STATUS OF NSLS-II BOOSTER

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The National Synchrotron Light Source II is a third generation light source under construction at Brookhaven National Laboratory. The project includes a highly optimized 3 GeV electron storage ring, linac pre-injector and full-energy booster-synchrotron. Budker Institute of Nuclear Physics builds booster for NSLS-II. The booster should accelerate the electron beam continuously and reliably from minimal 170 MeV injection energy to maximal energy of 3.15 GeV and average beam current of 20 mA. The booster shall be capable of multi-bunch and single bunch operation. This paper summarizes the status of NSLS-II booster.

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INTRODUCTION

The injector system includes 200 MeV linac and booster with energy up to 3GeV. The conceptual design has been done by BNL [1]. The tender on the design, production and commissioning of NSLS-II booster was started in January 2010. Budker Institute of Nuclear Physics won this tender in May 2010. Preliminary Design Review was approved at BNL in October 2010, Final Design Review was approved in February 2011 and First Article was approved in August 2011. The First Article includes BF and BD dipoles, quadrupole, sextupole, corrector, MPS-6 power supply and the first girder assembled with magnets, vacuum chamber and pick-up electrodes.

The current status of the booster project and achieved parameters on the First Article are discussed in this paper.

1. MAGNETIC SYSTEM

Designed parameters of ramped magnets are summarized in Table 1. The dies, tooling for yoke stacking, coil winding and coil impregnation for all magnets have been produced.

The magnetic elements provide high quality of a field in the Booster operation range from 0.2 up to 3 GeV. The results of magnetic measurements of the BD and BF dipole prototypes are represented in Tables 2 and 3, respectively. In the aperture of (±20)×(±10) mm the field quality of BD dipole is not worse than $\pm 5\cdot 10^{-4}$, for BF dipole it is not worse than $\pm 7\cdot 10^{-4}$.

The higher harmonics of quadrupole magnet do not exceed $A_i/A_2 < 3.9\cdot 10^{-4}$ (i = 3…14) on radius of field decomposition of 2 cm. For sextupole magnet the maximal relative size of harmonics is $A_i/A_3 < 9\cdot 10^{-4}$ (i = 4...14) on radius of field decomposition of 1.5 cm.

The measured parameters of magnetic elements meet the requirements of the technical specification.

Table 1

Designed Parameters of Ramped Magnets

Magnets	Number	Magnetic length, m	Magnetic force for 3 GeV		
			T	T/m	T/m^2
BF Dipoles	28	1.24	0.46	8.2	36
BD Dipoles	32	1.30	1.13	-5.6	-43
Quadrupoles	24	0.30		20.4	
Sextupoles	16	0.12			±400
Correctors	36	0.13	0.13		

Table 2

Deviation of magnetic parameters of ramped magnets from designed one (BD dipole)

E, GeV	0.208	1.004	2.001	3.000
Δ L/L	0.05 %	0.07 %	0.07 %	-0.01 %
Δ h /h	-0.05 %	-0.07 %	-0.07 %	0.01 %
Δ K1/K1	0.35 %	-0.01 %	0.00 %	-0.25 %
Δ K2/K2	2.1 %	-2.6 %	-2.8 %	-0.2 %

Table 3

Deviation of magnetic parameters of ramped magnets from designed one (BF dipole)

E, GeV	0.211	1.008	2.004	2.996
Δ L/L	-0.09 %	-0.14 %	-0.14 %	-0.13 %
Δ h /h	0.09 %	0.14 %	0.14 %	0.13 %
Δ K1/K1	0.41 %	0.03 %	0.04 %	0.09 %
Δ K2/K2	3.8 %	-1.5 %	0.4 %	1.7 %

By results of magnetic measurements of the first articles BINP has started the serial production of magnetic elements.

2. POWER SUPPLIES

The Booster magnetic system requires 59 Power Supplies (MPS) with a total peak power of about 1.3 MVA. The Main parameters of the booster magnets power supplies are presented in Table 4.

