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# OPTIMIZATION OF KICKER LOCATION FOR PSEUDO SINGLE BUNCH OPERATION IN SPEAR3*

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*Abstract*

The Pseudo Single Bunch (PSB) operation mode is being developed at Stanford Synchrotron Radiation Lightsource (SSRL) to address growing interests from time-resolved experiments. To accommodate both regular user and timing user experiments simultaneously, a fast electron kicker will be installed in one of the long straight sections at SPEAR3. This kicker will provide a large spatial separation between the main bunch trains and the camshaft bunch. The resulting x-ray spatial separation from undulator beamlines will be highly dependent on the location of the PSB kicker to be installed. We present here considerations of the PSB kicker location with beamline simulations in both low and high repetition rate modes.

## INTRODUCTION

The third-generation electron storage ring SPEAR3 [1] at SSRL serves a large user community with high-intensity photon beams from VUV to hard x-ray regime. The machine is optimized to produce a high average photon flux for most user experiments. To simultaneously accommodate timing users, SPEAR3 is typically filled in a hybrid pattern with 500 mA total beam current distributed in four bunch trains and a camshaft bunch, as shown in Fig. 1. The camshaft bunch, with up to 20 mA current, sits in the middle of a 120-ns gap. The bunch spacing within the train is ~2.1 ns.

A Pseudo Single Bunch (PSB) operation mode is being developed at SPEAR3 [2] for timing experiments to further suppress the sample irradiation from the multi-bunch trains. For this PSB operation, a fast stripline kicker will be installed in one of the long straight sections [2] (see Fig. 1) to kick the camshaft bunch. This vertically separates the camshaft from the main bunch trains (or main beam). The kicker can be run in both Low Repetition Rate (LRR) mode and High Repetition Rate (HRR) modes [2]. In LRR mode, the camshaft completes a motion cycle in three revolutions in the ring, with turn 0, 1, and 2 respectively having 0, $\Delta y_1$, and $\Delta y_2$ separation from the main bunch train for a particular beamline [2, 3]. In HRR mode, the camshaft has approximately a constant separation from the main bunch train for a particular beamline. For example, Figure 2 shows the camshaft separation from the main beam for both LRR and HRR modes at the BL17 undulator center, with the PSB kicker centered at different locations in the straight section.

As can be seen, the location of the PSB kicker has a significant impact on the vertical separation between the camshaft

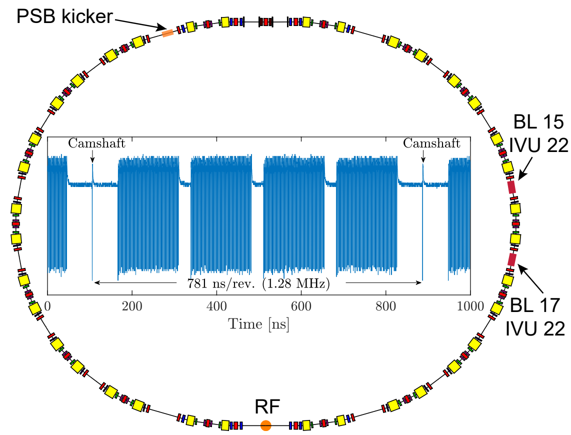


Figure 1: Layout of SPEAR3 lattice. PSB kicker and undulators for two beamlines (BL15 and BL17) used in this work are highlighted. Inset shows the typical fill pattern in SPEAR3 with a camshaft bunch sitting in the middle of two bunch trains with a ~120-ns gap.

and the main beam. For beamlines with a simple focusing element such as compound refractive lens or curved mirrors, the electron position separation $\Delta y$ is directly proportional to the x-ray beam separation $\Delta y_x$ (from the camshaft and the main beam) at the focal plane by $\Delta y \sim M\Delta y_x$, with $M$ the magnification of the focusing element. The electron angle separation $\Delta y'$ determines the number of photons that will pass through beamline components and arrive at the final focal plane. In principle, $\Delta y$ and $\Delta y'$ with the same sign have the best overall effect with large x-ray spacing and large rejection of the main beam. Here, we study the impact of the PSB kicker location on the rejection of x-rays from the

