

COMMISSIONING OF THE ALS WITH SUPERBENDS*

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Abstract

To expand the capabilities of the Advanced Light Source (ALS) and to satisfy the demand for high energy x-ray sources with high brightness, three 1.3 T normal conducting bending magnets were replaced with three 5 T superconducting magnets (Superbends) in 2001. The new magnets will ultimately provide 12 new beam lines for users. The x-ray brightness and flux of the Superbends at 12 keV is more than one order of magnitude higher than the one of the conventional magnets they replaced. The Superbend project was a major upgrade of the ALS since the 3 Superbends are an integral part of the machine lattice and perturb its original 12-fold symmetry. This paper describes the successful (and quick) commissioning period and the accelerator physics issues associated with the Superbend upgrade (especially the off-energy single particle dynamics).

1 INTRODUCTION

The ALS is a third generation synchrotron light source located at Lawrence Berkeley National Laboratory [1]. It was originally designed to provide very bright VUV and soft x-ray beams and has been in operation since 1993. The number of users is continuously expanding and in 2002 it will reach about 1400. Over the years an increasing demand developed to have more sources of bright beams of hard x-rays. This was especially true for applications in protein crystallography but also for high pressure diffraction and tomography. To serve this new community the Superbend project [2] was created with the objective to significantly enhance the capability and capacity of the ALS for hard x-rays, while not compromising the ability to serve the core VUV and soft x-ray communities. The concept chosen to fulfill these goals was to replace three center bending magnets in three of the twelve triple bend achromats of the ALS with superconducting magnets. While this allowed to retain the straight sections for soft x-ray undulators, it also created the main challenge for the project: the Superbends are an integral part of the machine. Therefore they cannot be switched off and had to work reliably and without deteriorating impact on the beam quality from day one.

The design of the Superbend magnets has been described in detail elsewhere [3, 4]. Fig. 1 shows a CAD drawing of one Superbend. The cryostats are installed around the normal warm aluminium vacuum chamber of the ALS. The cold mass consists of a laminated iron yoke with two iron poles and two superconducting coils. The magnets are cryogenically self contained, employ the conduction cool-

ing technique and use commercial cryocoolers to ensure very high reliability and cost effective operation. To minimize the heat input into the cold mass, high temperature superconductors are used as current leads. In addition there are cryogenic buffer reservoirs, which allow save operation even in case of a cryocooler failure.

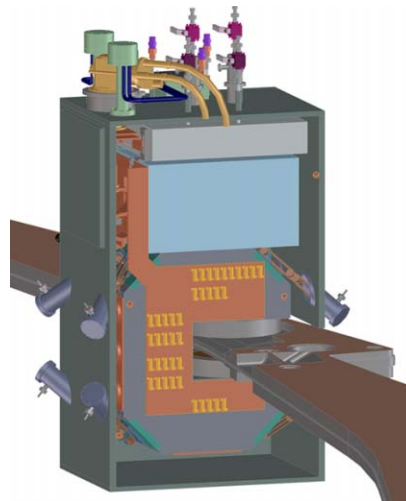


Figure 1: Schematics of a Superbend magnet.

Since the ALS provides over 5,000 hours of annual user time, the installation and commissioning of the Superbends had to be completed in a short time period. To achieve this and to minimize the risk of the commissioning, all components were tested extensively before their installation. In addition most of the components (except for the actual Superbends) were installed and commissioned early. Because of the high demand for hard x-ray beamlines, there was a significant push to complete the project in a timely manner. This put a significant time pressure on all tests.

The main concern in terms of accelerator physics was the impact the Superbends have on the non-linear dynamics. By breaking the original periodicity of the ALS from 12 to 3 and introducing strong systematic multipole fields (because of their longitudinal field roll-off) the Superbends did change the dynamics significantly. The goal was to ensure that the change in dynamics did not have a large effect on injection efficiency or lifetime.

2 PRECOMMISSIONING

As mentioned before, most non-Superbend items were installed more than one year before the actual commissioning. This included the new quadrupoles around the three Superbend locations and new power supplies for neighbouring quadrupoles, to provide the possibility to minimize the symmetry breaking. Furthermore the control system was upgraded, the complete storage ring aligned and the

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vacuum chambers at the future Superbend locations were machined in situ to allow the cryostats to fit. In parallel extensive tests were carried out with the Superbends and other systems. One of the magnets completed 10,000 ramp cycles, equivalent to about 4 years of normal operation. To preserve the good orbit and energy stability of the ALS, the power supplies of the Superbends are especially stable (5 ppm) and they stay always connected to the magnet. At the same time measurements confirmed that the existing power supply of the main bending magnet chain fulfills the same stability requirement.

