STATUS OF BEAM DIAGNOSTICS FOR NSLS-II BOOSTER

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Abstract

For the NSLS II third generation light source, a full-energy Booster ring has been designed and produced by Budker Institute of Nuclear Physics. For the Booster commissioning and operation, a complete set of beam diagnostic instruments have been provided: 6 beam flags, 36 electrostatic beam position monitors (BPMs) with signal processing electronics, 2 synchrotron light monitors (SLMs), 1 DC current transformer, 1 fast current transformer, Tune Measurement System (TMS) including 2 strip-line assemblies. All the equipment has been installed in the Booster ring and Injector Service Area. Control software of the beam diagnostic devices has been developed and incorporated into the NSLS-II control system using the EPICS environment. A number of high-level applications has been developed using Control System Studio and Python. The subsystem integrated testing and the extended integration testing have been performed. Current status of the Booster beam diagnostic instrumentation is reviewed.

INTRODUCTION

For the NSLS II third generation light source, a full-energy Booster ring [1] has been designed and produced by Budker Institute of Nuclear Physics (BINP). The Booster will accelerate 200-MeV electron beams injected from the linac up to 3 GeV energy required for the Main Ring. The beam intensity varies from 0.5 nC in single-bunch mode up to 15 nC in multi-bunch mode. The nominal repetition rate is 1 Hz with a possibility to upgrade up to 2 Hz. Now, all the Booster equipment has been manufactured, delivered and installed.

A complete set of beam diagnostic instrumentation [2] has been designed, manufactured and installed: 6 beam flags, 36 beam position monitors (BPMs) with signal processing electronics, 2 synchrotron light monitors (SLMs), 1 DC current transformer, 1 fast current transformer, Tune Measurement System (TMS) including 2 strip-line assemblies.

Current status of the Booster beam diagnostic instrumentation is discussed in this paper.

BEAM FLAGS

Six fluorescent screens (beam flags) have been installed in the Booster to measure transverse beam profile and position in single-pass mode. These beam flags are designed to be used for commissioning and troubleshooting of the Booster. The first beam flag is used to adjust the injection septum and kickers. To close the first turn, we can observe the beam on the flags installed at the end of each arc. The beam flags located in the extraction section are designed for beam extraction optimization.

The Cerium-doped Yttrium Aluminium Garnet (YAG:Ce) screens have been produced by Crytur. Typical resolution of the screen is about 50 µm. Absolute light yield calibration of the YAG:Ce screen has been done in BINP [3] using a 350-MeV electron beam of about $7 \cdot 10^5$ particles (0.1 pC).

The screen is placed inside a stainless-still cylindrical volume, which can be moved inside and outside of the vacuum chamber. To move the beam flags, FESTO pneumatic actuators DSNU-25-80-PPS-A are used. Mechanical drives of the beam flags have been designed and produced by BINP.

CCD cameras GC1290 made by Allied Vision Technology with Tamron objective lens M118FM25 are used for the beam image registration. The CCD-cameras are placed outside the median plane of the accelerator and is radiation-protected by lead shields.

The beam flag components can be reconfigured and interchanged without vacuum deterioration. Now, all beam flags have been installed in the Booster tunnel and connected to the compressed air pipe and control electronics.

An integration testing of the beam flags including hardware, controls and software has been carried out in BNL. For the image calibration, we use LED to illuminate the YAG:Ce screen, which has visible markers as shown in Fig. 1. Using the markers, we can check and adjust the optics alignment and calibrate the image on line.

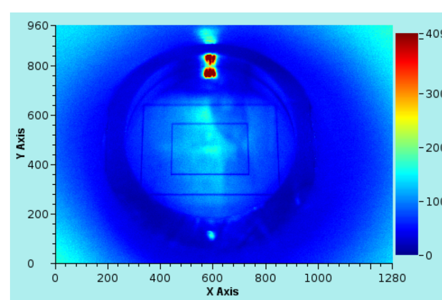

Figure 1: YAG:Ce screen with markers.

