SPEAR 3 UPGRADE PROJECT: THE FINAL YEAR[†]

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Abstract

During April, 2003, the SPEAR 2 storage ring, which served the high energy physics community from 1972 to 1987, and the synchrotron radiation community for an additional 15 years, was removed from its shielding tunnel in order to install the new 3-GeV, 500-mA SPEAR 3 light source. From May to November, SSRL will excavate the tunnel floor and pour a new concrete floor, and then install pre-assembled girders holding magnets, copper vacuum chambers, PEP-II-style rf cavities, and beam line front end components. At the same time, power supply, instrumentation and control, and other ancillary systems will be configured, leading to a commissioning period beginning in November 2003. The progress of accelerator component implementation and installation during the final year of the project will be reviewed.

1 OVERVIEW

The SPEAR 3 upgrade project [1,2] is in its final year with commissioning scheduled to begin in November 2003. The new ring, with basic parameters summarized in Table 1, will provide one to two orders of magnitude higher performance than SPEAR II and will benefit the materials science, molecular environmental science, structural molecular biology and macromolecular crystallography communities. The 4-year, 58 M$ SPEAR 3 upgrade project is administered by the DOE, with ~50% joint funding from NIH. Now >85% complete, the project will completely replace the tunnel floor, rafts, vacuum chamber, magnets, RF, power supplies and cable plant in a 7-month shutdown period that began March 31.

At this writing, the SPEAR 2 storage ring no longer exists. All SPEAR 2 magnet girders, vacuum chambers, power supplies, and most cables and controls have been removed from the SPEAR site (Fig 1). Shielding, utilities and other ancillary systems have already been modified, and a large fraction of the new cable plant has been installed in trays outside the tunnel. Modified transport line components and a new septum magnet are nearly complete and will enable 3-GeV injection. The 10-Hz booster synchrotron, which has been operating for 2.3-GeV injection since 1990, has been modestly upgraded for 3-GeV operation. The progress and difficulties of SPEAR 3 ring implementation are discussed below.

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 @ Imax	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

Figure 1: Removal of SPEAR 2 magnet/chamber girders.

2 ACCELERATOR SYSTEM PROGRESS

All of the 36 gradient dipoles [3], 94 Collins-type quadruoles, 72 sextupoles and 108 H/V corrector magnets, plus spares for each, have been received from IHEP, Beijing, magnetically measured, fiducialized, and are presently being installed on support rafts (Fig. 2).

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With a few modifications to fabrication methods, which included a small change to the quadrupole pole chamfer (Fig. 3), the magnets met or exceeded specification. Current-to-field transfer functions have been derived for each magnet family and fitted with 5th-order polynomials to be used for control. A ~2% reduction in the measured 15Q transfer function accounts for field truncation by nearby corrector field clamp shields. Magnetic measurement of the vertical Lambertson septum magnet is in progress; the end-field mirror plate is being modified to minimize field leakage (towards a goal of <10 G-m).

Figure 2: Magnet raft on installation rollers. Grouted mounting plate in foreground.

Figure 3: Sub-mm cut in quad chamfer reduced n =6 multipole to $<5\times10^{-4}$.

Production and bake-out of 56 copper girder vacuum chambers was successfully completed in April. The height of the slot between beam duct and antechamber, which is critical to minimize the risk of damage from mis-steered ID synchrotron radiation (SR), was held to ±1.75 mm per horizontal surface, measured using a novel device that utilized optical tooling to scan the inside walls of the completed chamber. The orbit interlock trip level was modified for an effective slot height of ~8 mm to accommodate vacuum deflection, alignment tolerances and measurement uncertainties. Additional engineering analysis was required during the production of these chambers to reduce stresses in the welds. Unanticipated, large hard plane bows from the machining of the copper created a need to optimize the machining process, welding set-up and bulk material production. Late beam position monitor (BPM) design changes coupled with a change in manufacturing facility resulted in a less robust unit than its PEP-II predecessor. Extensive weld parameter development limited stresses in the BPMs. Fabrication of straight section chambers and components is in progress or complete, including 3 new copper-plated ID chambers, septum chamber, injection kickers, tune driver, PPS-beam stoppers, DCCT [4], low-Z drift, transition chambers and 6 styles of rf-shielded bellows modules.

Figure 4: BM1 chamber after bake-out.

The PEP-II LER titanium sublimation pump design was adapted for this machine. Due to space constraints a smaller 8"-diameter pump was designed and the filament was reoriented from vertical to horizontal to increase the pump fin surface area that was exposed to Ti deposition. Delivery of the 4 PEP-II-style rf cavities from Accel in Germany was delayed because of welding-induced leakage problems with the copper plating that covers the water cooling channels. The problem was resolved by replacing the "brightened" copper plating, which contains an additive to form very small grain size that produces a hard, easy-to-machine coating, with pure copper plating, as was done for the original PEP cavities (Fig. 5). Three cavities from have now been received at SLAC, and two have been tested at full voltage (850 kV) with HOM loads and waveguide windows. Other rf system components are being installed, including the HV power supply (which had problems with oil leaks in the optically triggered crowbar SCRs), 1.2 MW klystron (which required repair after operation at PEP-II), and digital low-level control system (which had to be redesigned by an "emergency" task force to overcome the unavailability obsolete parts after the original designers left SLAC).

