THE COMPLETION OF SPEAR 3†

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Abstract

On December 15, 2003, 8 1/2 months after the last electrons circulated in the old SPEAR2 storage ring and 5 days after the beginning of commissioning, the first electrons were accumulated in the completely new SPEAR 3 ring. By January 22, the first 100-mA beam was stored, preparing the path for delivering beam to uers in early March of this year. The rapid installation and commissioning are a testimony to the SPEAR 3 project staff and collaborators who have built an excellent machine and equipped it with powerful and accessible machine modeling and control programs. The final year of component fabrication, the 7-month installation period, and present-day SPEAR 3 operation are described.

OVERVIEW

On March 31, 2003, the SPEAR 2 storage ring was turned off for the final time after 30 years of service, first for colliding beam physics, then in a time-shared mode to provide beams for both HEP and the SSRL synchrotron radiation program, and finally as dedicated light source for SSRL. During SPEAR's tenure, two Nobel Prizes were garnered (B. Richter, 1976 and M. Perl, 1995) and major innovations in light source science and technology were developed (e.g. the first use of wigglers and undulators for producing intense x-rays in storage rings). The original SPEAR ring, now sitting in a storage yard (Fig. 1), has been replaced with SPEAR 3 [1,2], a modern light source having the SPEAR 2 footprint, but providing 3rd generation light source capability for SSRL (Table 1). The new ring provides 1-2 orders of magnitude higher performance than SPEAR 2 and is already benefiting the materials and molecular environmental science, structural molecular biology and macromolecular crystallography communities.

Figure 1: The fate of two-time Nobel prize-winner SPEAR 2.

The 4-year, 58 M$ SPEAR 3 upgrade project, administered by the DOE with ~50% joint funding from NIH, was officially completed on November 15, 2004, when the last vacuum chamber component was installed in the ring tunnel. This date marked the end of a 7-month installation period that completely replaced the tunnel

Table 1: Parameters for SPEAR 2 and SPEAR 3.

	SPEAR 2	SPEAR 3
Energy	3 GeV	3 GeV
Current (max)	100 mA	500 mA
Emittance (w/ID)	160 nm-rad	12 nm-rad
RF frequency	358.5 MHz	476.3 MHz
RF gap voltage	1.6 MV	3.2 MV
Lifetime @ Imax	30 h	15 h†
Critical energy	4.8 keV	7.6 keV
Tunes (x,y,s)	7.18,5.28,.019	14.19, 5.23, .009
e- σ (x,y†,s) - ID	2.0,.05,23 mm	.35,.025,4.9 mm
e- σ (x,y†,s) -bend	.79,.20,23 mm	.13,.04,4.9 mm
Injection energy	2.3 GeV	3 GeV

†with 1% emittance coupling; 10 h with expected 0.1% coupling.

Table 2: Final project costs compared with baseline.

	WBS	Baseline Aug 2000	Actual Apr 2004
1.1	Magnets/Supports	8.3	8.421
1.2	Vacuum System	10.3	13.034
1.3	Power Supplies	3.1	3.162
1.4	RF System	3.9	4.494
1.5	I&C	3.5	4.072
1.6	Cable Plant	2.2	2.102
1.7	BL Front Ends	1.0	1.138
1.8	Facilities/Shielding	2.5	3.806
1.9	Install/Align	2.9	6.995
2.0	Mgmt, Accel Phys	3.8	4.014
	Directs Subtotal	**41.5**	**51.237**
	Indirects	5.8	6.756
	Contingency	8.0	0
	Escalation	2.7	0
	Total	**58 M$**	**57.994 M$**

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floor, magnets, vacuum chambers, support girders, RF system, cooling system, power supplies, instrumentation and control system and cable plant, and upgraded much of the tunnel shielding and beam line front ends. Project costs, shown in Table 2, include a large actual cost for Installation attributable to an increase in scope that included the concrete floor, seismic retrofits and a large amount of in-house labor costs adopted by the project.

