[main headline]

Superbend era begins swiftly at the ALS

[text - 2076 words]

Advanced Light Source (ALS) director Daniel Chemla confesses he has been sleeping a lot better since the successful installation and commissioning of high-field superconducting bend magnets (superbends) in three curved sectors of ALS storage ring. Not only was this the first time the magnet lattice of an operating synchrotron light source has been retrofitted in this fundamental way, but the ALS now offers an expanded spectral range well into the hard x-ray region without compromising either the number of undulators or their high brightness in the soft x-ray region for which the ALS design was originally optimized. In sum, when the superbend-enhanced ALS started up for user operations in October 2001, it marked the beginning of a new era in its history.

The superbends achievement is a testament to the vision, ingenuity, and dedication of a multitude of people who contributed over the course of many years to this daring project. Because the superbends are responsible for directing the paths of the electrons circulating in the storage ring, it is essential that they work properly and continuously. Unlike straight-section insertion devices such as wigglers and undulators, superbends cannot simply be turned off in case of failure or malfunction. So, the stakes were very high: the payoff would be an expanded spectrum of photons to offer users, but the risks included the possibility of ruining a perfectly good light source or, at the very least, causing unacceptable down time. Needless to say, the superbends had to work right, and they had to work right away.

Superbend project leaders were bracing for up to a six-week commissioning period. Instead, thanks to extensive modeling and planning beforehand, it took less than two weeks after installation began before the machine was ramped up to full strength. Superbend Project Team Leader David Robin describes it this way: "It's as if you performed major surgery and the patient immediately got up and walked away."

After some preparatory work during previous shutdowns, installation of the superbends began in August 2001. Superbends were to replace the center combined-function (gradient) magnets in Sectors 4, 8, and 12 of the ALS triple-bend achromat storage-ring lattice. The straight section upstream of Sector 12 is also where electrons are injected into the storage ring. The initial installation plan was very tight. From August 20–30 (11 days including a weekend), the superbend team removed three normal gradient magnets and a portion of the injection line, installed the superbends, modified cryogenic systems, and completed extensive control system upgrades. They also installed many other storage-ring items and prepared for startup with beam.

After the installation phase, the goal was to commission the ALS with superbends and return the beam back to users by October 4. This schedule allowed the month of September to commission the ring (with the exception of a four-day break for the installation of the front ends for two superbend beamlines), as well as a three-day period for beamline realignment. However, commissioning proceeded much faster than expected. One of the main reasons for the smooth progress was that the superbends were very well aligned, as demonstrated by a stored beam with very little orbit distortion. The quality of the alignment was a tribute to the careful and thorough work of the alignment and magnet-measurement teams.

At the end of the first day, a current of 100 mA and an energy of 1.9 GeV were attained. At the end of the first weekend, the injection rate and beam stability were near normal. By the end of the first week, the full 400 mA beam current was ramped to 1.9 GeV and studies of a new low-emittance lattice with a non-zero dispersion in the straight sections (designed to retain the high brightness the storage ring had without superbends) were begun. By the end of the second week, test spectra taken in some beamlines showed no change in quality due to the presence of superbends. And so it went.

An old American aphorism cautions, "If it ain't broke, don't fix it." Since the ALS was by all accounts performing splendidly as designed, why put in superbends at all? The short answer is that the development of superconducting bend magnets was intended to expand the capabilities of the ALS. As it developed, the superbend project dovetailed neatly with the extraordinary growth of protein crystallography research at the ALS in recent years. The superbends will allow up to 12 new beamlines at photon energies from 7 to 40 keV. This will be more than enough to accommodate the fast-growing protein crystallography community and to provide complementary diffraction, spectroscopy, and imaging capability for materials science in the higher energy range.

The long answer begins with the first discussions on incorporating superbends into the ALS, which took place in 1993, between Alan Jackson, who was the ALS Accelerator Physics Group Leader at the time, and Werner Joho, who was at the ALS on sabbatical from the Paul Scherrer Institute in Switzerland. The ALS, whose size is constrained by its site, was originally designed to be a third-generation light source operating at beam energies of 1 to 1.9 GeV with straight sections optimized to serve the vacuum-ultraviolet (VUV) and soft x-ray (SXR) communities. Since then, however, light sources have been trending upwards in energy. One way for the ALS to follow this trend would have been to use some of its scarce straight sections for higher-energy wigglers. A less costly alternative, proposed by Jackson and Joho, was to replace some of the normal combined-function magnets in the curved arcs with superconducting dipoles that could generate higher magnetic fields and thus synchrotron light with a higher critical energy.

