ALS TOP-OFF MODE BEAM INTERLOCK SYSTEM*

K. Baptiste, M. Balagot, W. Barry, P. Casey, H. Chen, R. Mueller, D. Robin, C. Steier, J. Weber, LBL, Berkeley, CA 94720, U.S.A.

Abstract

ALS has been upgraded by adding Top-Off Mode, a new mode of operation to the existing modes of Fill and Stored Beam. The Top-Off Mode permits injection of 1.9GeV electron beam into the Storage Ring, with the safety shutters open, once certain strict conditions are met and maintained. Top-Off Mode enables User operation without an interruption caused by mode switching between the Stored Beam Mode when safety shutters are open, to the Fill Mode with the safety shutters closed and back. The conditions necessary to permit Top-Off Mode are; stored beam is present, the energies are matched between the injector and storage ring, a select set of storage ring lattice magnets are operating at the correct current levels, and radiation losses are minimized. If certain combinations of these conditions are not met, a potentially dangerous condition of injecting electrons down a users beam line can exist. Therefore a system of mode control, energy match, lattice match and stored beam interlocks are needed to control the injected beam prohibiting potentially dangerous conditions. In this paper we will present the Top-Off Mode Beam Interlock system requirements, design, and operational parameters.

INTRODUCTION

The Advanced Light Source (ALS) has operated in Fill Mode or Stored Beam Mode since 1993. In Fill Mode the Storage Ring is filled by injecting electrons approximately every eight hours with the Personnel Safety Shutters (PSS) closed, thus interrupting User Operations several times a day. After filling, the ALS is switched to Stored Beam Mode where the PSS are open and the beam current decays over the next 8 hours. Earlier this year ALS began User Operation in Top-Off Mode, in which electrons are injected into the Storage Ring with the Personnel Safety Shutters (PSS) open. In order to accomplish this upgrade [1], the accelerator and beam line systems were analyzed to determine if electrons could be injected into a beam line creating a potentially dangerous radiation exposure on the experimental floor.

The analysis began with Radiation Transport Code to determine a point inside of the radiation shielding where the electrons could be allowed to impact, but still be safe for personnel on the experimental floor. Once this point was established at 1 meter from the inside surface of the exit port of the shielding, the Physics Group used a reverse tracking method [2] [3], which tracks particles back towards the injector from this safe point by accounting for abnormal and failure scenarios, energy and magnet field scanning, apertures, alignment tolerances, etc. Additionally, the shortest time for a magnet field to reach a field that could support a potentially dangerous condition was determined by including the effects of the vacuum chamber, power supply and magnet [4]. Finally, stored beam was required, which indicates that the ALS Storage Ring lattice magnets are set correctly. Table 1, The Top-Off Interlock Specification, shows the allowable operating ranges for the various magnets and beam currents determined by the results of the simulations.

Table 1: Top-Off Beam Mode Interlock Specifications

Power Supply	Intrlk Sys.	Nominal Current (A)	Acc. ±% of Nom.	Max Resp. Time (ms)	Intrlk Value (A)	Intrlk +/- Limits % of Nominal
BR Bend	EMI	982	0.1%	1	981.55	+0.268, -0.201
SR Bend	EMI	897	0.1%	1	896.82	+0.374, -0.348
SR4,8,12 Super-Bends	EMI	298	0.1%	1	298.5 298.6 298.46	+0.297, -0.284
SR QFA	LMI	492	0.1%	1	492.349	+0.519, -0.433
SR4,8,12 QFAs (Super-Bend)	LMI	521	0.1%	1	521.387	+0.64, -0.45
SR SF	LMI	373	10%	1	372.87	+2.77, -46.6
SR SD	LMI	250	10%	1	250.02	+24.5, -35.5
SRBeam (BPM)	SBI	500 mA	1%	1	500 mA	+120.0, >2.5%

RF system trips, beam scrapers or beam impacting the vacuum chamber prior to the 1 meter safe point. These losses are monitored and interlocked by dedicated radiation monitors, which have two parallel integration settings, one fast and one slow. In order to increase the reliability of the radiation monitor a sealed source was added to the unit to create a “keep-alive” dose count. If the count falls to zero for greater than 30 seconds the interlock will trip and cause the PSS to close.

Design Principles

Typical best practices for designing a personnel safety system include the following design principles: fail-safe, redundant, testable, visible, self-checking, and reliable. These principles are spelled out in more detail in LBNL publications and in the DOE document governing safety system designs [6]. A fail-safe device or system is generally defined as one in which the likely failure scenarios prevent unsafe operation. The Top-Off Interlock System as a whole was designed to meet all of these design principles wherever possible. However, due to the response time requirements, solid-state devices, which typically are not specified for fail-safe or high-reliability

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applications, were required to implement the Top-Off Beam Mode Interlock System.

