Targetry–Building Effective Beam Dumps for Electron Storage Rings
Letter of Interest for SnowMass 2021, Accelerator Frontier

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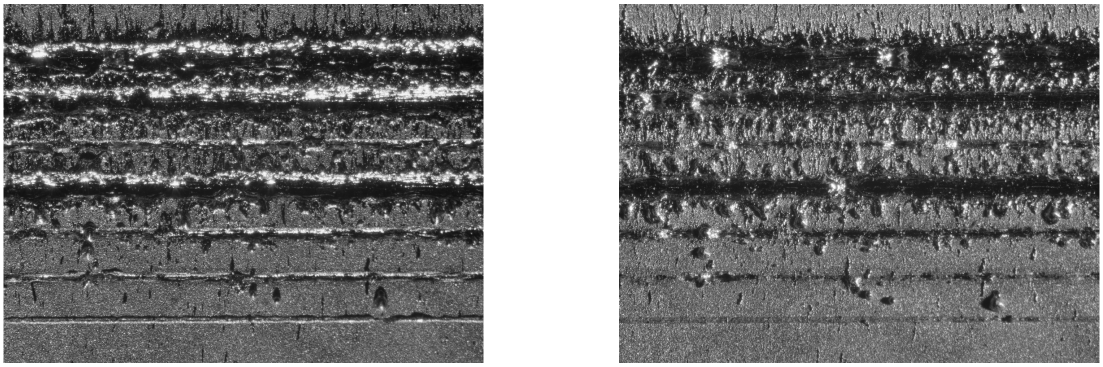
1 Introduction–Problem Statement

The push for brighter x-ray light sources also means higher energy densities in the e-beams that generate these photons. The energy densities in the Fourth Generation Storage Ring (4GSR) planned for the Advanced Photon Source Upgrade (APS-U) are expected to impart dose levels (absorbed energy per unit mass) of 30 MGy and higher on beam-facing components such as horizontal collimators during unplanned whole-beam dumps. Acute dosages of this magnitude result in complex behavior in matter including hydrodynamic and electrodynamic effects. Highly relativistic electron beams composed of short bunches carry strong, rapidly changing electromagnetic fields close to the bunch. For these reasons, the effects of high-energy density (HED) electron beams in matter is an area that requires additional attention in terms of theory, numerical analysis, and experiment. For the APS-U 4GSR, the above dose levels are attained with horizontal emittances of 30-40 pm and vertical emittances of 4-30 pm[1]. Recent discussions of a fifth-generation storage rings (5GSR) suggested emittances as low as 1 pm[2]. Energy deposition has been recognized as a concern in these discussions[3]. Energy deposition has long been a concern in hadron machines such as the LHC [4, 5, 6] and SNS [7, 8]; in the former instance, for safe beam aborts, and in the latter case, for reliable secondary particle (neutron) generation. Until now, machine protection for light source storage rings has focused on damaged that could be caused by synchrotron x-rays, not the electron beam itself.

