

SPEAR 3 UPGRADE PROJECT: A STATUS REPORT[†]

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Abstract

The SPEAR 3 upgrade project at SSRL will replace the original FODO lattice with a 234-m, 18-cell DBA lattice with gradient dipoles. The new hardware draws heavily on PEP-II B-Factory technology: a copper vacuum chamber, IGBT power supply technology, and mode-damped rf cavities to reach beam currents up to 500 mA at 3 GeV. First article magnets, supports, girders, vacuum chambers, pumps and RF components have been fabricated and a prototype girder assembly is nearing completion. I&C systems, radiation shielding and utility upgrades are in progress. In this paper we report on the status of the main accelerator subsystems.

1 OVERVIEW

To better serve the expanding SSRL user community, SPEAR is scheduled for a major upgrade in 2003 [1]. The 18 nm-rad, 500-mA SPEAR 3 will provide one to two orders of magnitude higher performance than SPEAR II.

The 4-year, 58 M\$ SPEAR 3 upgrade project is administered by the DOE, with ~50% joint funding from NIH. It will completely replace the tunnel floor, rafts, vacuum chamber, magnets, RF, power supplies and cable plant in a 6-month shutdown period. Shielding, utilities and other ancillary systems will be modified before the main shutdown period. A modified transport line and new

septum magnet enable 3 GeV injection. All magnets, supplies and chamber components are designed to operate at a top energy of 3.3 GeV (350 mA). Machine and beam parameters for SPEAR 2 and SPEAR 3 are compared in Table 1. More detailed descriptions can found in [1, 2].

2 LATTICE AND BEAM PROPERTIES

The double-bend achromat (DBA) lattice will maintain the present beam line alignment for twelve 3.1-m straight sections while providing four 4.8-m straights and two 7.6-m straights. Moderately low β -functions in the straights ($\beta_x=10.2$ m, $\beta_y=4.7$ m) provide small beam size ($\sigma_x=430$ μ m, $\sigma_y=30$ μ m) without jeopardizing dynamic aperture or injection. Peak β -functions below 20 m are maintained throughout the ring to reduce pumping requirements and sensitivity to field errors. Although the dispersion-free straights eliminate emittance growth from high-field IDs, reductions in β_x and ϵ_x are possible in the finite-dispersion configuration. Vertical β -functions in the range $\beta_y=2$ m are possible in the 7.6 m straights for future IDs [3].

The use of gradient dipole magnets in the arc cells creates a compact lattice, controls peak β_y in the dipoles, separates β -functions at the SD sextupoles and reduces β -functions in the straights. The remaining magnets were designed with comparable field gradients to facilitate energy ramping.

Betatron phase advances of $\phi_x \sim 0.75$, $\phi_y \sim 0.2$ provide cancellation of geometric sextupole aberrations across the standard cells. The phase advance and β -functions in the matching cells were optimized for large on-energy dynamic aperture. Sextupole strengths in the matching cells were optimised for off-energy aperture. The global tunes (14.19, 5.23) were chosen to provide robust aperture as a function of tune and to reduce sensitivity to resistive wall impedance. Tracking with magnet errors, ID aberrations and up to 3% energy oscillations yields a horizontal dynamic aperture in the ID straights of ~ 18 mm ($A_x=32$ mm-mrad). Vertical aperture is limited by ± 6 mm ID chambers (1% coupling, $A_y=7.6$ mm-mrad). Vertical coupling is adjusted using 14 skew quadrupoles.

The projected beam lifetime is 18 h (28 h gas scattering at 2 nTorr N_2 -equivalent press, 53 h Touschek scattering

Table 1: Parameters for SPEAR 2 and SPEAR 3.

	SPEAR 2	SPEAR 3
Energy	3 GeV	3 GeV
Current	100 mA	500 mA
Emittance (w/ID)	160 nm-rad	18 nm-rad
RF frequency	358.5 MHz	476.3 MHz
RF gap voltage	1.6 MV	3.2 MV
Lifetime @ I _{max}	30 h	>17h
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	0.43,0.3,4.9 mm
e- σ (x,y,s)-dipole	.79,.20,23 mm	.16,.05,4.9 mm
Injection energy	2.3 GeV	3 GeV

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at 500 mA). The Touschek value assumes 279 of 372 bunches are filled, 3.2 MV RF gap voltage, 3% energy acceptance and 1% coupling. The 93-bucket gap provides ion clearing. On-energy top-off injection can be used to maintain high average beam current.

