NSLS-II INJECTOR COMMISSIONING AND INITIAL OPERATION*

B. Bacha, G. Bassi, J. Bengtsson, A. Blednykh, E. Blum , S. Buda, W. Cheng, J. Choi, J. Cuppolo, R. D'Alsace, M. Davidsaver, J. DeLong, L. Doom, D. Durfee, R. Fliller, M. Fulkerson, G. Ganetis, F. Gao, C. Gardner, W. Guo, R. Heese, Y. Hidaka, Y. Hu, M. Johanson, B. Kosciuk, S. Kowalski, S. Kramer, S. Krinsky, Y. Li, W. Louie, M. Maggipinto, P. Marino, J. Mead, G. Oliva, D. Padrazo, K. Pedersen, B. Podobedov, R. Rainer, J. Rose, M. Santana, S. Seletskiy, T. Shaftan, O. Singh, P. Singh, V. Smalyuk, R. Smith, T. Summers, J. Tagger, Y. Tian, W. Wahl, G. Wang, G. Weiner, F. Willeke, L. Yang, X. Yang, E. Zeitler, E. Zitvogel, P. Zuhoski, National Synchrotron Light Source II, Brookhaven National Laboratory, Upton, NY 11793, USA
A. Akimov, P. Cheblakov, I. Churkin, A. Derbenev, S. Gurov, V. Kiselev, A. Korepanov, S. Sinyatkin, A. Zhuravlev, Budker Institute of Nuclear Physics, Novosibirsk, Russia

Abstract

The injector for the National Synchrotron Light Source II (NSLS-II) storage ring consists of a 3 GeV booster synchrotron and a 200 MeV S-band linac. The linac was designed to produce either a single bunch with a charge of 0.5 nC of electrons or a train of bunches up to 300 ns long containing a total charge of 15 nC. The booster was designed to accelerate up to 15 nC each cycle in a train of bunches up to 300 ns long. Linac commissioning was completed in April 2012. Booster commissioning was started in November 2013 and completed in March 2014. All of the significant design goals were satisfied including beam emittance, energy spread, and transport efficiency. While the maximum booster charge accelerated was only 10 nC this has proven to be more than sufficient for storage ring commissioning and operation. The injector has operated reliably during storage ring operation since then. Results will be presented showing measurements of linac and booster operating parameters achieved during commissioning and initial operation. Operating experience and reliability during the first year of NSLS-II operation will be discussed.

INTRODUCTION

The NSLS-II is a third generation electron storage ring at Brookhaven National Laboratory [1]. It was commissioned in 2014 and began user operations in February, 2015. The NSLS-II injector consists of a 3 GeV booster synchrotron, a 200 MeV S-band linac, the associated transport lines, and the storage ring injection straight (Fig. 1). The linac is capable of producing either a single bunch of up to 0.5 nC of charge or a train of bunches up to 300 nS long containing a total charge of 15 nC. The linac was commissioned in 2012 and met all of its design specifications with one exception: only 11 nC was accelerated in multibunch mode instead of the 15 nC specified [2]. Since then up to 13 nC has been accelerated within the specified 0.5% energy spread.

The 3 GeV booster is a 158.4 m circumference synchrotron developed jointly by Brookhaven National Laboratory (BNL) and the Budker Institute of Nuclear Physics (BINP) [3, 4]. Danfysik developed the dipole power supplies as a subcontractor on the booster project. The booster has a four-fold symmetric design lattice using combined function magnets to create a FODO-like lattice in each quadrant with matching quadrupole triplets at both ends of each quadrant [5]. The RF system uses a 7 cell PETRA type 500 MHz cavity. The booster operates at a 1 Hz repetition rate but was designed to be upgraded to 2 Hz. Booster commissioning was completed in March 2014 and has delivered electrons to the NSLS-II storage ring since then.

The storage ring injection straight contains 4 half-sine 8.5 mrad kicker magnets. Each kicker is excited by an IGBT pulser with 10 series stages of 20 parallel IGBTs per stage. The kicker magnets and pulsers were built at BNL. The kickers produce a 5.4 μsec pulse which is slightly longer than twice the 2.6 μsec revolution time of the storage ring. This has not been a problem so far but the pulse width can easily be reduced by using smaller pulse capacitors. The system was designed to pulse at 10 kV but only 7.9 kV is required for operation. Amplitude stability $\sigma<0.015\%$ was demonstrated over 24 hours of operation in the pulsed magnet laboratory in a non temperature controlled environment.

An out-of-vacuum, 150 μsec, 100 mrad septum from Danfysik is used for storage ring injection. The system has demonstrated an amplitude stability <0.1%, time jitter <10 ns, and leakage field <8 μT-m.

