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UPGRADES TO THE BOOSTER TO STORAGE RING TRANSFER LINE AT THE CANADIAN LIGHT SOURCE

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Abstract

Investigations into the booster to storage ring transfer process identified non-linear fields in the booster extraction septum as the cause for the poor transfer efficiency. We found that by correcting the trajectory through the septum, the transfer efficiency improved substantially. This motivated an upgrade project to reliably control the trajectory through the septum and transfer line, to provide improved diagnostics and to implement a set of four horizontal scrapers to reduce the horizontal emittance of the beam before it reaches the storage ring.

INTRODUCTION

The Canadian Light Source (CLS) booster ring to storage ring transfer process did not work as efficiently as desired. We define the total injection efficiency to be the total fraction of electrons that are present in the booster ring at extraction time and are then captured in the storage ring, and simulations predict that it should be > 90%. The actual total injection efficiency with no insertion devices was typically < 70%. Studies of the booster ring conducted as part of the 2017 recommissioning [1] gave no suggestion of the cause.

In 2019 we turned our attention to the booster to storage ring (BTS) transfer line. During a machine studies shift, we turned off all the quadrupoles downstream of the booster extraction septum. We viewed the beam on a phosphor screen 9.2 m downstream of the septum. Turning off the quadrupoles allowed the beam to drift and expand, and we show the results in Fig. 1. The synchrotron light monitor located on the booster ring showed a well behaved beam before extraction, as in Fig. 6 of [1], which suggested that the extraction septum may be the cause of the low efficiency. By ramping a vertical booster orbit corrector magnet, we were able to improve the beam trajectory through the septum and the distortion seen in Fig. 1 nearly disappeared. The distortion was being caused by non-linear fields in the septum. After further optimization, we achieved a total injection efficiency of 87% with no insertion devices.

Based on these observations, we created the BTS upgrade project.

BEAM TRAJECTORY

We could improve the total injection efficiency by ramping one or more booster orbit correction magnets, but doing so reliably required a diagnostics upgrade. There was only DC

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Figure 1: Pre-upgrade beam viewed on a phosphor screen after drifting 9.2 m from the booster extraction septum.

feedback from the corrector magnet power supplies, so we implemented a ramp monitoring system by digitizing the outputted ramp, as shown in Fig. 2. The red 'Feedback' waveform represents the digitized ramp feedback, the blue 'Setpoint' waveform is the setpoint sent to the power supply and the yellow 'Saved Reference' is a known good feedback that we have saved for comparison. Figure 2 shows one complete ramp on the control system graphical interface. The ramp takes 1 second, where injection occurs at zero and extraction occurs at the peak of the ramp.

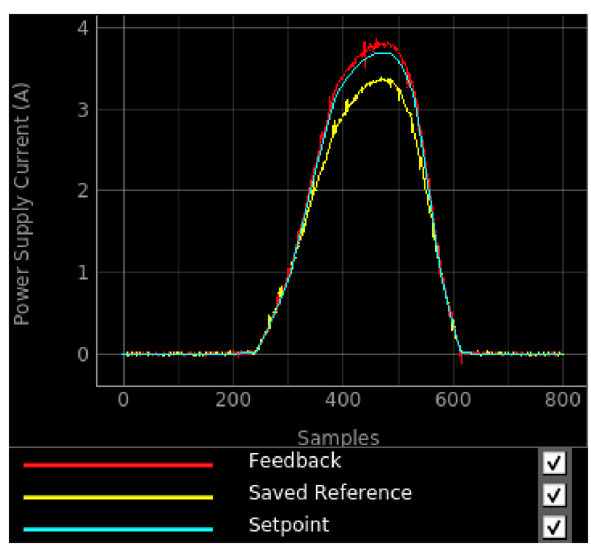

Figure 2: Demonstration of ramp monitoring for a booster ring vertical orbit corrector magnet with the setpoint artificially increased to show separation between the three lines.

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We compare the feedback against the saved reference and the setpoint, and generate an alarm for the operators if the difference crosses a threshold. This system was crucial for establishing reliable booster operation with ramping correctors as we encountered transient faults in a trigger system component.

We also considered the beam trajectory through the remainder of the BTS. We identified a location in the BTS that was a node in the vertical trajectory where no steering magnet could adjust the vertical beam position at that location. This node was at an inconvenient location, so we added an additional steering magnet to the BTS to steer the beam at the node.

VIEW SCREENS AND CAMERAS

The BTS view screens used free-running, analog cameras dating from the original commissioning in 2002. These cameras could be viewed on an analog television screen or digitally using a frame grabber.

