

DESIGN OF THE PSEUDO SINGLE BUNCH MODE IN SPEAR3*

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Abstract

With the growing interests and new experimental development in time-resolved studies at Stanford Synchrotron Radiation Light Source (SSRL), we are motivated to develop the Pseudo Single Bunch (PSB) operational mode to address the requirements from time-resolved and regular user experiments simultaneously. In this paper, we will present the physics design for this new mode. Beam line simulations for performance evaluation of the user experiments are also reported.

INTRODUCTION

SPEAR3 is a third-generation electron storage ring that provides a stable stream of intense x-rays for a large user community. Similar to many other synchrotron radiation light sources around the world, most user experiments in SPEAR3 have more demanding requirements on the high average photon flux than the timing details. Therefore, the storage ring is usually filled with multi-bunch trains for high average beam current and long beam lifetime. However, for the time-of-flight experiments, the users require single bunch with a lower repetition rate. To simultaneously meet the requirements from both timing users and high-brightness users, at SPEAR3, we deliver the stored beam in a hybrid filling pattern with a camshaft bunch being placed in a timing gap sufficiently long enough for the timing users to apply gating techniques for data acquisition.

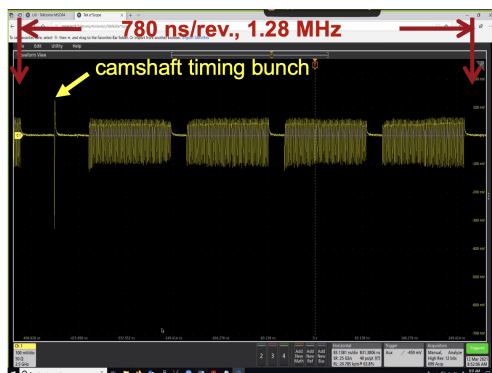


Figure 1: Filling pattern in SPEAR3 with the 20 mA camshaft bunch.

As shown in Fig. 1, the SPEAR3 revolution frequency is 1.28 MHz with an RF frequency of 476.31 MHz. As a result, the spacing between two adjacent buckets is about 2.1 ns. We normally fill the total beam current of 500 mA

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with 4 trains and the single camshaft bunch, up to 20 mA in current, in the middle of a 120-ns gap. Equipped with a fast Ytterbium-doped fiber laser, avalanche photo-diode (APD) detectors with ns response, and a fast liquid jet sample delivery system, the new beamline BL15-2 has developed experimental capabilities to take advantage of X-rays generated from the 20 mA camshaft bunch for time-resolved X-ray spectroscopy at SPEAR3. However, the presence of multi-bunch X-rays at the sample in the hybrid filling pattern is far from ideal. The unnecessary irritation from the multi-bunch X-rays can degrade the samples and cause challenges for data read out in some sensitive experiments. To address these problems, we will develop the Pseudo Single Bunch (PSB) operational modes to provide spatial separation between the main bunch trains and the camshaft bunch by applying a kick to the camshaft with a dedicated fast kicker.

SPEAR3 PSB MODES

Due to the wide range of camshaft repetition rates required by the SPEAR3 user experiments, we propose two PSB modes: Low Repetition Rate (LRR) mode and High Repetition Rate (HRR) mode. Both are designed to be transparent to high brightness users and improve the signal-to-noise for the timing users.

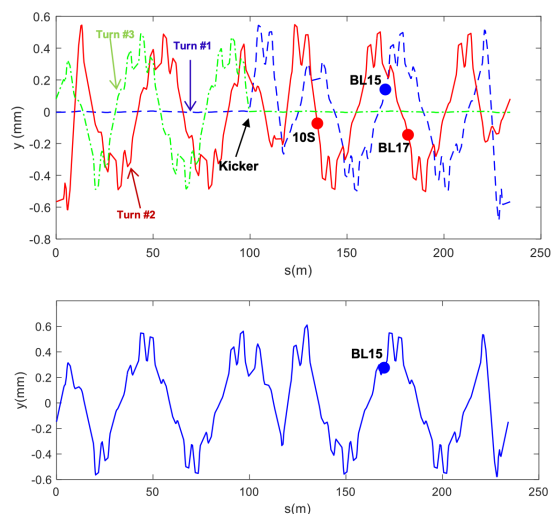


Figure 2: Camshaft orbits in the LRR mode (top) and the HRR mode (bottom) from tracking simulations.

