High Temperature Superconducting Generator

2005 Annual Peer Review

Superconductivity Program
for Electric Systems
U.S. Department of Energy

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Washington, DC

Project Objective

- **Project level goal:** Support the successful demonstration of 100 MVA generator HTS rotor retrofit

Areas of Emphasis

- **Emissivity** –Assessment of radiation heat load to HTS rotor coil
- **Quench and Stability** – Characterization of HTS prototype coils in order to predict coil performance during and after transients and overload conditions
- **Dielectrics** – Performance of coil winding when voltages are applied during normal operation of the coil and from changes in the operating conditions of the rotor

FY 2005 Milestones

- Expand emissivity investigation to observe whether other plated materials degrade similarly due to water and air contamination
- Refine measurement of emissivity degradation due to indirect contamination from outgassing
- Provide multiparameter curve fit for $R(T,I,I_c(B))$ to use in over-current simulations of generator
- Test dielectric insulations for partial discharge and advanced aging curves at 77 K and 25 K
- Test layer-to-layer insulation for impulse breakdown, PD, and pulsed aging
- Build prototype coils with preferred insulation and test partial discharge, impulse breakdown, and advanced aging

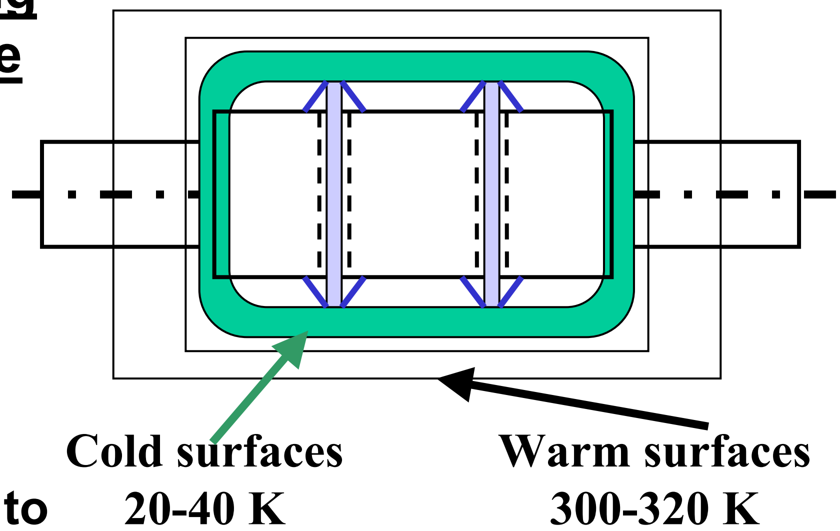
FY 2005 Results

- **Emissivity**
  - Characterized the emissivity at 30 K for several silver plated copper surfaces with different room temperature emissivities
  - Examined emissivity degradation effects due to direct water and air contamination.
  - Incorporated the outgassing of rotor structural components to provide relevant indirect contamination for emissivity degradation studies
- **Quench and Stability**
  - Reviewed quench protection scheme for 100 MVA generator in noisy backgrounds.
  - Worked with GE staff on quench and stability testing and analysis of demonstrator rotor coils
- **Dielectric testing**
  - Examined partial discharge in trapped air-filled gaps at temperatures between 295 K and 41 K.

Low emissivity surfaces reduce thermal radiation heat transfer on the HTS generator

Emissivity

- **Motivation – Due to constraints on thermal insulation in rotating cryostats, low emissive surface needed to minimize radiation heat transfer**



- **Issues:**
  - Emissivity at 30 K
  - Degradation of emissivity due to air and water
  - Sources
    - Seal leakage (direct)
    - Outgassing of structural components of rotor (indirect)

