LBNL-43004

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March 1999

Presented at the
1999 Particle
Accelerator Conference,
New York, NY,
March 29–April 2, 1999,
and to be published in
the Proceedings

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3/25/1999

"Paper Presented at 1999 Particle Accelerator Conference" New York/New York/U.S.A, March 29th- April 2nd.

*This work was supported by the Director, Office of Energy Research, Office of Basic Energy Sciences, Materials Sciences Division of the U.S. Department of Energy, under Contract No. DE-AC03-76SF00098

IMPACT OF SUPERBENDS AT THE ALS*

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Abstract

To satisfy a demand for more high energy, high brightness x-ray sources at the Advanced Light Source (ALS), a plan is in place to replace three 1.3 Tesla normal conducting bending magnets with three 5 Tesla superconducting magnets (superbends) in the year 2001. In this paper we discuss the impact of the superbends on the ALS beam parameters and particle dynamics. In particular we show the effect on the emittance, energy spread, and lifetime. We find that by adjusting the dispersion to be positive in the straight section we are able to largely restore the horizontal emittance. The vertical emittance can be adjusted independently to control the lifetime. The particle dynamics are investigated through particle tracking with a frequency analysis postprocessor. We find that by placing the three superbends symmetrically around the ring there is ample dynamic aperture for injection and lifetime.

1 INTRODUCTION

For applications in protein crytallography, high pressure diffraction, and x-ray tomography there is a desire for good sources at the ALS with photon energies of 10 to 20 KeV and beyond. In principle one can create high energy sources by placing wigglers or wavelength shifters in the long straight sections. However at this time there are very few unoccupied straight sections remaining in the ring — at present of the 12 straight sections only 2.5 are empty.

A way to introduce more high energy sources without using up any straight sections is to replace some of the bending dipole magnets with shorter, higher field magnets. This is the direction that the ALS has decided to pursue. A plan is in place to replace 3 normal conducting dipole magnets with 3 superconducting dipoles (superbends).

Operating with a beam energy of 1.9 GeV, the normal dipoles have a critical photon energy of 3.1 KeV whereas the superbends have a critical photon energy of 12 KeV. This increase in critical energy means that in both flux and brightness the superbend source is almost an order of magnitude larger than the normal dipole source at 10 KeV and almost two orders of magnitude larger at 20 KeV [1].

In this paper we discuss the modifications to the ALS lattice that are necessary to include the superbends. We discuss the changes to the beam parameters and the impact on the beam dynamics — particularly injection and lifetime.

2 LATTICE MODIFICATIONS

The ALS consists of 12 sectors. A typical sector can be seen in Fig. 1 (top). Each sector has 3 dipole magnets each of which bend the beam by 10 degrees. The dipoles are combined function magnets having both dipole and quadrupole field components. The plan is to modify 3 of the 12 sectors, replacing the center dipoles in those sectors with superbends.

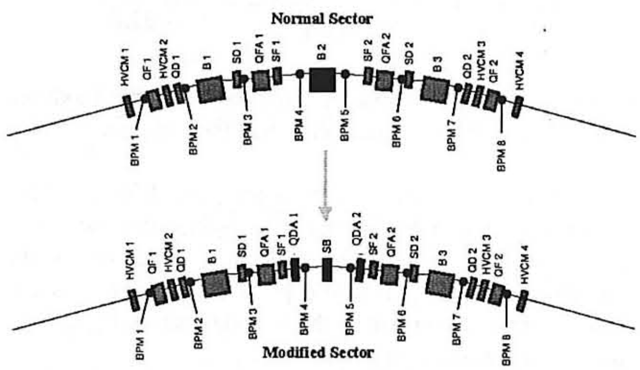

Figure 1. Magnet layout of a normal (top) and modified (bottom) sector.

In 1998 the Superconducting magnet group at LBNL in collaboration with Wang NMR successfully constructed and tested a prototype superbend coil and yoke [2]. One of the superbend field requirements, which was met by the prototype, is that the magnet bend the beam by 10 degrees while achieving a 5 Tesla field at the beamline ports.

Unlike the normal dipoles, the superbends do not have a large quadrupole focusing component. Therefore additional quadrupoles (*QDA*s) are placed on both sides of the superbend in order to compensate for the lack of focusing. Fig. 1 (bottom) shows a sector modified to include a superbend and two *QDA*s.

2.1 Matching the Lattice

Once the superbends and quadrupoles are installed, the magnetic fields of the quadrupoles and sextupoles in the ring must be adjusted to match the lattice functions. The goal of the matching is to minimize the distortion of the lattice functions as compared with that of the lattice with no superbends. The *QF*, *QD*, and *QFA* quadrupoles in the normal sectors are used to adjust the dispersion and betatron tunes. The *QF*, *QD*, and *QDA* quadrupoles in the modified sectors are adjusted to match the β-functions

*This work was supported by the Director, Office of Science, Office of Basic Energy Sciences, Materials Sciences Division, of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.
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and dispersion to the normal sector [3]. The *SF* and *SD* sextupoles are used to adjust the chromaticities [4].

