DIAGNOSING NSLS-II: A NEW ADVANCED SYNCHROTRON LIGHT SOURCE*

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Abstract

NSLS-II, the successor to NSLS (National Synchrotron Light Source) at Brookhaven National Lab, is scheduled to be open to users worldwide by 2015 as a world-class advanced synchrotron light source because of its unique features: its half-mile-circumference (792 m) Storage Ring provides the highest beam intensity (500 mA) at medium-energy (3 GeV) with sub-nm-rad horizontal emittance (down to 0.5 nm-rad) and diffraction-limited vertical emittance at a wavelength of 1 Å (<8 pm-rad). As the eyes of NSLS-II accelerators to observe fascinating particle beams, beam diagnostics and controls systems are designed to monitor and diagnose the electron beam quality so that NSLS-II could be tuned up to reach its highest performance. The design and implementation of NSLS-II diagnostics and controls are described. Preliminary commissioning results of NSLS-II accelerators, including Linac, Booster, and Storage Ring, are presented.

INTRODUCTION

The construction of NSLS-II (NSLS-2) began in Mar. 2009. Three years later, preliminary Linac commissioning started in Mar. 2012. The Injector, which includes Linac, Booster and transfer-lines in between, has been successfully commissioned by Feb. 2014. The Storage Ring commissioning is on going and in good progress -- 50 mA stored beam was achieved in July 2014. When the whole machine is fully commissioned and tuned up, NSLS-II will be the most advanced third-generation light source in terms of the following parameters:

1) The lowest horizontal emittance at 0.5nm-rad;
2) The smallest beam size at ~3um;
3) The highest beam current (intensity) at 500mA;
4) The highest photon spectral brightness due to the lowest emittance, the smallest beam size, and the highest beam current as stated above.

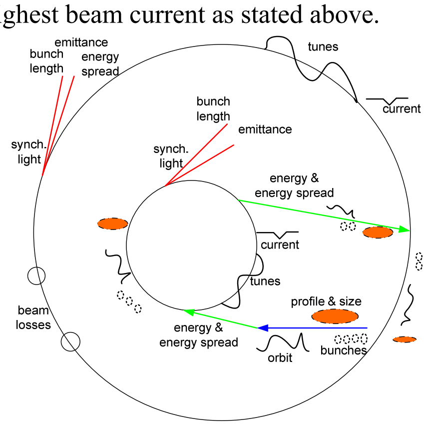

Figure 1: Beam Parameters Measured at NSLS-II.

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Machine commissioning and tuning up is all about diagnosing. To achieve the exceptional performance of NSLS-II, beam diagnostics and control systems are designed to monitor and diagnose the electron beam of NSLS-II accelerator complex. Diagnosing NSLS-II means measuring a variety of beam parameters (~10 types), including beam charge/current, filling pattern, beam position/orbit, beam size/profile, energy spread, tunes, emittance, bunch length, beam losses, etc., via a variety of beam monitors (~16 types, ~370 total device counts as shown in Table 1 below) distributed around the whole machine. Figure 1 briefly shows how the NSLS-II accelerators are diagnosed, i.e. what kind of beam parameters is measured from Linac to Storage Ring.

Effective diagnosing of NSLS-II accelerator depends on the effective combinations of a variety of beam monitors, control and data acquisitions (DAQ), and high level physics applications. Figure 2 shows how beam instrumentation, controls, and physics work together to diagnose the NSLS-II machine.

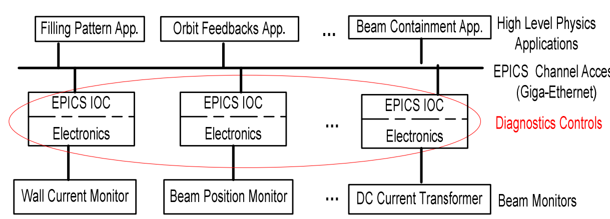

Figure 2: NSLS-II diagnostics and control architecture.

BEAM MONITORS AND SUBSYSTEMS

NSLS-II accelerators consist of one Injector and one Storage Ring (SR). According to the functionality as well as geographical distribution, the Injector is divided into 4 sub-accelerators: Linac, Linac to Booster (LtB) transfer line (including 2 beam dumps), Booster, Booster to Storage ring (BtS) transfer line (including 1 beam dump). Table 1 gives a summary of the beam monitors distributed over the whole machine.

From system functionality and application point of view, the variety of beam monitors as shown in Table 1 could be classified into a few subsystems such as beam position monitor (BPM), filling pattern (Wall Current Monitor, Fast Current Transformer), beam intensity (Integrating Current Transformer, DC Current Transformer), loss control and monitoring (Beam Loss Monitor, Scraper), beam profile (Screen, Visible Light Monitor, Streak camera), tunes, etc., as shown in Figure3.