During the tests, all optical instruments registering flag images were aligned and focused. Some modifications have been done in the control and data acquisition software to improve the system performance. A parasitic background was observed on the screen images. As it was found, this background results from the backlight reflection on inner walls of stainless tubes, inside of which light comes to the CCD cameras. This means the beam image will be affected by this background too. To fix this problem, a light absorber inside the tube was proposed to minimize the reflected light effect. A set of the absorbers has been produced by BINP and now installed into the flag tubes.

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BEAM POSITION MONITORS

Electrostatic BPMs are placed in the Booster ring for beam orbit measurement and correction. Turn-by-turn data acquisition is also provided.

The BPM housings have been designed and manufactured by BINP. There are two housing types: 28 BPMs for the Booster arcs have an elliptical cross-section of 41x24 mm^2, and 9 BPMs for the straight sections have a cross-section of 62x22 mm^2. In total, 37 BPM housings have been manufactured by BINP workshop, the designed mechanical tolerance of 50 µm has been checked using a Zeiss Coordinate Measuring Machine.

Each BPM contains four button-type electrodes (15 mm diameter) connected to vacuum-tight feedthroughs with 50Ω SMA plugs. The pickup-electrode assemblies have been produced by MPF Products. This part of BPM is exactly the same as for NSLS-II beam transport lines. A quality problem was faced when assembling the 1st BPM in the BINP workshop: the design dimensional tolerances of 0.005″ (127 µm) were not fulfilled. For all pickup-electrode assemblies, the button-flange angular misalignment and button-flange coaxiality have been measured with 2 µm accuracy using a Zeiss Coordinate Measuring Machine. Five defective buttons have been replaced by MPF according to manufacturer's warranty and the manufacturing process has been modified to improve the quality.

After assembling, the electrical characteristics of all BPMs have been measured using a test bench with a moving antenna simulating a beam signal. A 3rd–order polynomial linearization of the measured beam position is planned to be implemented in orbit measurement, especially during commissioning, when the beam offset from the BPM center can be quite big. Using the data measured, a table of polynomial coefficients has been calculated for each BPM.

The signal processing electronics for the Booster BPMs is designed and produced by BNL [4]. The button electrodes of each BPM are connected to the Pilot Tone Combiner (PTC) via short (about 1 m) pieces of SiO2 coaxial cable. The PTC is a passive unit providing use of a 465 MHz pilot tone signal. Analogue and digital signal processing is performed by BPM receivers located in the Injector Service Area. Design value of turn-by-turn BPM resolution is 30 µm for 15 nC of beam charge.

Each PTC is connected to the BPM receiver by long (up to 100 m) coaxial cables. To minimize the cable insertion loss, LMR400 cables (9 dB/100 m @ 500 MHz) are used for longer runs (1st and 2nd Booster arcs), whereas LMR240 cables (18 dB/100 m @ 500 MHz) are used for shorter runs (3rd and 4th arcs). The maximal signal attenuation introduced by the LMR coaxial cable is 9 dB. To minimize influence of eddy currents induced in the vacuum chamber by pulsed magnetic fields, the shield of each long cable is galvanically separated from common ground.

Now, all installation and cabling of the BPMs and signal processing electronics have been completed. The integration testing of BPM system was performed using the expert control software (see Fig. 2) and Pilot Tone signal, it turned out to be very useful.

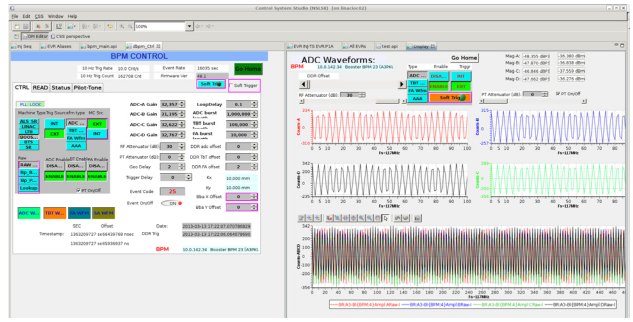

Figure 2: BPM expert panel.