We replaced all the free-running, analog cameras on the BTS with triggered, digital cameras. For most screens, we used inexpensive FLIR Blackfly S BFS-PGE-16S2M cameras. We integrated the cameras into our control system using the ADSpinnaker areaDetector driver [2, 3].

We kept the existing phosphor screens in most cases. At two locations, we upgraded the viewscreens to a three-screen system that allows us to switch between a marked phosphor screen for absolute size calibration, a yttrium aluminum garnet (YAG) screen for online beam profile optimization and an aluminum plate to produce optical transition radiation (OTR) [4] for optics measurements. For the two locations with three-screen systems, we used an Ophir Photonics beam profiling camera with BeamGage Professional software to provide online beam profile analysis.

Figure 3 shows the post-upgrade beam imaged on a YAG screen using the same accelerator configuration that we used to produce Fig. 1. The beam profile is much improved by using one vertical and one horizontal booster ring corrector magnet to adjust the beam trajectory through the septum. It is clear that the beam is not Gaussian and further optimization is possible. The BeamGage software was very useful during this optimization as it provided numerous on-line beam profile calculations. The vertical lines on either side of Fig. 3 are the edges of the YAG screen.

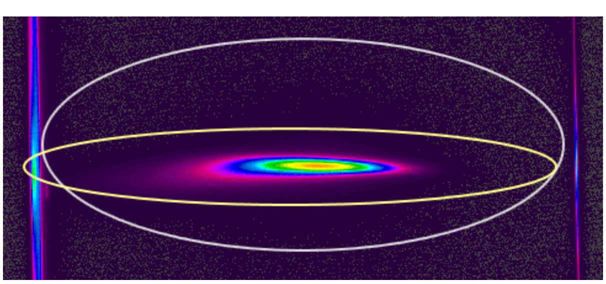

Figure 3: The beam of Fig. 1 imaged on a YAG screen by a digital camera after we improved the beam trajectory through the booster extraction septum.

EMITTANCE REDUCTION SCRAPERS

While adjusting the beam trajectory significantly improved the total injection efficiency, we were still losing electrons in the storage ring during injection. In order to maximize the storage ring capture efficiency, we implemented a set of four scraper blades to reduce the horizontal emittance of the injected beam. We are content to lose some electrons in the heavily shielded BTS area so that they are not lost near the comparatively thin storage ring ratchet wall and permanent magnet insertion devices.

Our design is based on work done at SPring-8 [5]. We use two pairs of scraper blades with each pair separated by $\pi/2$ radians in horizontal betatron phase. We used `elegant` [6] to perform all optics and particle tracking calculations.

The scraper blades are made of copper and are angled at 45 degrees so the OTR produced by electrons striking the blades travels downward and can be viewed using a FLIR camera. Figure 4 shows OTR produced when the electron beam strikes the closed upstream scrapers. The two parts of the beam appear at the top and bottom of Fig. 4 because the scraper blades are offset longitudinally to prevent collisions.

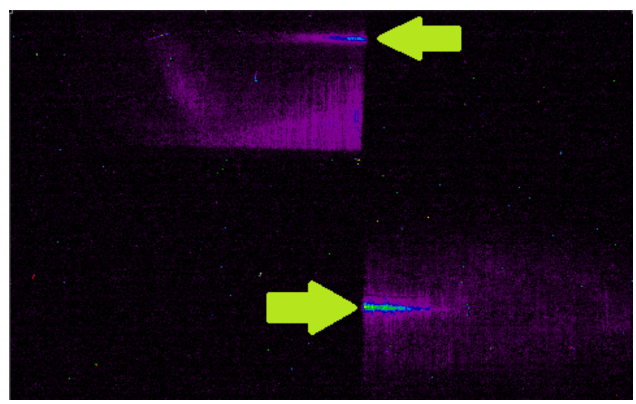

Figure 4: OTR from the upstream set of emittance reduction scrapers viewed from below while blocking the entire beam.

We used FLUKA [7] to calculate the effect of a scraper blade on the electrons. We required that 99% of the 2900 MeV electrons that interacted with a scraper blade would lose at least 113 MeV, ensuring that they would be swept into the yoke of the downstream dipole. This is accomplished in the FLUKA simulation if the electrons pass through 15 mm of copper.

The scraper blades can be moved horizontally by stepper motors and are controlled remotely. Figure 5 shows the scraper blades within the mechanical assembly. The OTR exits through the view port below the blades. There is a fixed aperture at the upstream port to ensure no electrons can go over or under the blades.

