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Influence of Proton Irradiation on Angular Dependence of Second Generation (2G) HTS

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INFLUENCE OF PROTON IRRADIATION ON ANGULAR DEPENDENCE OF SECOND GENERATION (2G) HTS*

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Abstract

In the Facility for Rare Isotope Beams (FRIB) the quadrupoles in the fragment separator are exposed to very high radiation and heat loads. High Temperature Superconductors (HTS) are a good candidate for these magnets because they can be used at ~30-50 K and tolerate higher heat generation than Nb-Ti magnets. Radiation damage studies of HTS wires are crucial to ensure that they will survive in a high radiation environment. HTS wires from two vendors were studied. Samples of 2G HTS wires from SuperPower and American Superconductor (ASC) were irradiated with a 42 μA, 142 MeV proton beam from the Brookhaven Linac Isotope Producer (BLIP). The angular dependence of the critical current was measured in magnetic fields at 77K.

BACKGROUND

This paper describes a radiation damage study of the superconductor that will be exposed to a high level of radiation in the magnets for the Facility for Rare Isotope Beams (FRIB) [1]. A 400 kW beam will hit the production target to produce a copious amount of various rare isotopes, one of which is selected in the fragment separator. Quadrupoles in the fragment separator are exposed to an unprecedented level of radiation (~20 MGy/year) and heat loads (~10 kW/m or 15 kW in the first quadrupole itself). High Temperature Superconductors are a good candidate for FRIB because they can be used at ~30-50 K and tolerate higher heat generation than Ni-Ti magnets [2-4]. It also has to tolerate field of 2 – 3T. In order to assure that the HTS will survive FRIB environment, radiation damage studies are crucial.

The magnet is being built using conductor from two vendors to demonstrate the feasibility of HTS in FRIB magnets [5]. The vendors are SuperPower and American Superconductor. Several samples of YBCO from SuperPower and American Superconductor (ASC) were irradiated with a 42 μA, 142 MeV proton beam from the Brookhaven Linac Isotope Producer (BLIP). 7cm long 4mm wide samples were mounted on five aluminium frames and inserted into the water-filled target tank of BLIP. Five different levels of fluence were achieved by progressively removing the aluminium frames after specific times to give 2.5, 25, 50, 75 and 100 μ A-hr (10^{16}, 10^{17}, 2 x 10^{17}, 3 x 10^{17} and 4 x 10^{17} protons/cm^2, respectively). 10^{17} protons/cm^2 (25 μA-hrs integrated dose) is equivalent to over 10 years of FRIB operation [6]. In a previous study, critical currents of irradiated 4mm wide YBCO conductors at self-field were measured as shown in Figure 1 [1]. The critical current before irradiation was ~100A. I_c decreases monotonically as dose level increases. Self-field measurements of YBCO from both vendors did not show much difference in critical current I_c.

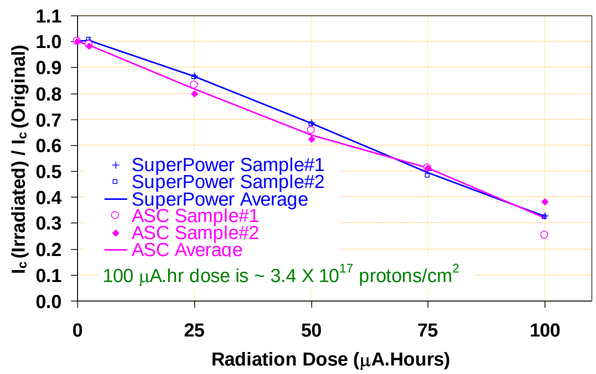

Figure 1 Normalized critical current versus radiation for self-field.

The purpose of this study is to determine the radiation damage as a function of field angle and field strength.

EXPERIMENT

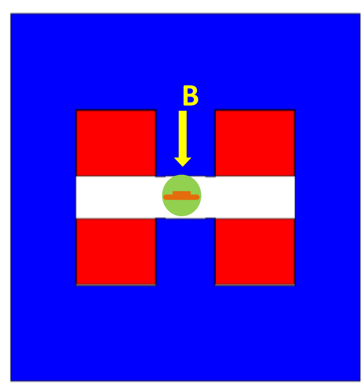

Figure 2: Top view of the magnet and sample holder. Field angle zero is defined as perpendicular to the tape surface.

