NSLS-II INJECTOR SYSTEM DIAGNOSTICS

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Abstract

The NSLS-II Injector System Diagnostics will provide instrumentation in the linac, Booster, Transfer Lines and Beam Dumps for measuring key beam parameters. These instruments will be adequate for staged commissioning of NSLS-II injectors, and will allow sufficient beam diagnostics for tune-up and top-up operations. This paper summarizes the status of the NSLS-II injector system diagnostics, focusing on those intended for the transfer lines, including the Linac to Booster (LTB) and Booster to Storage Ring (BSR).

INTRODUCTION

The NSLS-II is a state-of-the-art 3-GeV synchrotron light source being developed at Brookhaven National Laboratory. The injection system will consist of a 200 MeV linac, a 3 GeV booster synchrotron, and associated transfer lines. The instrumentation in the linac will provide sufficient beam diagnostics to determine bunch charge, length, transverse size, position, and beam losses. The LTB and BSR will include key instruments to be used for beam commissioning and tune-up, particularly the beam dumps and those diagnostics elements within the booster vault. Measurements of beam charge, bunch train, bunch charge, energy jitter, emittance, and energy spread can be achieved. Booster diagnostics will provide measurements for orbit correction, injection matching and transverse profile. In addition, elements are provided to measure beam current, bunch train pattern, tune and chromaticity. This paper will detail the implementation of these diagnostics components for the NSLS-II Injector System.

LINAC DIAGNOSTICS

A turn-key procurement, the NSLS-II linac is specified to have an output energy of 200 MeV, energy spread of 0.5%, bunch length of 20 ps, and normalized emittance of 55 mm-mmrad. The linac will be capable of operating in single bunch mode with a charge of up to 0.5 nC, or in multibunch mode with a bunch train of 80 to 150 bunches, separated by 2 ns with a charge per train of 22 nC. The linac will have a 100 kV electron gun with thermionic cathode, sub-harmonic pre-buncher, 3 GHz pre-buncher, 3 GHz buncher, and a 3 GHz acceleration section. Linac diagnostics will consist of a Wall Current Monitor (WCM) after the gun, and another before the buncher. There will be a WCM, FLAG, and Beam Position Monitor (BPM) before each LINAC tank. This will provide sufficient diagnostics to determine bunch charge, length, transverse size, and position. The WCMs will also provide a measure of the beam losses in the linac. Refer to the Diagnostics Table of Elements and the Plan View of Injector as shown in Table 1 and Figure 1 respectively.

Table 1: Gun and Linac Diagnostic Elements

System	Qty	Type	Abbrv.	Parameter Measured
Electron Source (Gun)	2	Wall Current Monitor	WCM	Intensity; longitudinal beam characteristics
Linac	3	Fluorescent Screens	FLAGS	Position; transverse profile
Linac	3	Wall Current Monitor	WCM	Bunch charge; intensity; beam loss
Linac	3	Beam position monitor	BPM	Beam position

BOOSTER DIAGNOSTICS

A turn-key procurement, the NSLS-II Booster is a 158 m combined-function-magnet synchrotron with an extraction energy of 3 GeV for top-up injection. The beam emittance will be damped below 50 nm-rad, with trains of up to 150 bunches. The bunch length will be 15 ps, and the energy spread will be 0.08% when fully damped. The expected total charge out of the booster is estimated at 10 nC when the linac is in multi-bunch mode. Booster diagnostics are chosen for commissioning and robust operation.

The booster will have 36 BPMs placed at strategic points in the ring to allow for robust orbit correction. Six flags will be located in the booster for commissioning, injection matching and transverse profile measurements. Beam current will be measured with a DCCT. An FCT will monitor the bunch train pattern. A pair of stripline kickers will be available for tune and chromaticity measurements, also serving in a beam cleaner system. Synchrotron light will also be used in conjunction with a streak camera to measure the bunch length. The diagnostic elements of the Booster are listed in Table 2.