For beam stability, a 100-Hz closed-loop orbit feedback system is planned. The goal is to reach transverse orbit stability of 20 μm horizontally and 5 μm vertically on a time scale of several hours at stable BPM sites. Coherent longitudinal bunch oscillations must be held to be $< \sim 0.3^\circ$ rms ($dE/E < 0.01\%$) to maintain $< 10\%$ position stability at dipole source points and to provide $< 10^{-4}$ energy resolution on undulator harmonics.

3 MAGNETS AND SUPPORTS

The SPEAR 3 magnet lattice has 36 C-shape gradient dipoles ($k = -0.33 \text{ m}^{-2}$), 94 Collins-type quadrupoles, 72 closed-yoke sextupoles, 54 horizontal and 54 vertical combined function dipole correctors (± 1.5 mrad horizontal and ± 0.75 mrad vertical). The magnet cores are made with AISI 1010 steel laminations with chamfered ends to improve integrated field quality. The complete magnets are being fabricated by IHEP in Beijing which has so far completed ~ 20 dipoles, ~ 40 quadrupoles and ~ 10 sextupoles (Figure 1), all of which meet or exceed field quality specifications. A 1.13-m Lambertson septum magnet with 8.79° vertical bend and 5-mm septum aperture is in the final design phase.



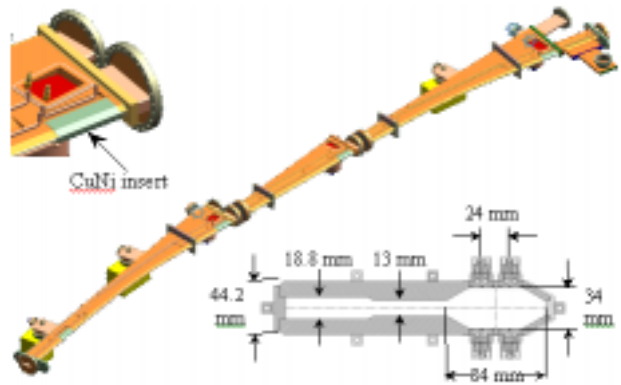
Figure 1: Gradient dipole, quadrupole and sextupole magnets received at SLAC from IHEP, Beijing.

Magnets and vacuum chamber sections will be mounted on 6-strut supports to 3 steel rafts per cell prior to installation. The first prototype raft is nearing completion to check all clearances. Each raft will be rigidly mounted to the new 12" thick concrete floor.

Dipole vibration measurements reveal a longitudinal mode of 17 Hz, attributed to the spring constant of the strut rod ends; all other modes for the dipole and focusing magnets are > 20 Hz.

4 VACUUM SYSTEM

To enhance beam stability and protect against high-power radiation strikes, the SPEAR 3 vacuum chamber will be constructed from machined copper plates with discrete photon stops and antechamber geometry. First articles for 2 of the 3 bellows-connected sections have been e-beam-welded at SLAC (Figure 2). Manufacturing and weld distortions in the clamshell halves are minimized by using quarter-hard copper from Revere, Inc.



CuproNickel™ inserts are welded under the corrector cores to increase AC field penetration from corrector magnets to ~ 100 Hz.

GlidCop™ masks and crenulated crotch-type absorbers designed to intercept 0.5-8 kW with power densities up to 20 W/mm^2 and photon fan heights as small as 0.5 mm are in fabrication at SLAC. Invar supports will restrain vertical vacuum chamber motion at BPM sites to $3 \mu\text{m}/^\circ\text{C}$. RF-shielded bellows are in production and 12 mm BPM buttons have been received from Kaman. The rf impedance of a modified DELTA-style injection kicker [4] is being measured at LBNL. Other chamber components, including DCCT, tune monitor, scrapers and transverse stripline kickers, all preserve the 34×82 mm chamber cross-section to minimize impedance.

5 RF SYSTEM

Four mode-damped PEP II-style RF cavities [5] operating at 476.3 MHz are being fabricated by Accel Instruments, Germany (Figure 3). The new cavities and copper chamber will provide stable operation to 500 mA at 3 GeV. Since the booster frequency remains at 358.5 MHz, it must be phase-locked to enable single-bucket injection. HOM loads, windows, couplers and other components are being built at SLAC.

A PEP-II style, 1.2 MW klystron manufactured by Marconi Applied Technologies, UK, has been delivered to SLAC for testing. At 1080 kW, the tube will drive the 3.2 MV gap voltage required for 500 mA operation.

