Project Title:	AC Loss Studies in HTS Conductors
Organization(s):	**Brookhaven National Laboratory, Los Alamos National Laboratory**
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FY 2003 Funding:	$200 K at LANL and $100 K at BNL

Project Purpose and Objectives FY2002: This project aimed to study aspects of the ac losses of BSCCO tapes and YBCO coated conductors.

Specifically, we aimed to;

a. Elucidate the mechanism for '2 phase' losses in BSCCO tape power cable short test sections
b. Determine if this loss mechanism affected all loss measurements in short sections and if so how to minimize its impact.
c. Test the applicability of theories for ac losses in YBCO coated conductors in perpendicular fields.
d. Carry out measurements on coated conductor from various sources in ac fields and carrying ac transport currents.

FY2003 Performance and FY2004 Plans: In 2003 we made substantive progress on all the objectives. The mechanism of '2 phase' loss was explained, theoretically and by experiment. We also determined that this mechanism will always be present in multi-phase short cable tests. A technique for mitigating the effect was also investigated. Comparison of ac loss measurements and theory for 'nearly ideal' films showed that good prediction of losses due to perpendicular magnetic fields requires the inclusion of the decrease of J_C with applied field.

In addition we initiated an inter-laboratory (BNL, LANL, NREL) collaboration on cryo-stabilization of coated conductors.

It now appears that a significant application for BSCCO 2223 tape will be in the 20- 40K temperature regime at moderate magnetic fields (perhaps to 4T). There is little ac loss data available in this regime – we plan to remedy this deficit over the next year.

For example;

- Measure ac losses in state of the art BSCCO 2223 tapes in the 20-40K temperature regime. These measurements will for example cover losses in dc background fields plus ac ripple fields. These data are pertinent to a number of machine designs now underway.
- From the above data assemble predictive equations for the losses in this temperature range to aid in machine design.
- Determine conductor temperature rises for BSCCO 2223 tapes in the 20 - 40K temperature regime exposed to large fluctuations in applied field when carrying dc currents (ie 1T increase in 1second). This is pertinent to the fault behavior of the conductor.

Studies of ac losses in coated conductor will continue at liquid nitrogen temperatures, this will encompass;

- Measurement of losses on various samples with ac transport currents and ac magnetic fields. The aim being data generation for prospective design studies.
- Measurement of losses with fields at various angles to the conductor, with the aim of determining the effect of ab plane and c- axis 'peaks' in I_C.
- Measurement of the effect of conductor interaction (stacks, arrays) on ac losses.

Additionally, in the coming year we intend to continue the newly initiated collaboration on cryo-stabilization of coated conductors under ac conditions. This will become increasingly important as the I_C of the available conductor increases.

FY2003 Results:

AC Losses in Cables and BSCCO tapes:

Previously we have reported the ac losses on short (1m) cable sections constructed of multiple layers of BSCCO tapes. We reported that the losses increased significantly when the cable was in a '3 phase' configuration compared to the single phase. This was not unexpected given results we reported on the losses of isolated BSCCO tapes carrying ac transport currents in applied ac magnetic fields.

What was unexpected was the losses generated in cables in the '2 phase' configuration (i.e. when the cable is not carrying current but is near to another energized cable). There was previously no known mechanism for these losses.

Since there was a possibility of this surprisingly large enhancement being an artifact of the short cable (~ 1 m) tests and also that short cable tests in 3 phase configuration may have am element of this unknown loss mechanism perturbing the data, we investigated possible mechanisms.

Tests on loops of BSCCO tapes in applied fields indicate that large currents could be circulating due to unbalanced emf's, we present data on these tests showing the enhanced losses. Since the losses in the loops were significantly greater (~ 5 – 10 times) than those in the single tapes, these results suggested that the observed enhanced losses in the three-phase cables are likely due to circulating currents around the loop of Bi2223/Ag tapes. Theoretical studies of the losses in the tapes and the loops were also carried out by John R. Clem at Ames Laboratory.

These tests suggested that the enhanced losses in cables were due to the short cables having a non-integer number of winding pitches and that short cable measurements will always be affected by this loss mechanism.

YBCO Coated Conductor Studies

One of the main concerns in the applications of these conductors to utility devices is the level of ac losses from the conductors in operating conditions. Particularly, the perpendicular component of applied fields dominates the losses in superconductors which are highly anisotropic in geometry such as the YBCO coated conductors. Fortunately, a number of excellent theoretical studies on the subject have been available over the years. Thus, in this year, we have focused our investigation at BNL on testing the applicability of these theories using nearly ideal YBCO films, i.e., the films on single crystalline substrates. Also, one can see how defects in the films manifest in the loss characteristics.

A) We have measured the losses from the films which were made by the so-called BaF_2 process at BNL and by a pulsed laser deposition process at LANL by Steve Foltyn. These were all deposited on $SrTiO_3$ and the diameters were made to be 5.3 mm. The thickness of the films was 1.0 μm for the BNL film and 0.2, 0.5, 1.0 and 3.0 μm for the LANL films. The losses were made in liquid N_2 by a magnetic technique and at 10 – 30 Hz and the field amplitudes of ~ 0. 2 T.

The following conclusions were drawn from the above measurements.

1) The theory, which included the magnetic field dependence of $J_c(B)$, the Kim model, could predict the losses for the entire field range of the measurements. When the Bean model was used for $J_c(B)$ in the theory, it could predict the losses only for the low fields, well below the full penetration field.
2) The measurements of the losses for the films with different thickness revealed that the low field losses are determined by $1/(J_c\ d)^2$ in thin films, (as predicted by the theories), rather than $1/J_c$ for bulk where d is the thickness of the film.
3) The films, which contained defects, exhibited the peak value of the normalized losses, $[Q(B)/(\pi B^2/\mu_0)](3\pi d/8R)$, less than 0.24. This can be used as a test for the uniformity of the film.

B) We also developed a new method of ac loss measurements of thin circular films with J. R. Clem, Ames Laboratory who developed an expression for the losses measured by a circular single turn pick-up coil surrounding a superconducting film. We have experimentally shown that the radius of the coil has to be greater than ~ 3 times that of the film to give the correct values of the losses.

Research Integration: This project is centered around a highly collaborative measurement effort between BNL and LANL. Coated conductor measurement samples are obtained as part of informal and formal agreements from most of the sources within the US producing material. This includes IGC-Superpower, American Superconductor and LANL. Test conditions are selected in response to industry requirements. We are also fortunate in that John Clem, Ames Laboratory has provided significant theoretical input to this project. Collaboration with Japanese researchers on techniques for ac loss measurements (under a US-Japan agreement) has also yielded useful information.