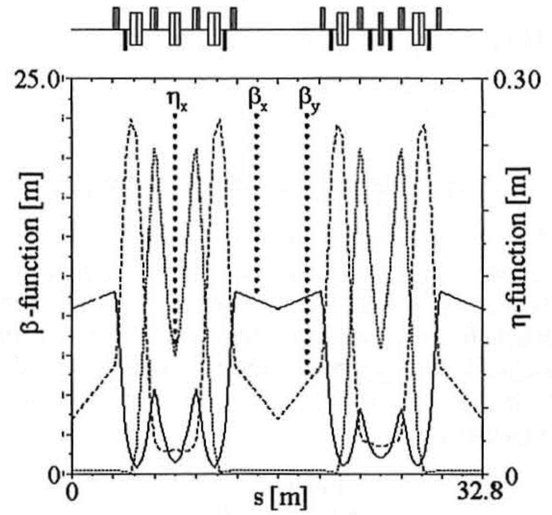

Figure 2. Twiss functions of a normal (left) and modified (right) sector fit to zero dispersion in the straights.

In Fig. 2 the lattice functions are plotted for a normal sector (left) and a modified sector (right) after the lattice has been matched with the dispersion fit to zero in the straight sections [5]. It is also possible to fit the lattice to have positive dispersion in the straight section by slightly increasing the strengths of the *QFA*s.

2.2 Impact on the Machine Parameters

In Table 1 the parameters of the ALS are given with and without the superbends. There are 3 columns in the table. In column 1 the parameters are given for normal ALS without superbends and matched to zero dispersion, η_x , in the straights. In column 2 the parameters are given with 3 superbends and matched to zero dispersion in the straights. In column 3 the parameters are given for 3 superbends matched to 6 cm dispersion in the straights. Due to increased quantum fluctuation with the superbends, the horizontal emittance, ε_x, increases. However by operating with finite dispersion in the straight section it is possible to reduce ε_x.

Table 1: Storage ring parameters with no superbends (η_x=0), 3 superbends (η_x=0), and 3 superbends (η_x=6cm)

	No S-Bends (η_x = 0)	**3 S-Bends (η_x = 0)**	**3 S-Bends (η_x = 6cm)**
Energy	1.9 GeV	1.9 GeV	1.9 GeV
ε_x	5.5 [nm rad]	13 [nm rad]	7.5 [nm rad]
σ_E	0.08%	0.10%	0.10%
ΔE/turn	232 KeV	281 KeV	281 KeV

The vertical emittance, ε_y, which is determined by coupling and vertical dispersion can be adjusted using skew quadrupoles. At present without powering the skew quadrupoles, the ratio of ε_x to ε_y is less than 1%. However with such a small ε_y, the lifetime, which is limited by intrabeam scattering, is unacceptably short — about 2 hours at 1.3 mA/bunch. To recover the lifetime (which in the case of the ALS is proportional to the squareroot of the product of ε_x and ε_y) ε_y is typically increased to 2%. Therefore an increase in ε_x with the superbends, allows us to operate with smaller ε_y for the same lifetime.

3 IMPACT ON BEAM STABILITY

It is important that there be no major impact on the operation of the ALS after the lattice is modified to include superbends. Therefore it is necessary to check that the region of stable motion for the particles is sufficient for good injection and lifetime. We know that the stability of the particle motion will be affected by increased resonance activity resulting from the superbends perturbing the ring's 12-fold periodicity [6] as well as introducing some nonlinear fields. The question is how big is the effect.

The condition for resonance excitation in a machine with *P*-fold periodicity is

$$\frac{N_x \nu_x}{P} + \frac{N_y \nu_y}{P} = M \qquad (1)$$

where ν_x, ν_y are the horizontal and vertical betatron tunes, N_x, N_y, and M are integers. The order of the resonance is given by $|N_x| + |N_y|$. From Eq. 1 it is clear that reducing the periodicity allows more low-order resonances to become excited. In the lattice without superbends the degree of periodicity is 12. With 3 superbends located symmetrically around the machine the degree of periodicity is 3. If the superbends are not located symmetrically around the ring, the periodicity drops to one.

2.2 Effect of Reduced Periodicity – Tune Scans

A useful way to visualize the impact of periodicity breaking is through tune scans. This is done in the following way. We use simple 4x4 matrix code to do the tracking where the sextupoles are modeled as thin kicks. The superbends are modeled as isomagnetic sector bends with linear hard edge fringe fields [7]. The strength of the magnetic field, *B*, and length, *L*, is adjusted such that the longitudinal integral of *B* and B^2 is the same as for the true superbend fields. The chromaticity is set to zero in both planes and the dispersion fitted to zero in the straight sections. Attached to the tracking code is a frequency analysis post processor that numerically computes the fundamental frequencies of an orbit [8].