In 1993, newly hired accelerator physicist David Robin was assigned the task of performing preliminary modeling studies to see how superbends could fit into the storage ring's magnetic lattice and to determine whether the lattice symmetry would be broken as a result. He concluded that three superbends with fields of 5 T (compared to the 1.3 T of the original combined-function magnets), deflecting the electron beam through 10˚ each, could indeed be successfully incorporated into the storage ring.

Then, beginning in 1995, Clyde Taylor of Berkeley Lab's Accelerator and Fusion Research Division (AFRD) led a Laboratory Directed Research and Development (LDRD) project to design and build a superbend prototype. By 1998, the collaboration (which included the ALS Accelerator Physics Group, the AFRD Superconducting Magnet Program, and Wang NMR, Inc.) produced a robust magnet that reached the design current and field without quenching (i.e., loss of superconductivity). The basic design, which has remained unchanged through the production phase, includes a C-shaped iron yoke with two oval-shaped poles protruding into the gap. The superconducting material consists of wire made of niobium-titanium alloy in a copper matrix, over a mile long, wound over 2000 times around each pole. The operating temperature is about 4 K.

By late 1997, wiggler Beamline 5.0.2 of the Macromolecular Crystallography Facility (MCF) had already debuted with spectacular success following immediately, and protein crystallographers were soon clamoring for more beam time. Howard Padmore, head of the ALS Experimental Systems Group (ESG), developed a "figure of merit" based on the flux within a phase space appropriate for crystallography to get a handle on how well superbends would meet the needs of the protein crystallography community. He concluded that a superbend would be an optimal x-ray source for most protein crystallography projects, similar to the performance of the existing wiggler beamline.

Furthermore, the ALS had undergone a Department of Energy (DOE) review (headed by Robert Birgeneau, then at the Massachusetts Institute of Technology). The review report released in November 1997 asserted that "important scientific issues which require UV radiation have decreased in number compared to those which require hard x-rays." (This was a controversial finding, especially since a later DOE review of the ALS in early 2000 headed by Yves Petroff of the European Synchrotron Radiation Facility reached the opposite conclusion.)

In response to the criticism, the ALS Workshop on Scientific Directions held in March 1998 supported the development of superbends as a way to provide higher-energy photons without diminishing support for the vital and active core VUV/SXR community. This direction was also endorsed by the ALS Science Policy Board and the ALS Scientific Advisory Committee. Against this backdrop and with the strong support of Berkeley Lab Director Charles Shank, Brian Kincaid, then the ALS Director, made the decision to proceed with the superbend upgrade, and his successor, Daniel Chemla, made the commitment to follow through.

The Superbend Project Team held a kickoff meeting in September 1998, with David Robin as Project Leader, Jim Krupnick as Project Manager, and Ross Schlueter as Lead Engineer. Christoph Steier came aboard a year later as Lead Physicist. Over the next three years, the team worked toward making the ALS storage ring the best understood such ring in the world. In every dimension of the project, from beam dynamics to the cryosystem, from the physical layout inside the ring to the timing of the shutdowns, there was very little margin for error.

To study the beam dynamics, the accelerator physicists adapted an analytical technique used in astronomy called frequency mapping (see SRNews, Vol. 13.6, Nov/Dec 2000, pp. 33-36). This provided a way to "experiment" with the superbends' effect on beam dynamics without actually requiring the use of the storage ring. Another technical challenge was to design a reliable, efficient, and economical cryosystem capable of maintaining a 1.5-ton cold mass at 4 K with a heat leakage of less than a watt. Wang NMR was contracted to construct the superbend systems (three plus one spare). Because so much was at stake, the storage ring was studied and modeled down to the level of individual bolts and screws to ensure a smooth, problem-free installation into the very confined space within the storage ring.

