NSLS-II POST MORTEM FUNCTION DEVELOPMENT AND DATA ANALYSIS OF BEAM DUMP*

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Abstract

The National Synchrotron Light Source II (NSLS-II) is a state of the art 3 GeV third generation light source at Brookhaven National Laboratory. The storage ring was commissioned in 2014 and transitioned to routine operations in the December of the same year. At this point the facility hosts 16 operating beam lines with beam current upto 250 mA. During beamline operation, various sources (protection system or subsystem malfunction) may cause beam dump. To identify the beam trip sources and improve the operation reliability, post mortem function was developed in NSLS-II to capture the sub-systems status and beam information prior and after beam dump, including RF system, power supply, BPMs and active interlock system. Most of the trip events have been identified and related source was improved. In this paper, we'll present the post mortem function development and data application to diagnose beam dump source.

INTRODUCTION

The National Synchrotron Light Source II (NSLS-II) is a new 3 GeV third generation light source at Brookhaven National Laboratory [1]. It can deliver a broad band of light with the brightness of 1022 photons/s/ mm2 /mrad2 /0.1%BW to support 60-70 beam lines at full built-out.

The storage ring was commissioned in 2014 and began its routine operations in the December of the same year. In 2015-2016 we have been continuously installing and commissioning new insertion devices, their front-ends and beamlines. At this point the facility hosts 16 beamlines in routine operation. Over past year we have been steadily increasing beam current to 250 mA with all ID gaps closed with two SRF cavity in operation. During beam studies we accumulated beam current upto 400 mA.

High operation reliability is always desirable. So it is important to understand each beam trip reason, fix the potential problems and avoid unnecessary beam trip. In the following section, we'll present the beam protection system, post mortem function development and post mortem data applications in NSLS-II.

ACTIVE INTERLOCK SYSTEM

The active interlock system (AIS) [2] is one of the major machine protection systems from the synchrotron radiation. The main purpose of AIS is to protect the insertion device (ID), frontend and storage ring vacuum chamber due to mis-steered synchrotron radiations from IDs (ID-AI) and Dipole magnets (BM-AI).

The required ID-AI system response time is within 1 ms, because through 1 ms duration damping wiggler (DW) aluminum vacuum chamber will increase the surface temperature to 100 C. System engaged beam current threshold is 2 mA. The safe beam envelope defined for device protection are beam position offset within 0.5 mm, and beam angle offset within 0.25 mrad at insertion device center both plane.

The required BM-AI system response time is within 10 ms. System engaged beam current threshold is 50 mA. The safe beam envelope is beam position offset along the ring within 5 mm in x plane and within 3 mm in y plane.

AI system trip source includes beam out of ID-AI or BM-AI envelope, external device failures or global communication glitch detected. It also includes fail-safe function to protect the system from unexpected faults condition, such as AIS Timing trigger error, Cell controller timing error, BPM fault condition (PLL unlock and ADC saturation, ID bpm, and BM bpm), PLC heartbeat status fault (1 Hz), DCCT system fault, DCCT PLC heartbeat status (5 Hz). AI system keeps monitoring these input signals and will dump the beam by turning off RF system under any abnormal condition.

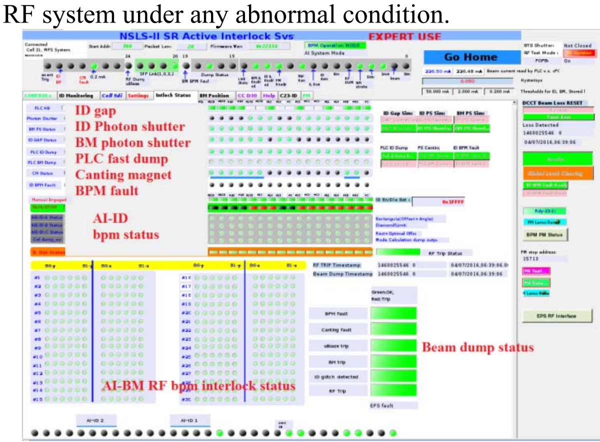

Figure 1: AI system expert page for monitoring all of the AI system status monitoring.