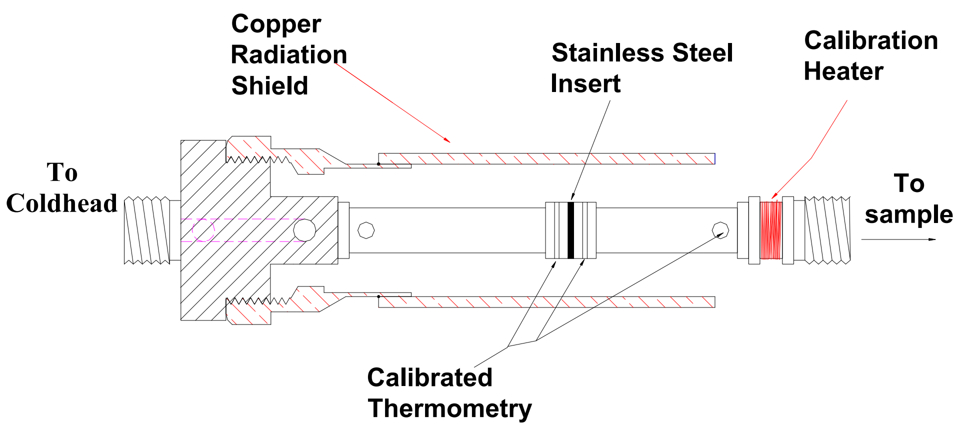
$$Q_{radiation} \propto \varepsilon$$

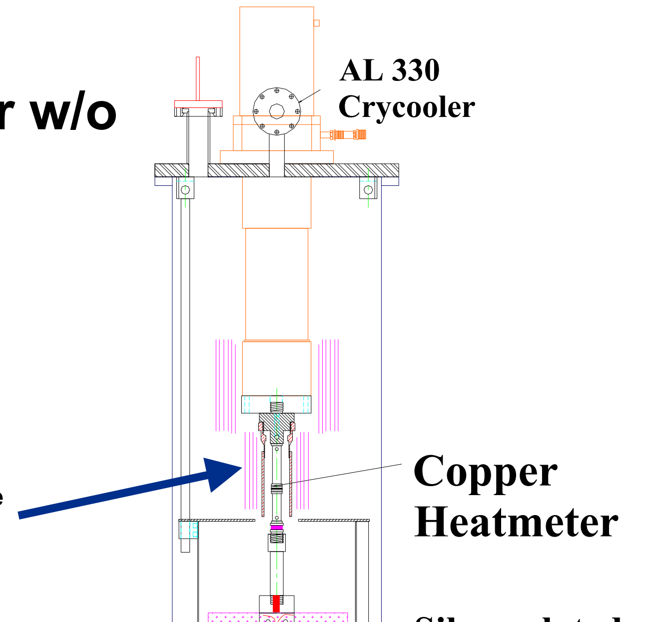
Refrigeration is one cost driver for final 100 MVA generator

Emissivity measurements test apparatus is based on energy balance of sample.

Cryogenic Experimental Setup

- Background heat load and heater w/o sample
- Radiation heat load with sample





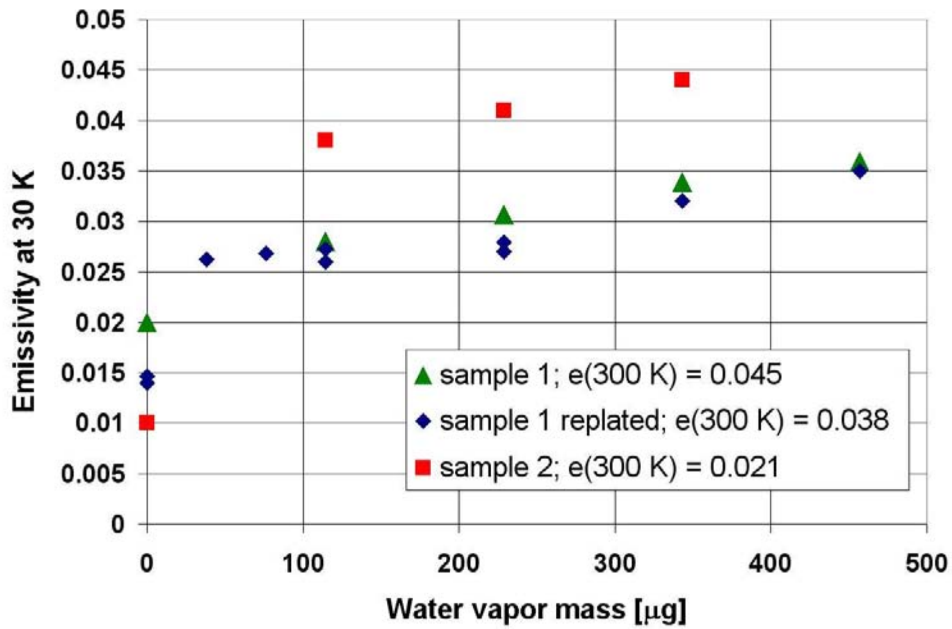
- Ag-plated copper samples
- Contaminants
  - Direct water vapor and/or air
  - Outgassing of non-metallic rotor materials

