ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-WEPRO023

PREVENTING SUPERCONDUCTING WIGGLER QUENCH DURING BEAM LOSS AT THE CANADIAN LIGHT SOURCE

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Abstract

The Canadian Light Source utilizes two superconducting wigglers for the production of hard x-rays. These superconducting wigglers often quench during beam loss, even though tracking calculations predict that the beam is lost on an aperture far from the wigglers. We present measurements that suggest the tracking simulations are correct and the electron beam indeed strikes the predicted limiting inboard aperture. By simulating the interaction of the beam with the aperture, we find that some scattered electrons can retain sufficient energy to remain inside the storage ring. The simulations show that some of these scattered electrons strike the wiggler vacuum chamber and deposit energy in the superconducting coils, causing the quench.

INTRODUCTION

The Canadian Light Source (CLS) has two superconducting wigglers installed in the storage ring. SCW2 [1] operates with a peak field of 1.9 T and SCW4 [2] operates with a peak field of 4.1 T. Both of these wigglers can quench during termination of the stored beam, causing a loss of helium and possibly damaging the devices. The stored beam is terminated by shutting down the rf system in one of several ways, depending on the type and severity of the interlock. The electron beam then begins to loose energy and spirals inboard, as the dispersion is positive everywhere. Tracking simulations suggest that the stored beam intercepts the limiting horizontal inboard aperture, which is far from the wigglers. This result suggests that the wigglers should not quench during beam loss, but they do. To resolve this discrepancy, we begin by performing measurements to observe the electron beam as it spirals inward.

OBSERVING BEAM LOSS

We observe the process of beam loss using three devices: A Libera Brilliance turn-by-turn beam position monitor (BPM), a Cherenkov detector and the intensified charge-coupled device (ICCD) camera on the optical synchrotron radiation (OSR) diagnostic beamline [3]. The data for the BPM and the Cherenkov detector are shown in Figure 1. The images obtained with the ICCD are shown in Figure 2. The vertical black lines in Figure 1 correspond to the camera trigger delays used to obtain the images in Figure 2. The BPM data and ICCD data were both obtained on the same day, 2013-04-24, whereas the Cherenkov data was obtained later, on 2013-08-06.

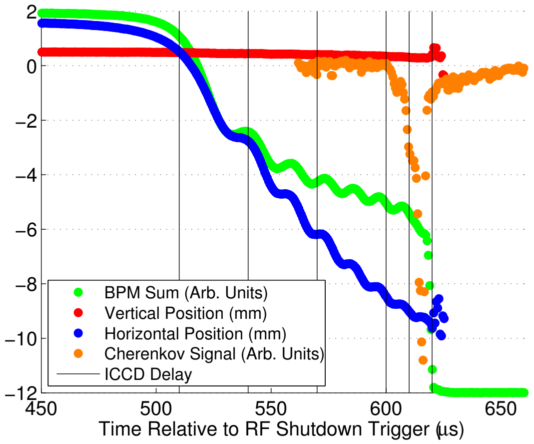

Figure 1: The Libera Brilliance turn-by-turn BPM and Cherenkov detector data showing a 175 mA beam spiraling inward and being lost. The vertical black lines show the delays used for the ICCD camera, who's images are shown in Figure 2.

The BPM data of Figure 1 shows the beam centroid spiraling inward. This data is the raw data returned by the BPM unit and we have not attempted to correct for the non-linear behavior at large amplitudes; as such the beam falsely appears to be lost at a horizontal position of −9 mm, whereas the limiting inboard aperture is at −18 mm. We have also not corrected an initial horizontal offset of about 1.5 mm, the origin of which is not fully understood. The BPM sum does begin to drop as the beam begins to spiral inward, but this is simply the response of the BPM unit and does not correspond to losing electrons. The Cherenkov detector, which was placed at a location near a limiting inboard aperture, does not see any lost electrons until the BPM sum makes a sharp transition to zero. There is no apparent vertical motion of the beam centroid.

While the BPM measurements show that the beam centroid spirals inward, it is possible that the beam undergoes more complex motion. We use the ICCD camera images, shown in Figure 2, to demonstrate that the beam does not undergo any disorderly behavior as it is lost.

These measurements support the tracking simulations, which indicate that the beam spirals inward and is lost on a limiting inboard aperture, far from the wigglers. Building a model where the beam is lost near the wigglers and agrees with these measurements requires distortions that are highly unlikely.