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Table 1: Beam Monitors at NSLS-II

	Linac	Ltb	Booster	BtS	SR
WCM	5				
Screen/Flag	6	9	6	8	1
BPM	5	6	37	8	180
FCT / FPM		2	1	2	1
Bergoz ICT		2		2	
Energy Slit		1		1	
Faraday Cup	1	2		1	
Bergoz DCCT			1		1
Streak Camera					1
Visible Light Monitor			1		1
X-ray diag. beam-line					1
Tune Monitor			1		1
Transverse Feedback					1
Beam Loss Monitor					5
Beam Scrapers					5
Photon/x-ray BPM					1 or 2 per BL

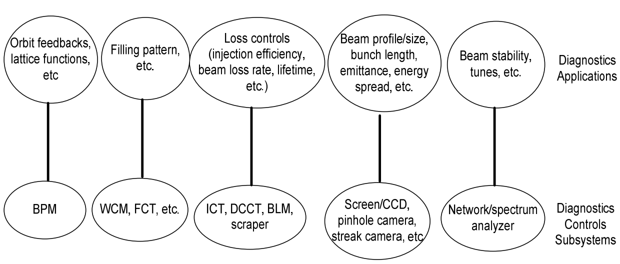

Figure 3: Diagnostics subsystems and applications.

CONTROLS AND DATA ACQUISITIONS

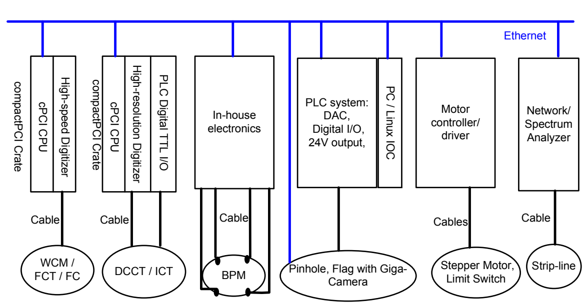

Figure 4: Diagnostics control interfaces.

NSLS-II beam diagnostics control system is completely EPICS-based [1]. Each type of beam monitor requires electronics to process its output signal. The electronics for beam monitors and associated EPICS IOC platform are listed in Table 2. Figure 4 shows the control interfaces for various beam monitors at NSLS-II.

Table 2: Diagnostics Electronics and IOC Platform

Beam Monitor	Diagnostics Electronics	IOC platform
WCM & FCT	Acqiris DC252 (2GHz bw, 10-bit, 4~8GS/s)	cPCI/Linux
DCCT & ICT	1)GE ICS-710-A (24-bit, 200KS/s, 8-ch) 2)Allen-Bradley PLC (DAC, Digital I/O)	cPCI/Linux
BPM	In-house BPM receiver [3]	PC/Linux
Profile / camera	PC/Linux	PC/Linux
Slit & scraper	Delta Tau GeoBrick LV	PC/Linux
Tune	Network analyzer	PC/Linux

PRELIMINARY DIAGNOSING NSLS-II

NSLS-II Storage Ring commissioning started in March 2014. A total of 50-mA stored beam in the Storage Ring was achieved with super-conducting RF recently (see Fig. 5). Although this is still far away from the designed value at 500 mA, it is a major milestone for the NSLS-II Project because the accelerators, including Linac, Booster, and Storage Ring, have been proven working in principle.

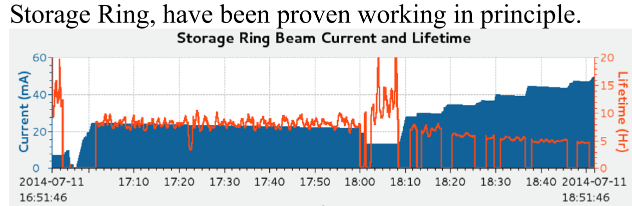

Figure 5: NSLS-II milestone -- 50-mA stored beam.

Beam Intensity Measurement

Beam intensity, also named beam charge (Q) or beam current (I_b), is one of the most important beam parameters for synchrotron light sources. 500-mA stored beam circulating in the Storage Ring is the ultimate goal, which is one of the factors making NSLS-II a world-class light source.

For single-pass accelerators including Linac and transfer-lines (LtB, BtS), the beam intensity is measured as beam charge (Q, nC) via the beam monitor Bergoz ICT. For ring-based circular accelerators including Booster and Storage Ring, the beam intensity is measured as beam current (I_b, mA) via the beam monitor Bergoz DCCT. The charge of circulating beam is actually the beam current multiplying the ring revolution period: $Q = I_b * T_{rev}$. In a sense, beam current and beam charge is interchangeable. Various injection efficiencies, such as

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Booster injection, Booster ramping, Booster extraction, and Storage Ring injection, are calculated by the synchronized shot-by-shot charge ratio between two adjacent ICTs or DCCTs along the beam path.

