ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-MOPRO088

COMMISSIONING OF NSLS-II BOOSTER

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Abstract

The National Synchrotron Light Source II is a third generation light source, which was constructed at Brookhaven National Laboratory. This project includes a highly-optimized 3 GeV electron storage ring, linac pre-injector, and full-energy synchrotron injector. Budker Institute of Nuclear Physics built and delivered the booster for NSLS-II. The commissioning of the booster was successfully completed.

MAIN PARAMETERS

The preliminary design was made by BNL [1]. The main booster parameters are given in Table 1.

Table 1: Main Booster Parameters

Circumference	158.4 m
Injection energy	170-200MeV
Extraction energy	3 – 3.15 GeV
RF frequency	500 MHz
Horizontal emittance at 3 GeV	< 40 nm*rad
Charge (Long pulse/Single pulse mode)	10nC / 0.5nC
Charge transport efficiency	> 75 %

The booster was commissioned at 1Hz without stacking, although its design allows stacking and upgrade up to 2 Hz. The magnetic lattice includes four quadrants. For the aim of dispersion suppression, every quadrant contains five regular cells with two modified cells at the ends of the quadrant. Each quadrant contains 8 defocusing and 7 focusing dipole magnets of combined function. For compensation of the major part of chromaticity, a sextupole component is incorporated in both the dipole magnets [2].

TIMELINE

The tender on the designing, production and commissioning of the NSLS-II booster was started in January 2010. Budker Institute of Nuclear Physics won this tender in May 2010. The booster was designed [3], produced and delivered in full to BNL by September 2012. The booster was assembled (see Fig.1) and all equipment was tested by 2013 [4].

In 2013, while waiting for the authorization to start the commissioning, Extended Integrated Testing of injector were fulfilled [5]. These tests included a heat run of all systems with beam signal emulation, calibration of the diagnostics system, debugging of the High Level Applications, and testing and improvement of the Equipment Protection System and the Personnel Protection System.

The authorization to start the commissioning of the injector was received in November 2013. The BNL and BINP teams started beam injection into the Booster on December 8. The first turn was closed soon by tuning the LTB and BR orbit correctors. The beam was monitored using the beam flags [6] and BPMs in the single-pass mode. The beam was accelerated to 3 GeV by the end of 2013. The commissioning of the booster was successfully completed in February 2014.

During the commissioning, a lot of time was devoted to Safety and Fault Studies, which included exploration of radiation environment at beam loss in different places. The results of the Fault Studies were analyzed and authorized before the next step of the commissioning procedure could be started.

Figure 1: NSLS-II booster; arc #3 before an RF straight.

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TUNING

The optical model of the magnetic structure was improved towards better booster ring parameters using data of the final booster survey and results from beam position monitors. Additional corrections to the alignment of the magnetic elements by survey measurements were introduced into the model. The standard deviation of the corrections does not exceed 75 µm in the radial direction and 42 µm in the vertical direction.

Then a global orbit correction along the ramp was performed based on the improved model of the magnetic structure of the booster ring; and corrections were made to the adjustment of the injection transport line for an booster equilibrium orbit. That allowed us to increase the capture efficiency from 30% to 70%.

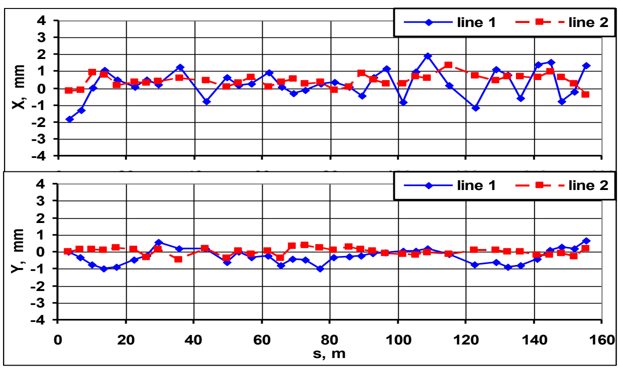

Figure 2: Horizontal and vertical orbit of beam at 200 MeV before (blue) and after (red) using the improved model.