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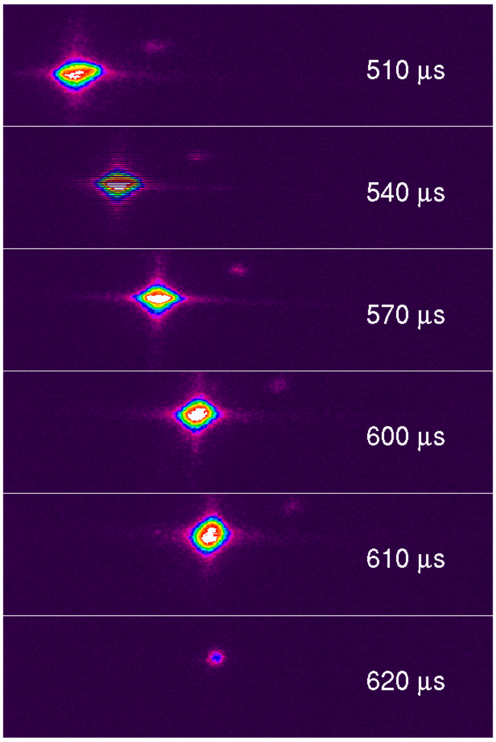

Figure 2: Images taken with the ICCD camera on the OSR bending-magnet diagnostic beamline with outboard being left and inboard being right. Each image used an exposure time of 570 ns and represents each electron passing the OSR source point once and only once. The trigger delays are shown in white text and are also marked with black vertical lines in Figure 1. The beam moves inboard as it loses energy. We overexposed the camera in order to look for flairs indicating disorderly behavior, such as the influence of a resonance, but none is observed. The cross seen in each frame is due to diffraction effects and the spot above and to the right of the beam is believed to be a reflection of unknown origin.

APERTURES

We now consider the size and location of important apertures. The CLS storage ring is built on a 12-fold symmetry with 12 straight sections, 9 of which are reserved for insertion devices. SCW4 and SCW2 are located in straights 5 and 6 respectively. There are two candidates for the limiting inboard aperture. A vacuum chamber in straight 11 has an ideal inboard limit of -18 mm and the photon absorber upstream of the injection septum has an ideal inboard limit of -18.7 mm. It is not clear which of these location the beam will strike first due to the possibility of misalignments, variations in dispersion and the complication that the beam is chicaned outboard 1.25 mrad in straight 11 in order to accommodate two insertion devices. The profiles of these apertures, along with the aperture upstream of the superconducting wigglers, are shown in Figure 3.

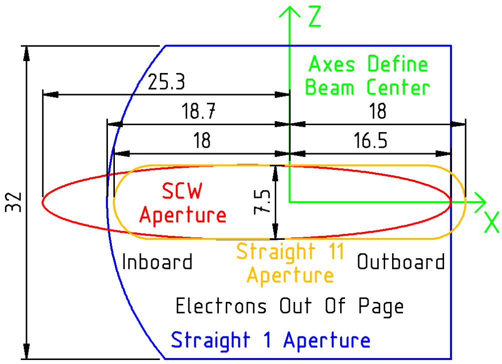

Figure 3: Profile of the physical aperture upstream of the superconducting wigglers (the same for SCW2 and SCW4) compared with two candidates for the limiting inboard aperture.

In order to ensure radiation levels remain at acceptable levels, CLS employs active area radiation monitors (AARMs) at several locations around the storage ring. During a beam loss event, the AARMs see a spike in radiation. In Figure 4 we show the relative amount of radiation detected under several configurations.

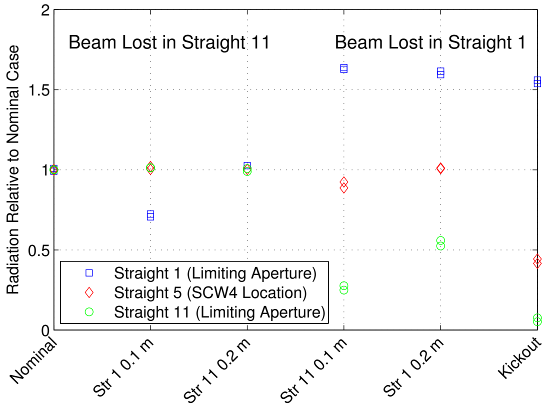

Figure 4: The radiation detected by three AARMs downstream of the apertures shown in Figure 3. The measurement was performed for the nominal configuration, four configurations with modified dispersion, and one using the injection kickers set at 1.7× their normal amplitude, to kick the beam into the absorber in straight 1 (‘Kickout’). Each measurement was done twice to demonstrate repeatability.