SYSTEM DESIGN

The Top-Off Beam Mode Interlock System consists of five interlock sub-systems: the Extraction Trigger Inhibit (ETI) [5], Stored Beam Interlocks (SBI), Energy Match Interlocks (EMI), Lattice Match Interlocks (LMI), Injection Mode Control/Beam Line Radiation Interlocks, and a pair of Control Devices: Booster Thin and Thick Septum magnets. Interlock signals from the SBI, EMI, and LMI systems, along with mode control signals from the Injection Mode Control, are sent to the ETI system. Each of these sub-systems consists of two parallel redundant interlock chains (labelled chains A and B). The exception to this parallel architecture is that each of the trigger signals pass through both chain A & B ETI modules serially.

The ETI is responsible for inhibiting triggers to two pulsed magnets, used for Booster Ring extraction, to prevent injection into the SR in response to an interlock trip, system fault, or change in operating mode. The ETI chassis are placed in the output signal path of the ALS Timing System prior to the fiber-optic transmitters. The Top-Off Beam Mode Interlock System is shown in Figure 1.

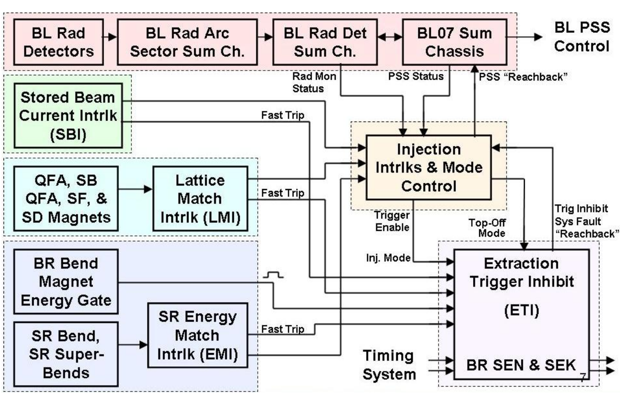

Figure 1: Top-Off Mode Beam Interlock System.

The Injection Mode & Control is used by accelerator Operators to set the Beam Mode. Each Beam Mode has its own distinct set of requirements that must be met in order to allow triggers to the Control Devices. The Beam Line Radiation Monitors control the PSS in all modes, but in Top-Off Mode a System Fault, the result of one of several system self-checks performed by the ETI system, can also "reach-back" and close the PSS.

The EMI and LMI systems monitor the magnet currents by using a current transductor, window comparator and high level logic latch. Each of the static magnet interlock modules are connected in series via redundant series/parallel optically isolated switches on a 10mA current loop interlock, which is the summation the system of magnet interlocks into a single interlock signal to the ETI system. For the Booster Bend magnet, the only ramped magnet, the same magnet current window comparator module is configured via circuit board jumpers to output a gate pulse equal in length to the time the Booster Bend magnet is at an acceptable energy This signal is connected directly to the ETI system.

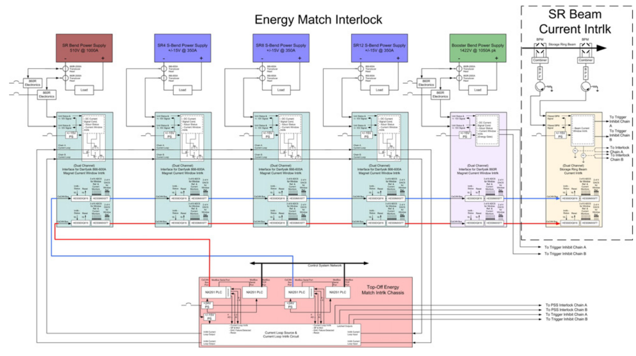

Figure 2: EMI & SBI block diagram.

The SBI system uses a set of Beam Position Monitor (BPM) buttons to monitor the stored beam in the Storage Ring. The BPM signals are summed, narrowly filtered for single bunch sensitivity, and detected. This DC signal is connected to an identical interlock module as the EMI or LMI magnets, which has been configured with circuit board jumpers for this specific application.

