THE SPEAR 3 LIGHT SOURCE[§]

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Abstract

SPEAR 3 is an upgrade of the 18-cell SPEAR 2 storage ring to 3GeV beam energy, 18nm-radian emittance and up to 500mA circulating current. The existing arrangement of photon beam lines remains largely unchanged, but opportunities arise for additional ID and dipole radiation exit ports. For optimum beam stability, the entire tunnel floor will be excavated and replaced with reinforced concrete. The magnet/vacuum-chamber supports will be mounted on rigid steel rafts (3 per cell). The cable plant and RF drive will be installed ahead of time while the power supplies, tunnel floor and pre-assembled rafts will be installed in a 6-month shutdown beginning April, 2003.

1 SPEAR 3 OVERVIEW

SPEAR 3 was designed with stable, robust operation in mind [1]. The magnet lattice is arranged in a racetrack configuration with a total ring circumference of 234.144m [2]. The two racetrack straights are 7.6m long, the four matching-cell straights are 4.8m long and the fourteen standard-cell straights are 3.2m long. Fourteen of the straights are available for insertion devices (1 @ 7.6m, 3 @ 4.8m, 10 @ 3.2m). Initially, five existing ID's and two replacement ID's will utilize seven 3.2m straights. Fourteen of the 36 dipole magnets have exit ports with four servicing existing branch lines (ε_c=7.6keV) [3].

Mechanically, each of the 54 magnet rafts is bolted directly to the tunnel floor. Each raft supports a section of copper vacuum chamber assembled in the classic ante-chamber/discrete photon stop configuration. Precision BPM/vacuum-chamber supports are constructed from Invar rods and a 4kHz orbit feedback system will be used to regulate beam position. Individual magnets are supported by kinematic 6-strut systems attached to the rafts. The lowest magnet eigen-frequencies are >20Hz.

On-energy injection is accomplished via a 133.6m, 10Hz booster synchrotron operating with a resonant White circuit and 358MHz rf drive. An ~2MeV rf gun, chopper magnet and 120MeV linac (2856MHz) serve as pre-injector. For historical reasons, the synchrotron resides outside the main ring and injection takes place through a vertical Lambertson septum. For personnel protection, power is limited to 5W in the injection line (125mA/min max accumulation rate).

Table 1: SPEAR 3 Machine Parameters

Parameter	Value	Units
Circumference	234.1440	m
Number of cells	18	
Cell type	DBA	
Energy	3.0 (3.3 max)	GeV
Current	500	mA
$Q_{x/y}$	14.19/5.23	
Loss/turn (dipole)	912	keV
Loss/turn (total)	~1200	keV
Emittance	18 (η=0)	nm-rad
Chamber material	copper	
Pumping per cell	~5,000	l/s
Average pressure	< 2 @500 mA	nT
Beam lifetime	18.6 @500 mA	hr
Dipoles	Straight, gradient=-3.3	T/m
Quadrupoles	Collins with trims	
Sextupoles	with skew quad coils	
Correctors	independent cores	
Harmonic number	372	
Cavities	4@PEP-II damped, Cu	
rf frequency	476.300	MHz
rf voltage	3.2	MV
rf bucket	0.03	dp/p
rf power	1@1.2 MW, klystron	MW

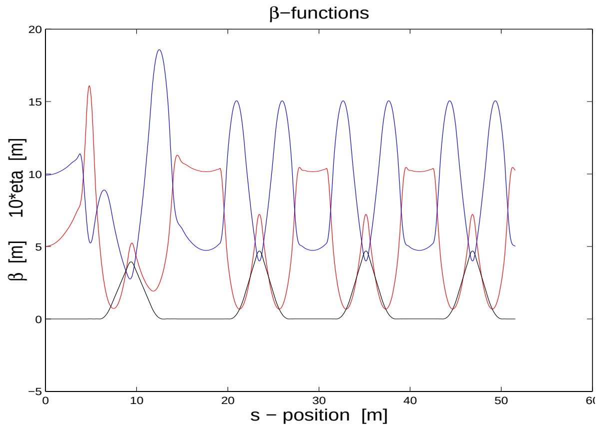

Figure 1: One quadrant of β-functions in SPEAR 3

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2 B-FACTORY TECHNOLOGY

SPEAR 3 is approximately 1:10 scale size relative to the PEP-II collider and carries ~¼ the beam current. The compact lattice, short dipole radius (ρ=7.86m) and intense x-ray output lead to comparable power densities at the strike points and the beam stability requirements are more stringent. For these reasons, key PEP-II technology advances and design personnel were central to the SPEAR 3 project from inception.