Emissivity

Significant change in emissivity due to direct water contamination at 30 K

- **Three samples with different values of ε(300 K) were examined.**
  - Sample 1 - ε(300 K) = 0.045
  - Sample 1 replated – ε(300 K) = 0.038
  - Sample 2 - ε(300 K) = 0.021

- **Repeatability of emissivity after contamination indicates that emissivity degradation is surface dominated.**

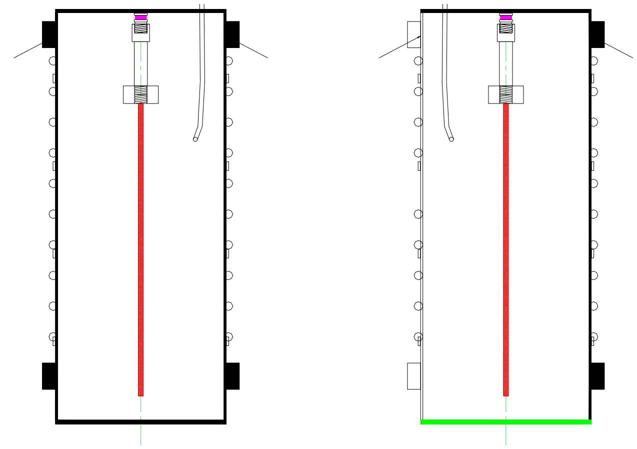


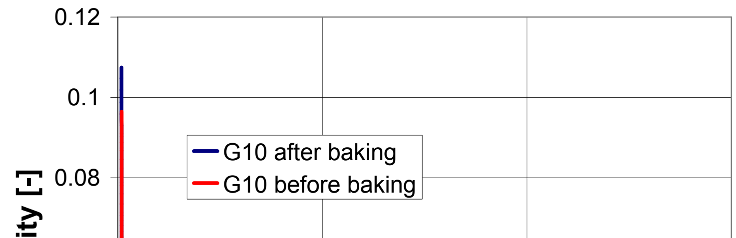
Emissivity

Outgassing of G10 component causes slight degradation of emissivity

Emissivity

- The bottom plate of the thermal shield was replaced with G10
- Results indicated that the outgassing rate is significantly lower than previously reported by LANL. This reduction is likely due to drop in shield temperature.
- In addition, vacuum baking G10 for one hours caused some reduction in the





Implication

Understanding and controlling emissivity effects and contamination sources allows the manufacturer of HTS equipment to minimize refrigeration heat loads and costs as well as the costs of contamination management in a production environment.

Partial Discharge in Air Gaps between Insulated Bi-Sr-Ca-Cu-O Tapes Degrades Electrical Insulation

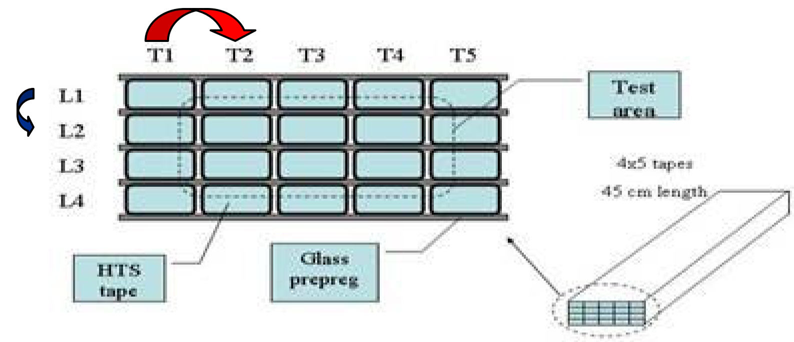
- **Motivation: From previous work, partial discharge was seen as a key issue in rotor voltage dynamics.**

Why is partial discharge important?

