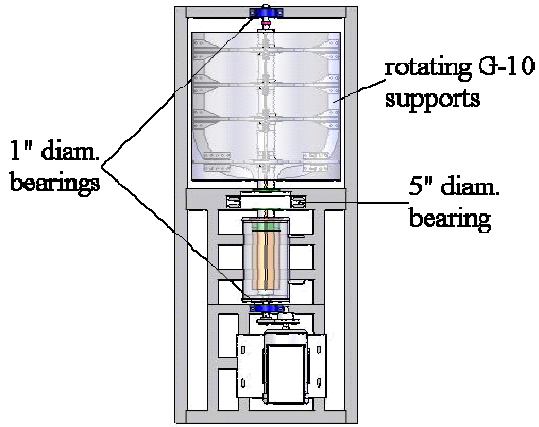
Stationary heat pipe tests were necessary to determine performance impact of bends

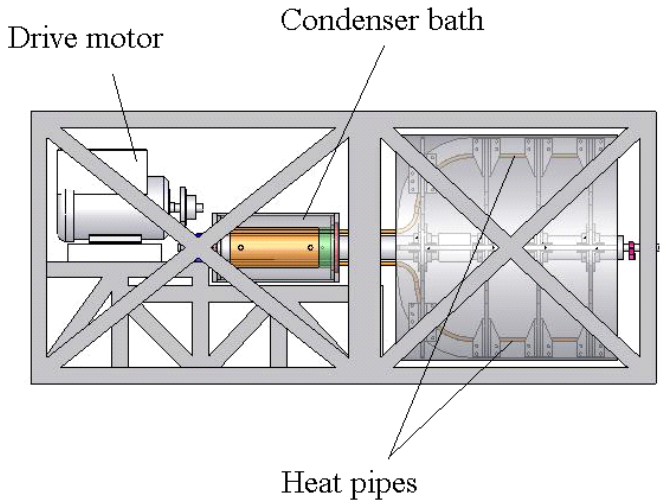
- Stationary test data before and after bending agree well with predictions
- The wick structure was not damaged during fabrication or bending





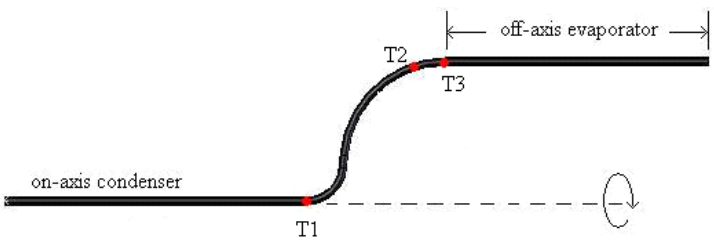
Rotating heat pipe test apparatus uses a paired heat pipe configuration

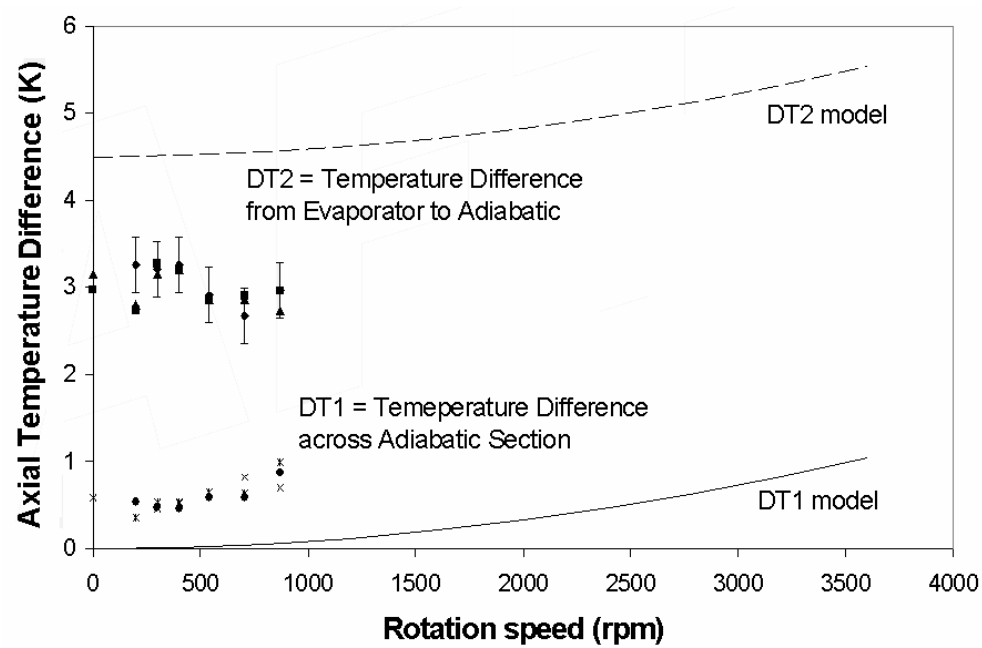




Low-speed rotating tests up to 1200 rpm were completed

- Low-speed tests show evidence of the expected dual mode operation
- Windage and shaft friction losses prevented significantly higher speed tests
- Did not encounter any heat transfer limitations during rotating tests even to high power



