DIAGNOSTICS CONTROL REQUIREMENTS AND APPLICATIONS AT NSLS-II*

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Abstract

To measure various beam parameters such as beam position, beam size, circulating current, beam emittance, etc., a variety of diagnostic monitors will be deployed at NSLS-II. The Diagnostics Group and the Controls Group are working together on control requirements for the beam monitors. The requirements are originated from and determined by accelerator physics. An attempt of analyzing and translating physics needs into control requirements is made. The basic functionalities and applications of diagnostics controls are also presented.

INTRODUCTION

State-of-the-art beam diagnostics and control systems are required for a smooth and rapid commissioning and for productive and successful operation of the NSLS-II storage ring. The NSLS-II beam diagnostics and control system is designed to monitor the electron beam of NSLS-II accelerator complex. The beam quality is measured by a variety of parameters such as bunch charge, bunch structure (filling pattern), beam position/orbit, beam size/profile, energy & energy spread, circulating beam current, tunes, beam emittance, bunch length and beam losses.

A correct measurement of beam parameters depends on the effective combinations of a variety of beam monitors, control and data acquisitions (DAQ) and high level physics applications. Figure 1 shows the relationship between these systems.

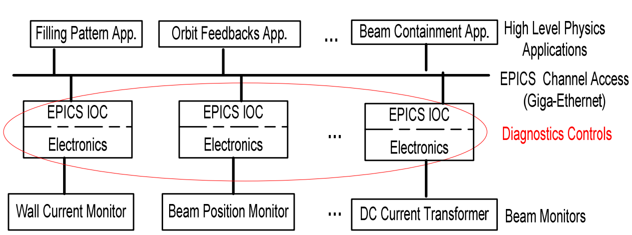

Fig. 1: NSLS-II Beam Diagnostics & Control Systems.

The following beam parameters will be monitored during regular operations:

- closed orbit (accuracy better than 10% of beam size);
- working point (tune for both planes with 10^{-4} resolution);
- circulating current (0.1% accuracy) and beam lifetime (1% accuracy);
- injection efficiency;
- filling pattern (1% of maximal bunch charge);
- emittance for both planes (10% relative accuracy);
- energy spread;
- individual bunch length (2 psec resolution);
- position of the photon beam for the insertion devices;
- coherent bunch instabilities;
- distribution of beam losses around the ring;

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CONTROLS REQUIREMENTS

To measure various beam parameters, a variety of diagnostic monitors will be deployed in NSLS-II. The Diagnostics Group and the Controls Group are working together on controls requirements for these beam monitors. These Requirements are determined by accelerator physics. According to NSLS-II PDR [1], the following beam parameters will be monitored during storage ring regular operations. An attempt of analyzing and translating physics needs into controls requirements is made.

Table 1 lists the beam monitors associated with beam parameters and summaries of controls requirement.

Table 1: Diagnostics Controls Requirements

Beam Parameter	Beam Monitor	Controls Requirements
Fill Pattern	WCM, FCT, BPM button	sampling rate: 4GS/s; resolution: 8-bit; IOC rate: 10Hz
Profile/Position	Flag	Binary control for pneumatic actuator CCD: 1620*1220@15fps, IOC@10Hz
Position/Orbit	BPM	Single Pass Resolution: 30um rms 1um rms@10KHz; 0.3um rms@10Hz
Bunch Charge	Bergoz ICT & BCM	20KS/s with 16-bit; IOC@10Hz
Beam Current	Bergoz DCCT	20KS/s with 18-bit;1Hz for injection efficiency calculation;
Bunch Length	Streak Camera	Windows software by vendor
Tunes	Striplines	Ethernet-based network analyzer
Emittance & Energy Spread	Pinhole Camera	Stepper motor control with readback; CCD: 1620*1220@15fps, IOC@1Hz
Beam Stability	Spectrum Analyzer	Ethernet-based instrument control

Closed Orbit

Requirement: accuracy better than 10% of beam size. The beam position and closed orbit is measured by BPM

(Beam Position Monitor). The smallest beam size is expected to be 3.1 um at short ID (Insertion Device) location. So, the BPM pickup buttons and associated electronics should provide position measurement resolution (RMS noise) at 0.3um (10% of beam size) for long-term orbit drift which can be compensated by slow orbit feedback based on 10 Hz Slow Acquisition (SA) BPM data. Additionally, NSLS-II BPM system will provide 10 KHz Fast Acquisition (FA) data for fast orbit feedback (FOFB) as well as turn-by-turn (TBT) data and ADC raw data for physics studies and BPM system debugging. These applications require less position resolution, usually at tens of microns.