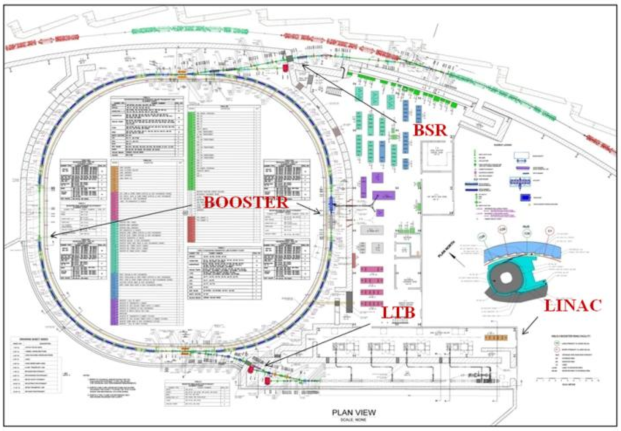

Figure 1: Injector system.

Table 2: Booster Diagnostic Elements

Qty	Type	Abbrv	Parameter or Role
1	DC Current Xfmr	DCCT	Beam current
1	Fast Current Xfmr	FCT	Bunch charge
1	Strip Line Detector	SLD	Tune meas.
1	Strip Line Detector	SLD	Bunch cleaning
6	Fluorescent Screens	FLAGS	Beam intensity, shape, position
1	Streak Camera	OBSC	Bunch length
1	FireWire Camera	FWC	Beam position, profile
36	Beam position monitor	BPM	Beam position; orbit

A Bergoz Fast Current Transformer (Figure 2) will be used for fill pattern monitoring. The FCT will be directly mounted on the beam chamber with a ceramic break and RF shielding, and will provide an

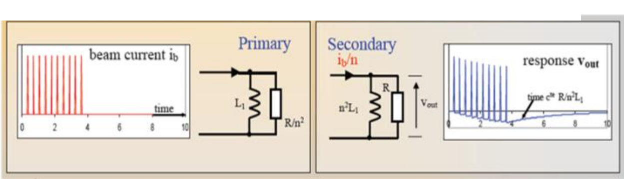

Figure 2. Bergoz fast current transformer.

electrical signal proportional to the charge of individual bunches. It has 1.75 GHz bandwidth with a 200 ps rise time. Fast ADC sampling (>1GS/s) of the FCT output voltage will make charge distribution available to the control system. The information obtained will be used in the top-off algorithm.

The ICT/BCM (Figure 3) will provide a multiply time integral output, which is proportional to the beam pulse charge irrespective of the bunch width or bunch frequency spectrum. For NSLS-II Linac injection, with the maximum 150 bunches (500 MHz RF), the bunch train to be integrated and measured is 298 ns long. It will pass through the ICT and the ICT output will be a 368ns long signal with a rise time of about 20 ns, a fall time of about 30 ns, and a flat top (if the 150 bunches are evenly charged). The Bergoz BCM is comprised of a chassis and module. It has a bipolar voltage output that is directly proportional to the total beam charge. BCM electronics are made in various versions. The BCM-IHR-E (Integrate-Hold-Reset) module has been selected to measure a single pulse or bunch trains up to 5 us long.

LINAC TO BOOSTER (LTB) TRANSPORT LINE DIAGNOSTICS

The layout of the LTB transport line was shown in Figure 1. It consists of 3 sections: a linac to achromatic section, an achromatic, and a matching section into the booster. In addition, there are two beam dumps located in the linac vault that will be used for commissioning, tune-up and diagnostics. Table 3 shows the available diagnostics in the LTB.

Table 3: Diagnostics—Transport Lines

Type	Qty (LTB)	Qty (BSR)	Resolution	Beam Parameter Measured
Screens (OTR + YAG)	9	10	10/30 µm	Energy spread; electron beam size, position
Fast current xfmr	2	2	~0.6 pC per bunch	Fill pattern; bunch charge
Energy slit	1	1	n/a	Beam energy spread
Integrating current xfmr	2	2	~10 pC per train	Injected bunch charge; injection efficiency
BPM (40× 90 mm elliptical)	1		30 µm	Beam position
BPM (40 mm round)	5	8	30 µm	Beam position
Faraday cup	2	1		Bunch charge

There are FLAGS at the start of the LTB, after the Energy Slit, and prior to booster injection that will be used for commissioning. An Integrating Current Transformer (ICT) and a Fast Current Transformer (FCT) measure the beam charge and bunch train at each end of the LTB (Figure 3). An Energy Slit will be placed at the maximum dispersion location in the achromat, to remove any low energy particles.

