# STATUS OF THE NSLS-II BOOSTER CONTROL SYSTEM

S. Karnaev, P. Cheblakov, A. Derbenev, R. Kadyrov, S. Serednyakov, E. Simonov, BINP, Russia,
M. Davidsaver, J. De Long, BNL, USA

*Abstract*

Third generation light source NSLS-II [1] is built at Brookhaven National Laboratory, USA. Budker Institute of Nuclear Physics (BINP) supplies a full energy 3 GeV injector synchrotron (booster) [2] for the main ring.

The booster control system is an integral part of the NSLS-II control system and includes IBM servers and VME3100 controllers connected via Gigabit Ethernet. Front-end electronics for vacuum control and interlocks are Allen-Bradley programmable logic controllers and I/O devices. A timing system is based on use of Micro-Research Finland Oy products: EVR 230RF and PMC EVR [3]. Power supplies control use BNL developed electronics. Software for the booster control is based on EPICS. High Level Applications are developed in Control System Studio and python. This paper describes the final design and status of the booster control system. The functional block diagrams are presented.

## INTRODUCTION

The booster control system provides full control [4] and monitoring [5] of power supplies operation, timing [6], beam diagnostics tools, vacuum monitoring, and interlocks.

The booster synchrotron is planned to operate with an acceleration cycle frequency of 1 or 2 Hz. Also, a double injection (stacking) in 100 ms is supposed to receive a lager charge of injected beam current in 1 Hz operation mode. The time of the beam acceleration is about 300 ms. The beam energy should be increased from 200 MeV up to 3 GeV in this time. An accuracy of matching of bending magnets and quadrupoles should be about 10-3 during the beam ramping. With a help of the BNL-developed set of PSC-PSI [7] the control system provides 10 kHz rate of PSs control and monitoring with relative accuracy better than 10-4.

The beam diagnostics is a part of the control system and includes the close beam orbit measurements which are provided by use of Beam Position Monitor receivers (BPMs) developed in BNL [8], BINP-developed Tune Measurement System [9], optical beam observation using Synchrotron Radiation, and destructive beam flags [10]. All devices are connected to the computers via Gigabit Ethernet and are available through the EPICS. Beam current is observed with two Bergozz devices: DCCT for the beam current measurement and FCT for the beam bunch-filling observation.

The timing of the booster cycle and all devices is provided by the sequence of events coming from the main EVG. These events are locked to the main ring RF. The events come to the input of the EVRs which provide delayed triggers for the booster devices.

The vacuum system is controlled with a help of VARIAN dual pump controllers and MKS vacuum gage controllers connected to the computer via RS232. Digital part (binary signals) of the vacuum controls is implemented with a help of Allen-Bradley industrial electronics which provide control of gate valves, interlock signals, and temperature measurements of the booster vacuum chamber.

The booster control software is based on EPICS [11]. Software is basically divided into three parts: (1) firmware running in device controllers, (2) EPICS Input/Output Controllers (IOCs) running in IBM servers and VME controllers, and (3) high level applications running in IBM servers and Operator Consoles located in the Control Room.

Not only input/output, but a lot of functions for data processing are implemented in IOCs: checking of uploading ramp waveforms [12], calculation of different parameters (beam energy, beta functions, etc.), calculation of scalar values taken from waveforms, etc.

High level applications are a set of Graphical User Interface (GUI) software and scripts that are intended for the booster operation control and monitoring: ramp control, visualisation of parameters, live and archived data browsing and comparison, save/restoring of the booster operation sets, work with power supplies and other devices.

## EQUIPMENT DESCRIPTION

The equipment of the booster control system can be divided into two parts: (1) computers and controllers with operation system in which EPICS IOCs run, (2) front-end electronics for input/output of signals and controllers for data processing.

A simplified block diagram of the booster control system equipment is presented in Fig. 1.