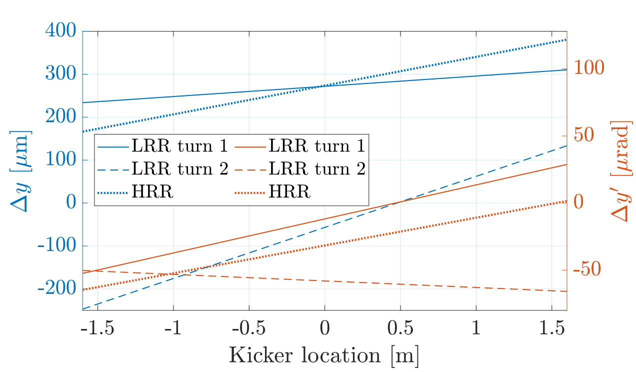


Figure 2: Vertical separation in position and angle between camshaft and main beam at the center of the BL17 undulator with a PSB kick angle of 85 $\mu$rad. Kicker location $z = 0$ refers to the midpoint of the long straight section.

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main beam, at the experimental focal points of BL15 and BL17 at SSRL, using ray-tracking simulations in SHADOW and OASYS [4, 5].

## SIMULATION

BL15 and BL17 have a similar beamline layout and are modeled as illustrated in Fig. 3. The location and detailed parameters of beamline components (monochromator, KB mirror, slits) are slightly different for these two beamlines, as listed in Table 1.

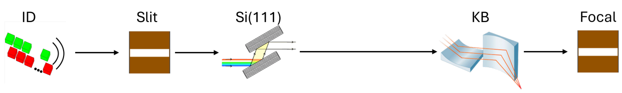


Figure 3: Illustration of the simulation setup in SHADOW.

BL15 and BL17 use the same type of in-vacuum undulator (IVU) with a period of 22 mm and ~87 periods. Figure 4 shows the vertical angular radiation distribution from this undulator calculated using SPEAR3 parameters (3 GeV, $\epsilon_x$ = 6.87 nm, $\epsilon_y$ = 8.3 pm) at different central energies and integrated in a 30 eV energy width, much broader than the Si(111) monochromator acceptance. An assumption in this work is that the undulator radiation from the vertically separated camshaft and main beam has the same properties, other than the difference in vertical position and angle offset originating from the source point. This assumption is justified because the magnetic field variation experienced by the two beams is negligible for the small vertical offset considered.

The x-ray beams from the vertically separated camshaft (three turns in LRR mode, one turn in HRR mode) and main beam are (incoherently) superposed at the mono slits, with a beam current ratio of 20 mA (camshaft) to 480 mA (main beam). The mono slits are aligned to the LRR turn 1 or turn 2 beam, or the HRR turn from the camshaft to reject the

Table 1: Location and Parameters of Major Beamline Components for BL15 and BL17

| | | | BL15 | | BL17 | |
|---|---|---|---|---|---|---|
| | | | **Value** | **$z$ [m]** | **Value** | **$z$ [m]** |
| ID | | | IVU 22 | 0 | IVU 22 | 0 |
| Slit | | | $x, y$ | 13.60 | $x, y$ | 10.42 |
| Monochromator‡ | | | Si(111) | 15.67 | Si(111) | 13.00 |
| KB | Vert. | $d_O^*$ | 26.936 | 26.936 | 27.04 | 27.04 |
| | | $d_I^\dagger$ | 2.044 | | 2.96 | |
| | Hori. | $d_O$ | 27.657 | 27.657 | 27.76 | 27.76 |
| | | $d_I$ | 1.323 | | 2.24 | |
| Focal plane | | | – | 28.98 | – | 30.00 |

‡ Only Si(111) is being considered. There is another set of Si(311) crystals.
* Object side distance.
† Image side distance.

