

# COMMISSIONING OF ACTIVE INTERLOCK SYSTEM FOR NSLS II STORAGE RING

S. Seletskiy<sup>#</sup>, C. Amundsen, J. Choi, J. De Long, K. Ha, C. Hetzel, H. Hseuh, Y. Hu, P. Ilinski, S. Kramer, Y. Li, M. Maggipinto, J. Mead, D. Padrazo, T. Shaftan, G. Shen, O. Singh, R. Smith, W. Wahl, G. Wang, F. Willeke, L. Yang, BNL, Upton, NY 11973, USA

## Abstract

The NSLS-II storage ring is protected from possible damage from insertion devices (IDs) synchrotron radiation by a dedicated active interlock system (AIS). It monitors electron beam position and angle and triggers beam dump if beam orbit exceeds the boundaries of pre-calculated active interlock envelope. In this paper we describe functional details of the AIS and discuss our experience with commissioning of the AIS for the first eight IDs installed in the storage ring.

## INTRODUCTION

The final phase of the NSLS-II Storage Ring (SR) commissioning [1-3] took place in the fall of 2014. This phase included commissioning of first eight insertion devices (three damping wigglers (DW), one elliptically polarized and four planar in-vacuum undulators) and raising stored beam current to 50 mA. The final SR commissioning phase also included commissioning of the six beamlines (two of three DWs do not have beamlines) and of respective beamline frontends (FE).

One of the most important tasks for this phase was commissioning of the ID active interlock (AI), which protects the SR and the FEs components from possible damage from ID synchrotron radiation (IDSR).

There is another part of the AIS, which protects the SR from bending magnets synchrotron radiation. This part of the system is not discussed in this paper.

Below we describe our experience with the AI commissioning.

## AIS DESCRIPTION

The active interlock is designed [4] to continuously monitor beam orbit in IDs and to drop the beam in case it exits predefined AI envelope (AIE) [5]. Typical AIE is an  $xx'$  or  $yy'$  phase space rectangle of  $\pm 0.5$  mm and  $\pm 0.25$  mrad. Fig. 1 schematically shows signals that the AI is monitoring for each ID.

The AIS calculates beam angle and deflection at the center of the drift between two neighbouring beam position monitors (BPMs) [6] from respective BPMs readings (10 kHz data). The beam current readings are obtained from the storage ring DCCT. In case of canted IDs the current of the canting magnets, which create a local bump on the beam orbit, are monitored by the AI as well.

The statuses of the bending magnet photon shutter (BMPS) and the frontend photon shutter, a.k.a. ID photon shutter (IDPS), are also monitored by the AI.

When the e-beam is not interlocked the BMPS and the IDPS protect the FE and the beamline from bending magnet synchrotron radiation and from IDSR respectively.

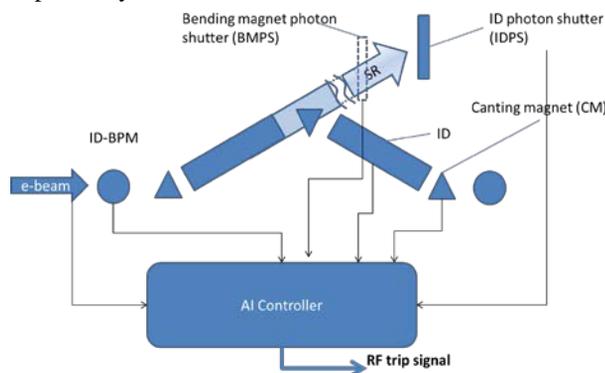


Figure 1: Schematic of signals from various hardware to the AIS. Here we show the canted IDs for the purpose of generality.

The overall structure of active interlock system is schematically shown in Fig. 2.

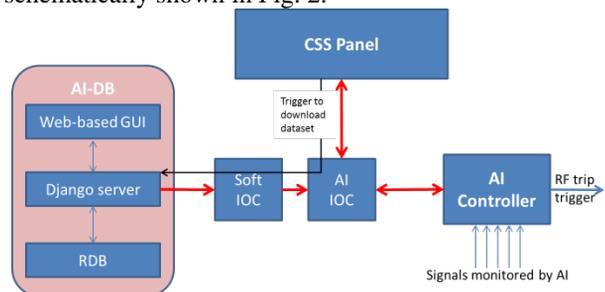


Figure 2: Schematics of the Active Interlock System.