- Partial Discharge (PD) is the primary aging mechanism for cold dielectrics in HTS power applications
- PD can reduce lifetime of insulation or cause catastrophic failure
- PD can occur in embedded voids, gaps, delaminations in solid dielectrics
- PD can occur in voids under repetitive pulse applications
  - **Could occur in rotor coil because of 360 Hz operation of exciter at +/- 750 V**

Layer to layer

Turn to turn

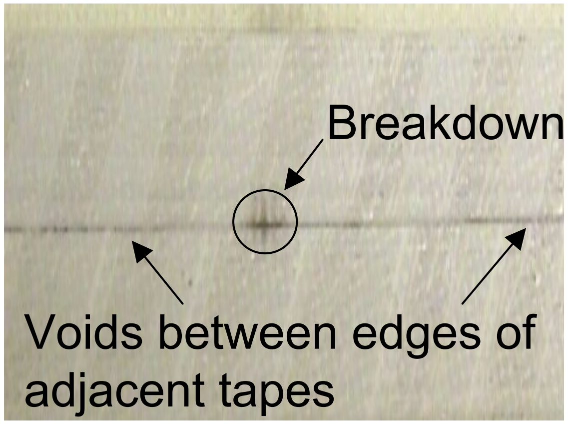


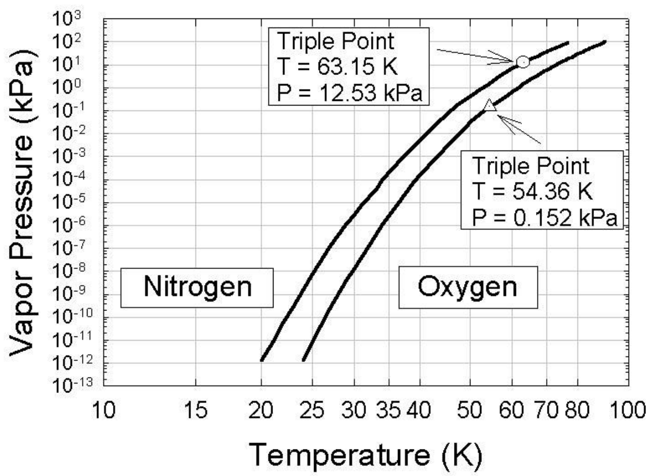
Fluoropolymer insulation wrapped on BSSCO tape

Dielectrics

Does PD onset change from 295 K to 30 K for enclosed voids?

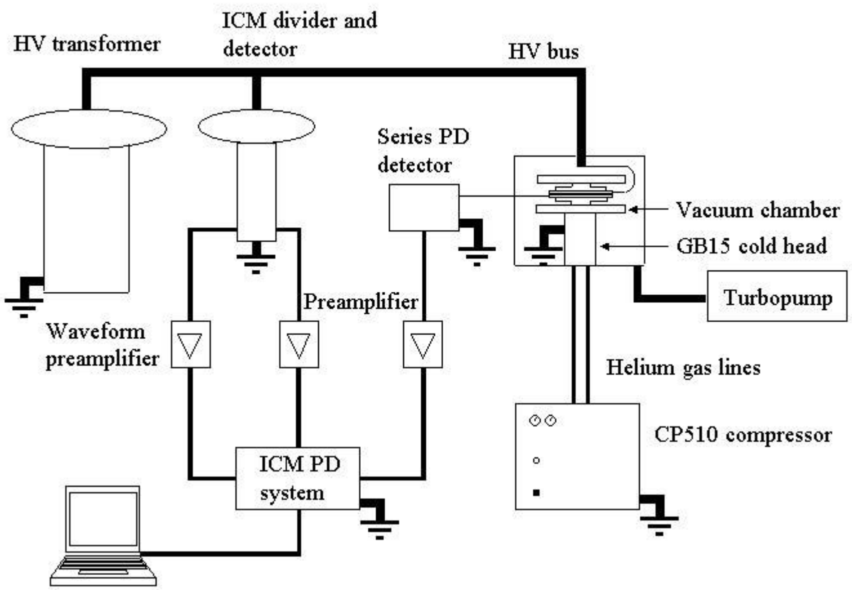
- **Gas in void may condense to liquid as temperature is lowered**
- **Below triple point ice layers may form on surface and leave vacuum in void**
- **Does PD onset increase for vacuum in void with ice layers as might be expected from Paschen's law?**
- **Experiment with cryocooler rig to measure PD vs. T**