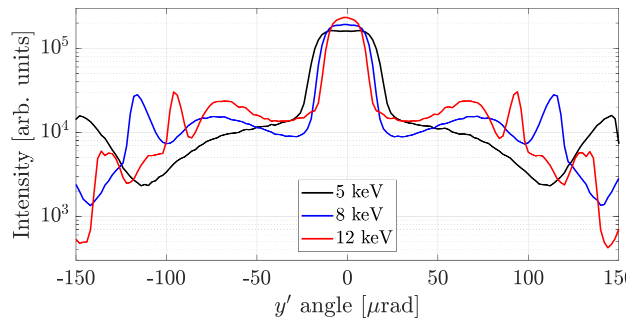


Figure 4: Vertical angular dependence of undulator radiation at different central energies 5 keV, 8 keV, and 12 keV (integrated within a bandwidth of 30 eV).

main beam. In the KB mirrors, realistic shape errors from DABAM database [6] are included.

For a particular kicker location, after the superposed x-ray beam passes all beamline elements shown in Fig. 3, a vertical beam profile at the focal plane is obtained. Figure 5 presents the beam profiles corresponding to various kicker placement locations in both LRR and HRR modes for BL15 and BL17. The results are shown at a typical operation energy of 8 keV for BL15 and 12 keV for BL17. The central vertical stripe in each of the six plots represents the camshaft beam that the slits are aligned to. Based on the results in Fig. 5, a rejection ratio $R$ of the main beam is calculated, which is the ratio of the integrated number of photons within the camshaft beam (at a particular turn) to that within the main beam

$$R = \frac{\int I_{\text{camshaft}} dy}{\int I_{\text{main}} dy}. \tag{1}$$

Figure 6 shows the rejection ratio of all six cases corresponding to Fig. 5. In particular, the rejection ratio for the current SPEAR3 operation without the PSB kicker is simply $20/480 = 0.04$. As can be seen, with the PSB kicker, the main beam background can be greatly reduced compared to the current SPEAR3 operation.

## DISCUSSION

Figures 5–6 show a clear dependence of the rejection ratio on the kicker location. A good region of kicker installation location for both beamlines would be $z \lesssim -1$ m or $z \gtrsim 0.8$ m. However, to avoid radiation damage to the kicker from the last dipole magnet in the arc cell before the long straight section, a kicker location with $z < 0$ is not desired. Therefore, only $z \gtrsim 0.8$ m region would be good to install the PSB kicker.

Note that the simulation results shown here are based on a typical x-ray energy for each beamline. As the beamline can be operated in a wide energy range, we also looked into simulations at different energies covering most of the beamline tuning range [7]. While the rejection ratio changes with x-ray energy, the optimum kicker location range does not vary significantly.