The main functional block of the AIS is the AI controller (AIC). It performs the monitoring of various hardware signals and “makes a decision” on whether the beam shall be dumped. The beam dump is realized by tripping low level RF. The FPGA was chosen for AIC to minimize the response time of the AIS.

The information about AIE for each ID and about respective BPMs is downloaded to the AIC from the AI database (AI-DB). The AI-DB runs on Django server [7] with underlying MySQL relational database and a web-based GUI.

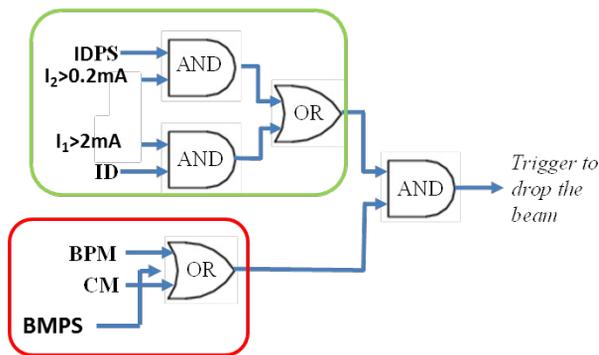
The GUI for the AIS is realized in Control System Studio (CSS) [8] as a standard CSS panel.

The logic of the AIC is shown in Fig. 3.

The logic gates encircled by the green line are responsible for engaging the active interlock. It is getting engaged either when the beam current is above 0.2 mA

<sup>#</sup>seletskiy@bnl.gov

and the IDPS is open or when the beam current is more than 2 mA and the ID gap is closed.



	0	1
IDPS	closed	open
$I_1$	< 2 mA	$\geq$ 2 mA
$I_2$	< 0.2 mA	$\geq$ 0.2 mA
ID (gap)	gap open	gap closed
BPM (positon/angle)	all within AI limits	some out of AI limits
CM (current)	within range	out of range
BMPS	open	close

Figure 3: Active Interlock Controller logic.

The first set of conditions protects the beamline components from excessive deposit of IDSR power. The beamlines were designed under assumption that the beam is contained within the AIE. Thus, the AIS must be activated for open IDPS at beam currents > 0 mA, and 0.2 mA is the smallest current value reliably read by DCCT.

The second set of conditions for enabling AI ensures that the beam stays within AIE when ID is closed (i.e. not fully open) and when the beam current is above the Safe Current Limit (SCL) of 2 mA. It was calculated that for beam current below the SCL none of the SR or FE components can be damaged by the IDSR for the beam allowed to be anywhere within the ring acceptance.

The “OR” logical gate in Fig. 3 encircled by the red line defines when the enabled AI drops the beam.

First possible reason for beam drop is for the beam orbit to exceed the AIE in any of the IDs.

Second possibility is that the BMPS got closed when the AI is enabled. The reason for this option is that the BMPS was designed to accept the synchrotron radiation power from the bending magnets only. The IDSR might damage the BMPS.

Finally, for the canted IDs, the canted magnets current out of range will cause the AI to drop the beam.

## COMMISSIONING PROCEDURE

Commissioning of the AIS with the beam relies on intentionally creating various fault conditions and observing the AI response. The whole commissioning is done at beam current below SCL so that safety of operation is not violated.

We devised the following commissioning procedure [9].

- First, we set the SCL to 1 mA and disable the actual RF trip signal. Next we inject ~1.5 mA beam into the storage ring.
- In this step we close each ID and check that the AIS is getting activated accordingly. Next, we create local bump that produces beam positional deviation in the ID larger than the AIE limit and check that the beam drop trigger is properly issued.
- Here we essentially reproduce the previous step but instead of positional bump we create the angular orbit bump in each ID.
- Next we check that closing ID gap when beam position is outside of AIE limits drops the beam. To do so we move beam orbit outside of the AIE in the ID with open gap and then close the respective ID gap.
- Then we check that increasing beam current above SCL when beam is outside of the AIE limits drops the beam.
- In this step we check that opening IDPS enables the AIS.
- Finally, we check that closing BMPS when the AI is engaged indeed does drop the beam. This step is performed with an enabled RF trip signal.

## AIS COMMISSIONING

The outlined procedure was performed for each ID in the ring. It went smoothly aside of couple programming bugs in the AIC, which were quickly detected and fixed. Nonetheless, we met a few difficulties of different type.