The samples were stored over a year after the irradiation to reduce radioactivity. Ex-situ measurements were conducted in an open cryostat with a resistive

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magnet. Figure 2 shows the schematic of magnet and sample space from the top. Zero angle is defined as magnetic field perpendicular to the tape surface, as shown. The sample stick was inserted into the magnet and the dewar filled with liquid nitrogen (LN_2). Temperatures were measured by diodes at the top and bottom of the magnet to ensure samples are always remain at 77K. Critical current (I_c) was measured in three adjacent 10mm sections of each sample. The middle section B is positioned to be at the center of the beam as shown in Figure 3. The middle section "B" has uniformity of ~±7% in exposure. The variation of the exposure on the two sides is larger, ~±40%. A photograph of the sample holder is shown in Figure 4. The sample is under the G-10 cover. Four copper strips under the G-10 cover serve as voltage taps.

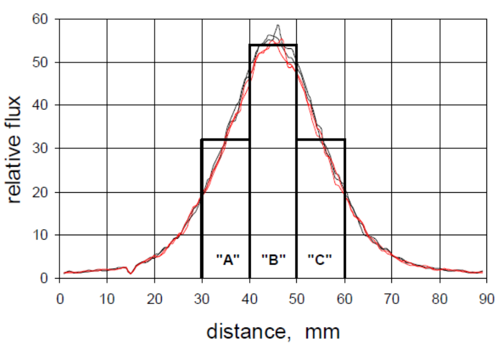

Figure 3: The position of the three 10mm segments in the beam cross section.

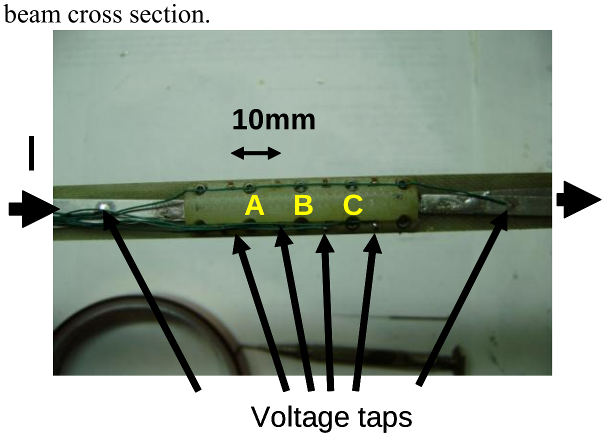

Figure 4: A photograph of a sample holder with 4mm YBCO tape and 10mm segments "A", "B" and "C" irradiated. A 4mm wide YBCO sample is placed under the G-10 cover. The position of voltage taps is shown. The direction of current is shown as left to right arrow.

RESULT

This section will describe the results of measurements of critical current as a function of field and field angle at different level of radiation dose. Firstly, the critical currents versus angle for different positions at 0.5 T are shown. Figure 5 corresponds to a dose level of 2.5 μA-hr and Figure 6 corresponds to a dose level of 100 μA-hr. The samples in these figures were from SuperPower. Although the critical currents are almost the same at A, B and C for the low dose sample in Figure 5, the critical current at position B (beam center sections) is more suppressed compared with the position A and C (side sections) for a high dose sample in Figure 6. This reflects lower dose level at side sections compared with the beam center section B. Samples from ASC also behaved similarly. This indicates uniformity of irradiation at beam center. So, in the following figures, only a critical current at section B (beam center) are shown.

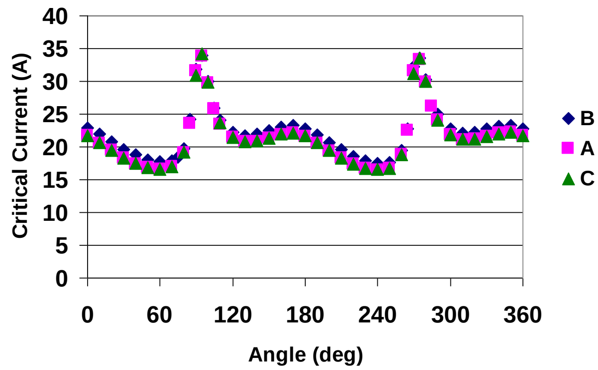

Figure 5: Critical Current at different sections at the same magnetic field (0.5 T) at a low dose level (2.5μA-hr) for SuperPower samples.