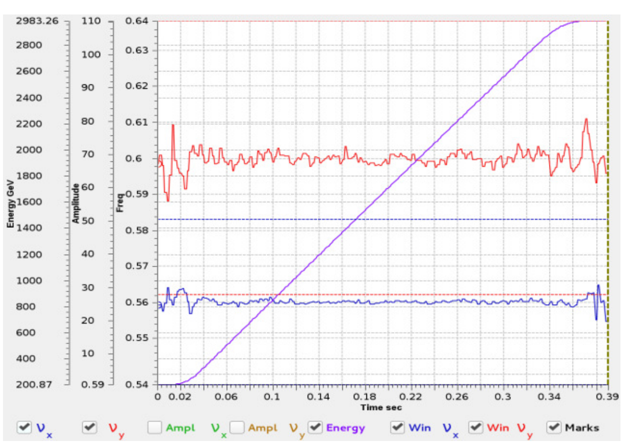

Figure 3: Horizontal (blue) and vertical (red) tunes throughout the ramp (purple).

A possibility to measure and correct the closed-orbit distortion (COD) during the beam ramp is an important task for commissioning of the machine. Special software was developed for this: IOC, which provides a set of forty orbits that are measured at forty moments throughout the ramp, and a COD correction application, which simultaneously corrects orbit distortions at these forty points of time. Another important task for beam acceleration adjustment is the measurement and correction of tunes. BINP developed a tune measurement system [7], which provides up to 500 tune measurements with a 1 msec interval during the ramp.

The optical functions and betatron tunes were corrected throughout the ramp (Fig.3). That reduced beam losses during the ramp to below 5 %. Besides, an additional adjustment of the optical functions of the linac-to-booster transport line was carried out, which resulted in increasing efficiency of particle capture and acceleration up to ~ 95 % (Fig.4).

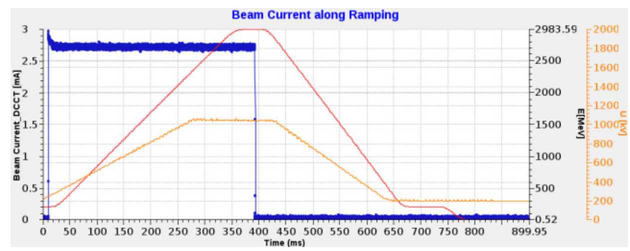

Figure 4: Booster beam current (blue); beam energy derived from dipole magnet currents (red); RF cavity voltage (orange) during 1Hz cycle.

EXTRACTION

The booster extraction system consists of four slow orbit bumpers, a AC septum, a DC septum, and a kicker [4].

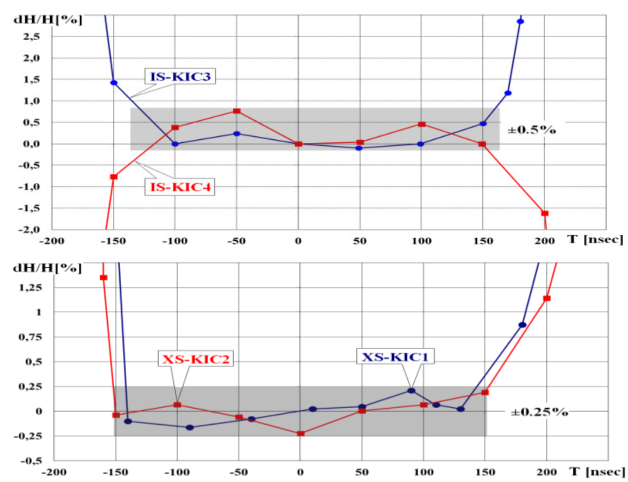

Figure 5: Shape of pulse top of injection (top) and extraction kickers (bottom).