Six BPMs are placed throughout the LTB. The first is at the end of the linac. One exists after the Energy Slit for online energy jitter measurement. Four BPMs are in the matching section for matching into the booster. There is also a Safety Shutter placed before the exit of the linac vault that will allow safe operation of the linac independent of the status of the booster. The beam dumps are equipped with FLAGs, including three FLAGs in the “straight ahead” beam dump for emittance measurement. The second beam dump will have sufficient dispersion to perform energy spread and energy jitter measurement. In each beam dump will be a Faraday cup, which will also act as a beam stop and will measure gross charge per train, capturing the entire charge of the electron beam and its shower for all dumps.

BOOSTER TO STORAGE RING (BSR) TRANSPORT LINE DIAGNOSTICS

Extraction from the booster is performed with a four bump scheme. A kicker imparts a 5 mrad angle, which is then followed by thin pulsed septum, and a large DC septum into the BSR line. The BSR line consists of 3 main sections, the booster extraction, an achromatic transport, and the matching section. There is also a beam dump in the booster vault for commissioning and tune up.

Extraction from the booster is performed with a four bump scheme. A kicker imparts a 5 mrad angle, which is followed by a thin pulsed septum, then a large DC septum leading into the BSR line. The BSR line consists of 3 main sections, the booster extraction, an achromatic transport, and the matching section. There is also a beam dump located in the booster vault for commissioning and tune up.

The BSR line has nine FLAGs. Two are placed before the first dipole to commission booster extraction. Three are in the achromat section for emittance measurements. Three are in the matching section for injection matching. The last FLAG is prior to the beam dump to allow for energy spread measurements. There is an FCT in the booster extraction section and near the injection point to measure the bunch train distribution.

There is an ICT (Figure 3) near the injection point to measure the bunch charge. Eight BPMs are placed in the transport line. Two BPMs are in the booster extraction section, three are in the achromat, and remainder are in the matching section. An Energy Slit near the maximum dispersion region limits the energy spread entering the storage ring. A Safety Shutter near the exit of the booster vault allows operation of the booster independent of the storage ring. The booster beam dump is equipped with a FLAG for energy spread measurements. It also has an ICT for bunch charge measurements. The beam dump will be used for booster commissioning and tune-up, allowing for characterization of the booster independent of the storage ring status. Incorporated into the beam dump will be a Faraday cup that will also act as a beam stop and will measure gross charge per train, capturing the entire charge of the electron beam and its shower.

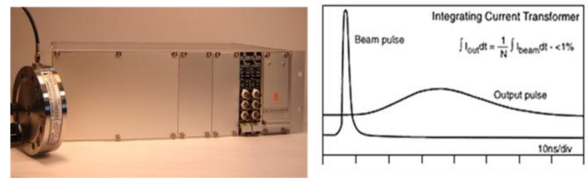

Figure 3. Integrating current transformer (ICT).

CONTROLS INTERFACE FOR DIAGNOSTICS

Diagnostics control subsystem will conform to NSLS-II control system standards. It will be EPICS-based and the preferred operating systems for IOCs (Input / Output Controller) are RTEMS (Real-Time Executive for Multiprocessor Systems) and Linux. For VME-based controls, the CPU board will be standardized as Motorola MVME3100. Whenever possible, diagnostics controls will use commercial off-the-shelf hardware to reduce cost as well to achieve better reliability. Although the NSLS-II Linac and Booster are turn-key solutions provided by vendors, the intention is to standardize the diagnostics controls for the whole machine. Each type of beam monitor requires controllers to process its output signal. The proposed electronics for the above groups and associated EPICS IOC platform are listed in Table 4.

BPM CHAMBER ASSEMBLY

The BPM system tracks the position of the beam by measuring the levels of the signals induced on the BPM pick-up electrodes. The signals are delivered to the receivers inside the temperature controlled rack outside the tunnel. The processed beam position is available to the control system for the orbit readback. Transport line parameters affecting the design of BPM receivers include; RF frequency of 499.68 MHz, 1-150 bunches, maximum multi-bunch charge of 39 nC in 80 bunches, and maximum single bunch charge of 1.0 nC. The BPM pick-up electrodes will be placed on two types of vacuum chamber. The first type (Figure 5) has a round vacuum chamber with inner diameter of 40 mm; the second type (Figure 7) has an elliptical cross-section with vertical aperture of 40 mm and horizontal aperture of 90 mm.

