# PULSE POWER SUPPLIES FOR KICKER MAGNETS OF NSLS-2 BOOSTER RING*

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*Abstract*

A set of identical ferrite kicker modules are utilized for the injection and extraction of the NSLS-2 booster ring. The pulse power supplies of these modules are based on the PFN-thyratron design. The pulse current amplitude up to 4 kA at 300 ns flat top duration and PFN charging voltage up to 23 kV was achieved on the extraction pulsers. The pulse to pulse repeatability of the output current waveform was measured and made up to 0.05% (sigma) at nominal current for the extraction pulsers. The injection pulsers have a specification on the reverse current overshoot to be less than 0.5% of amplitude. To fulfill this requirement a single turn saturated choke in the thyratron circuit was used. The design and the test results of the power supplies on NSLS-2 site are presented in the paper.

## INTRODUCTION

BINP has developed the booster synchrotron for NSLS-2 light source. For injection and extraction from the booster ring fast ferrite kicker magnets are used [1]. Each of four injection kickers is supplied by separate injection kicker power supply. Extraction kicker consists of four kicker sections identical to injection kickers and is supplied by two extraction power supplies (see Fig. 1). The power supplies' specifications are presented in Table 1.

Table 1: Power Supplies' Specifications

| Parameter | Extraction power supplies | Injection power supplies | |
|---|---|---|---|
| | PS#1,2 | PS#1,2 | PS#3,4 |
| Kicker current 1st pulse/ 2nd pulse, A | 2175/- | 650/- | 1545/ 970 |
| B-field integral 1st pulse/ 2nd pulse, G | 720/- | 215/- | 510/ 320 |
| Rise time, ns (0.4-99.7% - injection 0.2-99.8% - extraction) | <225 | <170 | <170 |
| Flat top duration, ns | >310 | >310 | >310 |
| Fall time, ns (99.7-0.4% - injection) | - | <220 | <220 |
| Pulse top ripples, % (including pulse-to-pulse repeatability) | ± 0.2 | ± 0.5 | ± 0.5 |
| Post pulse ripples, % | - | ± 0.5 | ± 0.5 |
| Delay time jitter, ns | < 5 | < 5 | < 5 |
| Load equivalent inductance, nH | 650 | 162.5 | 162.5 |
| PFN charging voltage, kV | 22.3 | 13.5 | 20.9/13.3 |

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Two scenarios of injection are assumed for the booster: single-turn injection and stacking mode injection. In the single turn injection only injection PS#3 and #4 operate (1st pulse). At the stacking the first beam is injected as at the single-turn injection. 100 ms later second beam is added to the circulating one using all 4 injection kickers with weaker kick (2nd pulse).

## POWER SUPPLY DESIGN

All injection and extraction power supplies have identical design. The single power supply consists of two parts: pulser unit located below the magnet in the booster tunnel and power supply unit (PSU) located about 50 m away from the pulser in the injection service area of the NSLS-2 building.

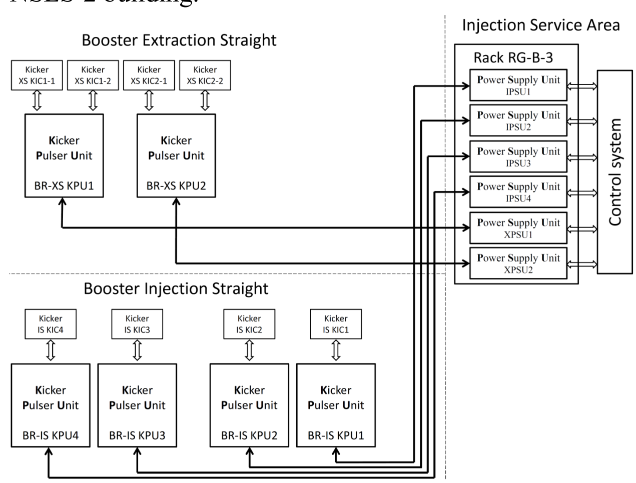


Figure 1: Kickers' power supply system block diagram.

Injection power supply block diagram is shown in Fig. 2. The output pulse generation is based on pulse forming network (PFN) discharge through the hollow cathode thyratron TPI1 10k/50 [2,3]. The duration of output current is defined by two propagation delays of the PFN. The rise time is propotional to $L_{load}/\rho_{PFN}$, where $L_{load}$ - total load inductance, $\rho_{PFN}$ - PFN impedance. For decreasing the rise time the kickers' buses are connected to the pulser with low inductance leads and are commutated in parallel. Therefore the pulser output current is two times greater than kicker bus current but equivalent inductance is 4 times less than it in the case of buses series connection. To absorb energy reflected from the load the end of line resistive-diode clipper circuits are utilized. To damp the high-frequency load current oscillations the damp resistors are connected at the pulser output. The injection kickers have tough requirements to the postpulse oscillations. They should be less than ± 0.5% of kick amplitude. To provide this specifications the one turn saturable choke is used in the pulser. It plays role of a diode having low impedance while conduct direct current of the pulser and providing high impedance with reverse direction of a current.