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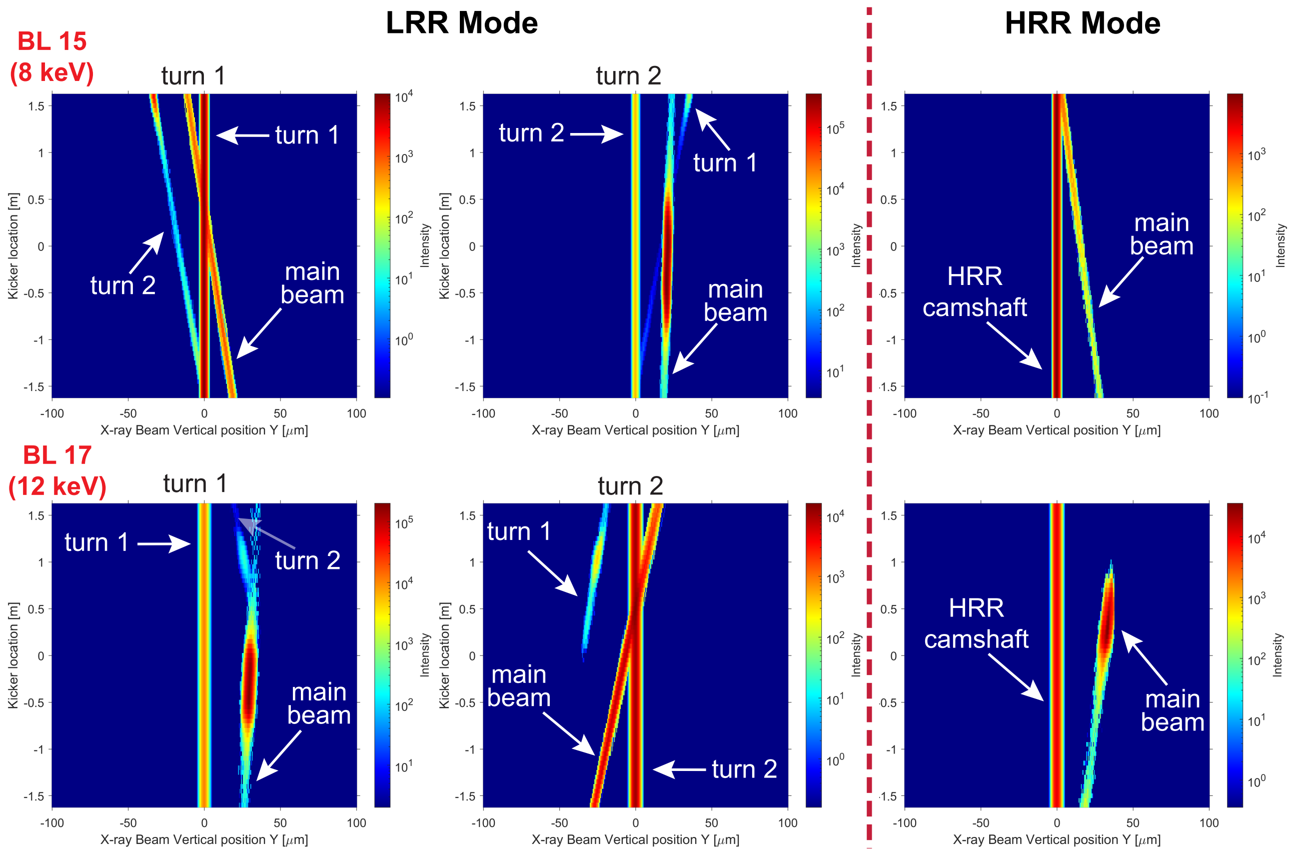


Figure 5: X-ray beam profiles (horizontal axis) at the focal plane of BL15 and BL17 as a function of PSB kicker location (vertical axis). First two columns represent profiles at LRR operation and mono slits aligned to turn 1 or turn 2 camshaft beam. Third column represents profiles at HRR operation and mono slits aligned to the camshaft beam.

The rejection ratio shown here also assumes LRR at the maximum operation frequency of 427 kHz (1/3 of the HRR frequency of 1.28 MHz). The rejection ratio will be decreased as the LRR operation frequency is reduced, with more mixing from the main beam. On the other hand, by introducing an aperture at or slightly before the focal plane, the main beam background can be further reduced greatly, with the complication of a tight setup near the focus or that the sample may need to be moved off focus longitudinally, where mirror-imperfection-induced beam structure is more pronounced. Alternatively, introducing an $M_0$ mirror [2] can create a virtual source upstream of the KB mirrors, where a beam-defining aperture could be placed to cut off x-rays from the main beam and further boost the rejection ratio.

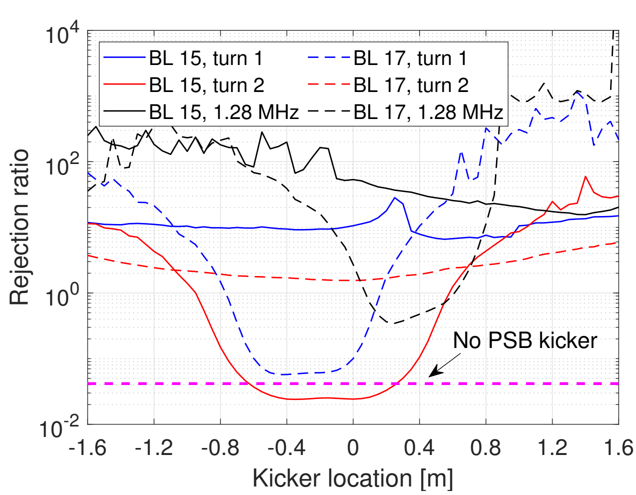


Figure 6: Rejection ratio (Eq. (1)) of cases shown in Fig. 5. The thick horizontal dashed line represents the rejection ratio of the current SPEAR3 operation without PSB kicker.

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