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SPEAR 3 - A LOW EMITTANCE SOURCE FOR SSRL*

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Abstract

SSRL is planning to upgrade the 3 GeV SPEAR storage ring in FY 2002 to reduce the emittance from 160 nm-rad to 18 nm-rad and to increase the beam current from 100 to 200 mA, and then towards 500 mA as photon beam lines are upgraded. The core of the 'SPEAR 3' project includes new magnets and power supplies for a DBA lattice, vacuum chamber, and a mode-damped RF cavity system. Beam lines will see one to two orders of magnitude increase in performance and future high brightness insertion device beam lines are planned. The ring conversion will take place in a 6-month shutdown period to minimize the impact on the SSRL user program. SPEAR 3 lattice, beam properties, and accelerator system components are reviewed.

1 OVERVIEW

The SPEAR storage ring at the Stanford Linear Accelerator Center was constructed in 1972 for colliding beam research and then dedicated as a synchrotron radiation (SR) source in 1989. SPEAR is now scheduled for a major upgrade in FY 2002 to better serve the growing user community at the Stanford Synchrotron Radiation Laboratory [1,2]. By reducing the emittance from 160 nm-rad to 18 nm-rad and raising the beam current to 200 mA, SPEAR 3 will be comparable with 3rd generation SR facilities. The focused SR flux density at experimental stations will increase by an order of magnitude for insertion device beam lines and by two orders of magnitude at higher photon energies on bending magnet beam lines. A lifetime of >30h at 200 mA will enable 24 h beam delivery times.

As beam line components are upgraded, the SPEAR 3 current will be raised towards 500 mA, with a proportional increase in beam focused flux density and beam brightness. New insertion device beam lines that exploit the low emittance and small size of the SPEAR 3 beam are also planned [3]. These include 4 m undulators having brightnesses approaching 10^{19} in the 1-5 keV regime and a vertically polarized wiggler requiring a small horizontal vacuum chamber aperture. The SPEAR 3 conversion entails replacing the existing storage ring magnet, vacuum chamber, RF, and most power systems in a 6-month shutdown period to minimize the impact on the SSRL scientific program. A compact double bend achromat (DBA) lattice has been developed that maintains the present beam line alignment and provides four enlarged 4.5 m straight sections adjacent to two 7.5m racetrack straights, in addition to twelve 3m straights. Magnet and vacuum chamber systems will be pre-assembled on new support girders (Fig. 1) to reduce installation time. Intensively cooled monochromators (including LN-cooled devices) and other absorber components will be installed on beam lines to handle the increased SR power load [3].

Table 1. Source parameters for SPEAR 2 and SPEAR 3.

	SPEAR 2	SPEAR 3
Energy	3 GeV	3 GeV
Current	100 mA	200/500 mA*
Emittance(w/ IDs)	160 nm-rad	18 nm-rad
RF frequency / h	358.5 MHz/280	476.4 MHz/372
Lifetime	30 h @ 100 mA	>30 h @ 200 mA
Critical energy	4.8 keV	7.6 keV
Tunes (x,y,s)	7.18, 5.28, .019	14.19,5.23,.007
e- σ (x,y,s) - ID	2.0, .05, 23 mm	0.43, .03, 6 mm
e- σ (x,y,s) -bend	.79, .20, 23 mm	.16, .05, 6 mm
Injection energy	2.3 GeV	3 GeV

* 200 mA phase 1; future increase to 500 mA as beam lines upgraded.

The upgrade project is administered by the DOE, with major funding contributions from the National Institutes of Health. Principal features of the SPEAR 3 design and beam properties are discussed below.

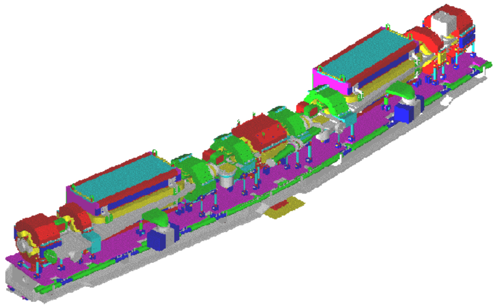

Figure 1. 8.9 m magnet girder with 2 gradient dipoles, 5 quadrupoles, 4 sextupoles, and 4 H/V correctors.

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2 LATTICE

The 234 m SPEAR 3 lattice has a double bend achromat (DBA) configuration with vertical focusing in the dipoles to enhance separation of the x and y focusing and reduce sextupole strengths [4]. There are 14 standard cells and 4 matching cells flanking the two long straight sections. Straight sections have nominal beta functions of 10 m horizontally and 5 m vertically to maximize photon flux density (Fig. 2). Betas are held below 18m globally to reduce sensitivity to field errors, and minimize beam stay clear. The magnet parameters were optimized to provide optical tunability and uniform field ramping to 3.3 GeV. The optics can be modified for finite dispersion in the straights to reduce emittance by up to 30%. Vertical coupling and beam size can be adjusted using a system of 14 skew quadrupoles. The matching cells can also be tuned for future applications requiring lower betatron functions in the long straights.