The "computer" part of equipment consists of:

- Six servers IBM System x3250 M3 are distributed on a functional basis: (1) one server for PSs control, (2) one server for interlock system and for different auxiliary software IOCs, (3,4) two servers for BPMs control and for orbit measurements, (5) one server for beam instrumentation control, (6) one server for tune measurement system.
- Four MVME3100 VME crate controllers: (1,2) two controllers are intended for BPM receivers timing control, they includes timing electronics, (3,4) two – for injection/extraction measuring electronics control including timing electronics also.
- One CT11 cPCI crate controller for communication with two cPCI digitizers: for FCT and DCCT.



ISBN 978-3-95450-139-7

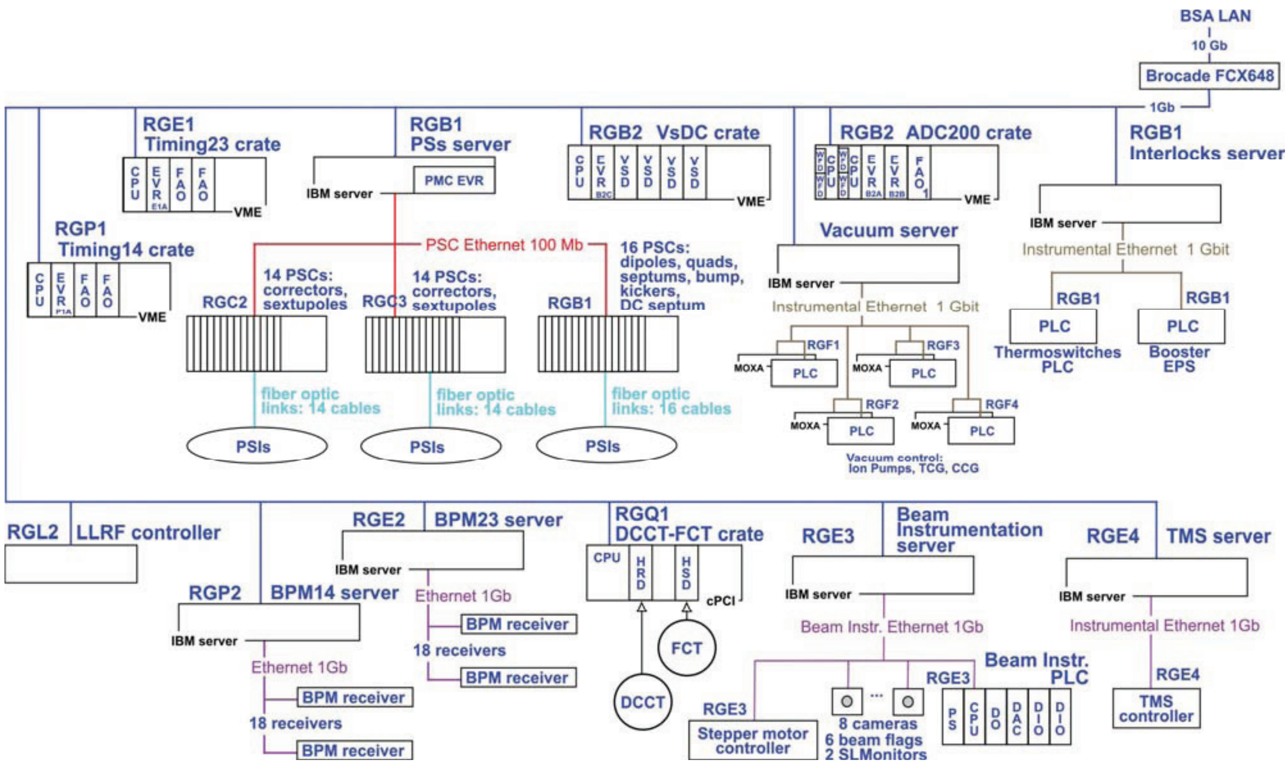


Figure 1: Block diagram of the equipment of the booster control system.