All EMI, LMI, SBI, and ETI interlock modules have redundant, CsCAN Bus networked Digital Input/Output (I/O), and Analog DAC/ADC modules. These remote I/O modules are connected to a Programmable Logic Controller (PLC), which is "Embedded" in the system as it is isolated from all other systems except for a serial ModBus connection to a second PLC referred to as the "Gateway". Additionally, the Embedded PLC does not participate, in a conventional sense, in the EMI, LMI, or SBI interlocks by reading in data and then control an output by making a decision based on its input. There are two reasons for this; first the PLC is too slow to meet the 1ms time response for an interlock and secondly PLCs are not safety rated devices. The Embedded PLC is used to set the remote DACs at each of the interlock modules and it also has self-checking code that ensures all network I/O peripherals are operating and all DAC outputs are correct. If a self-check fails the current loop interlock is broken, which inhibits the ETI ceasing Top-Off operation. The Embedded PLC is used in the Configuration & Control of set points, offsets, circuit board jumper configuration. The Gateway PLC can read all data from the Embedded PLC and can only write RESET bits. No other functionality is available using this serial ModBus port.

COMMISSIONING AND TESTING

A systematic approach was taken to prove all circuit boards operation by bench-testing before installation. After the PLCs and their network I/O modules were installed, testing began and quickly showed significant problems with the CsCAN network. Many hours were spent trying to isolate the problems to a network or I/O module. In the end we found the following problems: bad electrical connections, multiple ground points on the network cable shield, large resistive losses in the DC voltage distribution, network length exceeded spec, and communication timeouts for the I/O modules were set too short. Since corrected, the PLC network has had zero errors over the last five months.

Once the system was ready for a top to bottom commissioning test, we first executed the Configuration and Control procedure, which locks all electronic cabinets, enters all set point and operating values, and freezes the programs in programmable devices. Next the Commissioning and Test procedure was executed, which confirms the hardware settings match the PLC configuration, verifies all set point and window interlock voltages, tests all test features, tests all current interlock thresholds, measures system time response, tests all self-checking features, and tests each sub-system's power failure response.

The results of the testing have shown the interlock systems accuracy system wide is better than 0.05% and the system's time response, which is comprised of the uncertainty in the current measurement's temporal response in the test set-up (130us), interlock system's response time (<25us) see Figure 3, and the response time of the trigger to field of the Booster Thick Septum Magnet (140us) totals 295us. This is better than a factor of three faster than required by the specification, providing a conservative safety margin.

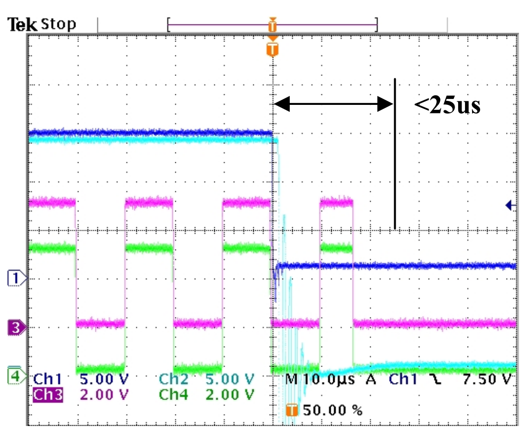

Figure 3: Interlock System Response Time.

SYSTEM OPERATION

The interlock system was designed, reviewed, and installed between October 2007 and August 2008. Debugging and commissioning of the interlock system took place during the next two months. Over the next three months the Physics group tested Top-Off Beam Mode operation while the remaining beam lines were made ready for Top-Off operation. Beginning in February of 2009 ALS began User Operations in Top-Off Beam Mode. Since February the interlock system has had failures, system faults and numerous interlock trips. See Table 2 for a listing.

The failures have no common system thread and all have been attributed to component infant mortality. The system faults have been reduced by increased staff training and by modifying the RSS test procedures. The interlock trips have been reduced by efforts to reduce system faults and future work is planned to reduce the temperature of several interlock cabinets by installing additional ventilation.

Table 2: Top-Off Beam Mode Operation Statistics

Interruption Type	Root Cause
Failures	ETI – relay, EMI – PLC I/O modules, fuse
System Faults	Failures, Op error, DAC-ADC matches, Self-Check Timing, RSS Test Procedure
Interlock Trips	System Faults, Magnet PS Trips, Mis-settings, Temperature

CONCLUSION

The Top-Off Beam Mode Interlock System's design has been based on a specification developed from the results of extensive beam loss simulations. Conservative margins have been achieved due to the interlock system's accuracy and time response. However, the commissioning and testing phase for this system found several problems with the CsCAN networks, which were later fixed.

There are several areas where improvements can be made. Automating the multiple interlock resets would help eliminate operator induced system faults and help reduce the amount of time to get back into Top-Off Beam Mode. Another possible area we will explore in the coming months is whether significant portions of the periodic re-test procedure can be automated, thus reducing the total amount of time needed for the re-test.

The system's operational experience, though brief, has shown that the system is operating quite well. However, even with the failures and faults experienced, the system has exceeded the expectations and the users are very happy with the increased average flux and uninterrupted injection.

REFERENCES

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