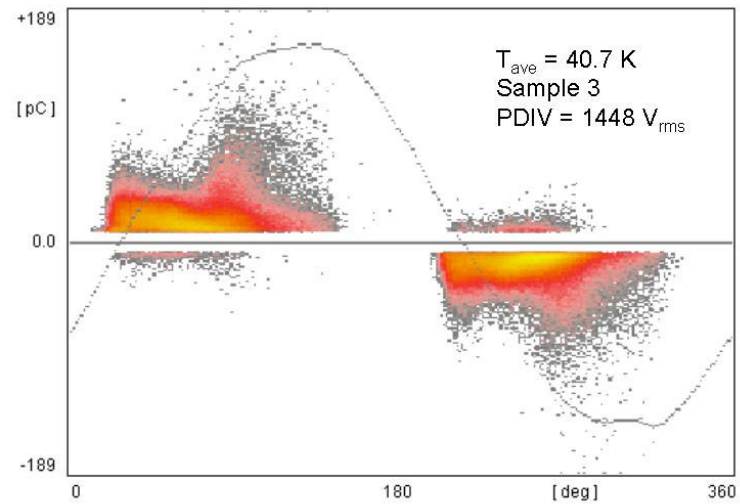




Dielectrics

PD measurements were conducted on actual HTS samples with polymer tape insulation





Phase-resolved PD pattern

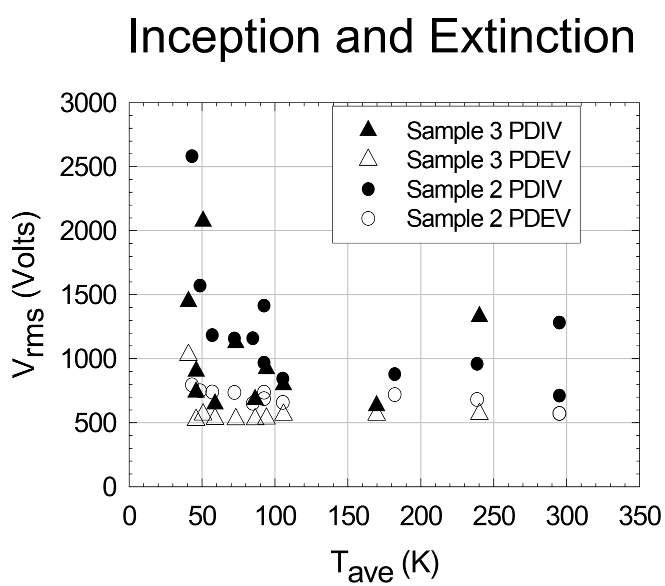
Dielectrics

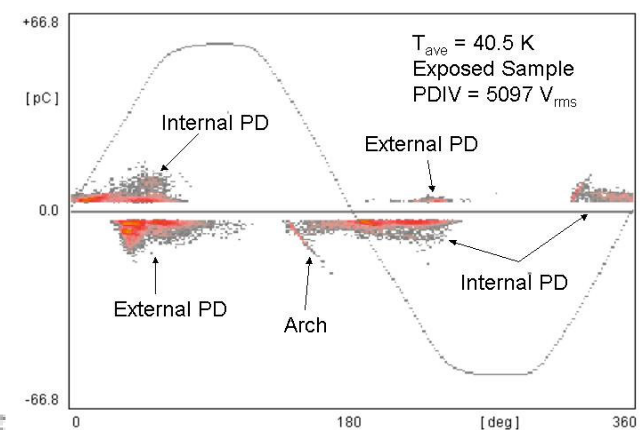
- **Tapes placed edge to edge with 1-2 mil void region**
  - **Samples cast in epoxy to trap air in void**
  - **Samples with void open to vacuum**
- **Samples mounted in cryocooler**
- **Phase-resolved digital PD detection system used**