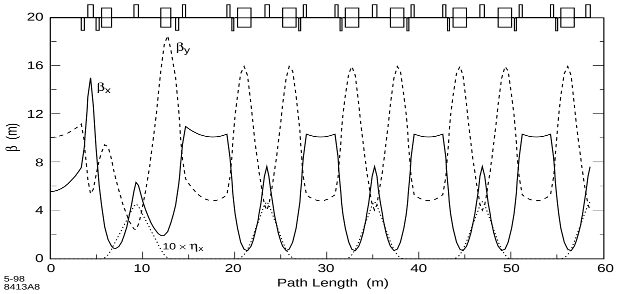

Figure 2. Lattice functions for one SPEAR 3 quadrant.

The phase advance per cell is ~1.5π horizontally and ~0.5π vertically to locally cancel chromatic betatron waves from quadrupoles and sextupoles and geometric sextupole aberrations. The layout, phase advance and sextupole strength in the matching cells leading into the two long racetrack straights were optimized to produce low beta functions and maximize off-energy dynamic aperture. Global tunes ν_x=14.19 and ν_y=5.23 were chosen to operate below the half integer to reduce resistive wall effects, to avoid strong resonance lines, to provide efficient injection, and to optimize dynamic aperture. Tracking data at ID locations indicate that with a full complement of magnet errors the horizontal dynamic aperture exceeds 20 mm with minimum reduction for off-momentum particles [5].

3 BEAM PROPERTIES

SPEAR 3 electron beam dimensions at photon beam source points are given in Table 1. Vertical beam size assumes 1% horizontal-vertical emittance coupling, which can be controlled by adjusting skew quadrupoles.

The goal for transverse beam stability is <10% of the photon beam size and divergence at beam line source points to maintain <0.1% intensity constancy past small apertures and precise beam alignment on small samples. This stability level can be achieved by minimizing magnet thermal motion and vibration relative to beam line optical components, and by using orbit feedback to maintain rms beam position to ~20 μm horizontally and ~5 μm vertically at BPM locations. Feedback bandwidth is on the order of 100 Hz to suppress low frequency orbit motion. Coherent longitudinal bunch oscillations must be $<0.4^{\circ}$ rms (dE/E <0.016%) to maintain transverse stability in dispersion regions and to prevent line width broadening of higher undulator harmonics.

HOMs in the mode-damped cavities and chamber are not strong enough to excite 500 mA coupled bunch instabilities[6]. Antechamber and beam duct are decoupled for modes at or below the cutoff frequencies (4.7 GHz TM and 2.1 GHz TE) by a 12 mm high, 5 cm wide slot. We are investigating <1 GHz TE modes in the wide antechamber sections that could influence BPM readings. A broadband impedance of ~1Ω is estimated using a resonator model having R_s = 12 kΩ, Q = 1, and f_{res}= 15 GHz, derived from the ~60 nH inductance caused by discontinuities and transitions in the 34 x 84 mm beam duct crossection (Fig. 3). The resistive wall instability is suppressed by setting the ring tunes below the half-integer and by head-tail damping achieved with positive chromaticity (~0.2 normalized). The threshold current is then 450 mA for a stainless steel chamber and >800 mA for a copper chamber (Sec.4). In either case the resistive wall impedance is dominated by small-gap stainless steel ID chambers.

The gas scattering lifetime is calculated to be 83 h at 200 mA assuming a 0.6 nTorr N_2-equivalent pressure, comprised of a 275 h Coulomb lifetime and a 120 h Bremsstrahlung lifetime. The Touschek lifetime is RF bucket-limited at 217 h for 200 mA in 279 out of 372 bunches, with 3.2 MV gap voltage, 1% coupling, and 3% energy acceptance. A 93-bucket gap (1/4 of the ring) is left empty to avoid ion trapping. The total lifetime is calculated to be 60 h at 200 mA, and ~20 h at 500 mA (assuming 1.5 nTorr N_2-equivalent pressure at 500 mA).

