

**2010 Advanced Cables and Conductors Peer Review
Project Summary**

Project Title:	Conductor Design for HTS applications
Organization:	Oak Ridge National Laboratory
Presenters:	Robert Duckworth and Yifei Zhang
FY 2010 Funding:	\$550K (DOE to ORNL) / \$50K (DOE to NIST)

Overall Project Purpose and Objectives:

The goal of this research is to provide application-relevant information on the impact of conductor design in YBCO coated conductors to wire developers and device manufacturers with an emphasis on electrical power applications such as cables, fault current limiters, transformers, and coils. Strategic research on conductors and YBCO prototype devices has been directed toward better understanding in the technical areas of ac loss, conductor stability, and splice joints that facilitates effective utilization of coated conductors by grid device manufacturers.

The objectives of this project were:

1. Complete benchmark characterization of 2G coated conductor splice joints
2. Extend splice characterization with respect to magnetic field and temperature.
3. Characterization of conductor stability and ac loss in low ac loss geometries with an emphasis on subdivided stabilization and modified filamentization.
4. Develop facility to allow for variable temperature characterization of 2G conductor coils

2010 Approach and Results:

Last year, benchmark characterization of American Superconductor (AMSC) recommendations for the fabrication of YBCO coated conductor splice joints was carried out and the findings led to revision of the existing recommendation. Utilizing the tools and knowledge that were developed from this study, benchmark characterization was carried out on SuperPower (SP) splice recommendations for commercially available 4-mm wide, copper-plated YBCO coated conductor (SCS4050). Qualification tests for the solders showed good solderability for the recommended 60Sn40Pb and 100In solders and fabricated splice joints utilizing either solder resulted in reproducible splice joint resistances as low as 20 n Ω (at 77 K) and no degradation during electromechanical testing that was carried out by NIST-Boulder. Characterization of the interface of the coated conductor splices showed no reaction layer or formation of intermetallic alloys within the splice joint region. The low resistance and the mechanical integrity of the splices suggested that the previously held view of the incompatibility of indium and copper does not appear to be applicable to this geometry.

In addition to splice joint resistance, voltage-current (V-I) characteristics of coated conductor splice joints were studied as a function of temperature and dc magnetic fields up to 5 T. At currents below the critical current, the change in resistance was found to be minimal for splices joints that were fabricated with both as-manufactured AMSC and SP coated conductors. As current went above the critical current, a transition occurred where the current sharing between the coated conductors within the splice joint led to a decrease in the n-value when compared to bare YBCO coated conductors. This lower n-value would indicate that less heating would occur at splice regions during fault currents, which is consistent with previous work on conductor stability of spliced YBCO coated conductors.

With respect to ac loss in YBCO coated conductors, prototype low ac loss geometries were fabricated to further understand the impact of stabilization and bridges on ac loss. Utilizing a 1.2-cm wide YBCO coated conductor with striated filaments along the entire length of the sample, ac loss was measured as a function of magnetic field and frequency at 77 K as different stabilization was added to the sample geometry. For insulated stabilization, it was found that the addition of

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copper caused the ac loss in the filamentary conductor to significantly increase, but the increase was reduced as the copper was subdivided along the length. With respect to the impact of bridges on ac loss, a collaboration with University of Houston and SuperPower has led to the introduction of virtual filament cross cuts within the YBCO coated conductor structure to assist in the reduction of ac loss. The reliable production of a defect has been demonstrated and the impact of the virtual cross cuts on ac loss and field penetration within the filament structures has been examined.

Building on our existing collaboration with NIST-Boulder, work was carried out on the fabrication of compact cables for low ac loss geometries. Utilizing as-manufactured, copper stabilized, YBCO (SCS4050) from SP, a series of compact cables were fabricated on a stranded copper former to determine the impact of the pitch length on cable performance in regards to cable critical current and transport ac loss. After taking into account the degradation of the tape performance from stranding, the cable performance did not change significantly as cables were wound onto diameters close to 4 cm.

To enhance our understanding of ac loss as YBCO coated conductors are wound into coil geometries, a facility was developed to allow for the electrical characterization of ac loss in YBCO coated conductor coils in the temperature range from 65 K to 77 K. Initial results from ac loss characterization of prototype 2G coils will be presented .

2011 Plans and Expectations:

For FY2011 the following areas will be studied:

1. Continue testing of YBCO prototype coil geometries with different turn and layer spacings to develop an engineering scale model to predict ac loss.
2. Develop and evaluate low ac loss geometries in lengths approaching 50-cm related to virtual cross-cut optimization.
3. Utilize benchmark results to splice joint fabrication methods to allow for connection of multiple, parallel coated conductor splices
4. Characterization of compact cable geometries with and without filamentary YBCO coated conductors as function of ac current and magnetic field in meter long lengths.

Technology Transfer, Collaboration, Partnerships:

This project involves collaboration across several different industrial and research organizations. With respect to wire manufacturers, discussion on the results and impact of the benchmarking study were held with both AMSC and SuperPower. Collaborations with University of Houston and Florida State University as well as the University of Tennessee Space Institute allowed for the fabrication and characterization of filamentary YBCO coated conductor geometries. Partnerships with NIST-Boulder and Los Alamos leveraged their facilities and expertise in the areas of mechanical strength and understanding the impact of conductor architecture on ac losses and splices in background magnetic fields. Our partnership with Waukesha Electric Systems has led to better understanding of ac loss in YBCO coil geometries as well as the ability to characterize these losses as a function of temperature. Results have been communicated to peers working in the DOE SPE projects and as invited papers and presentations at the 14th US-Japan Workshop on Advanced Superconductors, the 2010 Workshop on High Temperature Superconducting Wire, and the 2010 Applied Superconductivity Conference.