FUTURE NSLS-II INJECTOR UPGRADES*

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Abstract

Last year we began commissioning of the NSLS-II injection system. In 2013 the NSLS-II injector, which consists of 200 MeV linac, 3 GeV booster, transport lines and storage ring injection straight section, will be entering operations. During injection system development we invested substantial efforts in preserving options for future injector upgrades and enhancements. In this paper we discuss our vision and plans of incremental evolution of the NSLS-II injector by implementing planned upgrades, such as the second gun, flexible bunch patterns, beam stacking in the booster, emittance compensation techniques in the transport lines, etc. These upgrades will expand the facility capabilities, improve the beam quality and increase operational reliability.

INTRODUCTION

The NSLS-II [1] is a state-of-the-art 3 GeV synchrotron light source under construction at Brookhaven National Laboratory. It will provide ultra-bright synchrotron radiation of 10^{21}·photons·s^{-1}·mm^{2}mrad^{2}·0.1%BW^{-1} at 2 keV and high photon flux of 10^{15}·photons·s^{-1}·0.1%BW^{-1}. The facility will support a minimum of 60 beamlines. Construction started in 2009 and commissioning is expected to be completed in 2014.

The NSLS-II injector [2] is now being commissioned to deliver beam performance sufficient for initial storage ring operations at low current. At a later stage the NSLS-II storage ring capabilities will continuously expand to include high intensity operations and top-off mode. This expansion will require the NSLS-II injector to reliably deliver electron beam at a high charge rate, with low losses and high stability in all six phase space coordinates. To meet the requirements of high-intensity ring operation we designed in a large scope of the injector upgrades. The upgrades, described in this paper, aimed to increase the NSLS-II facility capabilities, improve beam quality and reliability of the facility operations.

LINAC UPGRADES

Production of Short Pulses

The 200-MeV NSLS-II linac is a high-performance accelerator delivering up to 15 nC per shot with the emittance of 70 nm rad within trains of 20 ps (RMS) bunches. These excellent beam properties can find applications in generating bright flashes of radiation in THz-visible and hard X-ray wavelength range. Top-off time format (1 injection cycle per minute) permits using the injector linac for other purposes during at least 50 seconds every minute.

Some of these parameters (bunch length and beam emittance) can be greatly improved by addition of an RF gun that delivers an LCLS-like beam performance.

With an RF gun the NSLS-II injector linac will gain potential in generating short bursts of radiation via:

- Short pulses of THz/IR via CTR or in an undulator
- Coherent sources in IR – DUV range of wavelengths
- Short pulse X-rays via Compton Scattering

We designed the linac tunnel in such a way that there exist an ample space ahead of the linac for developing a user end station and upgrading the linac energy for building a short radiation pulse facility (Fig. 1).

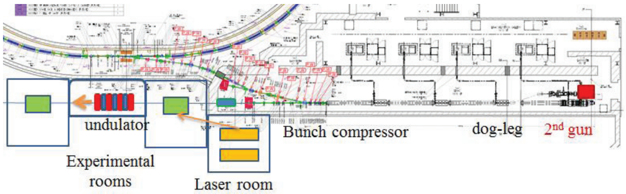

Figure 1: Potential layout of the short pulse facility.

Including the second gun [3] into the low-energy part of the linac will: a) increase reliability of the NSLS-II accelerator complex, b) enable more efficient operations in generating complex bunch patterns and, c) simplify switching between single-bunch and multi-bunch modes for the ring injection.

Generating Flexible Bunch Patterns

Specifications for the storage ring bunch pattern given by the NSLS-II users require sharp edges of the circulating bunch trains and uniform distribution of charge per bunch within a single train. This translates into challenging requirements on the gun pulser since its electronics defines the quality of the generated trains.

In order to enable generation of flat-top (relative bunch-to-bunch charge noise below 1%) trains with sharp edges (~2 ns) we proposed to include a short kicker (chopper) just upstream of the 100-keV gun (Fig. 2, [4]).

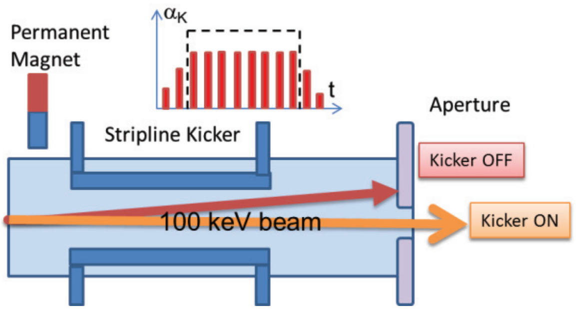

Figure 2: Schematics of the beam chopper.