The extensive cryogenic tests of the Superbends revealed problems on 2 of the 4 magnets. Because the tests were carried out early enough, the problems could be fixed without impact on the overall time schedule. Another early test which lead to a design change were the vibration measurements. The cold-head of the cryocooler induced significant (about one μm amplitude) vibrations of the cold mass. This was found in measurements with high precision accelerometers. A modification of the thermal link between the cold-head and the magnet solved the problem.

Last but not least extensive studies of the non-linear dynamics were carried out both in simulation and experiment. They included the development of new methods to study both the on-energy and off-energy single particle dynamics. The new methods consisted of the first experimental application of frequency map analysis [5, 6, 7]. The effects of the Superbends on the non-linear dynamics were experimentally studied in the real machine with these new techniques before the actual Superbend installation by using the new quadrupoles around the Superbends to simulate the symmetry breaking. Some results of the measurements concerning the momentum aperture will be shown later.

3 COMMISSIONING

The final installation of the Superbends was accomplished in just one week and a half. For the commissioning one month was allocated and a very detailed commissioning plan was developed and reviewed in advance.

After the installation was finished on August 30, 2001, the commissioning was very successful right from the start: Fig. 2 shows the current history of the first commissioning day. First beam was stored just after midnight, 5 minutes after trying to inject. The alignment and field calibration of all new elements was good enough and the lattice set well enough that only some steering of the transfer channel was necessary. Within one hour, 100 mA were stored (limited by vacuum pressure due to outgassing of new Superbend photon stops). On the same afternoon, beam was ramped successfully from the injection energy of 1.5 GeV to the normal operation energy of 1.9 GeV.

The commissioning continued at a quick pace. After correcting the lattice symmetry using the results of an orbit response matrix analysis, the nonlinear dynamics properties of the lattice were measured. The dynamic aperture and momentum aperture were about the same as before the Su-

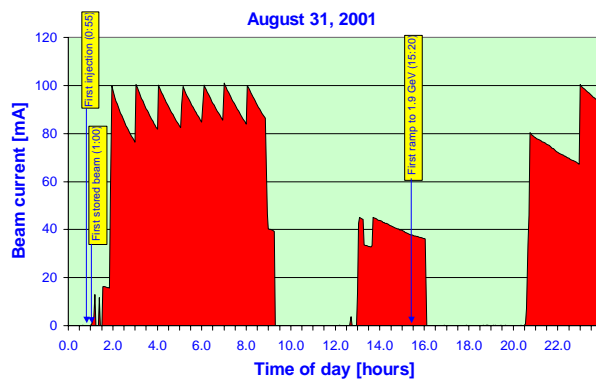


Figure 2: Beam current history of the first commissioning day with Superbends. Some accomplishments are labeled on the plot.

perbends. All details (because of the change in lattice symmetry, many details of the measurements changed) agreed extremely well with the predictions of simulations.

The orbit stability and jitter were measured (see Fig. 3). They were virtually the same as before the installation of the Superbends (as expected after the design change due to the vibration measurements). Natural emittance (10.5 nm) and coupling (below 1%) were measured and agreed well with the predictions.

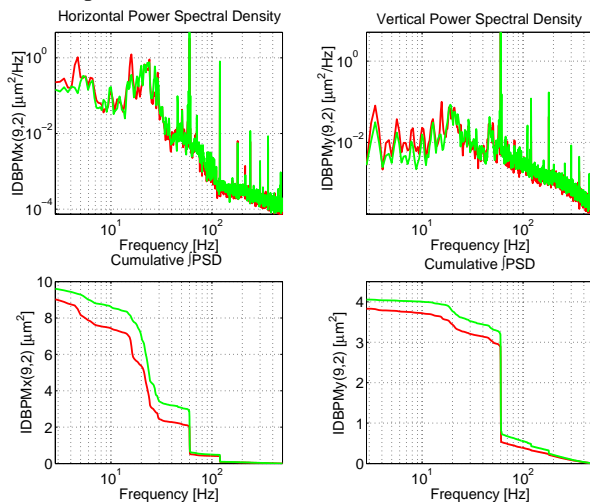


Figure 3: Power spectral density of the closed orbit oscillations in the ALS before (red) and after (green) the installation of the Superbends.

So after just three days of commissioning, all minimum performance goals with Superbends were already successfully reached, well in advance of the milestone, which allowed 22 days.