Turn-on of the accelerator systems began during the last month of installation when the ring was secured at night for magnet power supply, control system and RF testing [3]. By December 8 the ring was aligned, water cooling systems were completed, machine protection and personnel safety systems were certified, radiation shielding was installed, accelerator systems were tested and declared operational, and permission was given to begin commissioning SPEAR 3. The first beam signal was seen on December 10, the first beam was stored on December 15, the first 100-mA fill was reached on January 22, 2004 (Fig. 2), and beam was delivered to users on March 15. The commissioning period between December 10 and March 15 was filled with a remarkable array of machine measurement and characterization programs [4], facilitated by powerful MATLAB-based control application programs [5] and a commissioning team comprised of visiting experts from international light sources [4] and the SPEAR 3 accelerator staff.

The success of SPEAR 3 is testimony to the project staff that built an excellent machine and installed it in a short 7-month period. The final year of the project is described below.

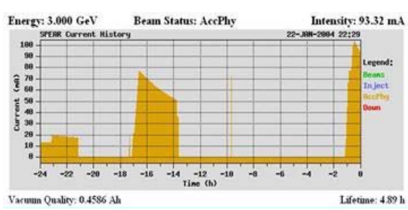

Figure 2: First 100-mA, 1/22/04.

FINAL YEAR OF CONSTRUCTION AND INSTALLATION

The original plan for the SPEAR 3 project was to complete the fabrication and assembly of all major system components prior to the removal of SPEAR 2 in order to maximize the probability of a successfully speedy installation. In early February, 2003, it was evident that the many vacuum chamber and RF system components would not be complete by the planned March 31 installation start. SPEAR 3 project managers met with SSRL directors to decide if the ring demolition should proceed as planned, or if a delay was in order that would extend the SPEAR 2 running time for the benefit of users. After careful review, it was determined the incomplete components would be ready in time for their installation in August and a decision to proceed was reached.

The installation program involved 3 phases summarized in Table 3: removal of SPEAR 2, modification of accelerator facilities for SPEAR 3, and the installation of new accelerator components. Each phase involved complex procedures that were planned in great detail and subjected to formal review by outside experts. The installation schedule ~3000 line entries listed in over 100 pages. Daily meetings were held to review program progress and to continually update the schedule. The nominal work schedule called for 10-hour days, five days a week, with weekends and night shifts reserved as contingency to meet schedule milestones. Ten contracts principal to the timely completion of the program, were awarded to outside companies, including those for accelerator removal and installation, tunnel excavation and concrete floor pouring, removal of old power supplies and installation of new ones, drilling and installing tunnel floor anchor bolts, installing raft support plates, installing cable trays and cables, and installing the high conductivity water system for RF components.

The removal of old SPEAR 2 components, including accelerator, cables, power supplies, insertion devices and beam line front ends, was completed ahead of schedule. Contractors removed the old 30-ft long magnet girders by dragging them through the tunnel to a single crane extraction point with a cable and pulley system. Safe and fast removal of the old cable plant was enabled by extensive planning and procedures that guaranteed all cables were de-energized before cutting. Many cables were labelled to be saved, but the majority of them were cut by the fast-moving contractors and had to be replaced.

The main activity during phase 2 of the installation was to remove the old tunnel asphalt floor, excavate 18 to 24 inches to reach solid sandstone, and pour a reinforced concrete floor. The floor for power supply building 118 was also excavated and replaced with concrete. These activities were completed by mid-June, a week ahead of schedule, enabling early installation of survey monuments, raft mounting plates and some 2000 anchor bolts in the floor. The new concrete was allowed to cure for 1-3 weeks before installing the alignment monuments; subsequent surveys indicate the fast-curing concrete did

Table 3: SPEAR 3 installation time line.

Begin:	Mar 31, 2003
Remove SPEAR2:	Mar 31-May 8
B118 renovation:	Mar 31-Oct 6
Pour concrete floor:	May 8-June 20
Install new monuments:	June 20-July 25
Install mounting plates and holes:	July 1-Aug 11
Install girders and straight supports:	Aug 11-Aug 29
Install cable plant:	Aug 25-Oct 20
Install vacuum hardware:	Aug 18-Oct 30
Leak-check, pump down:	Oct 20-Nov3
Survey, LCW turn-on, intlk checks:	Nov 7-15
Lock ring – installation complete:	Nov 15
System hot tests:	Nov 1-Dec 9
Final BL and shielding install/align:	Dec 1-9
Beam to SPEAR:	Dec 10

not show any appreciable settling (at the 100-µm level) after its initial cure. Alignment and grouting of the magnet raft support plates were completed a week ahead of schedule.