2.1 Main Magnets

The most challenging magnets were the 145cm gradient dipoles. For simplicity in assembly and measurement, the cores were manufactured straight. A 96mm 'good field region' accommodates the ±16mm trajectory sagitta. The pole tip contour was modeled after the ALS dipoles. Numerical integration of the beam path including fringe field profile was used to determine relative placement of full length (standard cell) and ¾-length (matching cell) magnets [4]. The quadrupoles have 35 mm pole tip radius and come in 4 lengths (15, 34, 50, 60cm). Each quadrupole has a main field winding and a separate 'trim' winding used for beam-based alignment. The sextupoles come in 21 and 25cm length with 42mm pole tip radius and k=50m^{-3} at 3.3GeV. Space constraints prohibit harmonic sextupoles so ($3\pi/2,\pi/2$) cell phasing was important [2]. Each sextupole has an auxiliary skew quad winding but only 14 will be activated initially. Corrector magnets have stand-alone cores to achieve pure field quality in the x/y planes. IHEP, Beijing constructed the complete magnet set which met or exceeded field quality specifications in all respects

2.2 Vacuum System

A machined copper clam-shell design was selected for the main magnet chamber as a means to (1) reduce the risk from x-ray burn-through, (2) reduce resistive wall impedance and (3) eliminate the need for in-situ bakeout [5]. Copper also provides excellent thermal dissipation for mechanical stability and electrical screening from power supply ripple. The main chamber has octagonal cross-section with 17 x 34mm radial dimensions and a 13mm radiation slot to the ante-chamber. The minimum 'stay clear' radii are x=25mm (septum) and y=±6mm ID chambers. CuNi inserts are used under fast corrector magnets to give –3dB field penetration at ~100Hz. Based on PEP-II experience, the copper clam-shell chambers were machined, e-beam welded and baked to 150^{o}C [6]. Brazed Cu-SS transitions are used where flange components are required. Due to space constraints, the photon beam absorber plates and BPM modules are welded in permanently. Bellows and chamber tapers closely follow PEP-II designs. 150 & 300 l/s noble gas ion pumps and 1,500 l/s titanium sublimation pumps (TSP) will be used for a total pumping speed of ~5,000 l/s per cell and average pressure <2nT at 500mA assuming $\eta=2\times10^{-6}$ [6].

2.3 Impedance and RF

Passive beam stability is achieved by a combination of low broad-band impedance chambers and low narrow-band impedance cavities (476.300MHz, PEP-II-style, mode-damped, room temperature). The four RF cavities fit into a 7.6m straight section to yield 3.2MV accelerating voltage. A 1.2MW klystron was chosen for compatibility with PEP-II systems at SLAC.

The impedance budget is met by using 10:1 transition tapers where possible, PEP-II style bellows and low impedance DELTA-style injection kickers [7-8]. Surprisingly, over 30% of the resistive wall impedance is due to ~17m of Al and SS steel ID vacuum chambers. Nevertheless, impedance calculations indicate longitudinal or transverse bunch-bunch feedback systems will not be required for stable operation [1].

2.4 Power Supplies

SPEAR 3 magnet power supplies conform to the PEP II specifications for modern insulated gate bipolar transistor (IGBT) and MOSFET switch-mode technology, remote digital control and monitoring, and form, fit and function for maintenance commonality. The vast majority of power supplies is commercially obtained and employs H-bridge topology. The notable exception is the dipole power supply, for which a buck regulator is the appropriate choice. The dipole power supply is based on the PEP-II design and is being fabricated in-house as a "build to print" project by SLAC/SSRL, since the PEP-II/SPEAR 3 performance requirements and ratings are congruent. Unipolar output power supplies, for which high output current stability is paramount, employ PEP-II vintage BitBus digital power supply controllers. On the other hand, closed orbit feedback correction mandates the speed of newly developed, Ethernet-based, digital controllers for bipolar power supply current regulation. Like PEP-II, whenever possible, SPEAR 3 magnets are series-connected as strings and powered from a common power supply for economy. Exceptions occur where optical tuning requires magnets with dedicated power supplies.

2.5 Pre-assembly, Installation & Commissioning

Prior to installation, each magnet/vacuum chamber raft is fully pre-assembled with power, water and diagnostic terminations in place. The installation will be a highly coordinated effort to clear the tunnel, excavate, pour a reinforced concrete floor, fiducialize new alignment monuments, and install the rafts. Major shielding modifications, cable plant and rf power components will be in place. Power supply installation proceeds in parallel. Low-level control signals, water flow, and hot power supply checks will be interleaved with vacuum link-ups, final cable connections and alignment in the last stages of installation.