AIS also latched its input signal status during beam dump and displayed them for operation purpose, as shown in Fig. 1. These top level status signals are very useful and convenient to direct the beam dump source, such as ID trip or canting magnet trip or BPMs out of envelope. However, AIS detected dump source can be the leading reason or can be the result of other system fail. One

*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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common question is whether RF system trip caused beam out of AI envelope or beam out of AI envelope caused RF trip. To analyse the event sequence, subsystem post mortem data is needed to answer this question.

POST MORTEM FUNCTION DEVELOPMENT

Figure 2 shows the diagram of the global PM configuration [3]. Once AIS detects an abnormal input signal, it generates a global PM trigger signal and a PM reset signal through the Event Generator (EVG) timing system. EVG assigned two event codes for PM: one for a trigger event, and another for reset trigger event. PM trigger and the data capture time are synchronized for the entire storage ring system during beam dump. NSLS-II post-mortem system includes AIS, Cell Controllers, BPMs, RFs, power supply systems (PSs) as well as the timing system. The beam trip event code will trigger these systems, frozen their memory buffer and PM client software then save the post-mortem data. These data record beam dump process signal and subsystem status during beam dump and will be used for an analysis of subsystem trip sequence.

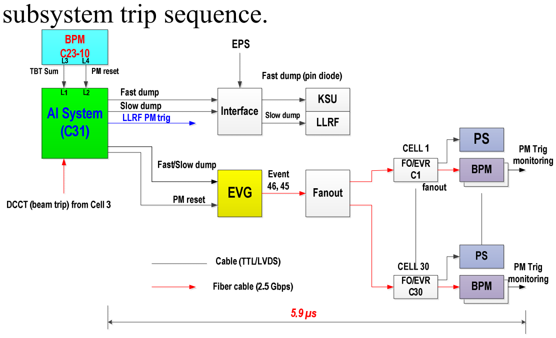

Figure 2: Post Mortem configuration diagram.

AIS PM waveform implemented total 3 seconds 10 kHz data saved to DDR-3 memory. Saved data files include AI system latched beam signal (BPMs 10 kHZ beam position, FPGA…), Power Supply (Quadrupoles, Sextupoles, dipole trims, DC and fast correctors, Canting magnet), BPMs turn by turn data (X and Y position, button sum signal, AI trigger stop address), RF system (cavity amplitude and phase, cavity forward/reverse power, RF section BPM's beam phase and beam intensity). The saved file is in hdf5 format with all PVs' timestamp.

POST MORTEM DATA APPLICATION

During the SR commissioning and operation, we experienced different fault such as RF vacuum trip, Power supply failure, BPM failure (saturation), BPM 10 kHz data communication glitch. Some of them, such as data glitch, are not real and caused unnecessay beam dump.

AI system has implemented data glitch ignoring function, i.e. if it only detects a single cycle data sudden jump, AI system treats it as a glitch with data latched without trip RF system, but if two consecutive cycle's data is out of the defined range, it is considered a real beam motion and will trip RF system.

Beam Trip Sources Analysis

During the operation, there are several different types of beam dump sources. The most common trip sources we experienced are AI , RF Cavity trip (vacuum, EPS, PPS), EPS (vacuum, temperature, utility…), PSs (klixon hot due to PS heat, power supply fails), BPM fail, injection kicker fail, PPS.

To analyze the event sequence, we developed an online application as an operation tool to show RF signal relative to AI trigger event. The input signals include two RF cavities' field and beam intensity signal, SR BPMs TBT sum signal. Since the data sampling rate are different, the RF signals are interpolated into the same time interval as BPM TBT data. Then both BPM's sum signals are processed to normalized beam intensity for the timing alignment. After this step, both RF cavity and SR BPM TBT signals are aligned to the same time scale. AI trigger event timing is latched relative to SR BPMs TBT data index. So RF cavity field change, beam intensity change and AI are all aligned into the same coordination. The whole process takes time within a minute.