4 ACCELERATOR SYSTEMS

The SPEAR 3 lattice has 36 C-shape gradient dipoles (k = 0.33), 94 Collins-type quadrupoles, 72 closed-yoke sextupoles, 54 horizontal and 54 vertical combined function dipole correctors, and a vertical Lambertson septum magnet [2]. Magnets and vacuum chamber are mounted on new steel support girders, each resting on three existing pylons embedded 2m in the ground plus a fourth new concrete support pad to increase stability. Magnets are optimized for 3 GeV operation but can be run at 3.3 GeV. Magnet cores are made with AISI 1010 steel laminations, either glued or compressed using end plates and longitudinal rails. Chamfered ends improve integrated field quality. A straight core was chosen for the 1.45 m dipole to simplify construction at the expense of a wider pole for the 33 mm beam sagitta. Main coils are made of water-cooled hollow copper conductor insulated with fiberglass and vacuum-impregnated with epoxy. Quadrupoles and dipoles have ~2% trim coils for beam-based alignment excitation; sextupoles have skew quadrupole trim coils. Laminated core correctors have ~200 Hz bandwidth for orbit feedback. Chopper-style power supplies will be used for all magnets. SLAC is collaborating with IHEP to build the magnets in Beijing.

An antechamber vacuum chamber design (Fig. 3) with discrete photon stops and nearby TSP vacuum pumps has been chosen to achieve low pressure and high mechanical stability under varying SR loads [7]. The 8.9 m girder chamber has three bellows-connected sections. Sloped masks and crenellated crotch-type absorbers intercept powers of 0.5-8 kW with power densities as high as 20 W/mm^2 and fan heights as small as 0.5 mm. The higher power density components employ GlidCop™ to handle the thermal stresses.

Two water-cooled chamber designs having 3-5 mm wall thickness in magnet apertures are presently being evaluated. A formed stainless steel chamber with 1 mm copper cladding and copper inserts in the chamber slot downstream of each ID is passively safe to 50 mA for both dipole and ID radiation. Without copper inserts, the safe current is 6 mA for ID radiation. A machined copper chamber option is passively safe to 50 mA for ID radiation and to >500 mA for dipole radiation. An orbit interlock ensures the electron beam stays within a ±1 mm vertical and ±5 mm horizontal window at source points for potentially damaging SR beams. The number of BPMs and interlock complexity is reduced by more than a factor of two for the copper chamber. The 12 mm slot height between beam chamber and antechamber is a compromise between a small gap for choking RF modes and a large gap that increases the safe orbit window.

The penetration and transverse uniformity of AC fields from fast orbit correctors are sufficient in the stainless chamber, and can be dramatically improved in the copper chamber by reducing eddy currents with high resistivity CuproNickel™ chamber inserts at corrector sites (Fig. 3). Chamber impedance is reduced by minimizing step discontinuities, providing 5:1 transitions between different crossections, and using RF-shielded bellows and slotted pipe injection kickers [8]. BPM thermal motion is minimized using bellows and temperature-stable supports (Invar or carbon fiber).

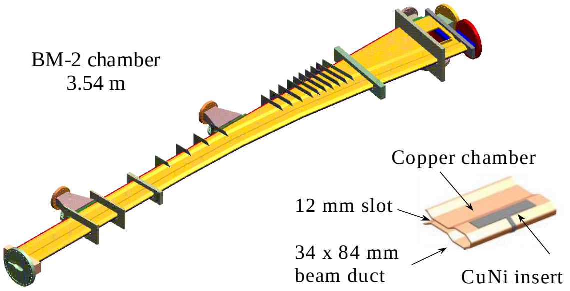

Figure 3. One of 3 girder chamber sections. Inset shows CuproNickel™ insert to reduce eddy current attenuation of corrector AC fields if chamber is made of copper.

Four PEP-II mode-damped 476.4 MHz RF cavities [9] in the West racetrack straight section will replace the present 358.5 MHz 5-cell cavity system to provide stable high current operation. The 1 MW needed to produce a 3.2 MV gap voltage for 500 mA will be supplied either by two 600 kW klystrons powered with existing HV supplies or by a single 1.3 MW PEP-II tube with a new supply. PEP-II RF controls will be used. Cooling water and cavity temperature will be stabilized to 0.1°C.

An expanded SPEAR computer control system will be enhanced with fast digital control links for orbit control and monitoring. The orbit feedback system will acquire orbit information from 92 BPMs and update setpoints for 108 correctors with a 2 kHz cycle rate. 36 orbit interlock BPMs are needed for the stainless steel chamber, while only half that many are needed for the copper chamber (2 BPMs per ID). A vertical beam size interlock is also needed to prevent chamber damage from vertically unstable SR beams. An AC quadrupole modulation system will be used for beam-based alignment and BPM calibration. Other beam diagnostics include upgraded tune and current monitors, a new SR monitor, and bunch phase and turn-turn position monitors. The timing system will be modified to enable injection from the 358.5 MHz booster into the 476.4 MHz ring. Machine and personnel protection systems will be expanded, and a new cable plant will be installed. Radiation shielding will be improved in some areas, and LCW and AC distribution systems will be refurbished.

5 ACKNOWLEDGMENTS

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