All the PSs are current sources with a current feedback loop for stabilization. The power supplies are synchronized with time interval corresponding to the rate of up to 2 Hz. Fig.1 shows a scenario consisting of two halves of cosine with small plateaus for injections and extractions (any acceleration shape is possible, here only the '1-cosine' shape is shown). The required current accuracy is 10^{-4} for the plateaus and 10^{-3} for the ramp up (calculated accuracy is related to current level and not to the maximum MPS output level).

Table 4

Main parameters of Power Supplies

PSs for	Number of PSs	Current (max), A	Peak Voltage, V	Peak output Power, (Total), kVA
Dipoles BF	1	900	220	180
Dipoles BD	2	750	700	1050
Quads	3	167	160	72
Sextupoles	16	6	60	6
Correctors	36	6	60	13
DC Septum	1	500	12	6

Due to the big difference between the required output peak power and the average power consumption, the power supplies are designed with recuperation into capacitor banks of the reactive energy stored in the magnets. The recuperation system will minimize the peak power being transferred from the AC mains.

Currently quadrupole PSs, sextupoles and correctors PSs are assembled and ready for tests. The power supplies for BF and BD dipoles are developed by Danfysik A/S as a subcontractor of BINP and will be assembled soon.

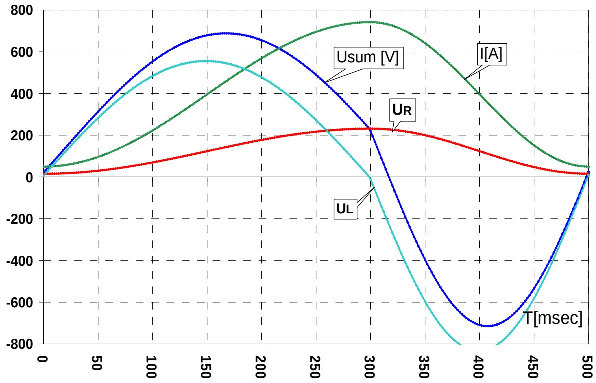

Fig.1. Current and voltage plots for 2 Hz cycles for '1-cosine' shape of current ramps

3. INJECTION AND EXTRACTION SYSTEM

Injection into the booster is performed with 200 MeV linear accelerator. There may be two types of injection into the booster:

- Single-turn injection of a single 0.5 nC bunch or a pulse train of 80 to 150 bunches separated by 2 nsec with a total charge of 15 nC.
- Accumulation mode. In this case, a new portion, which doubles the charge in each bunch, is added after 100 msec.

For realization of the single-turn injection and accumulation, four fast ferrite kickers and a pulse eddy-current type septum magnet are installed in the long straight section. The kicker and septum magnets are placed out of vacuum. The vacuum chamber of the kicker is made of aluminum oxide ceramic. There is a titanium (TiN) coating of 5 μm thickness on the inner surface of the chamber. The coating is made as strips of 3.4 mm width with 3.4 mm spacing.

Table 5

Main Designed Parameters of IES Magnets

Magnets	Q-ty	Magnetic length, m	Field, T	Angle, mrad	Pulse, μs
Injection System for 200 MeV					
Kicker	4	0.207	0.055	15	0.3
Septum (AC)	1	0.75	0.11	125	100
Extraction System for 3 GeV					
Bump	4	0.17	0.46	7.8	1500
Kicker	1	0.83	0.073	5.8	0.3
Septum (AC)	1	0.6	0.8	48	100
Septum (DC)	1	1.2	0.89	106	-

The booster extraction system consists of four slow orbit bumpers, AC septum, DC septum and a kicker. Injection and extraction AC septums and kickers are similar in design.

According to the technical specification: the total beam angular deviation dX' caused by instability of the systems involved in beam extraction from the booster should not exceed 20 % of angular beam spread. It means that stability of the field septum magnets shall be better than 0.02 %. The ripple and droop over the entire kicker flat-top of 300 nsec waveform shall be less than 0.2 %.