Figure 3 shows the examples of beam dump from RF cavity vacuum trip, AI trip, EPS trip, and injection kicker trip. The green lines are the AI trigger event launch time. Red line are for cavity C's signal and Blue line are for cavity D's. In the RF cavity trip case, it shows cavity D trips first, then caused cavity C unstable, resulting beam out of AI envelope and AI launches trigger event. The beam loss happens ~70 turns, due to synchrotron loss with one cavity supplying beam energy. In the EPS trip case, it shows both cavities were tripped at the same time from EPS trigger, resulting beam out of AI envelope and AI launches trigger event. The beam loss happens ~40 turns, due to synchrotron loss without cavity supplying beam energy. In the AI trip case, it shows both cavities were tripped at the same time after AI trigger. The beam loss happens ~40 turns, due to synchrotron loss without cavity supplying beam energy. In the injection kicker trip case, it shows both cavities were tripped after AI trigger with beam loss ahead of cavity trip. The beam loss happens in 2 turns (kicker pulse length is 2 SR revolution periods), due to beam large big kick angle and oscillates amplitude out of vacuum chamber limitation.

Beam Loss Location

BPMs post mortem sum signal are also used to analyse beam loss location [4] around the ring.

The BPM sum signal exhibited level of noise in excess of slow loss rate. Even with the normalized sum data BPM-to-BPM noise is still comparable with the beam loss in one turn and it is hard to judge where the beam is actually lost. To reduce the noise, the raw data was further processed by moving data average method. First, 180 BPMs different turns data was expanded into a long transport line in BPM sequence and turn sequence, as: $I_{raw} = [I_i^{p1}, \ldots, I_i^{pn}, I_{i+1}^{p1} \ldots]$, where pn is the BPM index number and i is the turn number. Then beam sum signal was processed via moving average as $\overline{I_i^{pj}} = mean(I_i^{pj}, \ldots I_i^{pj+k})$, where k is the slice number of averaged BPMs. The beam loss locations (Fig. 4) are indicated as sudden slope changes in the sum signal. The result shows that beam loss locations are injection straight section and scraper location during kicker fail. In other case, such as AI trip or RF cavity trip, beam loss located at the scraper region. This agrees with SR geometry that scraper was purposely positioned at 20 mm and AC septum limits aperture to 18 mm.