2 Experimental Data

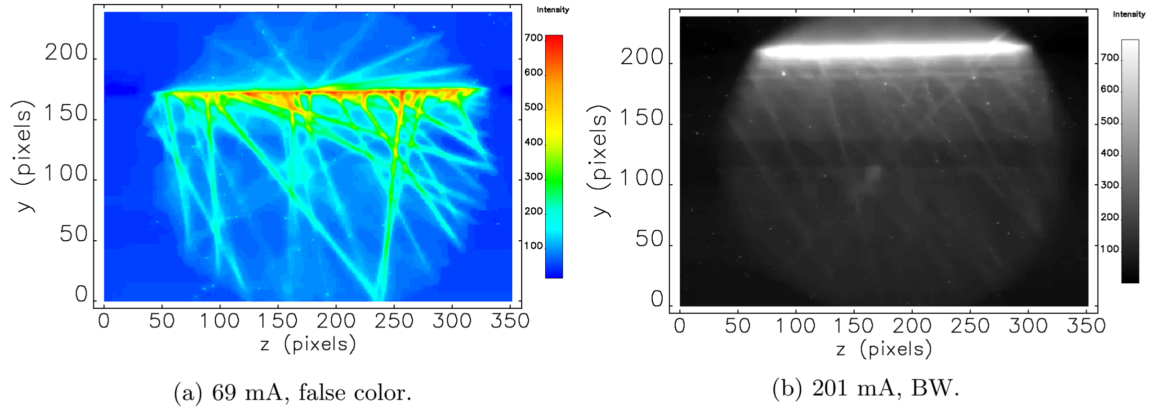
Recent experiments conducted in the APS SR replicating APS-U beam conditions showed significant damage in the regions of aluminum collimator test pieces struck during beam abort studies. Peak dosages in the collimator material were calculated to be 30 MGy (30 kJ/g). Previously, we had never observed any damage in aluminum components subject to beam dumps. Figure 1 presents two photographs of an aluminum collimator test piece exposed to beam dumps during the January 2020 experiment. The photos show the same region of the irradiated target with different lighting orientations to bring out the three-dimensional nature of the damage. Starting from the bottom of the image, beam currents were 34.6, 69.4, 99.1, 202.0, 100.0, 201.2, and 202.1 mA. The spacing



(a) Illumination bottom.

(b) Illumination right.

Figure 1: Aluminum collimator test piece exposed to beam aborts during the January 2020 collimator irradiation experiment. Starting from the bottom, beam dumps currents were 34.6, 69.4, 99.1, 202.0, 100.0, 201.2, and 202.1 mA. The nominal spacing between each case is 0.4 mm.



(a) 69 mA, false color.

(b) 201 mA, BW.

Figure 2: Irradiation Emission at 69 and 201 mA. A 0.8-mm gap between targets is visible in b.

between each beam dump event was nominally 0.4 mm. An initial beam dump of 18.1 mA (66.7 nC) in a region just below the edge of the photograph showed no observable damage. In the range of currents chosen, the material state of the collimator during a beam strike varies from one of unchanged solid to plastic deformation to energetic fluid motion.

Image data obtained during beam irradiation indicated a complex pattern of emission. The emission mechanisms likely include optical transition radiation and scintillation at low currents and blackbody radiation at high currents. Irradiation images suggest mass loss which is supported by the data in Fig. 1. Examples of irradiation emission are given in Figure 2. Emission is not only dependent on current but on surface morphology as well. Emission from subsequent beam strikes at currents above 60 mA, light emission was seen to drop dramatically. In the images presented above, beam moves from right to left, so the preponderance of ejecta ray in the upstream direction is an interesting effect. Also of interest is that during these experiments, the aluminum test targets became activated with Be-7. One method of generating Be-7 is when cosmic rays (high-energy protons) strike oxygen and nitrogen in earth's upper atmosphere. The mechanism for production of Be-7 in our Al test pieces is not clear.

3 Issues and Opportunities

We offer a list of several topics these tests have made us think about and may be of interest to a wider accelerator physics community. Note that some odd nuclides were generated in these experiments such as beryllium-7.

1. Theory of electron-beam-induced magnetohydrodynamics (MHD)
2. Electromagnetic effects including wakefields and MHD
3. Magnetic field reconnection and mass ejection
4. Numerical modeling and code integration–particle-matter, hydrodynamic, and beam dynamics including shower propagation (e.g., MARS[9], FLASH[10], and elegant[11])
5. Machine Protection Systems (MPS)–Systems and Impact, e.g., the effects of dose on HTSC materials.
6. Alternate uses of HED beams, for example targetry (high luminosity)
7. Nuclear physics

4 Summary

Pushing the envelope with ultra-high-brightness electron beams in current and planned 4GSRs and postulated 5GSRs presents both unique challenges and potential opportunities to study, control, and utilize HED matter.

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