By the present moment the magnets and its power supplies are under manufacturing.

4. VACUUM SYSTEM

An average pressure is below 10^{-7} Torr by integral of current of 1 Ampere-hour (an average flux of photons is 10^{19} ph/sec). The obtaining of this pressure is carried out by Gamma Vacuum ion pumps. The total quantity of ion pumps with pumping speed of 45 l/s (Nitrogen) is 71 pieces located with the distance of 2.5 meters. The calculations showed that the total photon-desorbed gas load is much higher than the thermal desorption gas load in spite of impact behavior of the booster. All vacuum chambers are to be made of stainless steel 316L.

Each arc vacuum section will have a convection-enhanced "Pirani" gauge, two inverted-magnetron cold cathode gauges as the primary gauges, and sixteen 45 l/s ion pumps. One set of vacuum gauges and two ion pumps (for Diagnostics and Injection straights) and three ion pumps (for Extraction straight) will be installed in the straight sections to handle the extra outgassing from RF cavities, kickers, septums and diagnostics. The residual gas analyzer heads will also be installed in the straight sections for diagnostics during operation and maintenance periods.

Press-molds for dipole vacuum chambers and the first arc vacuum chamber for first girder assembling have been produced. Press-molds for septum vacuum chambers are in production.

5. DIAGNOSTICS

For successful commissioning and effective operation of the projected NSLS-II Booster, a set of beam diagnostic instruments has been designed. Fluorescent screens are used for the Booster commissioning and troubleshooting. The closed orbit is measured using electrostatic BPMs with turn-by-turn capability. 36 BPMs are installed in the Booster, one more BPM is installed between the extraction septum magnets. The circulating current and beam lifetime are measured using a DC current transformer. The fill pattern is monitored by fast current transformer. Visible synchrotron radiation is registered for observation of the beam image, transverse profiles of the beam are measured. Betatron tunes are measured using two pairs of striplines, the first pair is for beam excitation and the second one – for beam response measurement. The beam diagnostic systems provide measurement and correction of the beam closed orbit, betatron tunes, beta functions and dispersion during the ramp.

Now, the strip-lines, BPM housings and button electrodes have been manufactured, the beam current transformers have been procured and tested, the laboratory testing of electronics developed for the BPMs and tune measurement system is in progress.

6. CONTROL AND TIMING SYSTEM

The booster control system will be designed and developed using EPICS to be easily integrated into the BNL control system. It will be built using all NSLS-II standards: use of EPICS for middle level control, front-end controllers will run Linux or RTEMS, and use of VME, cPCI cards and PLCs for I/O. The PLC controllers will be Allen-Bradley devices connected to EPICS IOCs via Ethernet. The instrumentation network will be isolated over separate ports. The operator interface will be PCs running Linux.

The NSLS-II booster Power Supplies (PSs) are divided into two groups: ramping PSs providing passage of the beam during the beam ramp in the booster from 200 MeV up to 3 GeV at 300 ms time interval, and pulsed PSs providing beam injection from the linac and extraction to the Storage Ring. A special set of devices was developed at BNL for the NSLS-II magnetic system PSs control: Power Supply Controller (PSC) and Power Supply Interface (PSI). The PSI has one or two precision 18-bit DACs, nine channels of ADC for each DAC and digital input/outputs. It is capable of detecting the status change sequence of digital inputs with 10 ns resolution. The PSI is placed close to current regulators and is connected to the PSC via fiber-optic 50 Mbps data link. The PSC communicates with EPICS IOC through a 100 Mbps Ethernet port. The main function of IOC includes ramp curve upload, ADC waveform data download, and various process variable control. The 100 Mbps Ethernet port enables real time display for 4 ADC waveforms.