4 DISTRIBUTED DISPERSION LATTICE

The ALS had always operated with a lattice with zero horizontal dispersion in the straights because it was not reasonable to operate with lower natural emittance since the Touschek lifetimes would have been too small. This lattice was used at the start of the Superbend commissioning as well, because it provided a relatively large dynamic aperture. But because of the high magnetic field

of the Superbends the natural emittance of the ALS in the zero-dispersion lattice would have gone up from 5.5 nm to 10.5 nm. To compensate for that effect and to minimize the impact on the soft x-ray brightness, a distributed dispersion lattice was commissioned which introduces 6 cm of dispersion in the straight sections. This lattice reduces the natural emittance with Superbends to 6.75 nm. In fact, we were able to reduce the vertical emittance with unchanged total lifetime, making up even more of the lost brightness. Overall, the new lattice provides about the same brightness to users of soft x-ray undulators and normal bend magnets as before Superbends, and significantly higher brightness to the hard x-ray users of the Superbends. Fig. 4 shows the beta-functions and dispersion function for one sector of the new lattice.

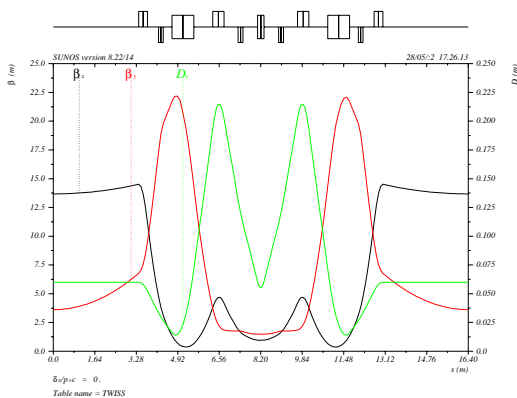


Figure 4: Lattice functions (β_x, β_y, η_x) of the ALS for the distributed dispersion lattice (6 cm horizontal dispersion in the straight sections). Shown is a sector with a Superbend magnet in the middle.

The nonlinear dynamics was again studied in detail for this new lattice. Because it reduces the dispersion in the arcs (i.e. at the location of the sextupoles), it requires significantly higher sextupole strengths, thereby increasing nonlinearities and the strength of resonances. The easiest way to quantify the impact on the lifetime is to measure the momentum aperture using a scan of the RF-acceptance. If the beam lifetime is Touschek dominated one expects a (slightly more than) quadratic dependence on the RF-acceptance, as long as it is the smallest aperture in momentum space. The point where the lifetime deviates from the quadratic behaviour is where other apertures become important. For the ALS the first one is the dynamic momentum aperture in the arc. As one can see in Fig. 5, the momentum aperture for the distributed dispersion lattice is indeed slightly smaller than for the zero dispersion lattice. But there is little difference between both cases with and without Superbends. All values agree very well with predictions based on tracking studies. At 1.9 GeV, the available RF-voltage at full beam current corresponds to an RF-acceptance of about 2.5%. This is very close to the measured dynamic momentum aperture for the distributed dispersion case. Therefore the reduction in lifetime at 1.9 GeV due to the dynamic momentum aperture is small (as long as the beta-beating is corrected to less than 1% rms).

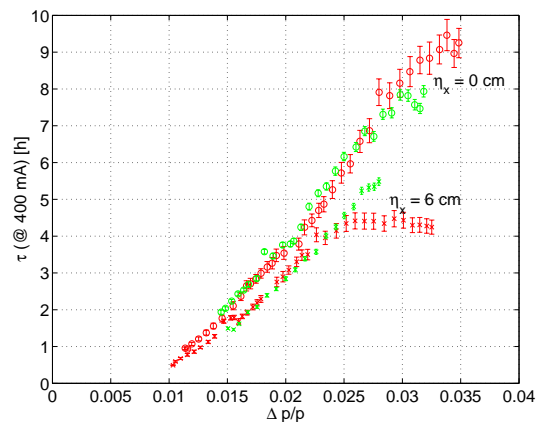


Figure 5: RF aperture scans before (red) and after (green) the installation of the Superbends. The slightly different vertical scaling is caused by the different emittances (bunch volumes) in the different lattices.

5 SUMMARY

The Superbend project at the ALS has been a complete success. All performance goals have been achieved, the installation has been accomplished on time and the commissioning progressed significantly faster than planned. Therefore additional performance improvements of the ALS could be implemented during the Superbend commissioning period. Overall, installation and commissioning have been completed in just 6 weeks. The beam quality after the end of commissioning was immediately better than promised (smaller emittances). Moreover, there was no Superbend related reduction in reliability.

6 ACKNOWLEDGEMENTS

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