BOOSTER COMMISSIONING RESULTS

Booster commissioning was started in late November 2013 and completed by March 2014. All major design goals for the booster were met except that the maximum charge accelerated in multibunch mode (MBM) was only 10 nC compared to a design goal of 15 nC. Since <3 nC per cycle from the booster has been required for the first year of storage ring commissioning and operation it was decided not to spend additional time increasing the

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#blum@bnl.gov

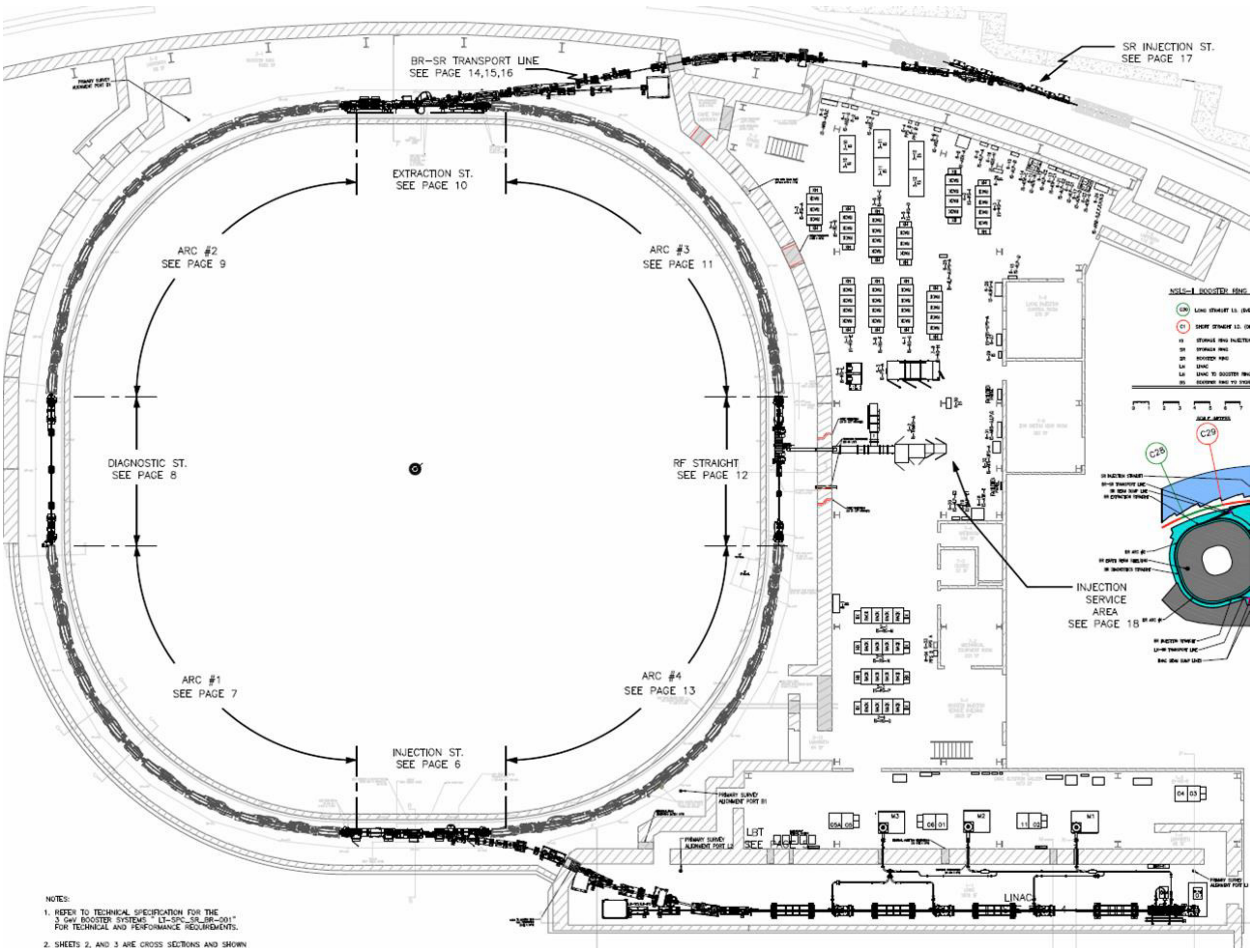

Figure 1: Scaled drawing of the NSLS-II injector complex. The linac is on the lower right side of the drawing and the storage ring injection straight is on the upper right.

booster current. The required single bunch mode (SBM) charge of 0.5 nC was readily obtained, Booster specifications and measurements are compared in Table 1.