BPM associated with its electronics/receiver, is the key diagnostic instrument. Diagnostics Group and Controls Group are putting much effort into it. NSLS-II BPM receiver [2] provides different data flows (117MHz ADC raw data, 379 KHz TBT, 10 KHz FA and 10Hz SA) for different usages.

Working Points

Requirement: both planes with 10^{-4} resolution. There're several methods to measure tunes (the fractional par). Most of them need pickup BPM and excitation stripline. One common method is based on network or spectrum analyzer. NSLS-II revolution frequency is 378.7 KHz and the tunes are expected to be 32.35/16.28. 10^{-4} frequency resolution means ~10Hz (0.28 * 379 KHz ~100 KHz) scanning step for the analyzer. Another is to utilize (FFT) BPM turn-by-turn data to measure tunes. 10-4 resolution means that at least 5120 (1/ (2N) < =10-4, N>=5000, N = 5*1024) TBT samples are needed for FFT.

Circulating Current and Beam Lifetime

Requirement: 0.1% accuracy for circulating current and 1% accuracy for beam lifetime. This is measured by DCCT and associated electronics. Bergoz NPCT with its analog electronics can provide +/-0.1% accuracy. The NPCT has 10 KHz nominal bandwidth. Large bandwidth gives more noise in the measurement so that filtering it to 500 Hz is always a good practice. In this case, one digitizer with 1KS/s sampling rate should be sufficient. The required resolution for digitizer is determined by the requirement on accuracy of beam lifetime measurement: 2% for 20 mA with 60-hour lifetime and 1 minute measurement interval. 18-bit ADC seems adequate for all these applications.

Injection Efficiency

This is done by comparisons between the charge measured by ICTs at transport lines and that measured by DCCTs at Booster and Storage Ring.

Filling Pattern

Requirement: 20% bunch-to-bunch charge variation. Filling pattern is measured by high-bandwidth (>500MHz) diagnostics monitors such as WCM and FCT. The pulse width of the output signal from Bergoz FCT is about 1 ns. Required 20% means less than 8-bit. So, high-speed digitizer with 2GHz bandwidth, 5GS/s sampling rate and 8-bit resolution should be sufficient for fill pattern monitoring.

Emittance

Requirement: both planes with 10% relative accuracy. emittance is not directly measured by diagnostics. It's calculated from β-function value (assumed to be a constant at the dispersion free location) and beam size (measured by one pinhole CCD camera at one diagnostics beamline). 10% relative accuracy should be achievable by well-designed pinhole optics and high-resolution (1620*1220) digital camera.

Energy Spread

It's also calculated from beam size which is measured by one pinhole CCD camera at another diagnostics beamline assuming the emittance is constant and has been measured.

Individual Bunch Length

Requirement: 2 psec resolution. Bunch length is measured by streak camera which can provide 2 ps resolution.

Position of the Photon Beam

This is measured by X-ray BPM and associated electronics (current-to-voltage converter and digitizer). Additionally, the blades of XBPM are moved and positioned by stepper motors.

FUNCTIONALITIES AND APPLICATIONS

The basic functionalities of diagnostics controls can be summarized as:

- Measurement of various beam parameters (~10) via a variety of beam monitors (~16).
- Acquirement and processing of the signals from beam monitors via different electronics and EPICS IOCs.
- Provision of the processed data as EPICS PVs for high level physics applications.
- Support of Top-off operation by providing filling pattern measurement to meet the requirements of initial filling storage ring from zero to full charge at 10Hz for Linac injection and at 1(or 2)Hz for Booster injection, as well as 1-minute top-off cycle after filling up.

From the point of view of controls and applications, diagnostics and controls systems can be classified into the following groups, as shown in Figure 2:

- BPM subsystem for orbit feedbacks, lattice measuring, etc;
- Filling pattern measurements based on WCM, FCT, stripline/synchrotron light with photo-diode;
- Loss Control and Monitoring subsystem as well as injection efficiency involving ICT, DCCT, BLM and scraper;

- Camera-based diagnostics such as screen/flag, pinhole system, streak camera, and synchrotron light monitor (SLM);
- Network/Spectrum analyzer-based tune measurement and beam stability monitoring;

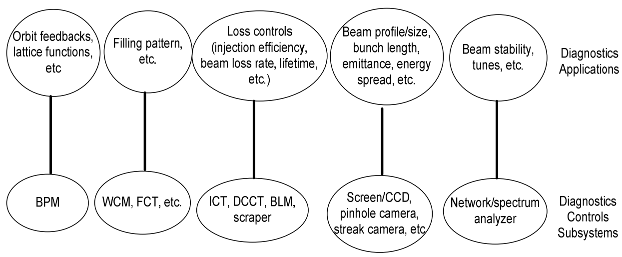

Fig. 2: Diagnostics Control Subsystems and Applications.