LRR Mode

The LRR mode provides an on-demand camshaft bunch (up to 20 mA) with user adjustable repetition rate up to 427 kHz (1/3 of the SPEAR3 revolution frequency). The technical approach of this mode will be based on the Kick-

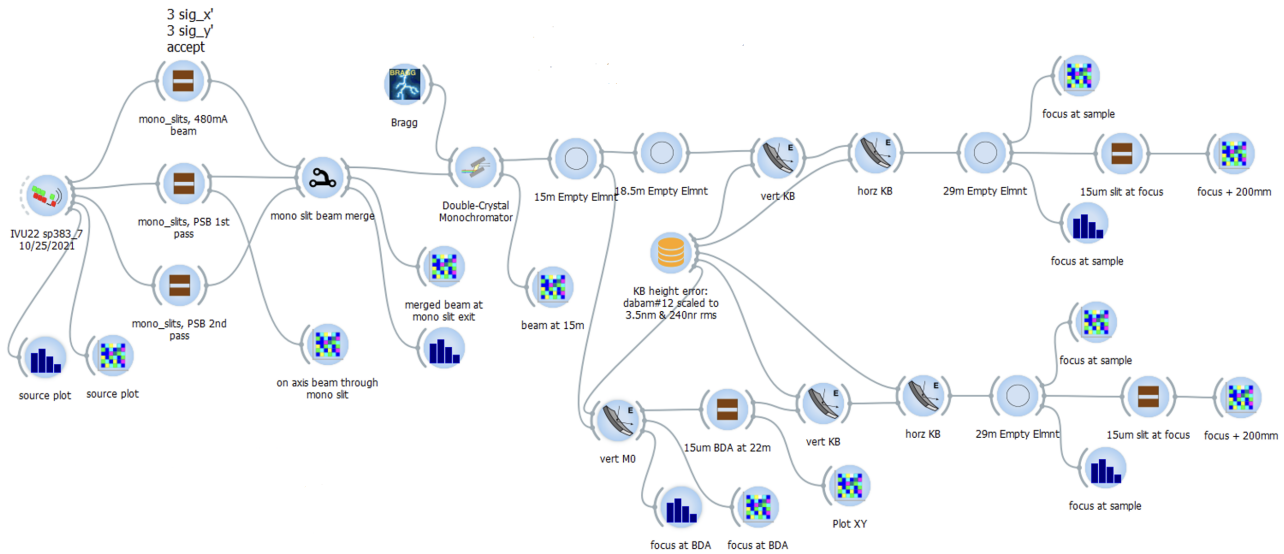


Figure 3: Beam line simulation setup.

and-Cancel (KAC) technique, first successfully demonstrated in Advance Light Source (ALS) [1–3]. To operate in this mode, the SPEAR3 lattice is required to be modified slightly to provide the fractional vertical betatron tune of 0.25. The tracking results of the camshaft orbit in the KAC mode is shown in the top plot in Fig. 2. With the quarter tune, the camshaft bunch is first kicked to a different vertical orbit (first turn, blue) by the PSB kicker before proceeding two more turns. At the third pass at the PSB kicker (third turn, green), the camshaft bunch has the same vertical offset but the inverse angle to that of the first pass. With another kick from the PSB kicker, the camshaft bunch will be placed back to the original orbit. This process can be repeated with variable intervals to generate different repetition rates. The LRR mode will mainly benefit BL15 and BL17. The first pass of camshaft will be chosen for BL15, while the second pass will be chosen for BL17 based on beam line performance simulations.

HRR Mode

In the HRR mode, the camshaft bunch is kicked every turn by the fast kicker and is permanently placed to a different closed orbit, as shown in the bottom plot in Fig. 2. As a result, the repetition rate for the HRR mode is fixed at 1.28 MHz. In addition, the HRR mode can be implemented directly to the operating SPEAR3 lattice. This mode is particularly designed for BL15. The two PSB modes are compared in Table 1.

BEAMLINE SIMULATION

The performance of the LRR mode has been simulated for BL17. Because of the similar source and optical setup, the performance for BL15 is expected to be similar. The simulation set up is illustrated in Fig. 3. The undulator source, tuned to 12 keV on the 7th harmonic, was generated

Table 1: Comparison of HRR and LRR Modes

	LRR	HRR
PSB Rate	≤ 427 kHz	1.28 MHz
Lattice	$\nu_y = 0.25$	ops lattice
Current	20 mA	20 mA
Kick	85 μ rad	85 μ rad
Pulser rate	Adjustable	Fixed, 1.28 MHz
Orbit (BL15)	140 μ m, 55 μ rad	276 μ m, 36 μ rad
Orbit (BL17)	-145 μ m, -54 μ rad	224 μ m, -47 μ rad

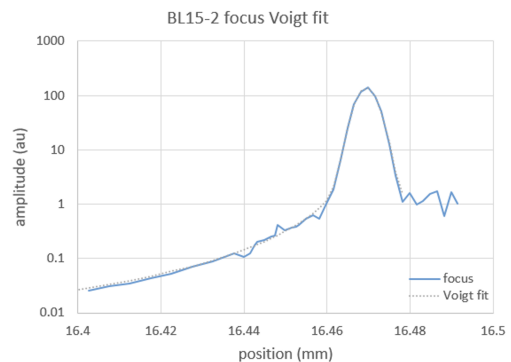


Figure 4: Empirical tail results at BL15-2.

in OASYS [4] with the horizontal and vertical emittance of 6.87 nm and 8.3 pm, respectively. The simulated source bandwidth was larger than that of the Si(111) monochromator acceptance for the full range of source angular offsets to ensure the simulation properly accounted for off axis radiation. Realistic optics shape errors were included. Ray tracing was performed for two optical configurations as depicted in Fig. 3. The upper branch depicts the existing BL17 optics, while the lower branch adds vertical M0 mirror which creates

a virtual source by focusing on the beam defining aperture (BDA), about 22 meters downstream from the source point. The addition of the M0 mirror and the BDA complements the upstream apertures to more effectively select the 2nd pass PSB and suppress the 1st pass PSB and the 480 mA beam. The BDA can eliminate the 1st pass PSB completely and most of the 480 mA multi-bunch beam except diffuse tails owing to mirror scattering from short wavelength shape errors. The effect of the diffuse tails is estimated using empirical results from the BL15 vertical KB mirror as depicted in Fig. 4.