The 90-kV, 27-A high voltage supply will be identical to those used for PEP-II. The supply has a SLAC-designed SCR voltage control. The digital EPICS-based PEP-II low-level rf control system [6] is being assembled.



Figure 3: Electroforming copper over RF cavity water-cooling passages (left), and a complete cavity assembly.

6 POWER SUPPLIES

The SPEAR 3 power supplies are modelled after the PEP-II design to achieve high performance and integrate maintenance responsibilities at SLAC. IGBT switch-mode unipolar power supplies will be used for all main magnets. The 1-MW dipole power supply (1.2 kV, 800 A) will be configured using 4 series/parallel-connected PEP-II chopper modules, each one rated for 600 V and 400 A. This and other supplies in the 35-135 kW range employ SCR rectifying bridges to provide soft-start DC voltage to the choppers. 10-ppm stability will be achieved by all main supplies using a SLAC-designed precision regulator unit [7].

IGBT bipolar supplies rated for $\pm 65\text{V}$ and $\pm 30\text{A}$ are in the construction phase. 108 modules will be used for fast orbit correction (~ 2 kHz supply BW) and 30 for ID trims, skew quads and quadrupole modulation. Each 8-module crate will have a single controller (SLAC design) comprised of a commercial VME CPU serially interfaced over a backplane to digital control daughter boards on the supply modules. 18-bit DACs will minimize corrector-induced noise on the beam. The CPU will provide optional closed-loop control external to internal regulators, and will be interfaced to the control system over a dedicated 100 Mb Ethernet.

IGBT technology is also being used for the 3 induction pulsers used for injection kickers [8]. Each pulser utilizes capacitor-ferrite core sections charged to ~ 2 kV in parallel and discharged in series to a kicker. The prototype 8-core pulser generates a 16 kV, 2.5 kA, 750 ns wide baseline pulse. Kicker cable length must be ~ 80 m to prevent the reflected voltage wavefront from arriving at the pulser before the IGBTs turn off.

7 INSTRUMENTATION AND CONTROL

A Channel Access Server has been added to the existing VMS control system to enable use of EPICS tools and applications. Many control and machine modeling applications will use MATLABTM. Some existing CAMAC systems will be kept, but new processing and interface systems will be configured in VME using PowerPC controllers that serve as EPICS IOCs and DSP engines.

The distributed orbit correction and feedback system, will have a 2-4 kHz cycle rate to achieve a closed-loop bandwidth of >100 Hz. The feedback system will acquire orbit information from 90 BPM processors in 4 remote processing stations and control 108 correctors. The main orbit acquisition system will employ 54 narrowband switched-button processors. Wideband non-switched processors that can detect first turn and turn-by-turn orbits are also under development. ECDR-814 digital receivers, developed by Echotek according to SSRL specifications [9], will detect the IF from both processor types. A test tone tuned ~ 640 kHz away from the ring RF will be used

to calibrate the parallel-button processors. A quadrupole modulation system will enable beam-based alignment and BPM calibration.

A UV light port is being designed to monitor beam size, bunch length and dynamic beam behavior using fast-gated CCD and streak cameras. A GlidCopTM cold finger will intercept the high-power x-ray beam core and protect a 9-degree flat mirror (rhodium-plated silicon) while permitting most of the UV and visible-light beam to pass. A Schwarzschild reflective focusing optic will be used to form a $\times 2.8$ image of the electron beam, which measures $182\ \mu\text{m}$ rms (H) $\times 51\ \mu\text{m}$ rms (V) at the dipole source point, in a diagnostic room outside the ring tunnel. Measurement resolution will be $\sim 20\ \mu\text{m}$.

PLC-based interlocks for vacuum chamber protection and magnet systems are being expanded. An orbit interlock using BPMs adjacent to IDs and a secure VME CPU system will be configured to prevent damage to the vacuum chamber from mis-steered photon beams.

8 BEAMLINER UPGRADES

Existing bend and wiggler beam lines will be upgraded and optimized for applications exploiting high flux density but requiring only modest beam collimation (many macromolecular crystallography measurements, XAS, etc.). Future ID sources under consideration include a 3.8-m elliptically polarized undulator for soft x-ray (250-2600 eV) applications and 2-m, small gap, in-vacuum undulators for high brightness hard x-ray (>6 keV) applications. These and other sources will exploit the three bend and five insertion device source points that are immediately available in SPEAR 3.

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