THE NSLS-II TOP OFF SAFETY SYSTEM*

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Abstract

Top Off operation is the desired mode of operation for 3rd generation light sources to ensure beam current stability for user experiments. However, top off operation introduces the hazard of injecting electrons into the front ends with the beamline shutters open. This hazard can be mitigated with the appropriate safety system. This past year, the NSLS-II has transitioned from decay mode to top off operation with the introduction of the Top Off Safety System (TOSS). Top Off was initially demonstrated September 22, 2015 and become standard mode of operating. In this paper we discuss the top off safety system, operation with the system, and future directions.

INTRODUCTION

Top Off operation is considered to be the standard mode of operation for all modern synchrotron light sources [1-3]. This mode of operation injects fresh bunches into the storage ring at frequent intervals to make up for beam losses. The goal is to maintain the requisite beam current stability to maintain a constant X-ray flux. This constant flux benefits the users not only in the flux itself but the thermal load on their optics is maintained. The steady thermal load improves beamline stability and scientific output.

Top Off operation introduces a new hazard for operation, which is injecting into the storage ring with the front end shutters open. This may allow the possibility of sending the injected electrons through a front end, beyond the ratchet wall, and into a beamline first optics enclosure. This would produce an unacceptable radiation dose on the experimental floor. Therefore an appropriate safety system must be installed to mitigate this hazard.

The installation and demonstration of top off operation was the highest priority for the NSLS-II in 2015. Top off was successfully performed for the first time on September 22, 2015. Since that time top off is the standard mode of operation for NSLS-II. In this paper we discuss the TOSS, operation of the system, and future directions.

TOSS

The design of the TOSS has been presented at the previous IPAC and therefore only a brief description will be given [4]. Each front end has a defined safe point, which is the point where all possible errant electron trajectories are not allowed to pass. This safe point is usually a collimator, but may be an optical element such as a mirror if it blocks all possible paths. If the safe point is a collimator, a backward tracking algorithm is used to track from the safe point into the straight section upstream of the front end [5-7]. A beamline is considered safe if the envelope of allowed trajectories terminates prior to entering the straight section. The results of this tracking defined a number of parameters which the TOSS must interlock against.

Once the front end is ruled safe from electrons passing the ratchet wall, FLUKA calculations are performed to investigate the radiological hazard resulting from electrons striking at or near the safe point with the maximum injection rate. If the results of these simulations show that the shielding policy cannot be met without additional measures, then additional shielding or area radiation monitors will be added to the beamline's first optics enclosure.

The net result of this analysis is that the TOSS will allow top off operation if the following conditions hold while the front end shutters are open:

- ±2% current window on the storage ring dipoles
- ±2% voltage window on the storage ring dipoles
- ±2% current window on the booster ring dipoles
- ≥ 50 mA of stored beam
- Injection Rate <45 nC/min

The TOSS will be required to inhibit top off injection within 15 ms if any of the dipole interlocks are violated. This is to ensure that the magnetic field of the dipole does not fall out of an acceptable range before top off is inhibited.

The booster extraction AC septum and the storage ring injection AC septum are interlocked by the TOSS if the first 4 conditions are not met. Two Accumulated Charge Monitor Interlocks (ACMI) [8] interlock the gun if the injection rate exceeds its limit.

The TOSS is designed as a dual chain system. Each chain is independent of the other. The safety specific hardware is different for each chain. Each chain was programmed by a separate programmer working from the same specification to diversify the software.

There are typically 4 to 5 apertures in the front end and the storage ring, specific to each front end which need to meet alignment tolerances as well. These tolerances are 2 to 5mm depending on the location. This is large compared to the alignment tolerance required for beamline operation and therefore do not pose any additional burden.

Figure 1 shows a block diagram of the TOSS.

TOP OFF DEMONSTRATION

The TOSS was installed, tested, and certified during the summer shutdown. Machine startup commenced on September 21, 2015 with the priority focused on demonstrat-

*This manuscript has been authored by Brookhaven Science Associates, LLC under Contract No. DE-SC0012704 with the U.S. Department of Energy

