IEEE/CSC & ESAS European Superconductivity News Forum (ESNF), No. 7, January 2009
Extended Abstract of Presentation 3F.12 at CCA08, Houston, TX, December 4-6, 2008

Impact of coated conductor architecture on conductor stability and ac loss for power applications

Robert Duckworth, Yifei Zhang, and Fred List
Oak Ridge National Laboratory

***Abstract*— Conductor stability and ac loss are two interrelated operational issues that can complicate the introduction of coated conductors into high temperature superconducting applications. With respect to conductor architecture, conductor stability and ac loss are currently being explored in as-manufactured coated conductors as well as prototype conductor geometries. In as-manufactured coated conductors, materials that are used for stabilization have been shown to influence conductor stability at either steady state and/or transient operating conditions. Stabilization can be utilized to either limit faults and suppress temperature rise, but the thickness and material properties can impact the ac loss on a single tape basis and more importantly when multiple conductors are integrated into a given device geometry. In prototype conductor geometries, different methods are being pursued to produce filamentary conductors that reduce ac loss. Processes that lead to low ac loss could compromise conductor stability due to the lack of current sharing between filaments. To improve the viability of low ac loss geometries, conductor stability needs to be part of the evaluation for a given conductor architecture and this evaluation needs to occur in both long length tapes and in prototype devices.**

I. Introduction

Due to its good in-field performance, $YBa_2Cu_3O_x$ (YBCO) coated conductors have expanded the possible uses of high temperature superconducting (HTS) power applications that operate at liquid nitrogen temperatures. While the properties of as-manufactured YBCO are acceptable for HTS cables [1-2], further work is needed to enable other applications such as transformers, superconducting magnet energy storage, and compact power generation to increase penetration of HTS devices into the power market. The unique YBCO conductor geometry influences conductor stability and ac loss, which can have an impact on the integration of YBCO into different application geometries. Most work in this area has been addressed at these issues separately.

With respect to conductor stability, stabilization of YBCO coated conductors is essential due to the high n-value ($n \approx 30$-40) that triggers a rapid transition into the resistive state. While the maximum temperature that an individual YBCO coated conductor can withstand is between 500 K and 900 K, several groups have found the addition of copper stabilization improves the maximum fault current before degradation occurred [3-5]. In addition to copper, stainless steel stabilization has been used in fault current limiting applications to increase the resistivity of the material and take advantage of the rapid transition of YBCO.

As conductor performance in YBCO started to exceed 200 A/cm-width, it was clear that the ac loss in perpendicular applied ac fields was greater than 1 W/m at fields greater than 100 mT. To reduce these ac losses, filamentization of the YBCO coated conductor is an option. Filamentized YBCO has been produced through the use of lasers [6], chemical lithography [4], or through direct inkjet printing [7]. All of these techniques also separate the stabilization of the filaments to prevent direct electrical connection between filaments that may lead to higher coupling losses.

When the conductor is stacked in multiple conductors, the loss is affected by spacing between the conductors in low fields. Amemiya [8-9] found that in stacks of conductors the ac loss per unit volume decreases in applied ac fields. There is very little difference between the volumetric ac loss of the tape stack and the single tape when transport current is also applied.

As the coated conductor geometry is adjusted to reduce ac loss, conductor stability needs to be considered, i.e. how conductor stability is impacted when ac loss geometries are introduced. This systematic study should be done on long-length samples as well as prototype devices to determine effectiveness of different conductor geometries.

II. Conductor stablity in low ac loss geometries

In low ac loss filamentary geometries, the lack of electrical connection could have implication on conductor stability when defects or areas of low-critical current appear within a filament. When transients are applied to a system with a filamentary conductor, current is transferred to the stabilization immediately above the filament. To date, the majority of investigation has been done on a theoretical basis as sufficient length of low ac loss conductor has limited experimental study [10-11]

Preliminary study of the effect of filamentization was conducted on low ac loss YBCO conductors from SuperPower that had seven filaments in a 4-mm wide tape with a superconducting bridge as shown in Fig. 1. In these tapes that only had a 3 μm of silver above the YBCO, the conductor stability at constant current for the low ac loss geometry showed a near instantaneous runaway and was not recoverable. When the low ac loss geometry was inspected damage was across all the filaments and not in a localized section.

Fig. 2 shows the ac loss as a function of field for the low ac loss geometry in Fig. 1 with and without superconducting bridges. While it is too early to determine whether superconducting bridges have any conductor stability benefit, Fig. 2 suggests that the bridges may be a compromise if a tangible benefit can be proven from a conductor stability standpoint.

An alternative conductor geometry is to have filamentized YBCO coated conductors with a continuous stabilization and a barrier material between the stabilizer and filaments as shown in Fig. 3. Through manipulation of the post-oxygen annealing conditions at temperatures between 200 °C and 450 °C, it has been shown that the interface resistance could serve as a barrier to reduce coupling loss [12]. When conductor stability was examined on 1-cm wide Ag-coated YBCO conductors that were annealed at the same conditions, there was a significant drop of the maximum impulse current possible when the sample was annealed at 200 °C as shown in Fig. 4. While the use of this concept over long lengths is a challenge, it might be possible to integrate either superconducting and/or resistive bridges to cut down on possible coupling losses.