Figure 3: Installation of magnet rafts on new floor in tunnel.

The assembly and pre-alignment of all magnet rafts was completed by the end of July. Phase 3 of the installation began when the first new raft was rolled into the tunnel on August 5 (Fig. 3). Thirteen working days later, all 54 rafts, weighing more than 1,250,000 lbs. total, had been installed on precision alignment pins in the tunnel. In-tunnel cable and LCW installation commenced.

Meanwhile, work continued to complete the fabrication and assembly of accelerator components, most notably the straight section vacuum chamber components. In August, the injection septum magnet and associated chamber were assembled and electrical testing of the three slotted-pipe injection kickers was completed. Fabrication of ring beam stoppers, DCCT chamber [Fig. 4], straight-section transition pieces, vacuum pump ports, RF-shielded bellows modules, drift and new insertion device chambers was completed in August through October. The four RF cavities were fully processed and installed in October.

Installation of straight section components took place in October and November (Fig. 5). Other systems finished in the last stages of the installation period included Booster-to-SPEAR instrumentation and vacuum pipe modules, the low-level RF system and klystron, the ring BPM and tune processing systems, the LCW and HCW system connections, and a large amount of new radiation shielding mandated by recently revised SLAC requirements. The final of the installation were marked by 7-day work weeks and frequent 3-shift work days to accommodate work in the tunnel and nightly system power-testing. The remaining budget contingency was consumed quickly during this period to cover labor costs for the large number of workers from SSRL and the SLAC Technical Division that worked heroically day and night to complete the project on time.

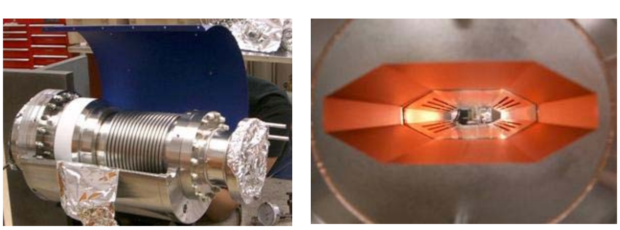

Figure 4: Low-impedance DCCT chamber.

Figure 5: Installed magnet rafts and RF cavities.

OPERATION

The SPEAR 3 commissioning is described elsewhere in these proceedings [4]. The facility is nearing the end of its first user run, delivering 100 mA fills 3 times a day, 7 days a week (Fig. 6) with micron stability using slow orbit feedback [5]. Problems encountered early in the run included frequent water flow trips caused by mis-sized needle valves and various RF system problems that have since been resolved. The lifetime at 100 mA is ~29 h, Touschek-limited from the small vertical coupling of ~0.1%. New radiation shielding and upgraded photon masks will be installed in September that will permit 500-mA operation during the next user run. A recent test run at 225 mA showed no instabilities. Improvements planned for the next year include installing beam scrapers and completing the UV synchrotron light monitor. Studies of a double waist, small β_y lattice with chicane for small-gap, in-vacuum IDs are in progress. Top-off injection is planned over the next 2-3 years.

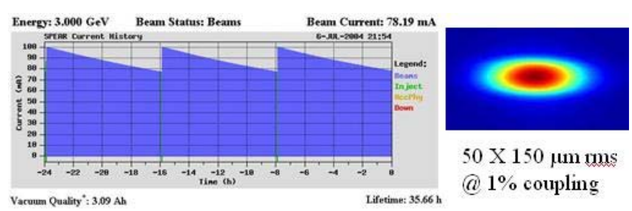

Figure 6: Typical SPEAR 3 operation with 8-h fills (left) and X-ray pinhole camera beam image (right).

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