The 480 mA multi-bunch beam and the two passes of the PSB are merged at the mono slits with relative weight factor of 72 and 1, respectively. With the existing BL17 optics, the beam profiles at the sample focus is shown on the top in Fig. 5. The 2nd pass PSB can be selected by introducing aperture at the sample focus, but the sample will be moved off focus longitudinally, where beam structure caused by mirror imperfections is more pronounced. Introducing the M0 mirror to create a virtual source at the BDA produces the beam profile at the BDA as shown on the bottom in Fig. 5. The BDA can effectively suppress the 1st pass PSB and the 480 mA beam. After a 15 μm BDA the net 480 mA pedestal on the 2nd PSB is conservatively estimated as 0.1 %, where the pedestal depends strongly on the M0 mirror surface error. One should note that the calculation is based on the highest repetition rate of 427 kHz. With a reduced repetition rate, the 480 mA pedestal will increase proportionally to the ratio of 427 kHz to the actual repetition frequency.

FAST KICKER

To implement the PSB modes in SPEAR3, a new fast kicker system will be installed in the ring. The stripline

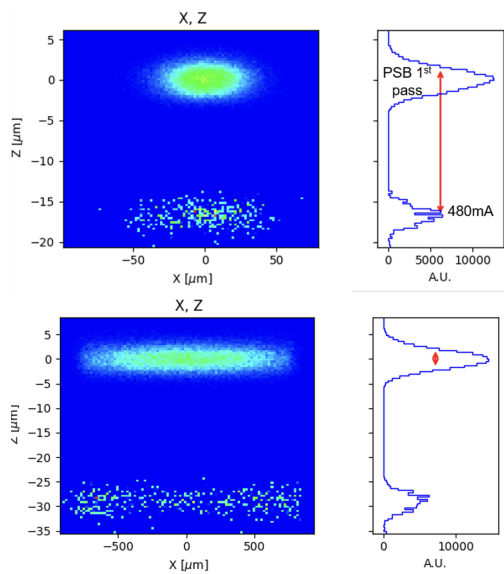


Figure 5: Beam profiles at the sample focus with the current BL17 optics (top); beam profiles at the BDA with the modified BL17 optics (bottom).

based kicker design similar to SPEAR3 transverse feedback kicker [5] is straightforward for this application. With the availability of the real estate space in the SPEAR3, it is determined that the kicker magnet will be installed in the 8S straight section. The design of the kicker geometry needs to conform to the accelerator physics requirement for the beam impedance and requires optimization. Some of the preliminary specifications are as following: the separation of the two electrodes is about 15 mm; the electrode length is about 90 cm; the kicker should be placed 1.832 meters from the upstream QF in the straight section, the field flatness should be better than 0.5% within 1mm range in the horizontal plane. The two kicker electrodes will be pulsed

Table 2: Preliminary specification for the pulser

Parameter	Unit	
High Voltage	1.6	kV
Residual	<5.7	V
Rise/fall time	<20	ns
Pulse width	≈ 20	ns
Pulse rate	1.28	MHz
Reproducibility	<2e-3	

by two high voltage pulsing power supplies in the push-pull mode: one with a positive pulse, the other with a negative pulse. The goal of the pulser is to supply high voltage when the camshaft bunch is present in the kicker and zero volts when the rest of bunches pass through. Based on the preliminary kicker specification, to achieve enough kick, the single pulse needs to reach about 1.6 kV in amplitude. Coupling with the 1.28 MHz repetition rate, the average power of the pulser is in the level of kW. In addition, the residual kick to the rest of the bunches should be less than 0.425 μrad , corresponding to about 2 μm perturbation. To our knowledge, there is no off-the-shelf commercial unit existing to meet these requirements. One should note that ALS developed and installed a high voltage pulsing supply with slightly lower specification [6]. We are currently investigating both built in-house [7] and commercial options. The preliminary specification is listed in Table 2.

SUMMARY

The SPEAR3 PSB project is aimed to deliver two PSB modes to the users. The LRR mode will benefit both BL15 and BL17 with user adjustable repetition rate up to 427kHz, while the HRR mode will mainly benefit BL15 only with fixed repetition rate of 1.28 MHz. The main investment for the PSB mode will be a new fast stripline kicker system planning to be installed in the 8S straight and modifications to BL15 and BL17 optics to introduce a mirror for the creation of a virtual source at a BDA on each beamline.

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