The booster timing system is a part of NSLS-II timing system which is based on Event Generator (EVG) and Event Receivers (EVRs) from Micro-Research Finland Oy. The booster timing is based on the external events coming from NSLS-II EVG: "Pre-Injection", "Injection", "Pre-Extraction", "Extraction". These events are referenced to the specified bunch of the Storage Ring and correspond to the first bunch of the booster. EVRs provide two scales for triggering both of the injection and the extraction pulse devices. The first scale provides triggering of the pulsed septums and the bump magnets in the range of milliseconds and uses TTL outputs of EVR, the second scale provides triggering of the kickers in the range of microseconds and uses CML outputs. EVRs also provide the timing of a booster cycle operation and generation of events for cycle-to-cycle updates of pulsed and ramping parameters, and the booster beam instrumentation synchronization.

7. GIRDER ASSEMBLY

All magnets in the booster arcs will be set on girders. Each girder has two support stands. Girders and support stands are produced from hollow steel tube of a rectanglular shape (500 × 300 mm) with wall thickness of 16 mm. After performing magnetic measurements, the magnets are aligned on the girder.

A typical girder assembly includes a girder with length of about 3.5 meters, BF and BD dipoles, corrector, sextupole and vacuum chamber with BPM (Fig.2). After delivery of girder assembly to BNL the accuracy of relative placement will be checked again during installation in the booster tunnel.

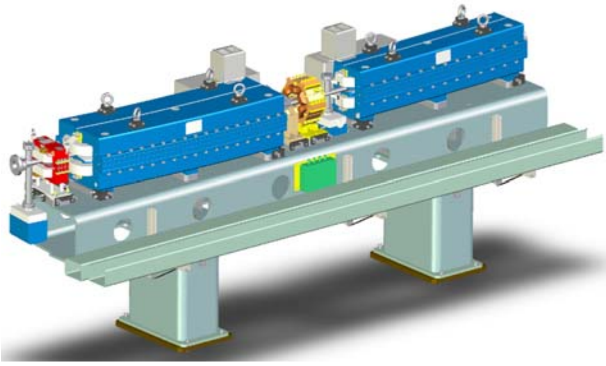

Fig.2. A girder assembly

At the beginning of July BNL and BINP team assembled the first girder with BF and BD dipoles, sextupole, corrector and vacuum chamber with BPM.

Girders are produced according to BINP design by Experimental workshop of ITAM SB RAS. At the middle of September, 20 girders out of 46 were produced and delivered to BINP.

CONCLUSIONS

NSLS-II booster project has gone through the First Article Acceptance milestone. The serial production is in progress. The booster tunnel is ready for installation of trays, cable and DI water tubes.

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СОСТОЯНИЕ РАБОТ ПО БУСТЕРУ ДЛЯ NSLS-II

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Национальный источник синхротронного излучения II является синхротроном третьего поколения, созданным в Брукхевенской национальной лаборатории. Проект включает: высокооптимизированное накопительное кольцо на 3 ГэВ, линейный ускоритель и бустерный синхротрон на полную энергию. Институт ядерной физики им. Г.И. Будкера создает бустер для NSLS-II. Бустер должен надежно и непрерывно ускорять пучок электронов от минимальной энергии инжекции 170 МэВ до максимальной энергии 3,15 ГэВ с током пучка 20 мА. Бустер должен быть способен работать в односгустковом и многосгустковом режимах. Эта статья суммирует состояние дел по бустеру для NSLS-II.

СТАН РОБІТ ПО БУСТЕРУ ДЛЯ NSLS-II

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Національне джерело синхротронного випромінювання II є синхротроном третього покоління, створеним у Брукхевенській національній лабораторії. Проект включає: високооптимізоване накопичувальне кільце на 3 ГеВ, лінійний прискорювач і бустерний синхротрон на повну енергію. Інститут ядерної фізики ім. Г.І. Будкера створює бустер для NSLS-II. Бустер повинен надійно і безперервно прискорювати пучок електронів від мінімальної енергії інжекції 170 МеВ до максимальної енергії 3,15 ГеВ зі струмом пучка 20 мА. Бустер повинен бути здатний працювати в односгустковому і багатосгустковому режимах. Ця стаття підсумовує стан справ по бустеру для NSLS-II.