NSLS-II BEAM INTENSITY MEASUREMENT*

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Abstract

Beam intensity, also named beam charge (Q) or beam current (I_b), is one of the most important beam parameters for synchrotron light sources. At NSLS-II, there are at least two types of beam intensity monitors including Bergoz ICT and Bergoz NPCT. The requirements of beam intensity measurements and the distribution of beam monitors are described. The controls and data acquisition systems for all intensity monitors are presented.

INTRODUCTION

For synchrotron light sources, accelerator uses electrons to produce photons that end users utilize for their research. There are two most important specifications for photons at fixed electron energy: spectral brightness (also named brilliance, its unit is $ph/mm^2/mrad^2/s/0.1\%BW$) and spectral flux density (ph/s/0.1%BW). From the units of the brilliance and flux density, one can conclude that the quality of photons is highly related to beam current ($I_b = Q / T$). That's why beam current is one of the most frequently cited parameters as well as the most important for Storage Ring.

NSLS-II is designed to deliver photons with average spectral brightness in the 2 keV to 10 keV energy range exceeding 10^{21} $ph/mm^2/mrad^2/s/0.1\%BW$ [1]. This cutting-edge performance requires the storage ring to support a very high-current electron beam (500 mA, this will be highest beam current in all 3rd-generaion synchrotron light sources) with sub-nm-rad horizontal emittance (~0.5 nm-rad) and diffraction-limited vertical emittance at ~8 pm-rad. To achieve this high-current (high intensity) requirement, NSLS-II will utilize a full-energy Injector which consists of a 200 MeV Linac, Linac to Booster transport line (LtB), 3 GeV Booster (BSR), Booster to Storage Ring transport line (BtS). The Injector will operate in top-off mode and must supply ~ 7.3nC of charge once per minute. For single-bunch injection mode and a moderate repetition rate of a few Hz, replenishing this amount of charge would take a few seconds, occupying a significant fraction of the overall beam time. Therefore, multi-bunch injection (80~150 bunches) has been adopted, leading to minimal disturbance for user experiments.

REQUIREMENTS AND APPLICATIONS

For single-pass accelerators including Linac and transfer-lines (LtB, BtS), the beam intensity is measured as beam charge (Q, nC). For ring-based circular accelerators including Booster and Storage Ring, the beam intensity is measured as beam current (I_b, mA) and this current is actually the beam charge by multiplying the ring revolution period: $Q = I_b * T_{rev}$. In a sense, beam current and beam charge is interchangeable.

There are many applications of beam intensity measurement and different application has different data acquisition requirements in terms of accuracy, sampling rate, etc.

One of the most important applications is injection efficiency measurements. This is done by comparisons between the charge measured by Bergoz ICTs [2] at transport lines and that measured by Bergoz NPCTs (also named DCCT) [2] at Booster and Storage Ring. For this kind of application, 1% measurement accuracy is enough. Figure 1 shows the distribution of beam intensity monitors at NSLS-II and the injection efficiency measurements around the whole machine.

Another important application is circulating beam current and beam lifetime measurements in the Storage Ring [3]. This is measured by Bergoz NPCT 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 1 kS/s sampling rate should be sufficient. The required resolution for digitizer is determined by the requirement on accuracy of beam lifetime measurement: it's 2% for 20 mA with 60-hour lifetime and one minute measurement interval for NSLS-II. An 18-bit ADC/digitizer seems adequate for all these applications.

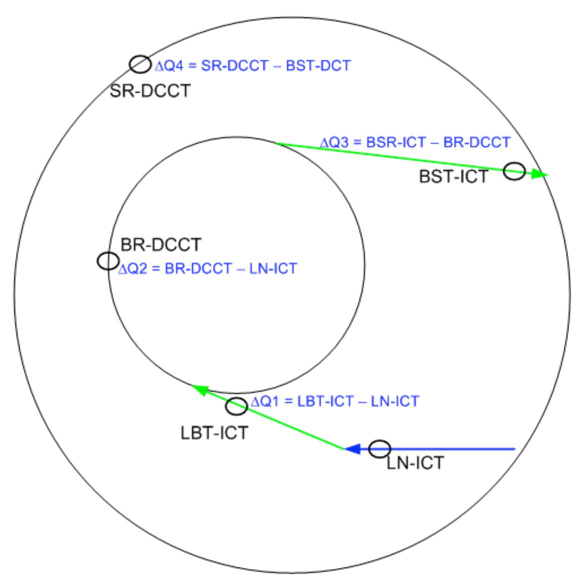

Figure 1: NSLS-II beam intensity monitors and injection efficiency measurements.

