SUCCESSFUL COMPLETION OF THE ALS SUPERBEND PROJECT*

D. Robin†, R. Benjegerdes, A. Biocca, P. Bish, W. Brown, W. Byrne, D. Calais, M. Chin, C. Corradi, D. Coulomb, J. De Vries, R. DeMarco, M. Fahmie, A. Geyer, J. Harkins, T. Henderson, J. Hinkson, E. Hoyer, D. Hull, S. Jacobson, J. Krupnick, S. Marks, J. McDonald, P. Molinari, R. Mueller, L. Nadolski, K. Nishimura, F. Ottens, J.A. Paterson, P. Pipersky, A. Ritchie, S. Rossi, B. Salvant, R. Schlueter, A. Schwartz, J. Spring, C. Steier, C. Taylor, W. Thur, C. Timossi, A. Wandesforde, J. Zbasnik, LBNL, Berkeley, CA, USA 94720
J. Chen, B. Wang, WANG NMR, Livermore, CA, USA 94550
W. Decking, DESY, Hamburg, Germany

Abstract

At the ALS there had been an increasing demand for additional high brightness hard x-ray beamlines in the 7 to 40 KeV range. In response to that demand, the ALS storage ring was modified in August 2001. Three 1.3 Tesla normal conducting bending magnets were removed and replaced with three 5 Tesla superconducting magnets (Superbends). The radiation produced by these Superbends is an order of magnitude higher in photon brightness and flux at 12 keV than the 1.3 Tesla bends, making them excellent sources of hard x-rays for protein crystallography and other hard x-ray applications. At the same time the Superbends do not compromise the performance of the facility in the UV and Soft X-ray regions of the spectrum. The Superbends will eventually feed 12 new beam lines greatly enhancing the facility's capacity in the hard x-ray region. The Superbend project is the biggest upgrade to the ALS storage ring since it was commissioned in 1993. In this paper we present a history of the project, as well as the installation, commissioning, and resulting performance of the ALS with Superbends.

1 INTRODUCTION

October 4, 2001 marked the completion of the Superbend Project — the biggest upgrade to Berkeley Laboratory's Advanced Light Source (ALS) since the synchrotron light source was first commissioned for users in 1993. On that day the ALS facility began user operation with three newly installed Superbends and first light generated from one of these Superbends reached the end station of the first Superbend beamline. With the successful completion of the Superbend project the ALS has transformed itself, greatly increasing its capability and capacity to deliver bright hard x-ray beams (up to 40 keV) to users [1, 2, 3]. There is a large demand for beamlines using Superbend radiation and the number of Superbend beamlines is rapidly growing. At the time of this conference, three fully operational beamlines exist with four more under construction, and several others under consideration.

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† DSRobin@lbl.gov

The ALS was designed to be optimized for the generation of radiation from the UV to Soft x-ray range (10 to 1500 eV). Over the years it has developed a strong user community in this spectral region. At the same time, the ALS saw a large growth in a user community outside of this core region — in the hard x-ray region. Prior to the installation of the Superbends there were two sources of hard x-rays: several of the regular 1.3 Tesla dipoles and one 2 Tesla wiggler. The wiggler beamline which uses 12 keV photons generated from the wiggler proved to be one of the most productive protein crystallography beamlines in the world demonstrating the capabilities of lower electron energy synchrotrons like the ALS to do hard x-ray science [4]. The success of beamline 5 together with the need for more protein crystallography beamlines worldwide [5] fueled the demand for more hard x-ray beamlines at the ALS. There was also a demand from the tomography and powder diffraction communities demanding even higher energy x-rays (up to 40 keV).

The idea of retrofitting the ALS storage rings with high field superconducting magnets to produce hard x-rays was conceived in the early 1990s. In 1995 a project began to see if it was possible design a superconducting coil and core of a magnet that would meet the needs of the ALS [6]. In 1998, based upon the successful tests of a coil and core [7] combined with the increasing demand from the user community, the ALS decided to embark upon the Superbend project [2, 4].

The main goal of the project was to modify the storage ring lattice by replacing three of the thirtysix, 1.3 Tesla, normal conducting, 10 degree, bending magnets with three, 5 Tesla, superconducting, 10 degree, bending magnets (Superbends) [8, 9]. This would be done by modifying three of the twelve ALS sectors. Fig. 1 shows how each of the 3 sectors was modified to include Superbends. A typical sector without Superbends can be seen in Fig. 1 (top) and one modified to include Superbends is shown in Fig. 1 (bottom). One sees that the central dipole, B2, in the sector is replaced by a Superbend. Unlike the normal dipoles, the Superbends do not have a quadrupole focusing component. Two new quadrupoles QDA1 and QDA2 are added to the lattice and the QFA quadrupoles in a Superbend sector are put on separate power supplies. It was necessary to make this change in the quadrupole configuration in order to better match the Superbend sectors to the non Superbend sectors to improve the particle beam dynamics.