For the purpose of the functional tests the AIC has a capability to work with various simulated data. During commissioning we realized that the AIC can be run in operational mode while still reading the simulated BPM data instead of real ones. Aside from disabling all simulation capabilities in operational mode this discovery also triggered the process of reviewing the AIS for various fail-safe conditions.

We identified a number of AIS failures and a number of failures of the systems the AIS depends upon and made sure that these failures would not compromise the AIS integrity. Just a few examples of this work include “BPM failure” and “failure of the IDPS position indication”.

If one of the BPMs integrated into AIS fails for any reason (lost timing signal, BPM saturation, lost BPM-AIS link etc.) then the position data reported to the AIS become erroneous, which significantly degrades AIS efficacy. To mitigate this potential problem we added capability of detecting BPM failures to our system. Such

failures are treated by the AIC as if the beam orbit was outside of the AIE.

To mitigate potential failure of the IDPS position indication we reversed the logic of the ID photon shutter position indicator so that a logic “Low” indicates an open shutter.

Another class of problems we met during the AIS commissioning was erroneous AI trips.

For instance, we had a number of mysterious beam trips caused by the AIS in one of the IDs. The beam was continuously dumped on the “orbit out of the AIE” condition even though the beam orbit was apparently fine. Our investigation showed that one of the BPMs in this ID section was intermittently shooting out large spikes in beam position reading. These fake “deviations” of beam orbit were causing the AIS to dump the beam.

The problem was fixed by swapping the faulty BPM box with a brand-new one.

Partially because of this experience we now developed a capability for post-mortem investigation of AI trips. Currently every AI trip latches 2 seconds worth of 10 kHz BPM data collected immediately prior to the trip for all SR BPMs. This functionality proved to be extremely useful for routine storage ring operations.

A similar, although much easier to detect problem happened in another ID. We noticed that one the BPMs there had a slow (in a time range of days) drift. Due to this drift the error in BPM readings became unacceptably high and we had to temporarily switch the AIC to the neighbouring SR BPM. After the vacuum chamber was opened it was confirmed that the drifting BPM had a faulty button.

One curious AIS-related problem was caused by the metal washer stuck to the magnet inside one of the undulators.

During commissioning of one of the IDs we noticed that the AI detects ~100 um beam displacement in one of the BPMs, which correlates with closing the ID to its minimum gap. This displacement was limited to just one BPM thus, it wasn't real beam orbit motion. We found that the cause of the problem was the washer stuck to the upper jaw of the ID. When the ID was completely closed the washer was physically moving the vacuum chamber and therefore displacing one of the BPMs.

The discussed deficiencies fall into the “grey area” of corrupt signals, which are not obviously bad (disconnected cable or saturated BPM) or good. Dealing with such problems requires fuzzy logic. We decided that creating an application that checks BPM readings vs. physical model and raises a warning if found discrepancies are too large can help detecting corrupt BPM signals.

The physical model for such application is very simple since in first approximation the AI BPMs and two neighbouring regular SR BPMs are located in a long drift. Therefore, we added some redundancy to our system by regularly comparing AI BPM readings to the readings of upstream and downstream regular BPMs and by raising a

warning if these BPMs are deflecting from the straight line by more than 100 um.

We created a simple script with operator-friendly GUI to automate the described checks of our BPMs.

## CONCLUSIONS

In this paper we discussed our experience with commissioning the Active Interlock System for protection of the NSLS-II Storage Ring and Frontends from synchrotron radiation produced by the insertion devices.

We described the structure and the logic of the AIS. We gave an outline of the AI commissioning procedure and itemized our hands-on experience with AI commissioning.

We discussed the importance of making the Active Interlock System as well as all subsystems it depends upon fail-safe.

We described a few unexpected problems we met during the AIS commissioning. Rather than prohibiting the AIS from dropping the beam when needed these problems created excessive AI trips instead.

Based on our experience with the AIS we developed new diagnostic capabilities to investigate the trips of our machine.

We added redundancy to our system by developing a code that checks readings of AI BPMs vs. physical model.

## ACKNOWLEDGEMENTS

We are grateful for support from the NSLS-II. This work is supported in part by the U.S. Department of Energy (DOE) under contract No. DE-AC02-98CH1-886.

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