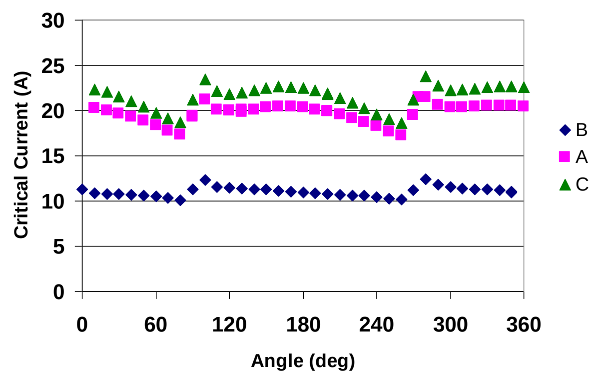

Figure 6: Critical current at three different sections at 0.5T at a high dose level (100 μA-hr) for SuperPower samples

The critical current versus angle for various dose levels of samples at the center section B in a field of 1 T are shown in Figure 7 (SuperPower) and Figure 8 (ASC). Although both samples originally had a strong angular dependence, these features were wiped out as the dose level increased. At 100 μA-hr, the critical current was greatly suppressed in both samples. These suppressions are confirmed at 0.25T, 0.5T, 0.75T, 1T and 1.25T for both SuperPower and ASC samples. Surprisingly, the critical current of 25 μA-hr sample is higher than at 2.5 μA-hr sample. This happens only under magnetic fields. The enhancement is clearer in SuperPower samples than ASC.

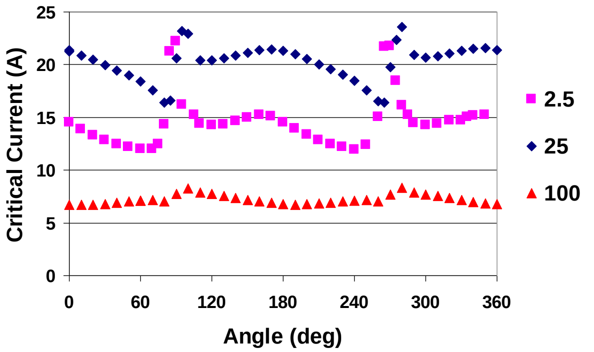

Figure 7: Critical current versus angle for YBCO from SuperPower at 1.0T, 77K

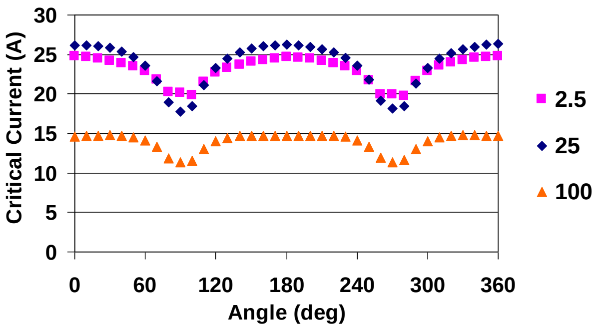

Figure 8: Critical current versus angle for YBCO from ASC at 1.0T, 77K

As a summary, the ratios of the Ic's at zero field angle before and after irradiation as a function of field strength are shown in Figures 9 and 10. The enhancement at 25 µA-hr can be seen at higher magnetic field. However, in general, I_c decreases as magnetic field increases for any dose level.

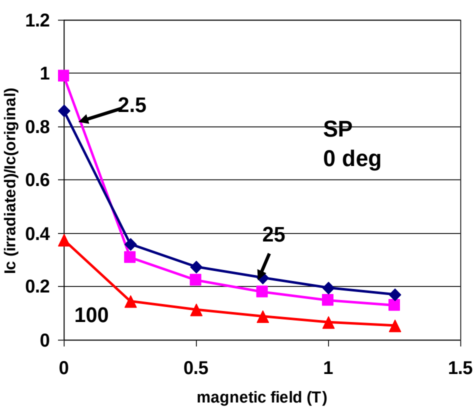

Figure 9: Normalized critical current versus magnetic field at zero degree position for SuperPower sample.

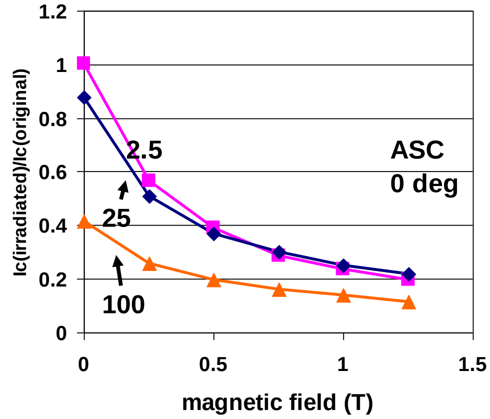

Figure 10: Normalized critical current versus magnetic field at zero degree position for ASC samples.

CONCLUSION

Measurement at 77K in 1 T applied field indicates that if the similar degradation is observed at ~ 40K and ~ 2T then YBCO from both SuperPower and ASC is acceptable for FRIB for 10 years, as required.

However, further investigation at lower temperatures down to 40K and higher magnetic fields above 2T will be carried out in the near future. These measurements will be the final confirmation of radiation tolerance of YBCO for FRIB.

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