Table 4: Controls Electronics and IOC Platform

Type	Controls Electronics	EPICS IOC Platform
WCM and FCT	Acquiris Digitizer DC252 (10 bit, 4-8 GB/sec)	CompactPCT/ RTEMS
DCCT and ICT	• Hytec 8002 carrier board • Hytec IP-ADC-8401 (8 channel, 16 bit, 100 kHz) • Agilent 3458 DVM (8.5 digit, 18 bit, 2 kS/s) • GPIB-to-Ethernet converter	VME/RTEMS
BPM	• I-Tech Libera Brilliance (baseline) • Custom electronics developed in house	Embedded Linux IOC
Gigabit Ethernet cameras	Motorola MVME 3100 (CPU)	VME/RTEMS
Stepper motor based	• PRO-DEX OMS MAXV-8000 • HYTEC MDS-8	VME/RTEMS
Instrument controls	Windows-based network/spectrum analyzer	X86/Windows
Digital I/O and DAC	• Hytec 8001 carrier board digital TTL I/O • Allen-Bradley compactLogix for 24V digital output • Hytec IP-DAC-8402 (16 channel, 16 bit)	VME/RTEMS

The pick-up electrodes can be mounted on the DelSeal CF flange with an SMA coaxial feedthrough (Fig. 4). A button mounted on the pin will have 15 mm diameter. For the elliptical vacuum chamber (40×90 mm) the distance between button centers will be at least 28 mm (defined by the CF flange size), while for the round vacuum chamber due to the 45° tilt of an assembly distance between centers will be about 28.3 mm.

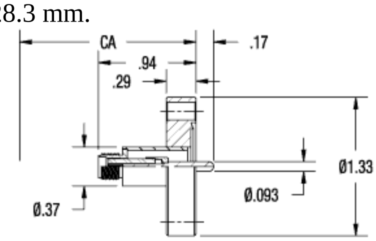

Fig. 4: Conflat flange with SMA coaxial feedthrough. Shown here is a possible model by MDC Vacuum Products. Dimensions in inches.

Round Chamber

Figure 5 shows the 40 mm round chamber assembly.

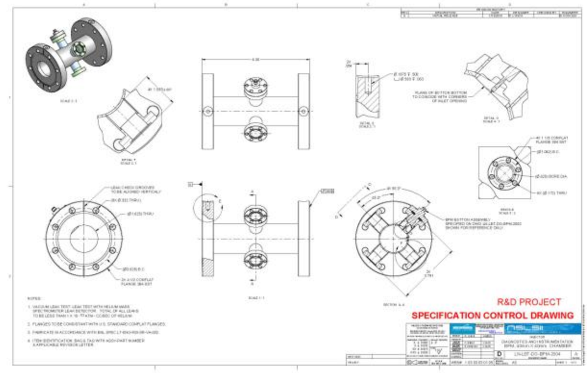

Figure 5: 40 mm round chamber assembly.

Sensitivity to the beam motion was found using a Matlab script for solving 2D electrostatic problems. The probe charge was placed in the different position inside a vacuum chamber and the induced charges on the buttons were found. For the round vacuum chamber, the ratio of difference over sum is shown in Fig. 6 for the horizontal and vertical planes.

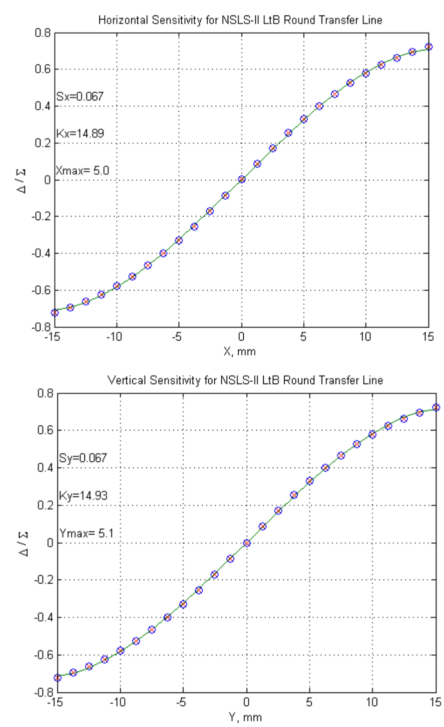

Fig. 6: Horizontal (top) and vertical (bottom) beam motion sensitivity for the round chamber. These figures have sensitivity numbers (Sxy), coefficients for calculating position from the measured BPM button voltages (Kxy), and limits were linearity drops by 10% from the central region. With centered beam, each button intercepts 12.4% of a passing charge.