Injection power supplies #3 and #4 have to operate in stacking mode that is the pulsers must have possibility to generate output pulses twice per booster cycle (with the time distance 100ms). To reduce requirements for charging power supply the filter capacitors at the charging voltage input of the pulsers are installed. The second pulse amplitude in the stacking is approximately 70% of first one so the PFN takes energy from filter for second pulse generation.

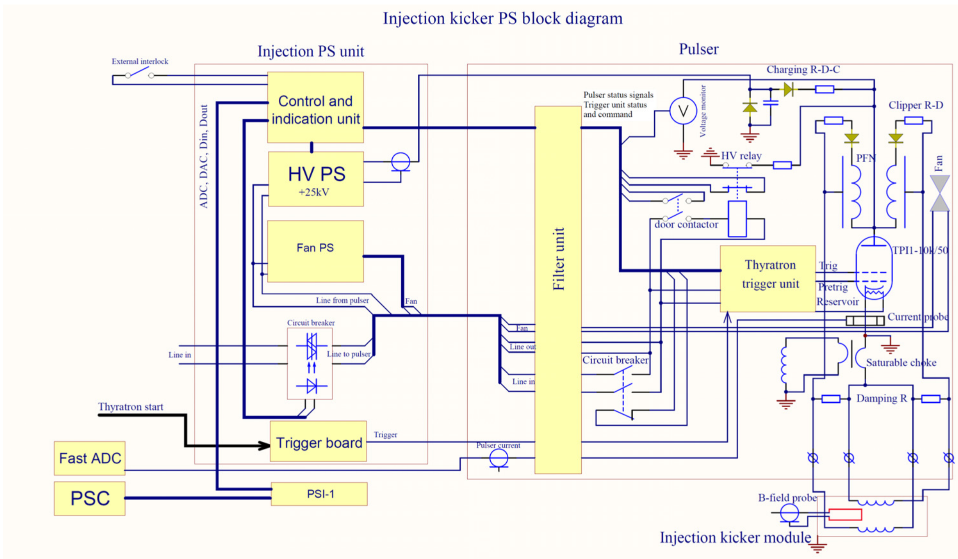


Figure 2: The injection kicker power supply block diagram..

The trigger unit supplies the thyratron reservoir and generates driving pulses. The cold cathode thyratron TPI1-10k/50 has two reservoirs, each of them requires up to 7 V, 2 A DC power supply. The thyratron auxiliary anode (pre-trigger electrode) is supplied with DC voltage to keep up the DC pre-ionization arc discharge (DC arc current is ~15 mA at ~300 V voltage drop), and it is also supplied with the 2 kV pulse voltage for the pulse pre-ionization arc discharge, 800 ns later the grid electrode is supplied with the 2 kV trigger pulse to switch on the thyratron. The thyratron life time is estimated as $10^6$ Coulombs, that could provide approximately 7 years of a continuous pulser operation in 2 Hz mode. However it is recommended to check the thyratron condition every year.

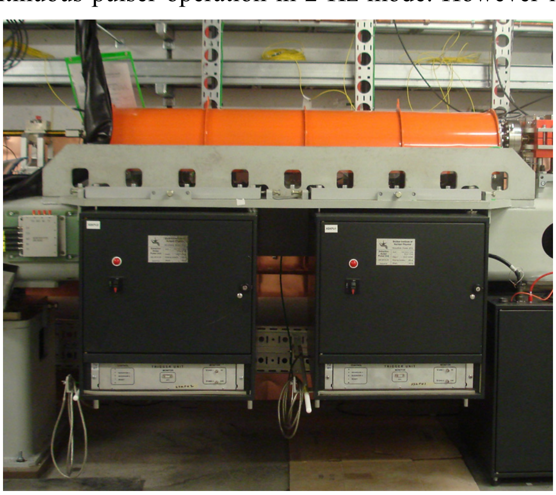

Figure 3: Extraction kicker pulsers installed in the booster extraction straight.

The output current of the pulser is monitored by the fast current transformer based on nanocrystalline core [4]. Each kicker section is equipped with searching coil for magnetic field monitoring. This is a single turn coil placed on the magnet pole between vacuum chamber and ferrite.

Unlike the injection the extraction pulsers have no the saturable choke because there is no requirements for fall time and postpulse ripples in this case. Another difference is load connection. Single extraction pulser supplies two kicker sections which are connected in parallel but have series connection of the buses. So the pulser output current is also twice of the kicker buses current as for injection.

The PSU is a 3U height 19” unit which contains high voltage charging power supply, auxiliary power supplies and control unit. All PSUs are identical. The remote control and monitor of the power supply is provided by power supply controller (PSC) wich is connected to the PSU through the power supply interface (PSI). PSI is 1U height 19” unit with a single channel DAC, 8-channel 10kHz ADC and input/output registers.