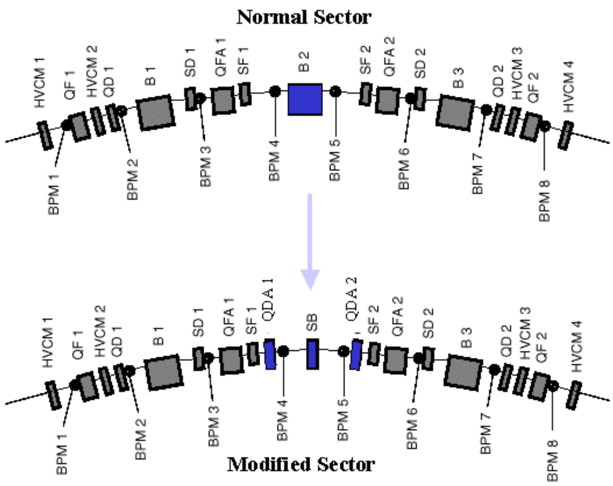

Figure 1: Magnetic layout of a normal (top) and modified (bottom) sector.

1.1 Superbends versus Wigglers

At an electron beam energy of 1.9 GeV, the Superbends have a critical photon energy of 12 keV and are a good source of photons up to 40 keV. In principle the ALS could have chosen to use wigglers or wavelength shifters to generate hard x-rays. However there were many advantages of the Superbend solution. First, by replacing normal bends with Superbends, none of the few remaining empty straight sections were used. Second, the Superbends provided a high capacity—up to 12 new beamlines (four from each bend) versus a wiggler that only can support 3 beamlines. This meant that the Superbends were very cost effective. Third, it is possible to perform the powerful technique of multiple-wavelength anomalous diffraction (MAD) on 9 of the 12 Superbend beamlines versus only 1 of the 3 wiggler beamlines. Fourth, the Superbends were higher in flux density than the wiggler (due to the smaller electron beam size) making them a superior source of 12 keV photons for protein crystallography [3]. This meant that the experimental beam time is shorter. Fifth, the total radiation power in the Superbend beamlines is significantly smaller than that of the wiggler making the beamlines simpler.

The Superbend solution was very challenging. This was the first-ever retrofit of superconducting bend magnets into the storage ring of an operating synchrotron radiation source. The Superbends would be an essential part of the storage ring lattice and problems with them not only affect the users of the Superbends but all users at the ALS. Therefore it was necessary to ensure that the transition to Superbend operation was transparent. Superbends needed to be installed and commissioned in a short period and the resulting influence on the existing users should be small. There could be no significant impact on brightness, lifetime, beam stability, fill times, or reliability.

2 SUPERBEND PROJECT

In order to ensure that the transition to Superbend operation was transparent, the Superbend team adopted the strategy of precomissioning as many subsystems (with and without beam) as possible prior to the actual installation of the Superbends. Much of the work has been described in previous papers. Here we just give a brief description of the project [8, 9, 10, 11, 12].

To minimize the impact on users, the Superbend installation was split into two medium length (6 week) shutdowns. In the first shutdown (which occurred in March 2000) all major components of the project, excluding the actual Superbend magnets were installed [9]. In the second shutdown (which began in August 2001) the Superbends were installed and commissioned [10].

Prior to installation, the Superbend systems were extensively modeled and tested. The team performed thorough cryogenic testing [11, 12], magnet measurements [13], vibration testing, powersupply and controls testing [9]. The results of these tests showed that the system was very reliable. During these tests one of the four Superbends was put through the equivalent of 4 years of ramping and cycling with no measurable degradation in cryogenic and mechnical performance of the Superbends. The backup cryogenic system was tested to ensure that the Superbends could transition smoothly to external cryogenic operation in the event of a cryocooler failure [8].

Extensive beam dynamics studies were performed primarily to accurately predict and minimize the impact of the Superbends on the lifetime and injection efficiency. We built upon experimental and theoretical studies using the technique of Frequency Map Analysis to study the dynamics of particles in the ALS [16, 17].

2.1 Installation and Commissioning

The installation and commissioning of the Superbends occurred in a 6 week period that began on August 20, 2001 and ended on October 3, 2001. A picture of the first Superbend being installed can be seen in Fig. 2. The installation period lasted for 11 days. During that time 3 normal magnets were removed, 3 Superbends installed, a portion of the injection line disassembled and reinstalled. In addition the new controls, powersupplies, diagnostics, and external cryogenics were installed and tested.