This kicker will permit passing beam only inside the desired macropulse deflecting bunches outside to the

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chamber wall. The gun pulser performance is therefore simplified since the gun will be emitting long bunch trains with loose requirements on the train edges. The kicker will select the most uniform part of the bunch train and cleanly chop off the edges.

Another advantage of this compact device is in limiting the useless and harmful charge outside of the bunch train thus minimizing it from being accelerated and reducing beam loss at high energy.

During the design stage we allocated sufficient space for the chopper system in the linac front-end.

Beam Loading Compensation

The linac is designed to deliver charge 15 nC per shot with up to 150 bunches. The beam loading induces voltage in the sub-harmonic pre-buncher (SPB) and acceleration sections, which results in a large energy spread at the nominal beam current.

We designed an alternative way of beam loading compensation via using a BPM and a screen in the large dispersion region of the transport line upstream of the linac. BPM button signal is split into two paths: one follows to the regular BPM system and the other to the bunch-by-bunch system. The bunch-by-bunch energy slew along the train can be measured from the fast BPM system, while the bunch train energy spread is measured at the beam screen. We use the train average energy spread and bunch-by-bunch energy slew as the RF feed-forward signal to compensate the beam loading effect in the RF system. Then the bunch train beam quality will be optimized and the energy spread, induced by the beam loading, can be minimized.

Linac Digital RF Controller Upgrade

The linac will be upgraded to use the digital cavity controller developed for the NSLS-II booster and storage ring RF systems. Specialized firmware will provide double clocking of the output DAC to improve waveform ramp smoothness, add feed-forward capability to keep TW structure field constant in the presence of beam loading and fix a Master Oscillator reference ambiguity upon reset that we have with the original system.

BOOSTER UPGRADES

2-Hz Repetition Rate

While the NSLS-II booster will soon be commissioned at 1 Hz repetition rate, which is adequate for the initial phase of facility operations, we designed all of the injector subsystems to operate at the double frequency. Expanding the injector operations to 2 Hz will halve the demand of the injected charge per shot, increasing beam quality and reducing beam loss. It will also help to reduce the top-off injection cycle thus shortening perturbations on the stored beam orbit in the storage ring.

Beam Stacking

To further reduce requirements on the linac charge per shot we studied and then implemented beam stacking system in the booster [5]. The beam stacking is realized via closed bump with four booster injection kickers (Fig. 3) accommodating two consecutive bunch trains from the linac separated by 100 ms. Accumulated beam is accelerated and extracted from the booster as a single high-current train.

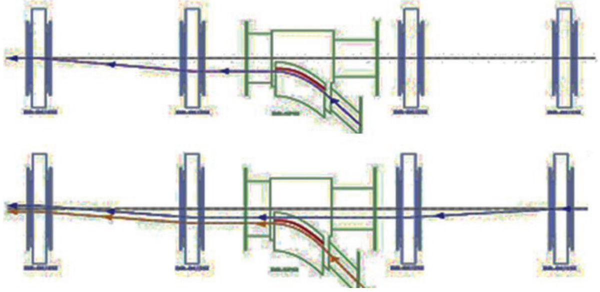

Figure 3: Concept of the beam stacking: upper and lower layouts show injection of the 1st and 2nd bunch trains.

Bunch Train Merging System

Another way of reducing linac output charge per bunch is in adding a high-frequency (i.e. 3 GHz) RF system and modifying the linac front-end to produce trains with 2ns/6=333ps bunch separation. After injection in the booster the 500 MHz RF system takes over and every six microbunches damp down into a single 500 MHz rf bucket. Decreasing charge per bunch should help increase capture efficiency in the linac front-end and reduce beam transverse emittance at 200 MeV for low-loss injection into the booster.

Bunch-by-Bunch Transverse Feedback System

High current circulating in the NSLS-II booster throughout the energy ramp may lead to development of instabilities, which will limit the injector output and create radiation losses in the injector complex. Sources of the potential instabilities include HOMs in the booster RF cavity, resistive wall, impedance of the vacuum chamber transitions and ion-related effects. In addition, bunch-by-bunch oscillations may lead to detrimental effects on the extracted beam quality. As such, the phase space area of the extracted beam may increase thereby increasing the beam emittance and creating losses in the storage ring.