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Beam intensity measurements involve timing, diagnostics, controls, etc. This paper focuses on data acquisition and controls: how to measure beam charge or current and make this information available in the EPICS-based [4] control system.

BEAM INTENSITY MONITORS

NSLS-II beam intensity measurement system provides absolute charge distribution along with the whole machine. This measurement requires combination of beam monitors (ICT, DCCT, etc.), data acquisition (DAQ) and controls (high-resolution digitizer, EPICS software, etc.) and Event Timing system [5]. Figure 2 shows the system architecture.

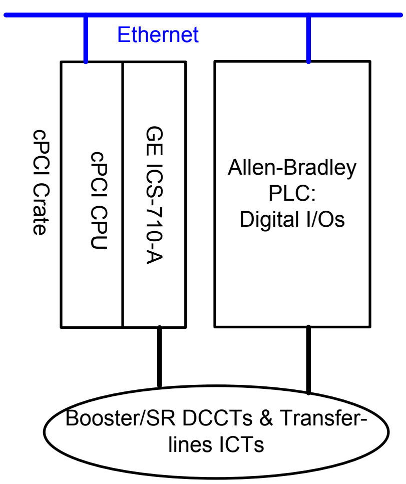

Figure 2: Overview of beam intensity measurement.

Everywhere possible, NSLS-II will use known, reliable, and cost-effective solutions for its subsystems. This policy is really true for beam intensity measurements. We're using two types of commercial off-the-shelf (COTS) beam monitors from Bergoz distributed around the machine (shown in Figure 1): 1 ICT (Integrating Current Monitor) in Linac, 1 ICT in LtB, 1 NPCT (New Parametric Current Transformer) in BSR, 1 ICT in BtS and 1 NPCT in Storage Ring.

Bergoz provides another current detector named Fast Current Transformer (FCT). But the main purpose of FCT is to measure filling pattern, the bunch-to-bunch charge information (number of bunches, BtB variation, etc.) [6].

Integrating Current Monitor

Bergoz ICT is a sensor only with one coaxial output. Its output voltage integral is in exact proportion to the beam pulse charge, irrespective of the bunch width, i.e. irrespective of the bunch frequency spectrum. For NSLS-II Linac injection with the maximum 150 bunches (500MHz RF), the bunch train to be integrated and measured is 298ns long. It will pass through the ICT and the ICT output will be a 368 ns long signal with rise-time (10%-90%) about 20 ns, fall-time (10%-90%) about 30 ns and a flat top (if the 150 bunches are evenly charged). The ICT's only drawback is that the original shape of the signal is lost.

Bergoz BCM (Beam Charge Monitor) is a piece of electronics in a chassis for ICT. It has a bipolar voltage output that is directly proportional to the total beam charge. BCM electronics are made in various versions. The version to measure single pulse or bunch trains up to 5us long is called BCM-IHR-E (Integrate-Hold-Reset).

We're using both ICT and BCM for beam charge measurements at NSLS-II.

New Parametric Current Transformer

DC current transformer (Bergoz NPCT) will monitor the stored current in Booster Ring and Storage Ring. The NPCT has large dynamic range and high bandwidth, making it a versatile device for measuring lifetime and injection efficiency. It is insensitive to a synchrotron revolution frequency and bunch fill pattern, with residual modulator ripple being eliminated, thus enabling full bandwidth operation down to a very low current. Its resolution is better than 1 μA/Hz½. Such a small noise will allow measurement of the expected 60 hours lifetime for 20mA circulating in one minute with 2% accuracy (assuming a 1 Hz sampling rate). The high bandwidth of the DCCT will allow measurements of the steps in the current after injection, and therefore provide a means of continuously monitoring injection efficiency.

DATA ACQUISITION & CONTROLS

High-accuracy beam intensity monitor requires high-resolution digitizer to sample its analog output signal. As the data acquisition requirements analyzed above, 18-bit digitizer should be adequate for all applications such as injection efficiency, beam lifetime, etc.

Hardware

As shown in Figure 2, GE ICS-710-A high-resolution compactPCI digitizer (24-bit, up to ~215KS/s, 8-channel, 4M Bytes memory, up to -10V~10V input range) is selected as standard for all slow-speed while high accuracy applications including beam intensity measurements. Beam monitors associated with controls hardware in each sub-accelerator are listed in Table 1.

Additional to the cPCI digitizer, Allen-Bradley PLC digital I/O modules (with Ethernet communication module) will be used to setup DCCT's and BCM's range, bipolarity, etc.