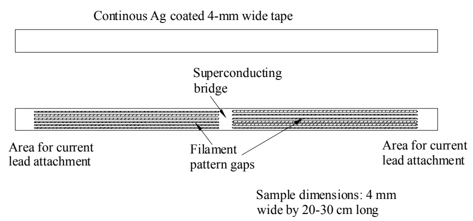

Fig. 1. Comparison of Ag-coated YBCO low ac loss geometry with filaments and bridges to as-manufactured Ag-coated YBCO conductor.

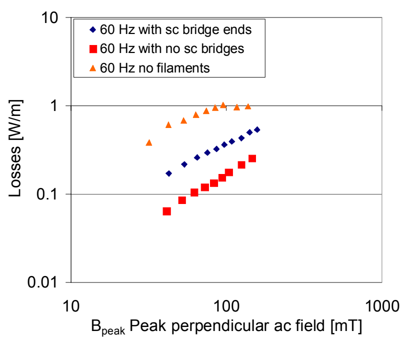

Fig. 2. Comparison of ac loss as a function of field in Ag-coated YBCO low ac loss geometry with and without superconducting bridges to as-manufactured Ag-coated YBCO conductor.

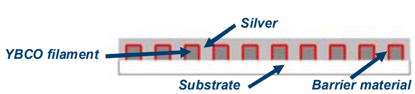

Fig. 3. Schematic of filamentized YBCO with continuous Ag stabilization and a barrier resistance between the filaments and the Ag.

III. Conductor Stability in Assembled Geometries

When YBCO coated conductors are placed in stacks, the interaction between individual conductors can play a key role in the ac loss and conductor stability. As previously discussed, the impact of conductor spacing plays a role at high fields, but when transport current is also applied the losses between the tapes on a per volume basis are similar.

With respect to conductor stability there are some issues to consider. The results that are mentioned above are for tapes with an insulated separation. If tapes are connected together electrically it may have impact on the ac loss due to circulating currents. Circulating current could also become an issue with respect to current distribution during operation and during a fault. Periodically tapes would have to be transposed to equalize the current distribution. Transposition in as-manufactured YBCO is currently difficult unless a Roebel conductor geometry is used [13].

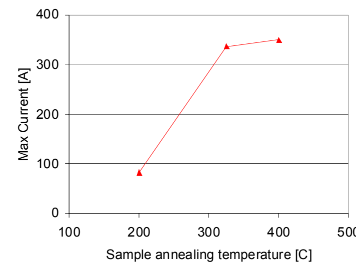

Fig. 4. Impact of maximum applied current under recovery for a set of Ag-coated YBCO conductors that were oxygen annealed at different temperatures.

IV. Discussion

Conductor stability and ac loss are two issues that need be considered jointly in order to have an optimal solution that is useful for the end user. While there are some benefits to doing short length conductor or tape research on different concepts, sub-scale prototype devices are required to address all performance issues. The challenge that this presents is that the wire manufacturers are currently geared to scale-up production, which makes new prototype conductor designs hard to fabricate in long lengths. Solutions ultimately need to be able to translate to manufacturing operations, which requires them to be low-cost and to be able to be integrated within existing structures. There is also a certain amount of flexibility that needs to be built into the processing of low ac loss geometries so that the manufacturers can readily meet demands of given applications.

Acknowledgment

The authors would like to thank the invaluable contributions of American Superconductor and Superpower as well as the support by the U.S. Department of Energy, Office of Electricity Delivery and Energy Reliability, Superconductivity Program for Electric Power Systems under contract DE-AC05-00OR22725 with Oak Ridge National Laboratory, managed and operated by UT-Battelle, LLC.

References

[1] Masuda T, et.al., *Physica C*, vol. 468, p. 2014, 2008.
[2] Maguire J, et.al., *IEEE Trans. Appl. Supercond.* 2008, submitted for publication.
[3] Iwasa Y, et.al.., *IEEE Trans. Appl. Supercond.*, vol. 15 p. 1683, 2005
[4] Selvamanickam V, et.al, *IEEE Trans. Appl. Supercond.,* vol. 15, p. 2596, 2005.
[5] Kim H M, et.al., *IEEE Trans. Appl. Supercond.*, vol. 14, p. 1290, 2004.
[6] Sumption M D, et.al., *Supercond. Sci. Tech.,* vol. 18, p. 122, 2005.
[7] List F.A., et.al., *IEEE Trans. Appl. Supercond.,* vol. 17, p. 3355, 2007.
[8] Jiang Z., et.al., *IEEE Trans. Appl. Supercond.,* vol. 17, p. 2442, 2007.
[9] Jiang Z., et.al., *Supercond. Sci. Tech.,* vol. 21, p. 015020, 2008.
[10] Levin G.A.,et.al., *IEEE Trans. Appl. Supercond.*, vol. 15, p. 2158, 2005.
[11] Levin G.A., et.al, *J. Appl. Phys.,* vol. 98, pp. 113909, 2005.
[12] Duckworth, R.C., *IEEE Trans. Appl. Supercond.* 2008, submitted for publication...
[13] Goldacker, W. *IEEE Trans. Appl. Supercond.,* vol. 17, p.3398, 2007.