The ‘Nominal’ data is for a trip with the nominal storage ring configuration, which was used for the data in Figures 1 and 2. The configuration with label ‘Str 1 0.1 m’ changes the dispersion in straight 1 to 0.10 m from the nominal 0.15 m, while leaving the dispersion in other straights unchanged. Likewise, the data with label ‘Str 11 0.2 m’ changes the dispersion in straight 11 to 0.20 m. These modified configurations favor losing the beam in straight 11. Likewise, labels ‘Str 11 0.1 m’ and ‘Str 1 0.2 m’ change the dispersion in those straights to favor losing the beam in straight 1. We also use the injection kickers at 1.7× their normal amplitude to kick the beam into the limiting aperture in straight 1 and label this configuration 'Kickout'.

From Figure 4 we see that the beam is lost in straight 11 under normal circumstances. By favoring straight 1 we can make it be lost in that straight. Even though the beam strikes an absorber in straights 11 or 1, we still detect radiation downstream of the wiggler in straight 5. The radiation detected downstream of SCW4 does not change, regardless of how we may alter the dispersion.

The only configuration which reduced the radiation near SCW4 is 'Kickout'. Indeed, we now use this scheme during normal operations to prevent the wigglers from quenching for most types of rf interlocks. Unfortunately, this scheme does not work for cases where the beam is lost before the kickers can be triggered, which includes interlocks due to superconducting rf cavity quenches, the personnel safety system or magnet power supply faults.

SIMULATING BEAM LOSS

We can now use this information to improve our simulations and propose a mechanism for the beam to deposit energy in the superconducting wiggler coils even though the beam is lost on the other side of the storage ring.

We use the charged particle tracking code elegant [4] to track the electron beam as it spirals inward. If we include the non-linear response of the BPM at large amplitudes and make a few reasonable approximations, we find good quantitative agreement with the BPM data in Figure 1.

We import the results of the tracking with elegant into Geant4 [5] to simulate the interaction of the beam with the physical absorber. Geant4 is a program that simulates the interaction of particles with matter. It is a Monte Carlo simulation that uses the knowledge of cross sections in order to generate a possible event. This Geant4 simulation outputs the phase space coordinates of electrons which are scattered by the aperture and we import these into a second elegant simulation.

We use elegant to transport the scattered electrons around the storage ring and we find that some of them strike the photon absorbers upstream of the superconducting wigglers.

We import these electrons into a second Geant4 simulation, which models the geometry of SCW2. An example strike is shown in Figure 5. Electrons strikes the photon absorber upstream of SCW2 and deposits energy in various elements of the geometry, including the superconducting coils of the wiggler.

CONTINUING WORK

There remains much work to make the qualitative results of the simulations quantitative. We must validate the Geant4 simulation of the beam interacting with the initial aperture and estimate how many electrons could remain within the storage ring. At the moment, the simulation under estimates the amount of energy deposited in the wiggler coils.

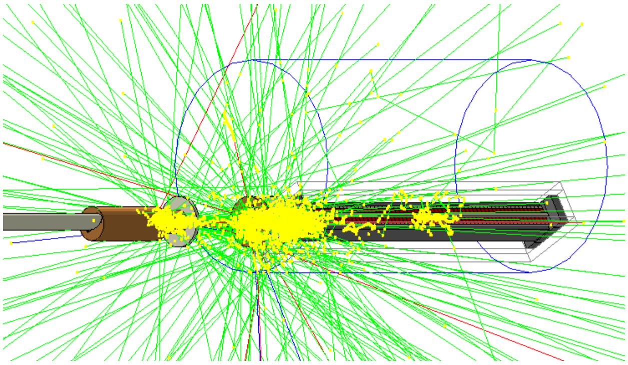

Figure 5: Geant4 simulation showing the progeny particles produced by a single electron striking the photon absorber upstream of SCW2. The vacuum chamber and photon absorber are at the left of the image. The blue cylinder is the liquid helium bath and the magnet yoke and superconducting coils are contained inside. Negatively charged particles are red, positively charged particles are blue and neutral particles are green. The yellow areas show where energy is deposited.

We are using the kickout scheme to prevent quenches, but we are not able to trigger the kickers before beam loss in all situations. We plan on restoring an inboard scraper, which had a manufacturing defect and was removed, and add more scrapers when we replace some vacuum chambers. We plan to use two inboard scrapers, one to intercept the beam as it spirals inboard and a second to intercept the scattered electrons as they undergo betatron motion, in order to implement a passive system for preventing superconducting wiggler quenches.

ACKNOWLEDGMENT

The CLS is supported by CFI, NSERC, NRC, CIHR, the Province of Saskatchewan, WD, and the University of Saskatchewan.

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