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SPEAR III - A BRIGHTER SOURCE AT SSRL*

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Abstract

By replacing the magnets and vacuum chamber for the 3 GeV SPEAR II storage ring, the natural emittance of the machine can be reduced from 130 to 18 nm-rad and the stored current can be raised from 100 to 200 mA with a 50 h lifetime. This configuration increases focused photon flux for insertion device beamlines by an order of magnitude and the photon brightness for future undulators would exceed 10^{18} at 5 keV. Due to a higher critical energy, the photon flux in the 20 keV range for bending magnet beamlines increases by more than two orders of magnitude. We present preliminary SPEAR III design study results and plans to implement the facility upgrade with minimal downtime for SSRL users.

1 INTRODUCTION

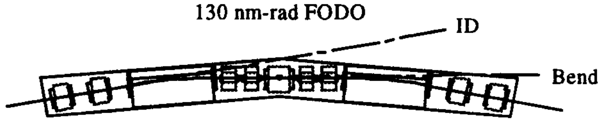
For the last 25 years the SPEAR storage ring has served both the high energy physics (HEP) and synchrotron radiation (SR) scientific communities, first as SPEAR I operating at a maximum energy of 2.4 GeV, and then as SPEAR II (1974), operating at up to 3.5 GeV. In 1990 SPEAR II became a dedicated 3 GeV, 100 mA light source with beam injected from a newly commissioned booster synchrotron. To this day, the SPEAR septum magnet limits the injection energy to 2.37 GeV and energy ramping to the 3 GeV user configuration is required. While other studies were made to reduce SPEAR emittance in the 1970s and 80s [1,2], the addition of a third injection kicker enabled a practical alteration the FODO lattice magnet settings in 1991 that reduced the emittance from ~500 nm-rad used for HEP to 130 nm-rad [3]. Alternative lower emittance lattices, which require new magnets and vacuum chamber, have since been considered and proposed [3,4]. These studies are now being extended for the 3 GeV, 200 mA low emittance SPEAR III proposal.

SPEAR II has eighteen magnet girders and eighteen straight sections. Seven straight sections are presently used for ~2 m insertion devices (IDs) and four more are available for future IDs, including one of the two long interaction region (IR) straight sections that could accommodate up to 17 m of ID. Four beamlines have bending magnet sources.

SPEAR III upgrade goals include:

- Reduce natural emittance to 18 nm-rad
- Increase stored beam current to 200 mA
- Achieve high lifetime at 200 mA (~50 h)
- Achieve high beam stability
- Maintain existing beamline alignment
- Create more long straight sections (~4 m)
- Inject at 3 GeV
- Maintain high operational reliability
- Reduce operating power costs
- Limit conversion downtime to <6 months
- Permit future upgrade possibilities

SPEAR II Girder
130 nm-rad FODO



Proposed SPEAR III Girder
18 nm-rad DBA

Figure 1: Magnet girders for SPEAR II and III

The basic upgrade plan is to replace the SPEAR II magnets with new magnets on the existing girders in a double bend achromat (DBA) configuration, leaving SR source points and beamline alignment virtually unchanged (Fig. 1). The four magnet girders flanking the two long IRs will be moved closer to the interaction points to increase the lengths of four straight sections from 2.7 m to 4.2 m while reducing the IR straight length to 12 m. The two existing RF cavities can be moved to the West IR (or an adjacent straight section) to create two new ID sites. The vacuum chamber will be replaced with a smaller aperture chamber rated for 500 mA to permit future higher current operation. A key aspect of the upgrade strategy is to limit the conversion period to one long downtime of six months (or less) together with normal two month shutdowns in order to minimize the impact on user programs. In the following sections we discuss photon and electron beam properties for SPEAR III and present preliminary design plans for beamline and accelerator systems.

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2 SPEAR III PHOTON BEAMS

2.1 Photon Beam Properties

For a broad range of experiments, focused flux density (photons/sec/mm^2/0.1%BW), or the number of photons one can fit through a small aperture at the sample, is a more important beam parameter than brightness (photons/sec/mm^2/mrad^2/0.1%BW). The reduced beam size and increased current and critical energy of SPEAR III (Table 1) result in an order-of-magnitude increase in focused flux density for ID beamlines, and a two order-of-magnitude increase for bend magnet lines, making them comparable to SPEAR II ID lines (Fig.2). A 4 m undulator in SPEAR III could produce a brightness of $>10^{18}$ in the 5 keV range, and $>10^{17}$ in the 10 keV range.