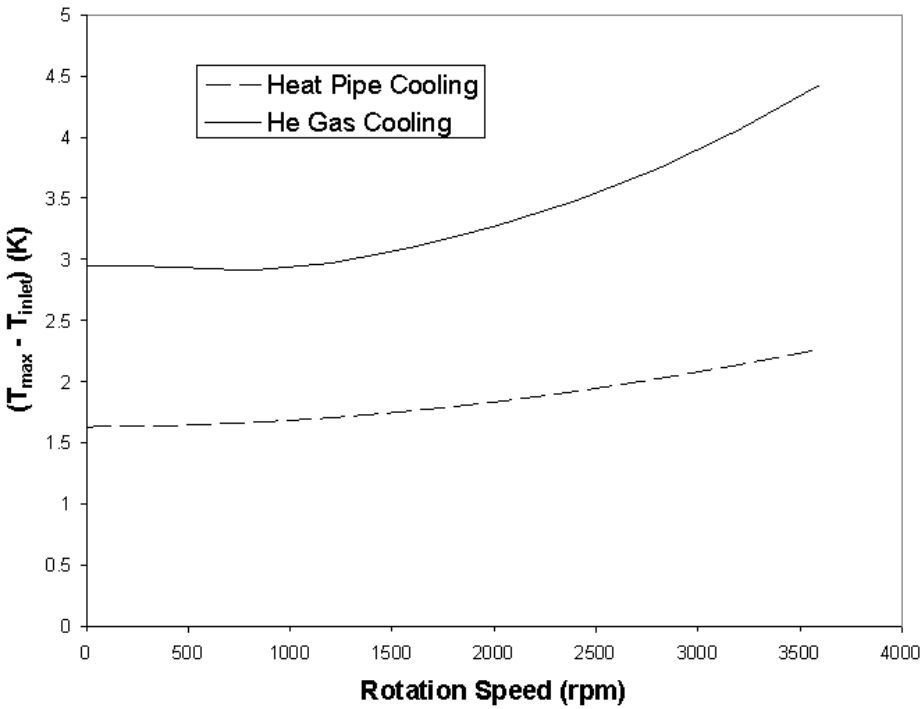


DT1 = T2 – T1

DT2 = T3 – T1

Heat Pipe cooling has lower temperature difference than circulating He cooling

- Heat pipe model was used to predict performance in full-scale generator
- Eight 0.25” diameter heat pipes each carrying an equal portion of the total heat load operating near 25 K
- Heat pipe cooling system is typically 1.5 to 2 K lower than the forced flow system



~50% ⇓ dT → ⇑ *efficiency* → ⇓ *refrigeration $*

Heat pipe cooling offers advantages to HTS rotating machinery

- Compared to forced flow system, the heat pipe system:
  - Lower temperature difference (dT) between rotor and coupling
    - Reduced temperature gradient of rotor
    - Increases efficiency => reduces refrigeration cost
  - May simplify the transfer coupling

- Low-speed tests do agree well with expectations
- High-speed tests (up to 4000 rpm) are needed
  - Ensure that working fluid continues to circulate
  - Verify assumptions used in modeling

FY 2006 Performance - 1

Plan

2nd Generation Conductor Impact

- Assess impact and document results

Thermal Modeling of Refrigeration and Cooling System

- Assist with baseline system development; steady state analysis as needed
- Develop transient model of system and document model

Performance

2nd Generation Conductor Impact

- ☐ Not performed due to premature ending of CRADA

Thermal Modeling of Refrigeration and Cooling System

- ☑ Assisted with baseline system steady state analysis; preliminary analysis complete
- ☐ Determined to be unnecessary and removed from LANL scope

FY 2006 Performance - 2

Plan

Rotating heat pipe experiment;

- Final stationary tests
- Low speed (< 1000 rpm) tests completed
- High speed tests

Passively pumped cooling experiment

- Modify rotating apparatus, acquire data, and document results

AC Loss/Over Current

- Acquire data, compare to model, and document results

Performance

Rotating heat pipe experiment;

- ☑ Stationary, bent, in apparatus tests complete
- ☑ Low speed tests complete
- ☐ Seeking additional funding to continue high speed tests

Passively pumped cooling experiment

- ☐ Deferred testing until higher priority heat pipe test complete

AC Loss/Over Current

- ☐ Continued modeling of actual coil and obtained preliminary results; not completed due to premature ending of CRADA

FY2007 Plans

- Commercialization of 100 MVA HTS Generator project has been postponed at GE
- CRADA ended 2nd Qtr FY06
- No FY07 work is planned

Research Integration

- Interaction between GE and LANL
  - Reports and teleconferencing to review direction, efforts, and results
  - Participated in GE 100 MVA Preliminary Design Review
- Interaction with LANL experts across organization and discipline boundaries (applied engineering ⇔ material science)
- Interaction with Prof. Razani of University of New Mexico on heat pipe development
  - Joint publications, conference and journal papers
  - Heat pipe research serving as basis for Ph.D. dissertation
- Rotating heat pipe development advances the "state of the art"
  - Other HTS applications including motors and other rotating machinery
  - Patent pending with disclosure available for licensing

Results

LANL contributions augment future HTS rotating machinery → cost reduction in 2nd generation and production units:

- Develop more efficient cooling system to reduce refrigeration cost
  - Completed low speed testing, which agreed with expectations
  - High-speed tests (up to 4000 rpm) are needed
    - Ensure that working fluid continues to circulate
    - Verify enhanced cooling phenomenon
  - Results indicate there are advantages of Heat Pipe Cooling compared to forced flow system
- Characterize AC Losses to improve thermal design margin
  - Performed preliminary modeling
- Provide expertise and thermal modeling of cooling system
  - Assisted with steady state modeling