DISCUSSION

We use an integrating current transformer (ICT) at the end of the BTS in order to separate injection efficiency into

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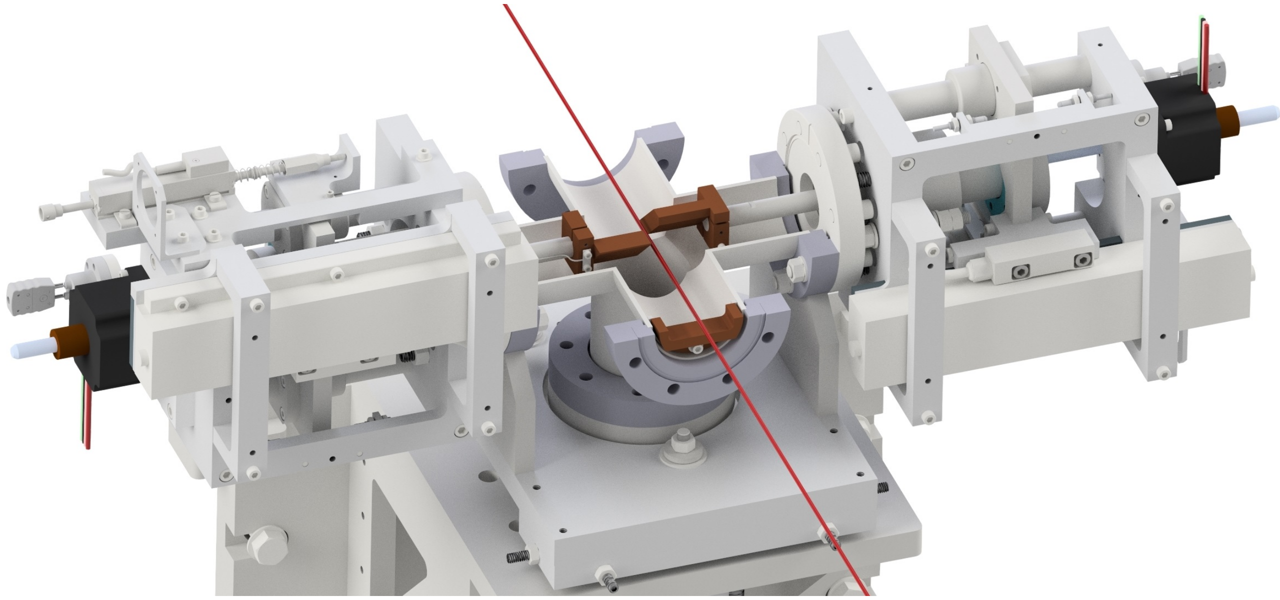

Figure 5: One pair of emittance reduction scrapers with the top of the vacuum chamber removed and a red line representing the beam axis.

stage 1 efficiency and stage 2 efficiency. Stage 1 efficiency is the transfer efficiency measured from the booster ring parametric current transformer (PCT) immediately before extraction to the BTS ICT. Stage 2 efficiency is the transfer efficiency from the BTS ICT to the storage ring PCT, measured well after the injected beam has damped. The total injection efficiency is thus the stage 1 efficiency times the stage 2 efficiency. Figure 6 shows the locations of the current transformers and the emittance reduction scrapers. There is some uncertainty in the calibration of the ICT, which results in some uncertainty in the stage 1 and stage 2 efficiencies. By using the emittance reduction scrapers, which are upstream of the ICT, we routinely achieve stage 2 efficiencies that are definitely > 96%, and probably > 99%. The total injection efficiency is currently around 65%, which is near where we started, but the losses now occur in a controlled location. In the future, we will attempt to improve the total injection efficiency while maintaining high stage 2 efficiency.

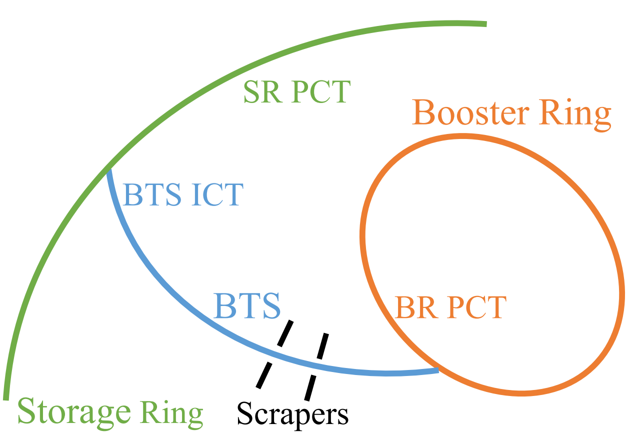

Figure 6: Locations of the current transformers and emittance reduction scrapers.

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