Orbit Feedbacks

BPM is the key diagnostics subsystem. BPM data is the source for NSLS-II storage ring fast orbit feedback (FOFB) and slow orbit feedback (SOFB). Orbit feedbacks are made of several parts including BPM pickup button, BPM electronics receiver, global BPMs data communication/exchange links, computing nodes for feedback algorithms, etc.

Diagnostics control system focuses on BPM receivers (Libera Brilliance or in-house electronics). It will provide 10 KHz fast acquisition (FA) data for FOFB over fast communication links (RocketIO-based Gigabit-Ethernet) and 10Hz slow acquisition (SA) data for SOFB over EPICS Channel Access (CA) network. Both FA and SA data from each BPM will be globally synchronized.

Besides orbit feedbacks application, BPM can be used for measuring turn-by-turn dynamics, chromaticity, dispersion, lattice functions, etc.

Filling Pattern Measurement

BPM Thanks to the high bandwidth of WCM (~3GHz), FCT (~1.7GHz), stripline (>1GHz), they can be used to observe individual bunch shape from the multi-bunch trains (80~150 bunches, 500MHz). So, WCM, FCT and stripline are chosen to measure filling pattern which is required for NSLS-II top-off operation.

The diagnostics controls will provide the data acquisition and process systems with over 1GS/s sampling rate and 8-bit resolution to observe the shape of each bunch whose duration is 2ns (500MHz) and calculate the charge of each bunch.

Loss Control & Monitoring

ICT (by Bergoz, coupled with BCM), DCCT (by Bergoz), BLM and scraper will be deployed in loss control and monitoring (LCM) which is designed for monitoring and controlling radiation losses in NSLS-II. LCM should be interlocked to top-off injection. The bunch charge losses (injection efficiency) will be monitored by ICT and DCCT. BLMs will be used to confirm beam loss locations around the ring. And scrapers can be used to intercept beam and control beam losses.

The diagnostics control system will digitize the DC voltage outputs from ICT&BCM, DCCT and then calculate the injection efficiency, beam losses rate, beam lifetime, etc.

Camera-based Diagnostics Applications

Various cameras will be used in beam diagnostics for measuring beam profile, beam size, emittance, energy spread, bunch length, etc. Screens (flags) coupled with CCD cameras placed over the whole NSLS-II accelerators are very useful to trace beam position and observe beam profile during machine commissioning. Synchrotron-light-based measurements in the Storage Ring diagnostics beamlines will be conducted on streak camera to measure bunch length and on pinhole camera to measure beam size, transverse emittances, energy spread, etc.

To standardize CCD camera controls, the digital cameras used in flags and pinhole-systems will be purchased from the same manufacture and have the same control/communication interface. Gigabit-Ethernet interface is preferable to FireWire (1394b) in terms of bandwidth, cabling, anti-EMI, etc. Prosilica Gig-E CCD camera is under evaluation. The diagnostics control system will acquire the digital image from CCD camera and then send the raw data (pixels) to MatLab-based high level application for image analyzing and processing(background subtraction, Gaussian fit, calibration, etc).

The streak camera system itself contains control & data acquisition software. It only interfaces to timing system. .

Network/Spectrum Analyzer-based Diagnostics

Tune monitor is used to measure transverse tunes by two strip-lines (signal pickup and source excitation) and one network analyzer. Beam stability monitor will observe spectrum of beam motion using one pickup strip-line and one real time spectrum analyzer.

Modern network/spectrum analyzers are usually equipped with Ethernet/GPIB interfaces and Windows XP operating system. For diagnostics controls, they can be characterized as Ethernet-based instrument control.

CONCLUSIONS

Collaboration between NSLS-II Diagnostics Group, Controls Group and Physics Group has been well established from very beginning of our project. Beam diagnostics requirements for controls are well understood.

REFERENCES

[1] NSLS-II Preliminary Design Report", http://www.bnl.gov/nsls2/project/PDR.
[2] Yong Hu, et al., "BPM Inputs to Physics Applications at NSLS-II", Proceedings of PAC 2011, New York, NY, US.