Table 1: Filling Pattern Monitors & DAQ Hardware

Sub-accelerator	Beam Monitor	Digitizer
Linac	1 ICT	1 ICS-710-A
LtB	1 ICT	Shared with Linac
Booster	1 NPCT	1 ICS-710-A
BtS	1 ICT	1 ICS-710-A
Ring	1 NPCT	1 ICS-710-A

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Software

NSLS-II beam diagnostics control system [7] will be completely based on EPICS. For OPI (operator interface) GUIs, CSS (Control System Studio) is our preference. The preferred operating systems are RTEMS (Real-Time Executive for Multiprocessor Systems) and Linux/Debian. For cPCI-based controls, the CPU board will be standardized as GE CT11 and diskless PXE booting Linux & EPICS driver is done by Debirf (DEBian on Initial Ram Filesystem).

The EPICS driver for ICS-710-A digitizer is developed and available on EPICS source forge [8]. The driver named ‘EtherIP’ for Allen-Bradley PLC is developed by SNS (Spallation Neutron Source) and also available on the source forge.

BENCH TESTS

We have performed bench tests on Bergoz ICT, Bergoz NPCT and ICS-710-A digitizer.

Bench Tests on ICT

We have purchased 4 Bergoz ICTs coupled with 4 BCMs. Figure 3 shows one of our acceptance tests: the BCM front-panel “Calibration” switch is on, the calibration pulse is during the first (subtracting) integrating window so that the BCM output signal is negative.

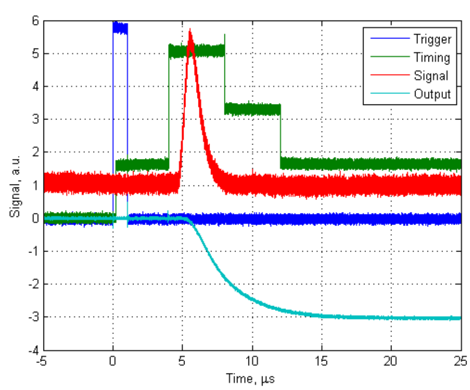

Figure 3: Bergoz ICT tested with BCM.

Bench Tests on NPCT

We have purchased one Bergoz NPCT including the sensor and its electronics. We have calibrated the whole system against precise current source from Krohn-Hite KH526. Noise of the measurement is another factor affecting the accuracy beside calibration so that noise measurements were performed. Figure 4 shows the spectral noise density for 200 mA range. The spectral noise density in the 2 kHz bandwidth is around 0.1µA/Hz½, which is well below the specified level of 1 µA/Hz½.

Bench Tests on ICS-710-A

We tested the digitizer in temperature-controlled rack (+/- 0.2 degree C variation) and its effective number of bit (ENOB) is almost 18-bit. We also calibrated the digitizer against Krohn-Hite KH526. Figure 5 shows its excellent linearity.

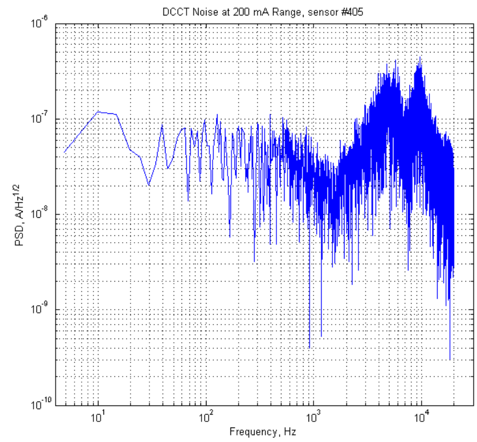

Figure 4: Bergoz NPCT spectral noise density.

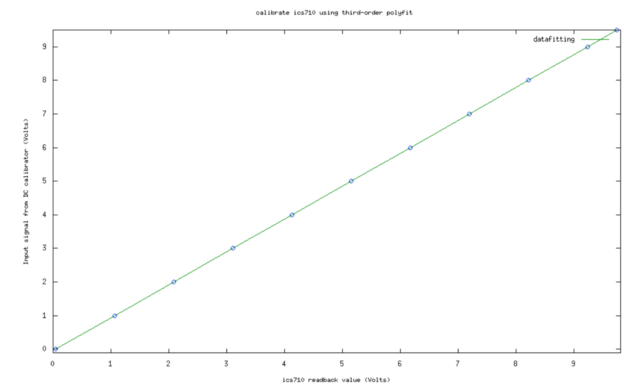

Figure 5: ICS-710-A digitizer linearity.

CONCLUSIONS

Beam intensity measurements are well understood and the controls hardware & software are well tested. We’re ready for NSLS-II Injector installation and commissioning.

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