Figure 5 shows shapes of magnetic field pulses in the kickers, which were determined from measurement of beam position on fluorescent screens in the booster and the extraction transport line. Prior to the measurements, the amplitude of beam deflection was calibrated by determination of beam deflection at a 10% voltage change for each kicker.

The transverse stability of the extracted beam was checked. Table 2 shows the maximum calculated beam

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deviation on flag VS-FLAG2 in the beam extraction line at the maximum allowable variation in different magnets. The phase shift between the booster extraction and flag VS-FLAG2 is about 0.25.

Table 2: Calculated Beam Variation

Magnet	Allowable variation, %	Shift on the flag, μm
Bump	± 0.02	± 4
Kicker	± 0.2	± 50
AC septum	± 0.02	± 45
DC septum	± 0.02	± 62
BD, BF (dE)	± 0.01	± 35
Total		±150

In fact, we observed transverse beam stability better than ± 27 μm (or ± 1 pixel) during 1 hour at a repetition rate of 1 Hz.

The phase volume of the extracted beam was estimated through measured beam sizes on the flag and the β and η functions, which were known from the optics of the line ($\beta_x \approx 9.5$ m, $\eta_x = -0.35$ m, $\beta_y = 6$ m). In the horizontal $\in_x \approx 38$ nm; in the vertical $\in_y \approx 6$ nm.

CONTROL SYSTEM CAPABILITIES

The booster control system [8] is based on EPICS and provides continuous control and monitoring of all booster equipment and beam parameters during a booster cycle. Each booster parameter is implemented as a PV (process variable): binary value, analog value, 1k measuring waveform, and 10k setting waveform. Continuous digital control of all power supplies (ramping, pulsed and DC) [9] is implemented via 10k waveforms, which can be easily uploaded to PS controllers at any time and will be started in operation in the next cycle of the booster.

A special monitoring technique [10] was designed for easy and fast search and visualization of fault devices. This software was successfully tested and efficiently used during the booster commissioning. Each 1k measuring waveform was renewed in each booster cycle. The monitoring process implies comparison of a live PV value with a reference one, and alarm is generated if the difference is too big.

The waveforms are compared point by point. Reference values are obtained while PV values (settings and measurements) that were saved earlier as a desired set of PVs are restored to IOCs: settings are restored to setting PVs and correspondent reference PVs, while measurements are restored to reference PVs only. A dedicated application for saving/restoring was developed for this purpose. If the absolute value of the difference between live and reference values exceeds a preset tolerance value, an indication (flag) PV is set. The flag PV can be used by a high-level application or mapped to the alarm server for alarm indication. Two modes of monitoring are supported in the booster PS IOCs. In the first mode, the reference value for a measured value is a correspondent set value. This mode is to be used in adjustment of machine parameters and indicates how well settings are executed by the booster PSs. The second mode assumes the reference value to be a value restored from the set of parameter values saved earlier. This mode is to be used for regular monitoring of booster operation.

CONCLUSION

The commissioning of the booster was successfully completed in February 2014. The beam passing through booster was up to 93%. All the booster systems work in line with the design. The commissioning of the Main Ring was started in March 2014.

ACKNOWLEDGMENT

We would like to thank all members of the BNL and BINP teams involved in the booster commissioning: A.Akimov, G.Bassi, E.Bekhtenev, A.Blednykh, E.Blum, W.Cheng, P.Cheblakov, J.Choi, J.De Long, A.Derbenev, R.Fliller, F.Gao, W.Guo, Y.Hidaka, A.Korepanov, G.Karpov, S.Kramer, S.Krinsky, Y.Li, M.Maggipinto, O.Meshkov, D.Padrazo, E.Petrova, B.Podobedov, J.Rose, S.Seletskiy, E.Simonov, O.Singh, T.Shaftan, D.Shatilov, W.Wahl, G.Wang, F.Willeke, L.Yang, X.Yang, L.Yu, E.Zitvogel, and P.Zuhoski. This work would have been impossible without close collaboration.

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