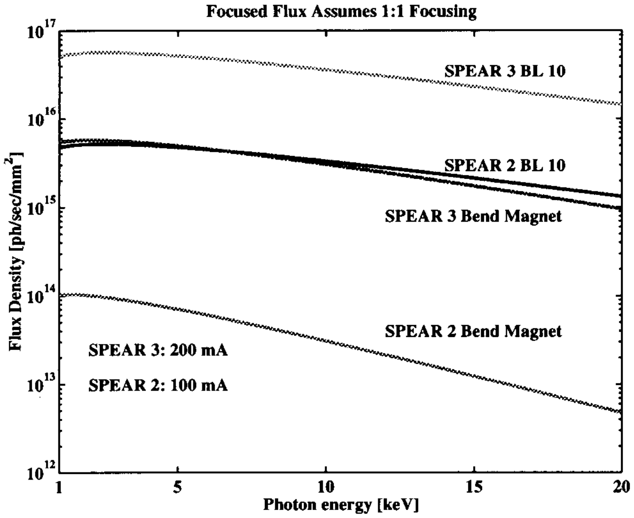

Figure 2: Flux densities for bend and wiggler (BL10) lines for SPEAR II and III.

2.2 Beamline Upgrades

SPEAR III provides two challenges for photon beamlines: (1) increased power loading on masks, slits and windows, and (2) the need for enhanced beamline optical performance in order to fully exploit beam source improvements. All beamline masks and windows will be upgraded for 200 mA operation; few changes are anticipated for ID beamlines built in recent years. Replacement components will utilize concepts developed for SSRL's newest and most powerful beamline 11 which develops a 4.5 kW/mrad^2 peak power density. Monochromators and mirrors on most ID lines will be replaced with versions using cooling technologies developed for third generation SR sources, which include pinpost and LN-cooled Si monochromator crystals, and internally and side clamp-cooled Si mirrors. Where possible, optics upgrades will extend beamline capabilities, for example, by changing mirror cutoff energies or optics acceptances.

	SPEAR II	SPEAR III
Current	100 mA	200 mA
Natural emittance	130 nm-rad	18 nm-rad
H-V coupling	1%	1%
Energy spread	.00074	.00087
Momentum compact.	.015	.0012
Nat. chromaticity (x,y)	-12, -14	-20, -20
Betatron tunes (x, y)	7.18, 5.28	14.75, 5.85
Critical energy	4.8 keV	7.1 keV
Lifetime at max. curr.	~30 h	~50 h
Average ring pressure	1 nTorr	1 nTorr
Beam sigma (x,y) – ID	1.85,.05 mm	.51,.04 mm
Beam sigma (x,y)-bend	.72,.18 mm	.16,.04 mm

Table 1: Machine parameters for 3 GeV SPEAR II and SPEAR III (approximate).

3 LATTICE

The 12.8 m bending radius SPEAR II FODO lattice will be replaced with an 8.38 m bending radius DBA lattice in SPEAR III. Since the new lattice is constrained by girder, ID and beamline locations, as well as by the RF-determined path length of 234.12 m, options for the numbers and placement of magnets are limited. The most conservative option uses separated function magnets with doublet quadrupoles and four sextupoles per cell (Figs. 1,3). Additional quadrupoles are placed in the long IRs for tune and optics control. Detailed study and optimization of this lattice is in progress. A combined function lattice that would increase arc straight section lengths by up to 0.5 m and reduce the horizontal beta functions in them by a factor of two is also being considered. A reduced horizontal beta is desired by users because of the smaller focused beam size, but it makes injection more difficult and may reduce the Touschek lifetime.

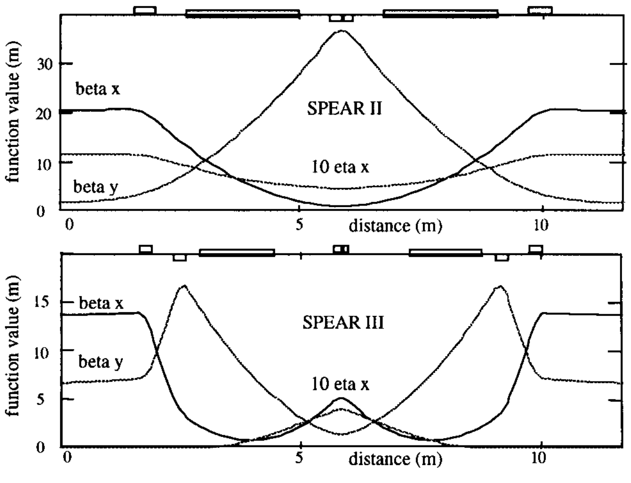

Figure 3: Lattice functions for SPEAR II and III cells.