A number of hardware issues has been found out and fixed (for example, loose connectors on a patch panel). During the test, some BPMs four buttons' signal shows different behaviour and noisy frequency up to a few kHz were observed. This is solved by modifying the oscillator and installing a microwave absorber. The BPM position noise level is now improved down to 1 µm.

DC CURRENT TRANSFORMER

A DC Current Transformer (DCCT) is used to measure average beam current, lifetime and injection efficiency. Bergoz In-Flange NPCT-CF4.5"-60.4-120-UHV-C30-H with radiation-tolerant sensor has been ordered for the Booster. The device should provide measurement of beam current in the range of 0-50 mA with resolution <5 µA/$Hz^{1/2}$ within the bandwidth from DC up to 10 kHz. The In-Flange version of the transformer is mounted in the vacuum chamber between two flanges; it has short axial length and includes a vacuum-brazed ceramic gap.

Before installation, principal parameters of the DCCT have been measured in a lab. The measured value of sensitivity is 10.05 V/20 mA DC; the bandwidth (−3 dB) is 13.5 kHz in 200 mA range and 7.75 kHz in 20 mA range, see Fig. 3. Now, the DCCT has been installed in the vacuum chamber and the chamber is under vacuum. Signal processing electronics and digitizer have been installed in the rack and connected to the DCCT.

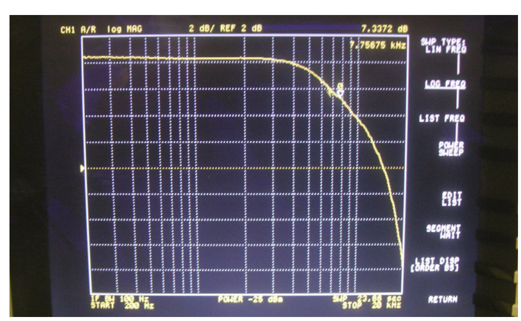

Figure 3: DCCT frequency response.

After installation and cabling, integrated testing of the DCCT, electronics and control software has been performed, the testing results are acceptable.

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FAST CURRENT TRANSFORMER

A fast current transformer (FCT) is used to measure beam filling pattern in multi-bunch mode. The In-flange version of wideband current transformer Bergoz FCT-WB-CF6"-60.4-40-20:1-UHV-H has been installed as a part of the Booster vacuum chamber.

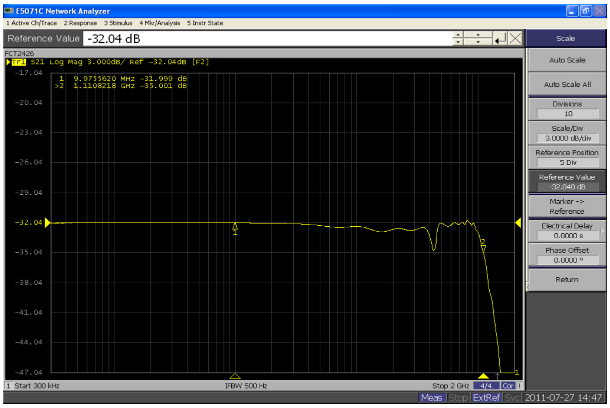

Figure 4: FCT frequency response.

Before installation, a laboratory test of the FCT was performed. The upper cut-off frequency measured at −3 dB level is 1.1108 GHz as it is shown in Fig. 4, whereas the specified value is 1750 MHz for this model. The capacitance of the gap in the in-flange model is the main limiting factor. Final (50 Ω) source resistance is a contributing factor as well. The tested model has nominal sensitivity of 1.25 V/A, the observed 2.75% deviation in the sensitivity is well within specification tolerances on the termination impedance. The droop of the output signal due to the high cut-off frequency has also been measured, the measured value of 0.85%/µs is well within the specifications (should be below 10%/µs).