Among the methods of battling the instabilities in the booster we assessed a concept of bunch-by-bunch feedback system, whose implementation for the booster may be similar to that in the storage ring. The diagnostics straight of the booster ring is long enough to accommodate a long stripline kicker fed by a broadband RF generator. The feedback will rely on measurements of bunch-by-bunch orbit deviations in the booster BPMs and adapt the waveform in accordance to the amplitudes of oscillations of consecutive bunches in the circulating train.

Emittance Correction System

Quality of the injector beam can be compromised by collective effects or through errors in the extraction line (i.e. ripples in the pulsed magnets). Consequently, bunches in the train may exit the booster with modulation

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in angle or position inflating the resulted projected beam emittance.

This parasitic bunch-by-bunch modulation can be corrected using a stripline installed at the exit of the booster, i.e. at the beginning of BSR transport line.

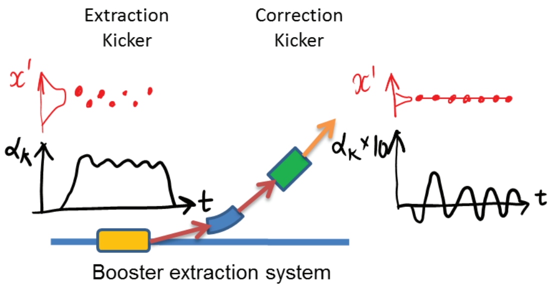

Figure 4: Concept of the horizontal emittance compensation.

The stripline will produce a modulated field waveform, so that bunches passing the stripline will receive negative angular kicks to minimize the angular spread along the extracted bunch train (Fig. 4, [6]).

STORAGE RING INJECTION SYSTEM UPGRADES

Slow Bump in the Injection Straight Section

Performance of the storage ring kickers will significantly contribute to the overall reliability of the NSLS-II accelerator complex. It is prudent therefore to reduce the maximum voltage on the kicker pulsers. We considered and analysed a solution of adding a 3 DC/Slow correctors [7] in the injection straight section, which will produce a closed bump helping the pulsed kickers. For sufficiently fast correctors the closed bump can be turn on during every injection cycle reducing the kicker maximum voltage by 30%. The storage ring injection straight section contains space sufficient for adding these three correctors.

Pulsed Sextupole

During the injection straight design we assessed injection via a pulsed multipole pioneered at SPring-8 [8]. In [9] and [10] we analysed the sextupole injection in details and concluded that integration of a strong pulsed sextupole into the storage ring injection straight will require substantial revisions of the BSR transport line optics. However we considered testing this alternative injection scheme at a later time.

Storage Ring and Booster Bunch Cleaning Systems

As demonstrated by experience of several synchrotron light sources the bunch cleaning systems are necessary to satisfy user requirements on quality of storage ring bunch pattern. Primarily for these experiments that deal with precise timing of their detectors it is required to maintain sharp edges of the storage ring bunch trains with the stray charge in the RF buckets between the trains below 0.01%. There exist two sources of the stray electrons in the storage ring buckets: a) charge outside of the injected bunch trains and, b) electrons scattered out of full SR RF buckets via Touschek effect (multiple scattering). The latter is inherent property of a high-current storage ring and requires implementation of the SR bunch cleaning system. Estimates on the rates of accumulation of the Touschek-scattered electrons in the SR RF buckets are available in (Fig. 5, [11]).

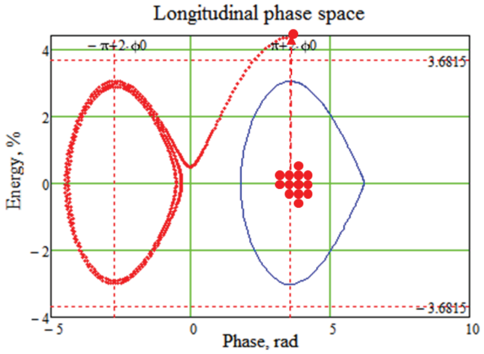

Figure 5: Accumulation of Touschek-scattered particles in an empty bucket.

Modern bunch cleaning system consists of a stripline driven by an RF generator, an aperture for constraining the vertical betatron amplitude of these electrons that are excited by the stripline, and a high-sensitivity bunch pattern monitor [12]. Motion of the unwanted bunches is driven by the stripline field until their vertical oscillation moves them outside the aperture. The bunch pattern monitor controls the purity of the circulating bunch train. We designed in provisions for integrating the required hardware for the bunch cleaners in both booster and storage ring.

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