Meanwhile, on the beamline end, Alastair MacDowell, Richard Celestre, and Padmore of the ALS ESG and Carl Cork of the MCF had demonstrated, at Beamline 7.3.3, the feasibility of doing protein crystallography easily and cheaply at a normal bend-magnet beamline. On the strength of this demonstration, users Tom Alber and James Berger of the University of California, Berkeley, (UCB) with David Agard of the University of California, San Francisco, (UCSF) agreed to build "Beamline 9.1," a normal bend-magnet beamline for protein crystallography. Fortunately, it was soon recognized that, right next door in Sector 8, a superbend would become available that would be an even better source. The UCB/UCSF participating research team (PRT) decided to take the plunge and committed to building the first-ever superbend beamline (Beamline 8.3.1). The detailed plans that were developed for this beamline were subsequently instrumental in convincing representatives of the Howard Hughes Medical Institute (HHMI), which was interested in investing in a West Coast facility for its protein crystallography investigators, to fund two more superbend beamlines in Sector 8.

The UCB/UCSF and HHMI beamlines provided the necessary momentum for other groups to follow suit: additional proposals were submitted and construction of beamlines was begun even before a single superbend had been installed. The Molecular Biology Consortium (MBC, affiliated with the University of Chicago) and a PRT from The Scripps Research Institute have also committed to building superbend beamlines. Non-crystallography beamlines currently in the works include one for tomography and one for high-pressure research, two areas for which superbends are even more advantageous than they are for protein crystallography, because they more fully exploit the higher energies that superbends can generate. Many other areas, including microfocus diffraction and spectroscopy, would also benefit enormously through use of the superbend sources. In addition to paying for their beamlines, each PRT contributes funds to help offset the cost of the superbends (estimated at $4.5 million). The PRTs will get 75% of the beam time on their respective beamlines, with 25% of the beam time allocated to independent investigators.

Eight years in the making, with a large supporting cast of physicists, engineers, technicians, and others too numerous to list, the remarkably successful installation and commissioning of the superbends—not the end of the story—but the beginning of a new chapter in the history of the ALS. Well-deserved thanks go to all the Superbend Project Team members, all of whom assumed the full measure of their responsibilities in ensuring the success of the project. Their technical achievement of integrating three superbends into the ALS storage ring will permit this facility to achieve balanced growth in many areas of science, well into the future.

[authors and institutions]

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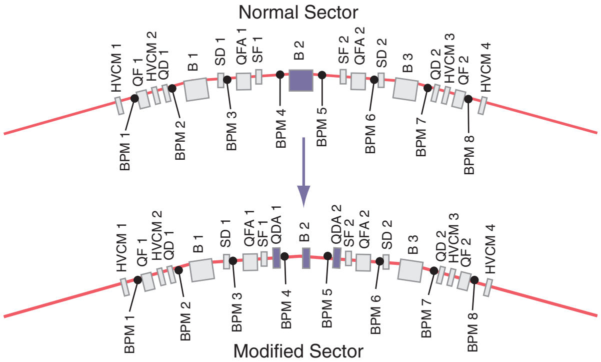
[Figure 1]
One of three superbend magnets in the ALS storage ring.




[Figure 2]
Changes made to the ALS lattice in a typical superbend sector. One normal-conducting combined-function magnet (B2, top) was replaced by a superconducting dipole magnet and two quadrupole magnets (B2, QDA1, QDA2, bottom).