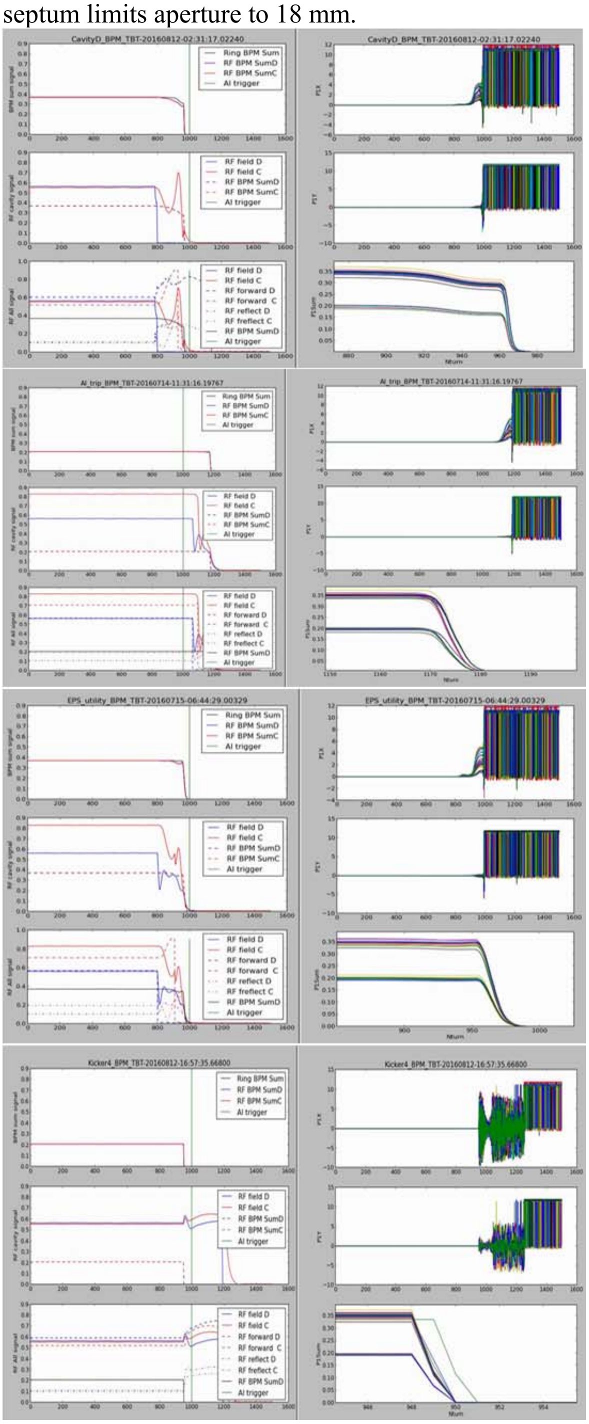

Figure 3: PM data from different trip source (from top to bottom: RF cavity, AI , EPS, injection kicker).

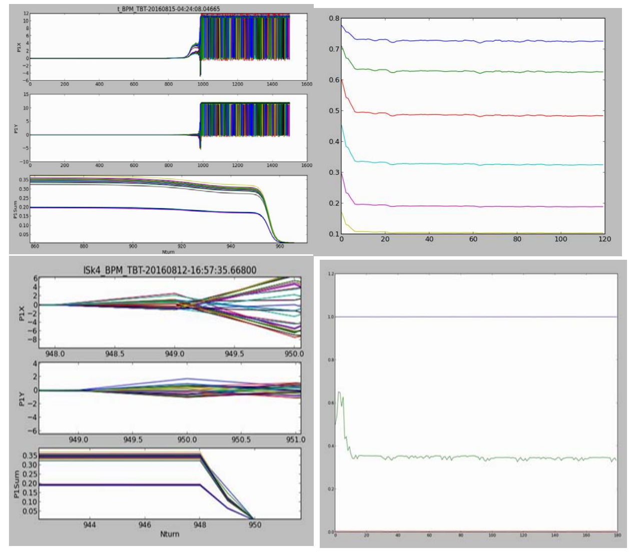

Figure 4: beam loss localization from AI and kicker trip.

NSLS-II OPERATION

In FY 2016, top off routine operations started on October 1, 2015 at 150 mA. Now the beamline operation beam current is 250 mA with 10 hrs beam lifetime. The total operation time is 3600 hrs.

The beam operation reliability is 91.4%. The mean time per failure is ~14 hrs.

In Fig. 5, it shows SR operation failure distribution. The main trip sources are the RF cavity and power supply.

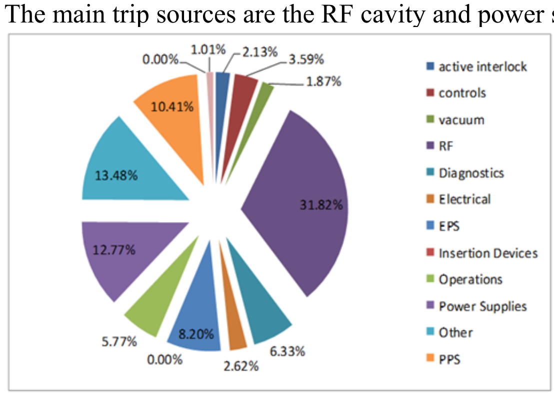

Figure 5: SR operation failure distribution.

SUMMARY

NSLS-II post mortem function was developed to snapshot the machine status and beam signal during beam dump. Online tools were implemented to diagnose beam trip event sequence and help to diagnose the subsystem imperfections (such as signals glitch), avoid unnecessary beam trip and improve the machine operation reliability.

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