The front-end electronics of the booster control system includes:

- 44 PSC-PSI sets for PS control [7] developed in BNL for NSLS-II project which provides continuous 10 kHz reference voltage output, nine 10 kHz analogous inputs, eight digital inputs and sixteen digital outputs for each PS.
- 36 BPM RF receivers [8] developed in BNL for NSLS-II project for processing of RF signals from pick-ups; BPM receiver provides two modes of operation for the booster control: turn-by-turn beam position measurements, 10 kHz averaged beam orbit measurements.
- Tune measurement controller [9] developed in BINP; the controller provides measurements of betatron tunes with a frequency of 1 kHz during a whole beam ramp.
- 9 Allen-Bradley 1769-L32E PLC chassis for vacuum control, beam diagnostics system auxiliary control and for interlock system.
- Cavity Field Controller for the booster RF system control.
- Agilent U1065A Acqiris high-speed cPCI digitizer for digitizing of a signal from Bergozz Fast Current Transformer (FCT); this signal corresponds the bunch-train filling pattern.
- ICS-710A CompactPCI ADC for digitizing of a signal from Bergozz DCCT; the signal from DCCT corresponds the beam current.
- 4 VsDC3 VME Volt-second digitizers [13] developed in BINP for measurement of values of magnetic field in pulsed magnets.
- 4 ADC200 VME 200 MHz digitizer developed in BINP for registration of values of kicker's currents.
- 5 EVR230RF for triggering of devices.
- 1 PMC EVR for timing of PSCs.

## CONTROL SYSTEM STRUCTURE

### *Control System Parts*

The booster control system can be divided functionally into several parts:

- Timing System
- Power Supplies Control System
- Vacuum Control system
- Interlock System
- Beam Instrumentation Control

All subsystems are synchronized from the timing system which provides a synchronous operation and control of all parts and devices of the booster synchrotron. Timing system provides synchronization of the booster devices by generation of trigger pulses.

The booster interlock system produces signals enabling operation of the booster devices in case of normal conditions. Interlock system receives some signals from Vacuum Control System [14].

A block diagram of the booster control system parts is presented in Fig.2.

ISBN 978-3-95450-139-7

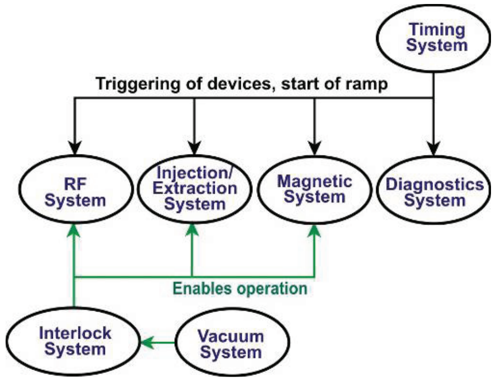


Figure 2: The booster control system interface diagram.

### Timing System

The booster timing system is controlled with a help of a sequence of events from the main event generator distributed on the NSLS-II facility via optic link. These events define the booster cycle and start pulsers in EVRs resulting in delayed output TTL triggers to devices. Also events start BPM receivers inner EVR.

All events are locked to RF and to the NSLS-II main ring revolution frequency for provision of injection to defined separatrix of the main ring. There is 10 kHz event which is also locked to RF which provides timing clocks for the equipment: PSCs and BPMs. These clocks allow precise synchronization of all devices during the ramp.

Events are distributed between the equipment with a help of twelve-channels fan-out modules [3].

An example of the event sequence for case of stacking (double injection) mode of the injector operation is presented in the Table 1 below.

Table 1: Event sequence for 1 Hz with stacking mode

| Event # | Delay | Function |
|---|---|---|
| 25 | 0 | Start PSCs and device cycle start time |
| 15 | 8 ns | 1st Linac Cycle Start |
| 21 | 8 ms | Booster injection 1 |
| 16 | 10 ms | Linac electron gun trigger 1 |
| 15 | 102 ns | 2nd Linac Cycle Start |
| 22 | 110 ms | Booster injection 2 |
| 16 | 112 ms | Linac electron gun trigger 2 |
| 26 | 400 ms | Booster extraction |

The resolutions of the event and pulser delays are 8 nsec. 0.4-ns resolution CML outputs of the EVR are used for triggering of injection and extraction kickers.