Table 1: Booster Specifications and Measurements

Parameter	Specification	Measurement
Beam Energy	3±0.15 GeV	~3 GeV
Accelerated Charge	0.5 nC (SBM) 15 nC (MBM)	0.5 nC (SBM) 10 nC (MBM)
Bunch Train	1..160 bunches	1..75 bunches
Energy Spread at 3 GeV	0.08%	0.10%
H Emittance	38 nm-rad	33 nm-rad
V Emittance	4 nm-rad	4-8 nm-rad
Transport Efficiency	>75%	~80%

The other significant difference from the design specifications was in the measured vertical emittance. While the emittance measured from the synchrotron light profile of 4 nm-rad agrees with the specification, the emittance measured from the light produced by the beam striking an yttrium aluminum garnet (YAG) screen in the booster-to-storage ring transport line was 8 nm-rad or twice as large as expected. The discrepancy may result from the fluorescence of the YAG which usually overestimates the beam size compared to other phosphors. The energy spread, as measured by synchrotron light in a dispersive region of the booster is also slightly larger than expected but the measurement of the beam size was complicated by stray light in the image. By contrast the synchrotron light image from a mirror in a nondispersive region used for the emittance measurements was cleaner.

OPERATING EXPERIENCE

The injection system has been providing beam for NSLS-II commissioning and operations since March 2014. Fig. 2 shows a plot of the transport efficiency from the end of the linac to the end of the booster-to-storage ring (BTS) transport line during the last week that the storage ring operated in April 2015. It shows the ratio of the beam charge measured on an integrating current transformer in the BTS line to the charge measured on an

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integrating current transformer at the end of the linac. The average efficiency that week was 78±12%. The large jitter in the efficiency largely comes from variability in the capture efficiency of the injected beam in the booster at the start of acceleration. The cause of these losses must still be determined.

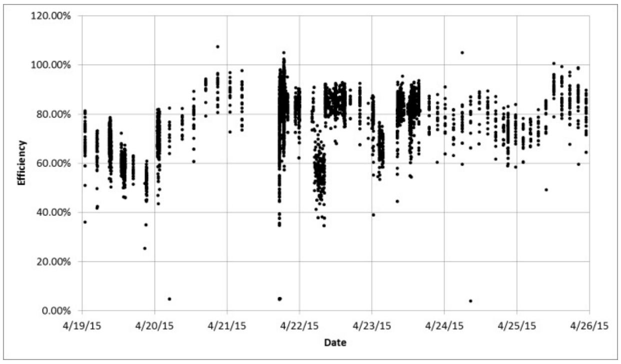

Figure 2: Transport efficiency from the end of linac to the end of the BTS transport line during the last operating week in April, 2015. Gaps correspond the periods when injection is not required.

The performance during the week shown in Fig. 2 is typical of the entire year. Adjustments must be made to the position of the beam leaving the booster to maintain peak efficiency. The current supplied the DC septum at the start of the BTS is particularly sensitive. This will be studied in the next year.

Similar statistics are available showing the capture efficiency in the storage ring are also available but have not been compiled. Capture efficiency in the storage ring frequently approaches 100%.

Fig, 3 shows storage ring downtime caused by the linac, booster, and transport lines from the start of storage ring commissioning until the end of March 2015. It is divided to show downtime from three systems with major downtime- linac RF, booster RF, and booster pulsed magnets- as well as downtime from other injector systems. The figure does not show downtime from

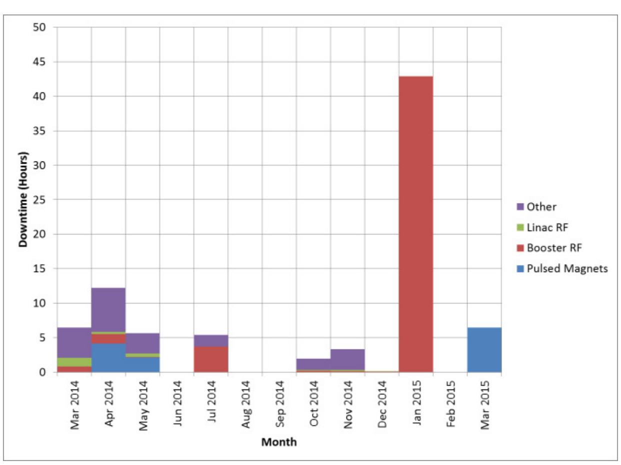

Figure 3: Injector downtime each month characterized according to system.

storage ring injection pulsed magnets for which statistics are available but were not compiled.

Downtime from injection systems was minimal, generally less than seven hours per month except for two months. During April 2014, early in storage ring commissioning, there were over twelve hours of downtime including many failures of the booster pulsed kickers. Reliability of the booster kickers, which use cold cathode thyratrons, has since been enhanced by replacing the auxilliary power supplies and grid trigger pulsers with improved designs. The long booster RF downtime in January 2015 and also the shorter booster RF downtime in July 2014 resulted from failures of the high voltage modulator for the transmitter. The computer controls and protection circuits have since been modified to address the cause of the failures.

CONCLUSION

The NSLS-II injector was successfully commissioned and meets all major requirements for storage ring injection. It has been operating since March 2014 for storage ring injection and operation. Downtime is minimal and beam transport efficiency through the booster is generally around 80%.

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