4 COLLECTIVE EFFECTS AND LIFETIME [5]

The two SPEAR II 5-cell RF cavities will be used initially for SPEAR III. These cavities have numerous high order mode resonances, necessitating longitudinal and transverse feedback systems to damp multibunch beam instabilities. Computed instability thresholds are below 10 mA, assuming zero chromaticity and the overlapping of synchrotron sidebands with HOM resonances. A future upgrade possibility, especially if the stored current is increased beyond 200 mA, is to install single-cell, mode-damped cavities to reduce or eliminate the need for feedback.

The broadband impedance of the ESRF was scaled to the SPEAR circumference to yield $|Z/n| = \sim 2.5$ ohms and a Q=1 resonance centered at 30 GHz. This impedance will initiate a turbulent regime at 0.6 mA. Bunch lengthening and widening coefficients will be 1.9 and 1.5 respectively for a 2.8 mA single bunch current (200 mA in 70 out of 280 RF buckets).

A 70 h Touschek lifetime has been computed assuming a 3% momentum acceptance, 2.7 MV RF voltage, and 200 mA in 70 bunches. This value can be increased by filling the same current in more buckets (i.e. a factor of 4 increase for the maximum 280 bunches) or by using a bunch lengthening cavity.

A 100 h Coulomb scattering lifetime has been calculated for an N_2-equivalent pressure of 0.25 nTorr and a minimum vertical full aperture of 12 mm in one ID chamber. The bremsstrahlung lifetime is 300 h assuming a 3% momentum acceptance.

The total 200 mA lifetime is 36 h for 70 bunches and 60 h for 280 bunches.

5 ACCELERATOR COMPONENTS

5.1 Vacuum System

The girder vacuum chambers will be designed to accommodate smaller magnet gaps and higher SR power loads. The chamber cross section has ~36x90 mm inner dimensions. Many of the existing straight section chambers will be kept, including those for the IDs, kicker magnets, and some diagnostic components. Tapered transitions from new to old chambers will be required in some cases to reduce impedance. RF-shielded bellows elements will be designed to minimize parasitic mode losses. Beamline front end masks and absorbers will also be upgraded for higher SR power.

To maximize beam lifetime, we seek an average ring pressure of order 1 nTorr. An antechamber design with discrete photon absorbers would achieve this goal and maximize chamber stability under varying SR power load. Since an antechamber design may be more costly and may necessitate more expensive C-core or Collins-type magnets, we are also considering a narrow chamber design. Since absorbed SR power may cause this chamber to move, beam position monitor modules would need decoupling bellows and stable supports to reduce transverse motion to the 10 μm level as requred by the orbit stabilizing system.

5.2 Magnets and Supports

The preliminary separated function SPEAR III lattice requires 36 dipoles (50 mm gap), 94 quadrupoles (70 mm bore diameter), and 72 sextupoles (80 mm bore diameter), and 54 pairs of horizontal and vertical correctors. The operating field for the 1.5 m, 10.6° dipoles will be 1.19 T at 3 GeV. Quadrupole gradients are ~20 T/m at 3 GeV. Sextupole strengths are on the order of 300 T/m^2. These field designs will permit 3.5 GeV operation with acceptable core saturation. A C-core dipole accommodates the SR beamline exit chamber. It has not been determined if open-core quadrupoles and sextupoles will be needed.

The new magnets will be mounted on existing 10 m concrete girders, each of which is now supported by three piers sunk 1.5 m into the ground. These girders have a rotational oscillation mode at ~5 Hz about the long axis that could be stabilized with a fourth support. The magnets will be mounted on the girders using kinematic struts. New girders will be installed for the four repositioned magnet cells flanking the IRs.

5.3 Injection

The booster synchrotron and booster-to-SPEAR transport lines will be upgraded for 3 GeV injection. A new septum magnet will be needed for the higher injection energy and the reduced displacement between incoming and stored beams (~15 mm). The three existing vacuum-core kicker magnets will be reused.

A possible future upgrade is to move the injection point to a long straight section unsuitable for beamline use and to install shorter ferrite-core kickers. This would liberate two arc straight sections and the second 12 m IR straight section for IDs.

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