SYNCHROTRON LIGHT MONITORS

Two synchrotron light monitors (SLMs) have been designed for routine measurements of transverse beam profiles and sizes with spatial resolution better than 50 µm. Each SLM consists of an in-vacuum water-cooled metallic mirror, light output window, image formatting optics and a CCD camera. Pre-aligned fixed mirrors made of copper with aluminium-plated reflecting surface have been installed inside the vacuum vessel to reflect the visible part of SR out of the vacuum chamber. The in-vacuum parts of SLMs and the optical benches have been designed and manufactured in BINP.

For each SLM, fine alignment of the light beam is provided with two remote-controlled mirrors placed on the optical bench outside the vacuum chamber. These mirrors are mounted on the motorized mirror mounts 8MBM24 produced by STANDA. To control the mirror mounts, DELTA TAU Geo BRICK LV DRIVE is used.

Now, all equipment of both SLMs has been installed in the Booster tunnel and Injector Service Area. During installation and integration testing, it was found that SLMs need some modification. To match the mirror mounts with a new 8-channel model of DELTA TAU controller, an interface module has been designed and produced by BNL. To increase the visibility area, the CCD cameras have been moved closer to the last external mirrors. As a result of integration testing, the optics has been tuned and focused; control and data acquisition hardware and software have been tested, see Fig. 5.

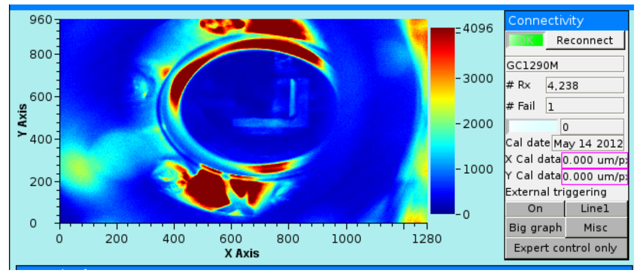

Figure 5: Mirror image acquired by SLM software.

TUNE MEASUREMENT SYSTEM

Tune measurement system (TMS) has been developed and manufactured by BINP [5]. The system provides measurement of fractional part of betatron tunes: horizontal ν_x and vertical ν_y. For an injected beam, the synchrotron tune ν_s can be measured too. Coherent beam oscillations are excited by a stripline kicker with the excitation frequency close to $(k \pm \nu_{x,y})f_0$, where f_0 is the revolution frequency, k is an integer. When the excitation is switched off, free beam oscillation is registered by a stripline pickup. The betatron tunes are obtained by digital spectral analysis of turn-by-turn beam position data. The measured tunes are available for the control system during whole energy ramp.

TMS consists of two identical sets of four 50-Ω striplines (one set of striplines is used as a kicker, the other – as a pickup), pickup electronics, beam excitation electronics and an IBM server. Striplines and passive front-end electronics for the pickup and kicker have been installed in the Booster tunnel, all other electronics – in the Injector Service Area.

Control and data processing software has been developed. The expert panel (Fig. 6) with enhanced possibilities of TMS control is used for the system tuning, testing and troubleshooting. The operator panel is designed for routine tune measurement and visualization.

A system integration testing of TMS including both hardware and software has been performed without a beam. The beam signal was imitated by a sine 500 MHz signal, betatron oscillations were modeled by amplitude modulation. The results of testing show that TMS can reliably operate in the beam charge range of 0.05-15 nC in both single-bunch and multi-bunch mode. The tune measurement error is less than $2{\cdot}10^{-5}$ for 0.5-15 nC and less than $5{\cdot}10^{-5}$ for 0.05-0.5 nC range. Time of a single measurement (ν_x and ν_y) (energy ramp mode) is about 1 ms, time of one scanning in full frequency range (scanning mode) is 300 ms.