Figure 5: RF cavity body plated with leaky "brightened" copper (left) and leak-tight pure copper (right).

All magnet power supplies (1- MW dipole supply, 6 large supplies (~100 kW) for magnet strings, 80 intermediate supplies (~10 kW) for individual magnets, and 150 bipolar supplies for correctors and ID trims) have been delivered and are being tested. These supplies use IGBT chopper technology and are digitally controlled. The 3 IGBT kicker magnet induction pulsers (Fig. 6) are also complete and tested. The pulsers, intermediate and bipolar supplies are being pre-assembled in racks to reduce installation time.

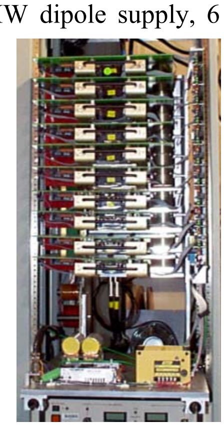

Figure 6: 15-kV IGBT kicker pulser.

Implementation of software and hardware interface components will continue up to the end of the project. Channel Access servers have been added to the existing VMS computers to enable EPICS compliance. Several EPICS IOCs have been configured on PowerPCs using the RTEMS real-time operating system [5], including those for power supply control, BPM data acquisition, and for interfacing to PLC protection systems. Machine modelling and control applications are being configured by the accelerator physics group using MATLAB™ with Channel Access [6]. Applications include SVD orbit correction and slow feedback, quadrupole modulation lattice calibration [7], LOCO [8], the Accelerator Toolbox [9], orbit interlock verification algorithm, and lattice parameter control. Hardware interface components are in production, including units to receive analog signals from commercial BPM processors, filter the signals, and distribute them to the digital orbit acquisition system and to the analog orbit interlock.

The majority of the BPM processing system (54 out 94 channels) consists of switched-button processors, which have been received from Bergoz, and are now being tested. The multiplexed down-converted button signals are digitized directly with 16-bit ADCs for precise orbit detection, bypassing the analog de-multiplexing and difference/sum circuitry in the processors. The analog-processed signals are used for the orbit interlock. Non-multiplexed, parallel-button RF-IF processors with externally coupled test tone are also being designed, which, in combination with Echotek ECDR814 digital receivers, will provide 1st-turn, turn-turn (with micron resolution), and high-resolution averaged orbit acquisition. Orbits will be acquired from the two types of processors at a 4 kHz rate over dedicated 100-Mb Ethernet LANs to a central CPU, which will perform an SVD orbit feedback algorithm at that rate and serve low-pass-filtered orbits to the control system. 24-bit orbit corrector setpoints will be transmitted to 54 vertical and 54 horizontal bipolar power supplies over digital control links at the 4 kHz rate [10], enabling a closed-loop feedback bandwidth of ~200 Hz.

Other I&C systems to be completed by October include PLC-based machine protection systems, the orbit interlock system (that prevents damage to the vacuum chamber and photon beam lines from mis-steered synchrotron radiation), a beam current interlock (that prevents over-filling the ring), and a UV synchrotron light monitor capable of resolving the 50-μm vertical beam size [11]. The rf and timing signal generating system and the 358 MHz I/Q phase shifting unit used to control injection timing in the booster are complete.

3 INSTALLATION AND OPERATION

With the removal of all SPEAR 2 components and the excavation of the tunnel and power supply room floors complete, the remainder of the SPEAR 3 installation can begin. The pouring of new concrete floors for the tunnel, which has been excavated ~18" to solid sandstone, and for the power supply room is about to commence. In a month, the low-shrinkage concrete will have stabilized enough to begin installing new alignment monuments. In July, raft mounting plates with alignment pins will be set precisely into the floor and hundreds of support mounting holes will be drilled. The pre-assembled magnet rafts and straight section assemblies will be rolled into the tunnel and secured over a 2-week period beginning in mid-August. Vacuum hardware will be installed and pumped down between mid-August and mid-October. The tunnel cable plant and IDs will be installed in this period as well. Final alignment will take place during the last half of October, with ring lock-up scheduled for October 30. System check-outs will take place in November, and commissioning with beam will begin in December. Photon beam lines will be commissioned as well, and will be used by local users as beam becomes available. A gradual transition from commissioning to user operation is expected during the first several months of operation, with monthly days-long ring accesses anticipated for continuing beam line component and shielding installation and accelerator maintenance.

The first SPEAR 3 operational run will be at 100 mA since most of the photon beam lines will not have been upgraded for 500 mA operation. To reduce the installation period, not all ring shielding and ID chamber masks needed for 500 mA will be in place at first; these components will be installed by the second run beginning Fall, 2004. Periodic 500-mA operation will then be possible, with un-upgraded beam lines locked shut. 500-mA operation for all beam lines is scheduled for 2007.

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