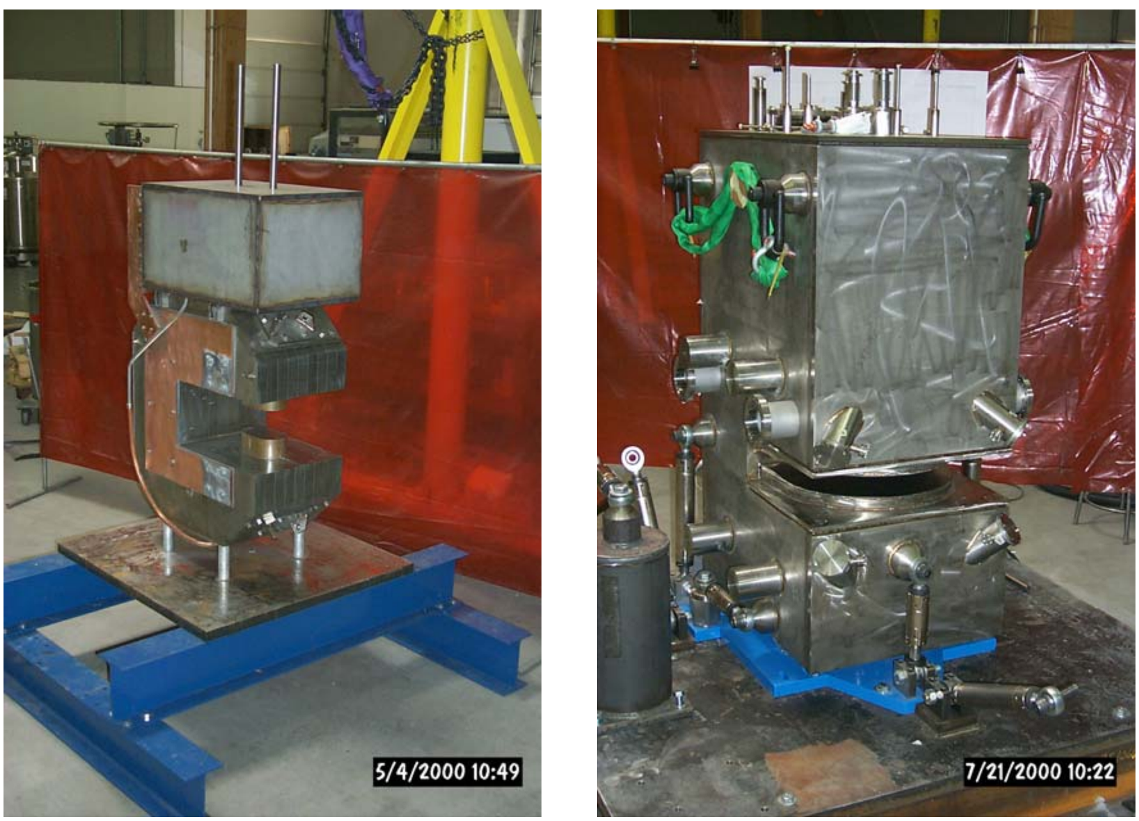
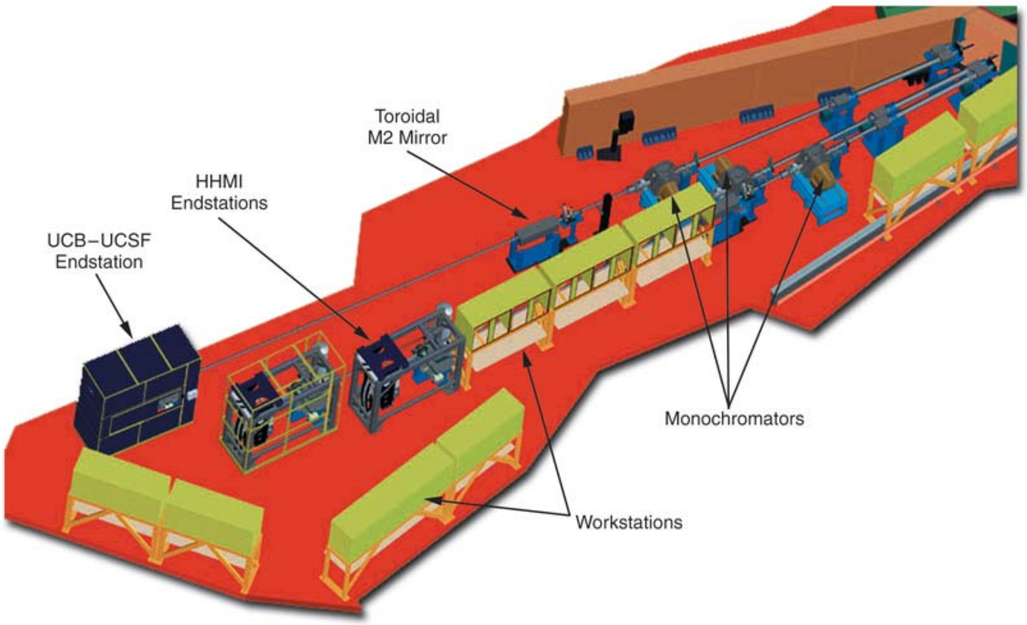



Figure 3]

(left) Iron C-shaped superbend yoke, with oval pole visible, and a liquid helium vessel on top. (right) Superbend enclosed in cryostat.




[Figure 4]
Layout of Sector 8 of the ALS showing the UCB/UCSF and HHMI protein crystallography beamlines and their corresponding end stations.