PD onset at low T can be low – important design criteria

Conclusions

- Gas in void condenses and/or freezes as temperature is lowered
- PDIV can be relatively low even at 41 K with nitrogen and oxygen "ice" layers
- PDIV without ice greater than with ice at 41 K
- Presence of ice layers may decrease PDIV over that for actual vacuum – possible desorption of gas





With a minimum 500 V at which PD occurred, this provides a significant amount of margin given that the turn to turn voltage is a fraction of the +/- 750 V of the exciter.

Dielectrics

ORNL FY 2005 Performance

FY 2005 Plan

- Expand emissivity investigation to observe whether other plated materials degrade similarly due to water and air contamination
- Refine measurement of emissivity degradation due to indirect contamination
- Provide multiparameter curve fit for $R(T,I,I_c(B))$ to use in over-current simulations of generator

FY 2005 Performance

✓ Measured baseline emissivities of Ag-plated Cu samples at 30 K

✓ Characterized effects of direct water and air contamination on emissivity degradation of Ag-plated Cu samples

✓ Added indirect source of contamination from G10 and characterized emissivity degradation

✘ Task deleted due to demonstration of flux flow resistivity model in other coil simulations.

✓ Participated in 1.5 MVA demonstration coil quench experiments and analysis

ORNL FY 2005 Performance

FY 2005 Plan

- Test dielectric insulations for partial discharge and advanced aging curves at 77 K and 25 K
- Test layer-to-layer insulation for impulse breakdown, PD, and pulsed aging
- Build prototype coils with preferred insulation and test partial discharge, impulse breakdown, and advanced aging

FY 2005 Performance

✓Examined partial discharge in trapped air-filled gaps at temperature between 295 K and 41 K.

✘Task deleted due to focus on partial discharge measurements

- In progress. Test coils with surrogate conductor are being fabricated to address other rotor issues. Will take sections and run through voltage testing in late FY2005/FY2006

ORNL FY 2006 Plan

FY 2006 Plan

- Examine full scale coil with surrogate conductor with preferred insulation and test partial discharge, impulse breakdown, and advanced aging at room temperature and 77 K.
- Further develop quench detection system and test with prototype coils
- Examine integration issues of 2G tapes into rotor design and build a prototype coil to characterize.

ORNL assistance with GE Generator Risk Mitigation Issues

Area of Concern	Solution
• Uncertainty in refrigeration heat load	• Knowledge of emissivity degradation can lead to identification of: – Proper refrigeration tolerances – Determination of whether outgassing from non-metallic components present a long term problem
• Quench protection	• Information on quench dynamics in prototype coils can identify the methods to detect and mitigate quenches in the 100 MVA generator
• Characterization of HTS coil insulation	• Testing in pulsed aging, partial discharge, and impulse breakdown can lead to use of proper insulation that can sustain voltage tolerance for field installation

Research Integration

- Teleconferences with GE has lead to efficient use of resources of ORNL and GE and ensures R&D objectives, efforts, and results are in accord with project objectives
  - Exchange of information between LANL and ORNL has lead to productive discussion as to the role of materials within rotor vacuum space and their impact on vacuum quality and calculations of heat loads
- Presentations and publications during the year
  - Emissivity poster and paper to be presented at Cryogenic Engineering Conference in August 2005
  - Papers presented at the 2004 Applied Superconductivity Conference and 2004 Conference on Electrical Insulation and Dielectric Phenomena (both Oct. 2004)
- Web Sites
  - ORNL Superconductivity Web Site includes Annual Reports, Peer Review presentations and other project information
    - www.ornl.gov/HTSC/htsc.html