Final commissioning with beam requires tuning the rf gun, tuning the linac, processing the booster synchrotron to 3.0GeV (presently 2.3GeV) and transport line tuning (new optics, 3.0GeV). New kickers and the septum magnet require tuning at the entrance to SPEAR 3. A 12-

14mm beam offset is expected in a 20mm dynamic aperture (β_x=10mm). Machine protection requires immediate BPM calibration via beam-based alignment in quadrupoles, and commissioning of a 4kHz orbit interlock heartbeat at 7 ID locations. A MATLAB-based accelerator model complete with EPICS link, 'middleware' to simplify communication protocols and high-level graphical application programs will be in place to expedite commissioning [9-11]. Response-matrix analysis will be used to calibrate lattice optics [12].

3 PHOTON BEAM LINES

The existing SSRL beam lines maintain their present locations with optical upgrades to accommodate increased power density and ten-fold stability improvements. Although SPEAR 3 is 350mA/3.3GeV capable, the initial operational goal is 500mA/3.0GeV to ensure that side stations on existing wiggler beam lines are well illuminated. All beam line front ends will be upgraded for 500mA operations by start up. Resources permitting, most ID beam lines will be 500mA capable by the startup with dipole beam lines to follow.

Table 2: Electron beam source parameters, 1% coupling

Characteristic	SPEAR 2	SPEAR 3
$\sigma_{x/y}$ (dipole, μm)	790/200	160/51
$\sigma_{x'/y'}$ (dipole, μr)	236/11	43/6
$\sigma_{x/y}$ (ID, μm)	2070/54	430/30

3.1 Dipole Beam Lines

Initially, four existing bend magnet beam lines servicing nine independent experimental stations will benefit from the transition to SPEAR 3. Coupled with reduced source size and higher current, the increase in ε_c from 4.8 to 7.6 keV renders SPEAR 3 dipole beams comparable to SPEAR 2 ID beams in hard X-ray performance. Typical bend flux and bend brightness enhancements are 10-fold to 190-fold in the hard X-ray regime, and 5-fold to 90-fold in the VUV/soft X-ray regime. While SPEAR 3 provides a 24 mrad bend magnet exit port in each of the 14 standard cells, seven of these are relatively difficult to instrument. Thus, initially only three new exit ports will be instrumented. Potential applications include macromolecular crystallography, micro-focus applications, SAXS, and LIGA.

3.2 Insertion Device Beam Lines

SPEAR 2 has seven ID's servicing 16 experimental stations. Under SPEAR 3, each ID will deliver a 5-fold flux and 43-fold brightness improvement. Three existing stations can already accommodate the power increase, and upgrades scheduled on the remaining stations. In addition, the two oldest ID's (9-pole electromagnets) will be replaced with 20-pole hybrid ID's to produce a 15-fold flux and 127-fold brightness enhancement.

The improved performance of SPEAR 3 ID beam lines will provide adequate beam intensity for all but the most brightness-sensitive applications. To meet these needs, six new ID straights are available with potential for two small gap, in-vacuum undulators that would utilize a chicane in a 7.6 m drift with optics for β_y reduction [13] for high brightness in the hard X-ray regime. The remaining four easily-accessible straights can accommodate two 2.3m and two 3.5m ID's. Potential new devices include a 250-3000eV soft X-ray undulator (3.5m) and a macromolecular crystallography station on one of the small gap, in-vacuum undulators.

Table 3: SPEAR 3 insertion device parameters

Beamline	# Period	Period (cm)	Field (T)	K
4,7	10	23	2	43
5	10/15/24/30	18.3/12.2/7.6/6.1	<0.5	<8.5
6	27	7	1.0	6.5
9	8	26	1.95	47
10	15	12.85	1.45	17
11	13	17.5	2.0	33

4 SUMMARY

The current project status is approximately 90% completion of the technical design phase and 60% completion of machine fabrication. The magnet set was produced in collaboration with IHEP, Beijing, the vacuum chamber is a copper clam-shell design built in-house, and the rf system is the PEP-II design. Upgrades are underway to accommodate the increased power load from both bend magnet and ID beam lines. Following the 6-month shutdown period in 2003, SPEAR 3 will deliver photon beams in early 2004.

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