Commissioning began on August 31, 2001 and proceeded faster than expected. First beam was injected within 5 minutes of first attempt, 100 mA stored within 1 hour, first energy ramping with beam later that day, and the impact of the Superbends was evaluated within 2 weeks. The beam was delivered back to users on October 4, 2001 with first Superbend light in the first Superbend beamline. The results of the installation and commissioning are described in detail in another paper at this meeting [10]. During commissioning a lattice with 6 cm dispersion in the straights

Figure 2: Installation of the first Superbend.

was adopted. This allowed us to minimize the change in emittance from the Superbends.

2.2 *Impact of Superbends on the ALS*

The Superbend project met all, and in many cases exceeded, the project goals. They were installed with no significant impact on the non-Superbend users [10]. Immediately following the installation of Superbends, the lifetime was the same as before, fast orbit stability was the same, slow orbit stability was better, injection and ramping times were comparable and there was a small change in the beam sizes (see Table 1) and no noticable change in brightness. The hard x-ray community is making use of the new capabilities. The first Superbend beamline is in production mode and at the time of this conference has more than 25 structures have been solved. The performance of the beamline compares favorably to the wiggler beamline. The second two Superbend beamlines 8.2.1 and 8.2.2 are also in production mode.

Table 1: Comparison of parameters before and after Superbends at the insertion device beamline (.0) and the bend magnet beamlines (.1, .2, .3, .4)

Parameter	**Before Superbends**	**After Superbends**
Natural emit.	5.5 rad nm	6.75 rad nm
Energy spread	0.08%	0.1%
Beamline	Hor. beam size	Hor. beam size
x.0	250 μm	310 μm
x.1	50 μm	57 μm
x.2 and x.3	100 μm	100 μm
x.4	60 μm	65 μm
Beamline	Ver. beam size	Ver. beam size
y.0	30 μm	23 μm
y.1	65 μm	54 μm
y.2 and y.3	20 μm	15 μm
y.4	60 μm	52 μm

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4 REFERENCES

[1] B. G. Levi, ”Gamble Pays Off at the Advanced Light Source”, Physics Today (2002), January; 55, pp. 17

[2] D. Robin, A. Robinson, L. Tamura, ”Superbends expand the scope of Berkeley’s ALS”, CERN Courier, (2002), March; Vol. 42, No. 2, pp. 28-31

[3] L. Tamura and A. Robinson, ”Superbends Era Begins Swiftly at the ALS”, Synchrotron Radiation News, (2002); Vol 15, No. 1, pp. 30-34

[4] R. Service, ”Upgrade Brings Hope to Berkeley’s Advanced Light Source”, Science (1999) August 27; 285, pp. 1344

[5] R. Service, ”Wiggling and Undulating Out of an X-ray Shortage”, Science (1999) August 27; 285, pp. 1342-1346

[6] C. E. Taylor and S. Caspi, ”A 6.3 T Bend Magnet for the Advanced Light Source”, IEEE Trans. Magnetics 32, No. 4, (1996), pp. 2175-2178

[7] C. E. Taylor, et al., ”Test of a High-Field Magnet for the ALS”, Transactions on Applied Superconductivity 9, No. 2, (1999), pp. 479-482

[8] “Superbend Magnet System Conceptual Design Report”, Lawrence Berkeley National Laboratory Publication, PUB-5457, Apr. (2000)

[9] D. Robin, et al., ”Superbend Project at the Advanced Light Source”, Proceedings of the 2001 IEEE Particle Accelerator Conference, Chicago, 2632 - 2634 (2001)

[10] C. Steier, et al., ”Commissioning of the Advanced Light Source with Superbends”, these proceedings, (2002)

[11] J. Zbasnik, et al., ”Test of a GM cryocooler and high Tc leads for use on the ALS Superbend magnets”, Published in the proceedings of the (1999) CEC, Montreal, July 1999

[12] J. Zbasnik, et al., ”ALS Superbend Magnet System”, IEEE Trans. on Applied Superconductivity, Vol. 11, No. 1, March, (2001), pp. 2531-2534

[13] S. Marks, et al., ”ALS Superbend Magnet Performance”, Published in the proceedings of the 17th International Conference on Magnetic Technology, Geneva, (2001)

[14] S. Caspi, M. Helm, and L. J. Laslett, ”The use of harmonics in 3-D Magnetic Fields”, IEEE Trans. Magn. Vol. 30, No. 4, (1996)

[15] H. Nishimura and D. Robin, ”Impact of Superbends at the ALS”, Proceedings of the 1999 IEEE Particle Accelerator Conference, New York, (2001) pp. 203 - 205

[16] D. Robin et al., ”Global dynamics of the Advanced Light Source revealed through experimental frequency map analysis”Phys. Rev. Lett., 85, pp. 558, (2000)

[17] C. Steier et al., ”Measuring and Optimizing the Momentum Aperture in a Particle Storage Ring”, Phys. Rev. E 65, 056506 (2002)