Fast ADC (PMC module) with 12 bits resolution and 200MSPS sample rate is used for digitizing of the pulser output current. This signal is used in control system for kickers’ amplitude and waveform stability monitoring. The extraction pulsers installed in the booster tunnel are shown in Fig. 3. They are attached to the girder from below.


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## TEST RESULTS

All pulsers were tested at test stand before installation to the booster. The PFNs were turned to obtain required waveform of the magnetic field. The single turn long coil was used as a magnetic field probe. The resulting signal was derived from probe signal by digitizing and integrating. Example of the extraction magnetic field waveform at the amplitude of 720 G is presented in Fig. 4. This waveform is a result of averaging among 100 shots. The same waveform for injection power supply is shown in Fig. 5.

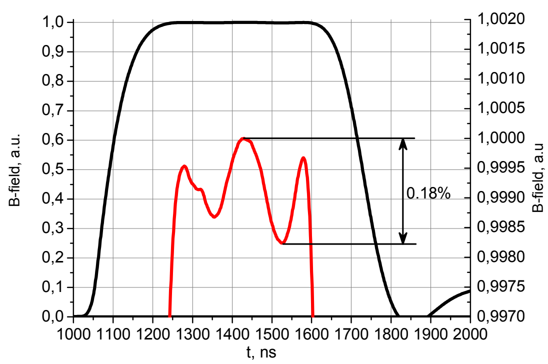


Figure 4: Extraction kicker B-field waveform normalized to maximum (720 G).

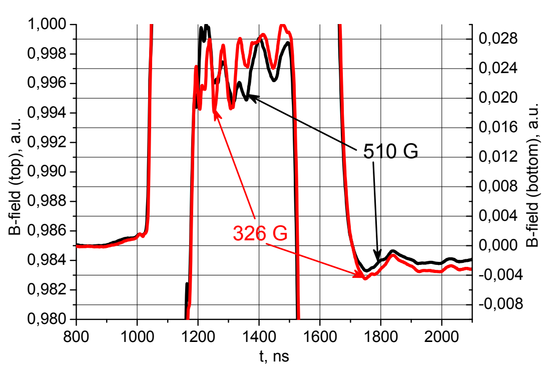


Figure 5: Injection kicker B-field waveforms normalized to maximum (510 G and 326 G).

At present all kicker power supplies are installed in the tunnel of NSLS-2 booster. The integrated test of the pulse power supply system was performed. Long term drift of pulser output current and magnetic field was observed. The graphs in Fig. 6 shows how injection kicker power supply #3 output parameters are changing during 5 hours run at stacking mode. Decreasing of the output amplitude can be explained by heating of the PFN capacitors which have negative temperature coefficient of 4700ppm/°C. Applying the program feedback on the reference voltage of the charging power supply the long term stability improves and becomes within the requirements (Fig. 7). Nevertheless some modification of the pulsers racks' are planned to improve PFN case cooling.

The standard deviation of achieved pulse to pulse stability of the output current can be estimated at 0.043% (self-noise of ADC is 1.1mV (sigma)). For two extraction pulsers relative amplitude instability makes 0.024% and 0.051%. Taking into account addition of two independent quantities the standard deviation of extraction kick makes up 0.028%.

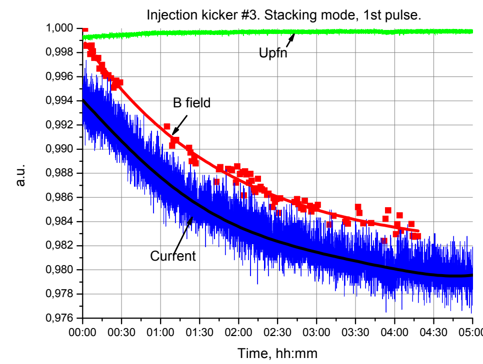


Figure 6: Temperature drift of injection kicker PS#3 output parameters in stacking mode.

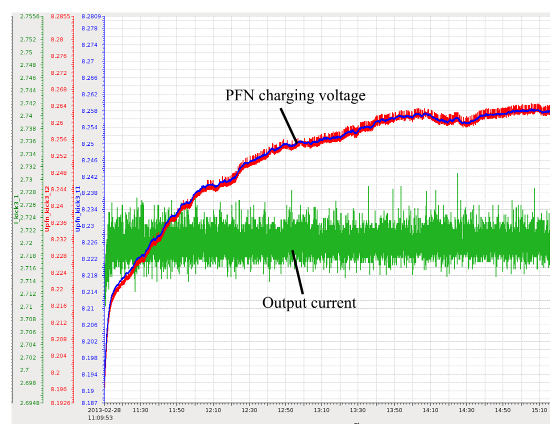


Figure 7: Long term test of injection PS#3 in 1 Hz mode with feedback.

## SUMMARY

The power supply system for injection and extraction kickers of the NSLS-2 booster was designed, manufactured, assembled on the NSLS-2 site and tested. The designed parameters of the system were achieved.

## REFERENCES

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