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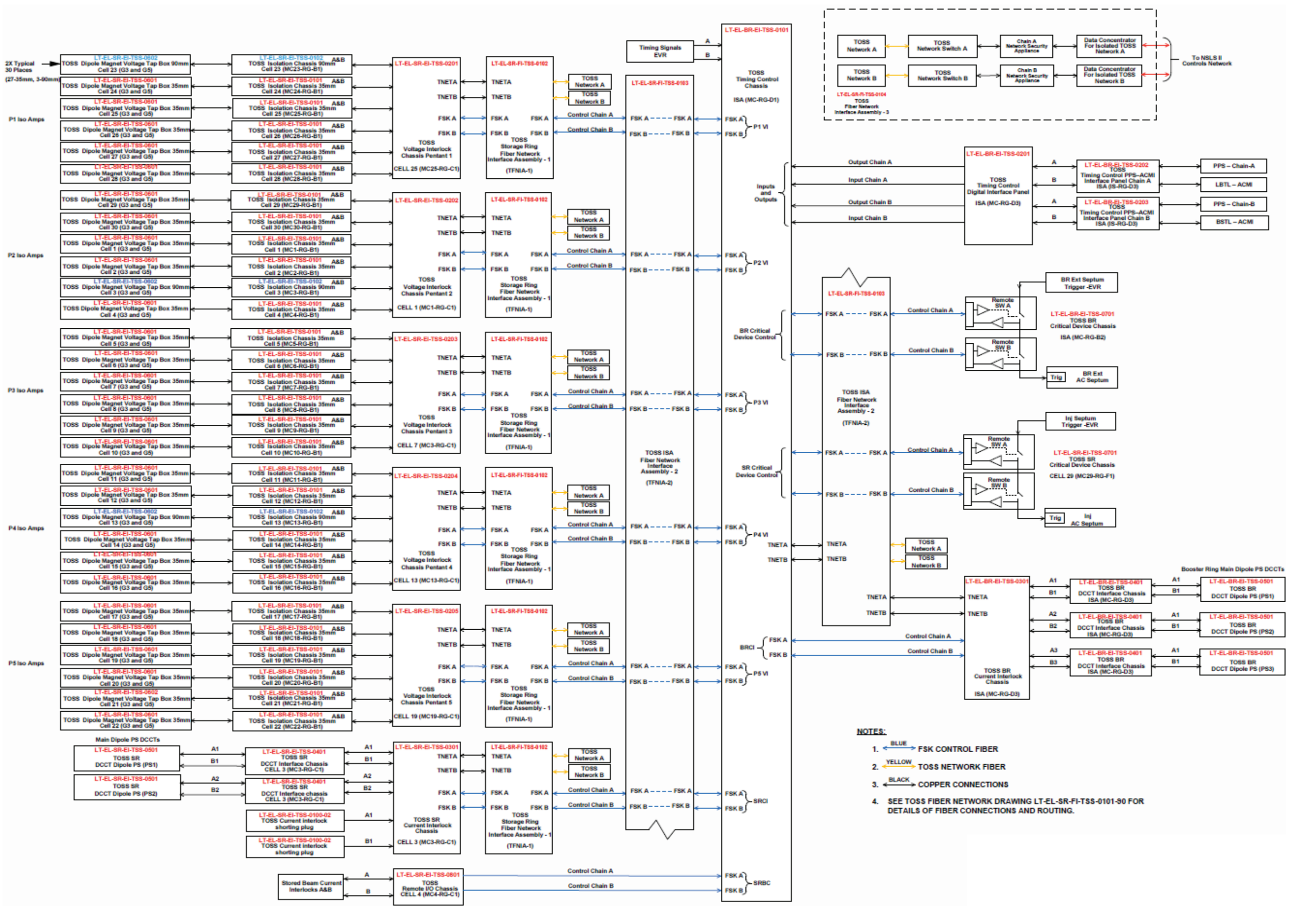

Figure 1: Schematic diagram of the TOSS. Blue lines denote safety related communication, yellow is non- safety diagnostic information, and black is raw signal.

ing top off, commissioning the top off controls, and performing the necessary radiation surveys prior to the start of operations.

After receiving all required approvals, a studies shift was scheduled for September 22, 2015 to demonstrate top off operation. The following needed to be achieved declare the first successful top off operation:

- Store enough beam to clear the TOSS stored beam current interlock
- One of the beamlines was required to receive X-Rays with their ID gap closed during the demonstration.
- The beam current needed to be maintained for one hour.

The Coherent Soft X-Ray beamline (CSX) was chosen as the beamline for the demonstration, as they were the most prepared to receive beam during the studies period.

The storage ring was filled to 125 mA. An initial, unintentional, difficulty of a tripped heartbeat detection between the TOSS and the Booster Personnel Protection System tripped the gun when the front end shutters were open. Once this was reset, the beam current had decayed to 120 mA, and we decided to run the test that this current.