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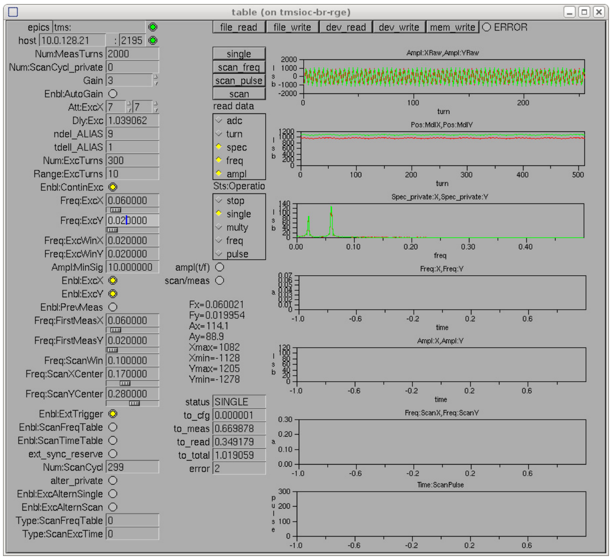

Figure 6: Screenshot of TMS expert panel.

CONTROL AND SOFTWARE

Control of the beam diagnostics is an integral part of the total Booster control system based on EPICS and has three layers. The lowest layer includes the electronic devices, which are processed signals from sensors and operate with different-kind field devices: beam flags, strip lines, cameras, BPMs, current transformers. The field devices except the cameras do not include precise analogue or digital circuits. All signals come to the racks in Injection Service Area (ISA), where the first layer electronics is located: BPM receivers, TMS controller, ADCs in VME crates, PLC chassis. These devices process the analogue signals and provide digital data to the second level of the diagnostics control – to IOCs running in IBM servers and VME controllers. Each electronic device is served by its own IOC that provides a flexible processing of the data received from the field devices. Totally, there are more than 50 IOCs running under Linux in four x3250 M3 IBM servers. Also, some ADCs and timing electronics are located in three VME crates with M3100 controllers running under RTEMS. The racks with electronics and IBM servers are located in ISA near the Booster tunnel to minimize the cable lengths and therefore to reduce signal damping. Every booster cycle, the IOCs provide a set of beam parameters: beam position 10 kHz 4k data and 4k turn-by-turn data for each BPM, 40 beam orbits sampled at certain points of the energy ramp, beam current along the ramp, beam images from the flags, beam filling pattern, betatron tunes along the ramp measured with a step of 1 ms.

High Level Applications (HLA) for the Booster beam diagnostics has been developed and incorporated into the NSLS-II control system. The IOCs communicate with high level applications via Channel Access Protocol over Gigabit Ethernet links. All HLAs has been developed using CSS and Python, including 1st turn beam passing observer, Beam orbit monitor, BPM expert screens, Beam current monitor, DCCT and FCT expert screens, Booster tune monitor and TMS expert screen, operator and expert screens for Beam flags and Synchrotron light monitors.

To prepare for the booster ring commissioning, we carried out a pre-commissioning procedure with simulated beam signals, called extended integrated testing (EIT) [6]. During the EIT, the hardware operates as during the actual commissioning with the beam. The beam signals are simulated and generated by a computer program, ELEGANT. Then they are transported into the control system by the same data channel as the real beam signal would travel.

This process is helpful to test and optimize all the operation screens, high level applications by subsystem with the actual hardware controls but only with simulated beam signals and safety systems. This phase helps us to reduce the duration of the booster and transport line commissioning with the beam, train the commissioning team and reduce safety concerns related to the commissioning and operations. The EIT activities consist of 4-hour shifts per day with the shift teams including both BNL and BINP specialists. A shift schedule, daily shift meetings, plans and summaries, which are closely corresponding to the actual beam commissioning, have been developed.

The high level application code were debugged and tested with hardware and “beam” signal. It simulates the commissioning steps from passing beam to injection septum, first turn injection, circulate the beam, orbit correction along ramping, extraction control to the beam parameters measurement in the diagnostics line.

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