### Power Supplies Controls

The power supplies control is based on use of PSC-PSI sets [7]. 34 dual-channel (with two DAC outputs) and 10 single-channel (with one DAC) PSCs located in three chassis are connected to the PS control IBM server via 100 Mbit Ethernet. Each PSC sends two 10k and nine 1k readback waveforms for each DAC channel each cycle of the booster operation that provides a continuous observation of all PSs parameters during the cycle. Start of the PSC cycle is locked to the cycle initial event 25 (see Table 1).

### Vacuum Control System

The vacuum control is based on use of standard industrial electronics: Varian Dual Ion Pump Controllers and MKS-937B Vacuum Gage Controllers connected to the IBM server via CN2650 16-port Moxa terminal servers. Vacuum valves control and vacuum chamber temperature monitoring systems use Allen-Bradley 1769 Compact I/O modules assembled in four chassis. All vacuum electronics is connected to vacuum IBM server (not presented in Fig.1) which is intended for the whole injector vacuum control including two beam transport lines.

### Interlock System

The interlock system is also based on Allen-Bradley 1769 Compact I/O modules assembled in two chassis. The system protects equipment in case of different faults: magnets overheat, beam losses. One PLC chassis processes the signals from thermo switches mounted on the magnets water cooled coils. Another chassis provides general protection of equipment. It receives and processes hardware signals coming from different systems and creates output signals to Linac interlock system and to power supplies. The vacuum leakage protection system is implemented in four vacuum chassis.

### Diagnostics Controls

The diagnostics system control includes a wide variety of electronics and devices:

- 36 BPM receivers connected to two IBM servers via Gigabit Ethernet send each cycle 4096-length waveforms with beam coordinate and current values in 10-kHz or turn-by-turn (TBT) measurement modes. These waveforms are processed in IOCs in IBM servers to calculate the beam orbit for both modes of operation and betatron tunes for TBT mode.
- 8 Prosilica GE cameras for six beam flags and two Synchrotron Light Monitors (SLMs) are connected to Beam Instrumentation IBM server via Gigabit Ethernet. 8-channel GeoBrick stepper motor controller is used for SLM mirrors adjusting. The beam diagnostic service PLC chassis with Allen-Bradley 1769 I/O modules is also connected to the Beam Instrumentation IBM server for provision of auxiliary functions: control of flags position, flags lighting.
- Signals from FCT and DCCT are digitized with a help of 8 Gs Agilent U1065A Acqiris cPCI digitizer and 200 kHz ICS-710A cPCI digitizer correspondently. The beam current data are processed by IOC to 10k waveform which is matched with the booster cycle.



ISBN 978-3-95450-139-7

- The Tune Measurement System [9] provides waveforms of 512-points with X-, Y-tunes and amplitudes of the beam oscillation each booster cycle. The step of measurements in the waveforms is about 1 ms.

## SOFTWARE

The booster control system software is based on EPICS client-server architecture. Figure 3 shows the software architecture.

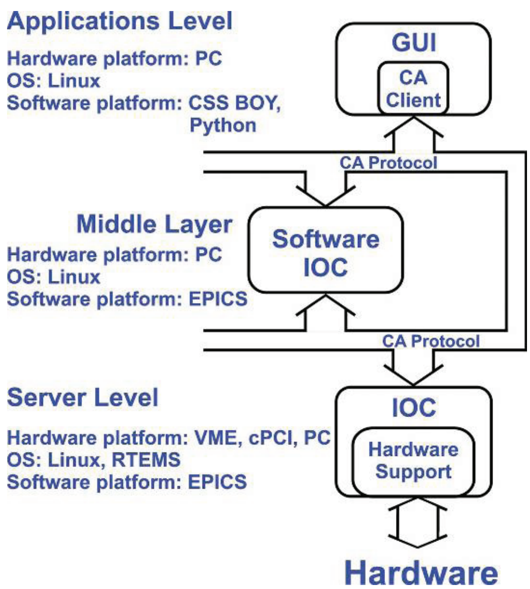


Figure 3: The booster software architecture.

