DESIGN OF THE NSLS-II TOP-OFF SAFETY SYSTEM*

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Abstract

The NSLS-II accelerators finished commissioning in the fall of 2014, with beamline commissioning underway. Part of the design for the NSLS-II is to operate in top off mode. The Top Off Safety System (TOSS) is presently being installed. In this report we discuss the Top Off Safety System design and implementation, along with the necessary tracking results and radiological calculations.

INTRODUCTION

All modern synchrotron light sources are built to operate in a mode of quasi-continuous injection known as top off injection [1-3]. This mode of operation allows for more stable operation by keeping the beam current constant, and hence the thermal load on beamline optics constant. However, this mode of operation presents a unique safety hazard, that is, injection into the storage ring with the photon shutters open. This may allow the possibility of freshly injected electron beam to pass through a beamline front end into the first optics enclosure and cause unacceptably large radiological dose on the experimental floor. A properly designed safety system is required to prevent this from occurring.

The design of the Top Off Safety System (TOSS) for the NSLS-II is the culmination of many years of work.[4-6]. In this paper, we report on the requirements and design of the various interlocks of the TOSS. We discuss the various interlocks and apertures required for safe top off and the maximum credible incident in the event of an errant injected bunch.

HAZARD ANALYSIS

The tracking which was performed to specify the interlocks for top off safety is discussed in various places. [4,5,7]. In brief, a safe point is specified in the beamline front ends and the goal of the tracking is to ensure that no injected electrons can go beyond the safe point. For reasons of computational expediency, the decision was made to track positrons backward from the safe point into the nearest straight section of the storage ring. Particles which can be tracked to the nearest storage ring straight section denote unsafe trajectories. Certain apertures in the storage ring and front end, along with a set of interlocks are specified eliminate all unsafe trajectories. The interlocks will be the same for all front ends, and the apertures will be specified on a per front end case.

Common designs of the front ends simplify the specification of apertures, with similar apertures called out for multiple beamlines.

Figure 1 shows a typical analysis. Tracking starts at the right of the figure and attempts to find all trajectories which can propagate through all of the apertures to the left. The red lines show the envelope of trajectories. The various magnets are shown by the colored boxes. The dipole magnet deflects the trajectories into the vacuum chamber for all possibilities allowed by the interlocks and aperture misalignments. Because no trajectories propagate to the left and therefore this beamline is safe.
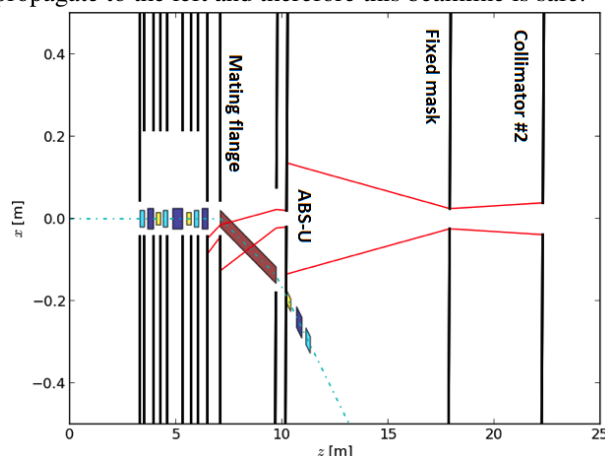

Figure 1: Example of particle tracking for SRX beamline. Tracking starts at Collimator #2 on the right and attempts to get to the storage ring straight on the left. The red lines denote the envelope of trajectories. No trajectories pass to the straight, therefore these are safe.

The tracking calculations do not assume the presence of stored beam in the ring. Neglecting this allows the calculations to find unlikely scenarios where injected beam may escape the ring, but may be incompatible with stored beam. The interlocks and apertures render all trajectories safe. Including a stored beam interlock removes the possibility of many of these scenarios, making the possibility of injected beam escaping down a front end to the safe point even more unlikely.

When x-rays are being delivered to a beamline during top-off, the safety shutters are in theopen position and the first optical enclosure (FOE) will be secured with no access to the personnel. The primary radiological safety concern for the top-off injection is where injected electrons are conveyed through the front-end and strike the safe point, which is closest to the ratchet wall collimator.