The procedure was the following: First the betatron tunes were set. Then a particle was launched with an initial offset of 10 mm horizontally and 1 mm vertically and tracked for 1024 turns or until lost. If the particle survives 1024 turns the frequency post processor computes the fundamental frequencies for that particle. The procedure is then repeated for many different tunes. In total the machine is adjusted to 900 tunes (on an evenly spaced grid of 31x31 tunes between ν_x = 14.1 to 14.4 and ν_y = 8.1 to 8.4). The results are plotted in Fig.3.

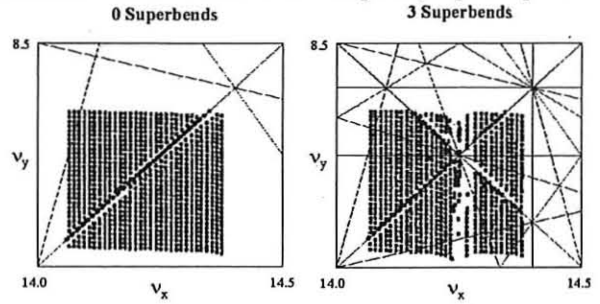

Figure 3. Tunescans: A comparison of 0 and 3 superbends.

On the left in the figure is the lattice with no superbends. on the right side of the figure is a lattice with 3 superbends evenly spaced. Superimposed on the plots are lines plotting all allowed resonances up to 5th order (Eq. 1. with P = 12 in the left plot and P = 3 in the right plot). The dots correspond to the numerically calculated frequencies. Excitation of resonances can be observed either from missing points or distortion in the point spacing.

In the case of no superbends one only sees the influence of the $2\nu_x - 2\nu_y = 6$ resonance. In the case of 3 evenly spaced superbends one sees that there are more resonances excited. In particular one sees a 4th order resonance, $4\nu_x = 57$, that is strongly excited and also several coupled resonances which cross at the ν_x = 14.25 and ν_y = 8.25. In these regions the motion of large amplitude particles is chaotic. However even in the case of 3 superbends evenly spaced there still seems to be large regions in tunespace where it is possible to operate. This is not true in the case of 3 superbends located asymmetrically around the ring. In that case the tunescans were greatly distorted with many missing points.

Based upon the tunescans for the 3 evenly spaced superbends, a working point was chosen (ν_x = 14.25 and ν_y = 8.2) for more detailed tracking studies.

3.2 Results of Tracking Studies

For more quantitative particle tracking studies we use a 6-D symplectic integrator. We include a ±25mm horizontal and ±4mm vertical physical aperture. Quadrupole gradient errors are included that match the existing machine producing a 5% horizontal and vertical β-beat and 1% coupling. For the superbends we included an integrated sextupole ($-5.6m^{-2}$) and decapole ($-4.1m^{-4}$) which are the values measured in the prototype [2].

At the ALS injection is made off axis in the horizontal plane. It is necessary to have at least a 7mm horizontal aperture to capture the beam. So for injection studies the particles were launched with different horizontal offsets and no energy offset and tracked for 512 turns or until lost. Without superbends the smallest aperture with errors was calculated to be 14 mm. With superbends it reduced to 11 mm. But there still exists a sufficiently large region for injection.

As previously mentioned the lifetime is determined by intrabeam scattering. Therefore it is important to insure that the momentum aperture is acceptably large. In the ALS the dynamic momentum acceptance is smallest in the arcs and largest in the straight section [9]. We were particularly concerned that a reduction in the momentum acceptance in the arcs could be less than the RF acceptance and reduce the lifetime. To determine the dynamic momentum acceptance the particles are launched with an initial horizontal offset and an energy offset and tracked with synchrotron oscillations. The results of the tracking showed that the dynamic momentum acceptance (in the arcs) reduced from 2.8% to 2.4% with superbends. However this is still larger than the RF acceptance which is 2% at 1.9 GeV. Therefore there should be no impact on the lifetime.

4. CONCLUSION

The superbends will provide excellent sources of high energy radiation for the ALS. There will be an increase in the horizontal emittance but that increase can be minimized by operating with finite dispersion. Tracking studies indicate that there should be no major impact on injection or lifetime.

5. ACKNOWLEDGEMENTS

We are grateful to W. Decking, B. Feinberg, E. Forest. J. Laskar, J. Krupnick, A. Jackson, H. Padmore, R. Schlueter, C. Taylor, and H. Zyngier for interesting comments and encouragement.

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[3]The *QFA*s were set to the same values in the modified and normal sectors. However they can be adjusted independently.

[4]For all results presented in the paper the chromaticity is set to zero.

[5]At present the ALS operates with the dispersion matched to zero.

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