Figure 2 shows the storage ring current and the injected current for the length of the demonstration. Top off injections were controlled via an automated program. The development and operation of these controls are the subject of other papers in these proceedings and not discussed in detail here.[9, 10] Injections occurred at 51 second intervals with 100 bunch trains, and an average charge of 0.8 nC per shot. The CSX beamline received X-Rays during the entire demonstration. The beam current remained within 0.8% of the desired current for the length of the demonstration. Train uniformity remained

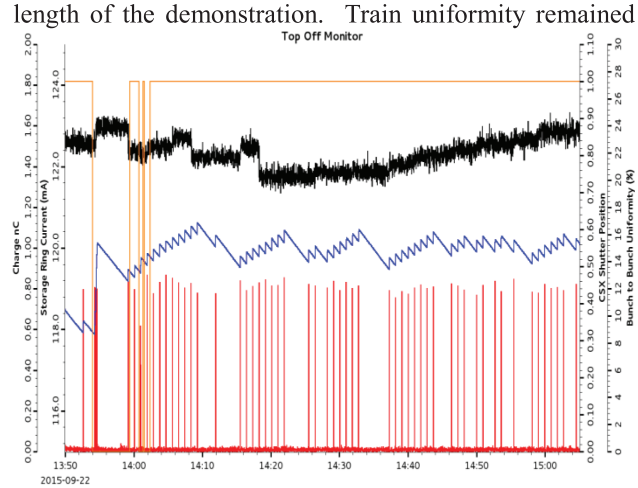

Figure 2: Storage Ring Current (blue) and injector output (red) during the top off demonstration. CSX shutter position is in orange. Bunch Train Uniformity is black.

between 20 and 24%. Radiological surveys of the CSX first optics enclosure showed no increase in radiation above background levels with top off running.

This initial demonstration was followed by studies periods to optimize the controls for top off and to perform radiation surveys on all of the first optics enclosures.

Operation for users with top off began on October 1, 2015.

TECHNICAL ISSUES

Other than the initial heartbeat issue mentioned in the previous section, there were a small number of technical issues that arose in the TOSS during initial running of the system. None of these affect the safety function of the TOSS, but did impact its operation. None of these issues delayed operating NSLS-II in top off mode.

Initially it was noticed that the timing signal received by the TOSS was not the correct signal. The TOSS receives a signal indicating the next injection is going to occur, which triggers a number of self tests, which if successful enable the TOSS to allow injections assuming all other conditions are met. The initial signal given to the TOSS occurred at every machine cycle, not just on injections. This was remedied by changes in the timing system.

It was noted that the ACMIs, which monitor the charge injected during top off operation, counted all injector shots to the storage ring as top off shots if the TOSS is enabled, even if all front end shutters are closed. This is a safe condition, but not necessary as no top off hazard exists if the shutters are closed. The downside of this is that if the TOSS remains enabled during a ring fill, the ACMIs will quickly interlock the gun as the injection rate during a fill is higher than the top off rate. Therefore, the operators must disable the TOSS via a key switch located in the control room during fills. This can be improved in the future by augmenting the TOSS enable signal with information about the front end shutters.

During the initial studies period it was also seen that one chain TOSS Stored Beam Current Monitor (SBCM) would occasionally not give permission to enter top off when the beam was above threshold. This was eventually traced to a resistor which was out of specification in the comparator portion of the circuit. This would cause the SBCM comparator to oscillate between states, causing the safety relay to chatter and ultimately stick in the open position, which would prevent top off. The immediate solution was to power cycle the defective chain. Ultimately, the SBCM was modified and recertified to improve the hysteresis on the comparator.

NEW AND MODIFED FRONT ENDS

The safety of every new or modified front end for top off must be analysed before the beamline is allowed to operate. This is necessary to determine what apertures in the storage ring and front end must be credited for top off, and what, if any, additional safety measures must be taken to assure that radiation dose in the event of a top off accident is kept ALARA. Changes to the beamline do not need to be analysed.

To date, there are 8 operating front ends approved for top off, with 3 more approved. A number of other front ends are being analysed for beamlines under construction.

CONCLUSION

Installation of the Top Off Safety System and subsequent demonstration of top off injection was the highest priority for the NSLS-II for the 2015 fiscal year. Top off injection was successfully demonstrated on September 22, 2015. Operation in top off mode started on October 1, 2015 after initial radiation surveys of the beamline first optics enclosures.

Since the start of top off operation, 5 more front ends have been approved for top off operation, with 2 of them successfully commissioned. Front Ends continue to be analysed and approved for top off.

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ISBN 978-3-95450-147-2