The lower (server) level provides operations with equipment. It consists of IOCs which run in front-end computers (see Fig. 1):

- 6 IOCs for different type of PSs in IBM server for PSs control. These IOCs communicate with PSCs.
- 36 IOCs in two IBM servers for BPM receivers.
- 8 IOCs in Beam Instrumentation IBM server for Prosilica GE cameras.
- IOC for tune measurement system.
- Equipment protection and thermo switches IOC in Interlock IBM Server.
- IOCs for VME electronics (EVR, VsDC, ADC200) in four VME controllers under RTEMS.

The middle soft IOC layer performs data processing for calculation of different machine parameters: beam orbit, betatron tunes, beam energy, etc. There are several IOCs running in three front-end IBM servers. Also the middle level includes IOCs with auxiliary PVs used for communication between high-level applications and IOCs.

All high-level applications are developed with a help of Control System Studio (CSS) BOY [15] and Python. When the only data observation is required the CSS screens are preferred. High-level applications run both in IBM-servers and operator consoles.

The application level includes a wide set of GUIs for different aspects of the booster operation control: engineering screens for PSs control and testing, operator panels for vacuum and interlocks observation, the Ramp Manager tool [12], tools for save/restore and archiving, screen for the booster status monitoring [16], a lot of beam diagnostics screens (beam orbit, tunes, etc.).

## CONCLUSION

The booster control system is basically completed both in hardware and software parts. All hardware components are installed in racks and was checked during the machine extended integrating tests [17] in summer 2013. Software includes a sufficient set of components both on IOC and application levels to provide a successful booster synchrotron commissioning which is planned now at the end of 2013.

## REFERENCES

[1] F. Willeke, "Status of the NSLS-II project", Proceedings of IPAC'11.
[2] S. Gurov et al., "Status of NSLS-II booster", Proceedings of IPAC'13.
[3] J. Pietarinen, "MRF Timing System", Timing Workshop CERN, February 2008, http://indico.cern.ch/getFile.py/access?contribId=9&resId=0&materialId=slides&confId=28233
[4] P. Cheblakov et al., "Software for Power Supplies Control of the NSLS-II Booster Synchrotron", Proceedings of IPAC'13.
[5] A. Derbenev, et al., "Monitoring and Archiving of NSLS-II Booster Synchrotron Parameters", this conference, TUPPC021, ICALEPCS'13.
[6] P. Cheblakov et al., "NSLS-II Booster Timing System", Proceedings of ICALEPCS'11.
[7] W. Louie et al., "NSLS-II Power Supply Controller", Proceedings of PAC'11.
[8] K. Vetter et al., "NSLS-II RF Beam Position Monitor", Proceedings of PAC'11.
[9] E.A. Bekhtenev et al., "Fast Tune Measurement System", Proceedings of RuPAC'12.
[10] O.I. Meshkov, V.V. Smaluk, "Beam Diagnostic Instrumentation for the NSLS-II Booster", Proceedings of RuPAC'12.
[11] www.aps.anl.gov/epics
[12] P. Cheblakov et al., "NSLS-II Booster Ramp Handling", this conference, THPPC053, ICALEPCS'13.
[13] A. Pavlenko et al., "Electronics for Precise Measurements of Accelerator Pulsed Magnets", Proceedings of IPAC'13.
[14] R. Kadyrov et al., "NSLS-II Booster Interlock System", this conference, MOPPC051, ICALEPCS'13.
[15] Control System Studio BOY, https://github.com/ControlSystemStudio/cs-studio/wiki/BOY
[16] A. Derbenev et al., "Monitoring and Archiving of NSLS-II Booster Synchrotron Parameters", this conference, TUPPC021, ICALEPCS'13.
[17] G.M. Wang et al., "NSLS-II Injector Integrated Testing", Proceedings of IPAC'13.

ISBN 978-3-95450-139-7