The radiological calculations use the front end with the largest apertures to date, which is the SRX beamline. The dose rate during top off operation was calculated for

different scenarios. FLUKA simulations show that if the injection rate is limited to 45 nC/min, the dose rate with the worst scenario during top off is < 100 mrem/h, which is within our shielding policy. Figure 2 shows the dose rate at 15 nC/s. Scaling them to 45 nC/min, the maximum dose rate during top off operation is < 100 mrem/h.
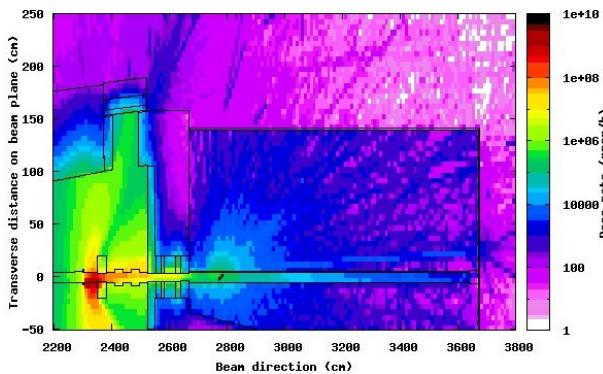

Figure 2: Radiation Dose pattern for electron beam striking the safe point. Dose outside the First Optics Enclosure is less than 2000 mrem/h for 15 nC/s incidence rate.

SPECIFICATION

Based on the hazard analysis the following interlocks will be required to enable top off:

- ±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 will have their triggers inhibited by the TOSS in the event that the interlock conditions are not satisfied. This will prevent injecting beam into the storage ring. The inhibit will used safety rated switches to interrupt the trigger signal to the power supplies.[8]

All front end apertures called out as critical for top off are subject to configuration control to assure their position. These apertures are subject to survey after maintenance on them and a two year intervals. There are approximately 5 apertures per front end.

OVERALL DESIGN

Figure 3 shows the overall design of the TOSS. The TOSS will consist of two independent chains for redundancy.

The dipole voltage interlock consists of a pair of voltage taps on each dipole, leading to an isolation amplifier, which then sends a signal to the voltage
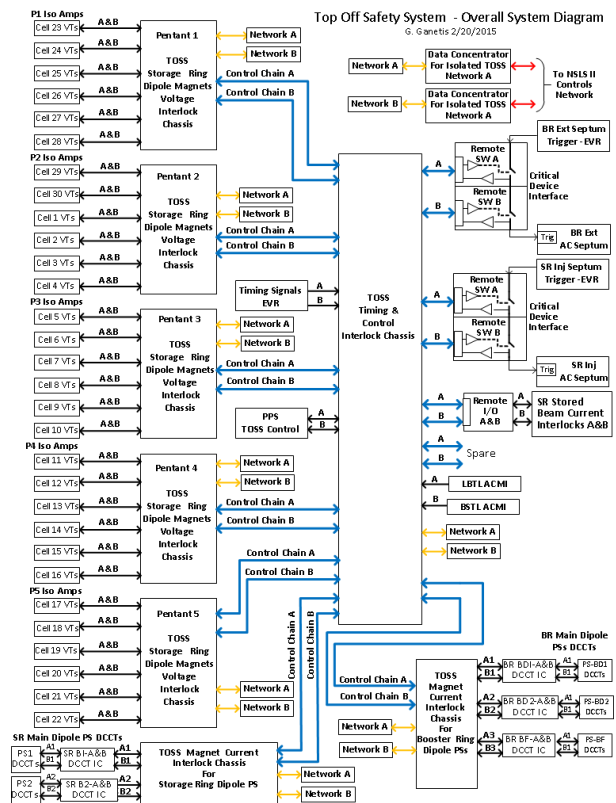

Figure 3: Schematic diagram of the TOSS. Blue lines denote safety related communication, yellow is non-safety diagnostic information, and black is raw signal.

interlock chassis for the pentant. The interlock chassis looks at the voltage across each dipole and the difference in voltage between the two dipoles in a cell. Measuring the difference in the dipole voltage in a cell allows for better sensitivity in measuring for a short, while allowing for resistance changes due to temperature, etc. If the voltage difference between the dipoles is too large, the voltage interlock chassis sends a signal to the timing and control chassis.