During NSLS-II accelerator commissioning, the beam current monitors, i.e. Bergoz ICT and DCCT, have been proven very useful and reliable instruments for measuring absolute beam charge with accuracy ~1%. We had noise issues on the ICT & DCCT systems. But we managed to reduce the noise as low as possible by various methods such as adding ferrite beads around the cable, adding low-pass filter (50 Hz) for the Storage Ring NPCT / DCCT, adjusting trigger delay for the BCM / ICT, etc.

Filling Pattern

To achieve ultra-high stored beam current, i.e. 500 mA and meet various beam-line users' requirements, NSLS-II Injector is capable of delivering flexible filling patterns (also named bunch pattern or bunch structure): multi-bunch (80~150 bunches) beam with total charge up to 15 nC or single-bunch with beam charge up to 1 nC per shot. High-bandwidth beam monitors, such as Wall Current Monitors, Fast Current Transformers, together with high-speed digitizers (max. 8GS/s) are used for filling pattern measurement, which provides data of number of bunches, bunch-to-bunch variation, turn-by-turn bunch charge, etc.

During NSLS-II Storage Ring commissioning, we successfully filled any RF bucket using different patterns as shown in Fig. 6.

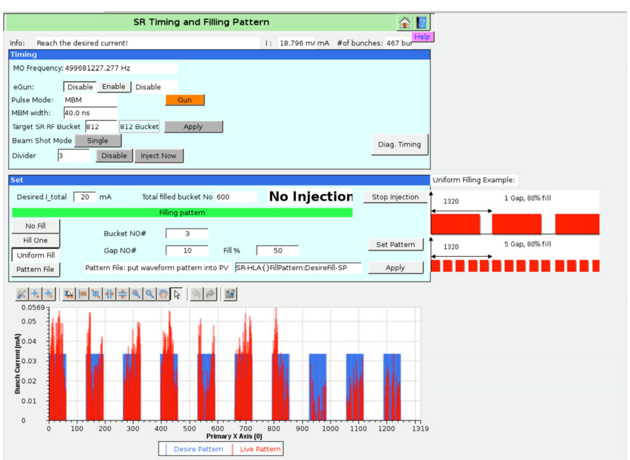

Figure 6: Storage ring filing pattern.

Beam Position Monitor

BPM is the largest as well as the key sub-system for NSLS-II beam diagnostics and controls. Eventually, NSLS-II Storage Ring will reach the lowest emittance and the smallest beam size at ~3 um, which requires BPM resolution at 0.3 um (10% of beam size) to monitor beam position stability. This requirement for the BPM system is quite challenging. Huge efforts have been put in the development of in-house BPM electronics [2], which has demonstrated excellent long-term resolution performance and provided flexible data flows (see Table 2) for various physics applications during machine commissioning.

The BPM has played a vital role during NSLS-II machine commissioning: by using all BPMs' ADC raw data and turn-by-turn data, we made the first-turn beam in the Booster and Storage Ring quickly; by analysing BPMs' turn-by-turn sum signal drop, we found a hanging RF spring in the vacuum chamber, which resulted in the sudden beam loss [3]; The slow orbit feedback was tested and proved to be working as shown in Fig 7.

Table 2: BPM Data & Physics Applications

Data Flow	Data Rate	Applications	Requirements
ADC	117 MHz	diagnostics, debugging	on demand; ~ 3.8K samples
TBT	378 kHz	tunes, phase advance, injection damping, etc.	on demand; 1 um resolution; ~ 380K samples;
FA	10 KHz	fast orbit feedback, machine protection	continuous; 0.4um resolution;
SA	10 Hz	beam-based alignment, response matrix, closed orbit, life-time	continuous; 0.3um resolution;

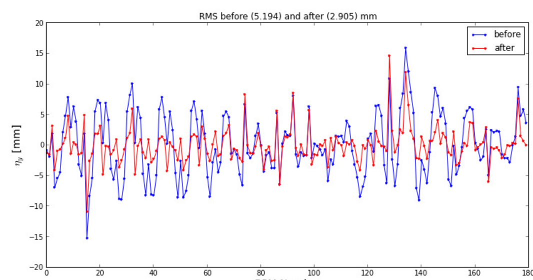

Figure 7: Preliminary test of slow orbit feedback.

CONCLUSIONS

Although we have made a very good start of commissioning NSLS-II accelerators, there are still lots of improvement opportunities for us to make the machine reach its highest performance and make it a world-class light source in the near future. Beam diagnostics and control systems have been tested with beam, proven to be functional, have played and will continue to play important roles for diagnosing NSLS-II.

REFERENCES

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