Elliptical Chamber

Figure 7 shows the elliptical (40 x 90 mm) chamber assembly.

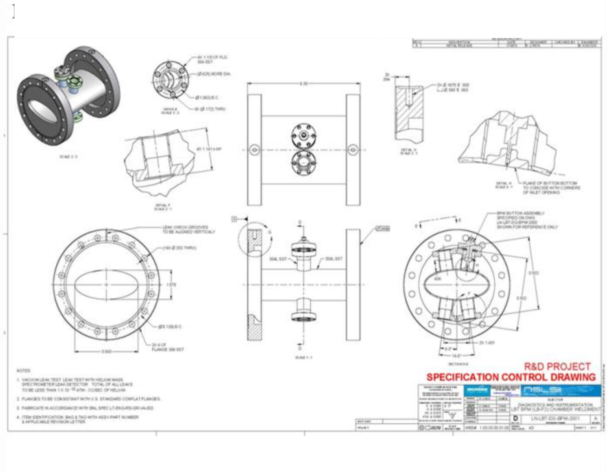

Figure 7: Elliptical (40 x 90 mm) chamber assembly.

For the elliptical vacuum chamber, the ratio of difference over sum is shown in Fig. 8. The sensitivity for beam motion in the horizontal plane is better but in the vertical plane is half as great. The latter fact can affect accuracy of vertical beam position measurements in the wide vacuum chamber.

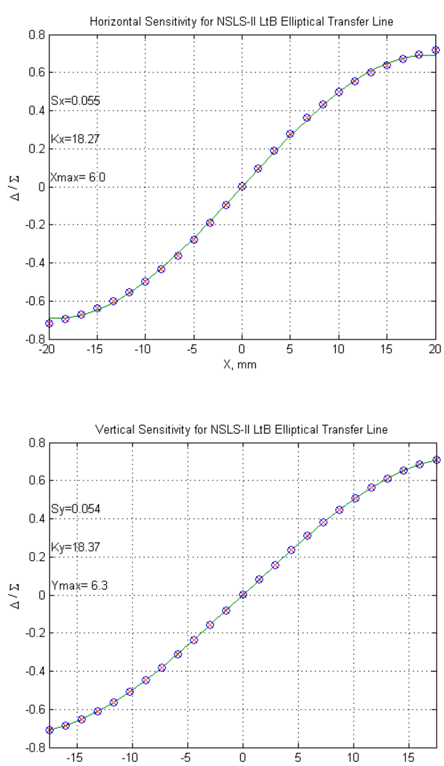

Fig. 8: Horizontal (top) and vertical (bottom) beam motion sensitivity for the elliptical chamber.

With the centered beam, each button intercepts 11.6% of a passing charge. Using the value for the fraction of induced charge, the signal on the button was evaluated for the button with 2.5 pF capacitance and 1 nC single bunch (Fig. 9). The power level of 6.4 dBm at 500 MHz frequency is for CW beam with 1 nC in each bunch. For a single pass the duration of the signal will be extended by a RF front end filter. For Libera Brilliance it is approximately 300 nanoseconds (therefore it will not be able to distinguish between single bunch and long pulse modes). Previous tests showed that for a 1 nC single bunch, Libera Brilliance provides resolution of 10 microns with k=10 mm. In our case, due to the larger vacuum chamber size, sensitivity is lower. Nevertheless, we should be able to reach the specified parameters of 10 × 1.5 / 0.5 = 30 microns.

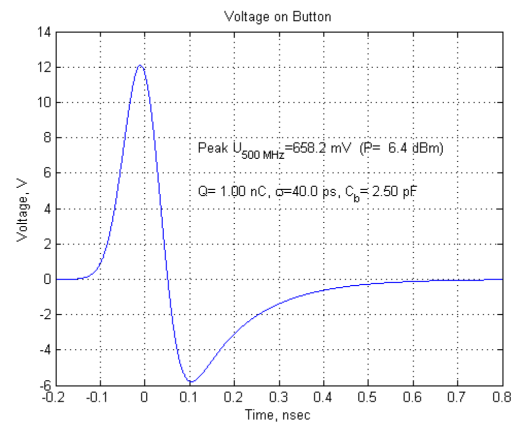

Fig. 9: Signal induced by a centered single bunch with 40 ps (rms) length and 1 nc charge on a button in the elliptical chamber.

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