Two independent DCCTs read the current signal on the storage ring power supply. These DCCTs will be independent of other DCCTs used for other safety functions. They feed the Current Interlock Chassis for the storage ring. If the dipole power supply is out of specification, an inhibit signal is send to the timing and control chassis.

The three booster dipole power supplies have their currents monitored in a similar way. There is no booster voltage interlock.

The stored beam current interlock consists of two of beam position monitors which are dedicated for this purpose and not part of the BPM system. The sum signals from these BPMs are down converted and compared against a DC reference to determine if there is more than 50 mA of stored beam in the ring. The buttons will be calibrated with the beam to the storage ring DCCT used to measure beam current. This DCCT is calibrated to a standard. It is not necessary that the stored beam

current monitor accurately measure the beam current through the entire operational range. It need only determine if the beam current is above or below 50 mA.

The injection rate interlock is monitored by two independent Accumulated Charge Monitor Interlocks (ACMIs). The ACMIs monitor the charge passing through an integrating current transformer, and trip the linac gun via the linac PPS system if the running integral of charge exceeds certain thresholds. One ACMI is presently installed in the linac to booster transport line to monitor the charge coming from the linac. Another is being installed in the booster to storage ring line. Each of these will monitor the injected charge during top off and trip the linac gun if the charge rate approaches 45 nC/min. A signal will also be sent to the TOSS that the trip has occurred. This is not a safety function.

The Booster Extraction AC septum and the Storage Ring Injection AC septum are the critical devices selected to stop top off injection. A pair of safety rated switches will inhibit the trigger to each septum. Each switch is controlled by one chain of the TOSS. Inhibiting the triggers are sufficient to ensure safety. Removing the AC power is disruptive to operation and may shorten the lifetime of components. Misfires of the septa when the triggers are inhibited are not a concern as this would require both septa to misfire together at the proper time for top off. Analysis has shown this probability to be extremely unlikely. [9]

The TOSS Timing and Control Chassis is the heart of the safety system. It communicates with all of the interlock chassis, the booster PPS system, and inhibits the septa. The Booster PPS indicates to the TOSS that the injector is configured to inject into the storage ring, and that a front end safety shutter is open, thus we are in a state where the conditions for top off must be met. If all of the front end shutters are closed or the injector is not configured to inject to the ring, then the conditions for top off do not need to be met, and the Timing and Control chassis will allow the septa to pulse normally. The Timing and Control chassis receives a pretrigger from the timing system to indicate that the gun will fire. A number of pretests will occur to test the TOSS circuitry. In particular all storage ring current and voltage interlocks chassis will do a self-test to ensure that the measured signals are correct. This is necessary as these signals are normally DC. The booster is a ramping machine and does not require a self-test as the condition for top off are only met at the extraction current if the timing is correct. If all of the conditions are correct for top off, the TOSS will close the switches to septa and allow them to fire.

The Timing and Control chassis relays information to a dedicated gateway computer to communicate to the controls network. This is required for diagnostic purposes, and has no safety function. It will not be possible to access the TOSS directly from the controls system, except for the timing signal.

The Voltage, Current, and Timing chassis will use Hercules Safety Rated Microcontrollers from Texas Instruments [10]. A different microcontroller model will be used for each chain. These controllers were chosen because to meet the fast response time needed for the dipole interlocks. Commercially available safety rated PLCs will not be able to inhibit injection within 15 ms.

CONCLUSION

The Top Off Safety System is scheduled to be operational prior to October 2015. The installation schedule is governed by two month long shutdowns in May and August/September. All detector installation which requires interrupting operations must be completed during the May shutdown. The final tie in of the TOSS to the PPS system, final testing, and certification will occur in August.

All front ends which will be operational at that time have been analysed and approved for top off. Analysis continues on newly constructed front ends.

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