A LOW EMITTANCE LATTICE FOR THE ADVANCED LIGHT SOURCE*

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Abstract

The possibility exists of achieving significantly lower emittances in an electron storage ring by increasing the horizontal betatron tune. However, existing magnet locations and strengths in a given ring may be inadequate to implement such an operational mode. For example, the ALS storage ring[1] could lower its emittance to one third of the current value by increasing the horizontal tune from 14.25 to 16.25. Nevertheless, this would come with the cost of large chromaticities that could not be corrected with our existing sextupole magnets. We discuss such operational issues and possible solutions in this paper.

LOW-EMITTANCE LATTICE

The storage ring of ALS (Advance Light Source) nominally operates at tunes (Nux, Nuy) = (14.25, 9.20) and Eta=0.06 [m] (dispersion at the center of the long straight sections) with the emittance of 6.8E-9 [m*rad] at 1.9 [GeV].

Many experiments at the ALS would benefit by increasing the horizontal brightness. Horizontal brightness is proportional to flux and inversely proportional to the beam size and beam divergence.

The emittance varies strongly with Nux and Eta as shown in Fig.1 and can be significantly reduced to increase the brightness.

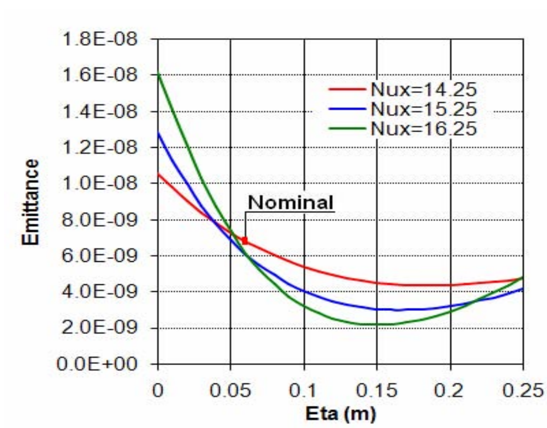

Figure 1. Emittance of ALS at 1.9 GeV

Let's examine a low-emittance mode at Nux=16.25 and Eta=0.15 [m] that gives the emittance of 2.17E-9. This emittance is less than 1/3 of current emittance.

One of the 12 cells of the nominal and low-emittance lattice functions are shown in Fig.2 and 3 respectively.

The major quantitative changes are the dispersion and the horizontal beta function that are larger in the straight sections and smaller in the center bend. Table 1 shows the major parameters of these modes.

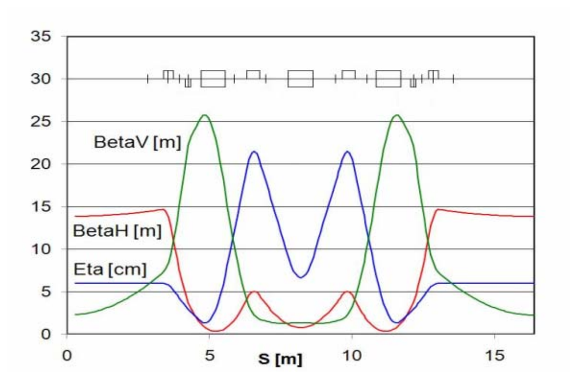

Figure 2. Optics of the Nominal Mode

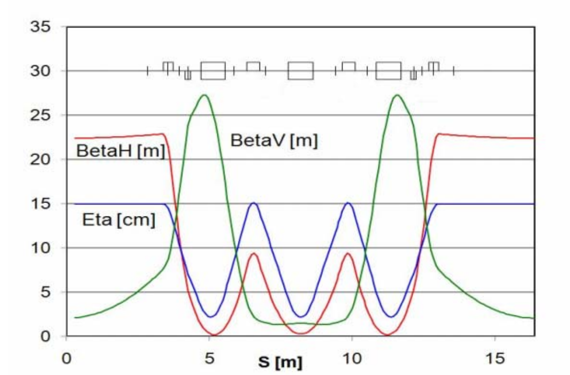

Figure 3. Optics of the Low Emittance Mode

Table 1. Major parameters of the nominal mode and the low-emittance mode. (*) straight section / center bend.

Parameter	Nominal	Low E.
Nux	14.25	16.25
Nuy	9.2	9.2
Dispersion [m] (*)	0.06/0.067	0.15/0.022
Beta H [m] (*)	13.85/0.79	22.39/0.31
BetaV [m]	2.26	2.07
Mom.Compaction	1.37E-03	8.72E-04
Energy Spread	9.77E-04	9.57E-04
Chromaticity H	-27.02	-50.02
Chromaticity V	-32.33	-35.06
Emittance	6.81E-09	2.17E-09
Beam Size [mm] (*)	0.31/0.10	0.26/0.033

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CHROMATICITY CORRECTION AND MODIFIED QUADRUPOLES

Embedded Sextupole in Quad

At present there are two families of sextupoles, SF and SD, located inside the ALS cell arc. Shown in Fig.4 is one of the 12 cells of the ALS lattice. These existing sextupoles are not sufficient to correct the large chromaticities of the low emittance lattice. SF is already close to its maximum (Table 2).

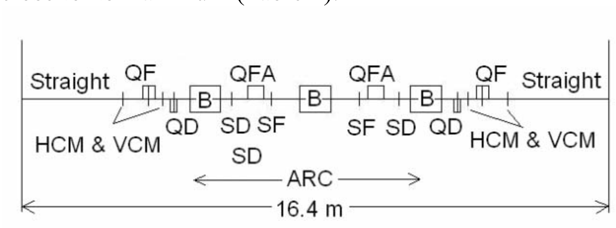

Figure 4. Magnets in the ALS unit cell

Table 2. Integrated K of the sextupoles required to correct chromaticities to zero.

	Nominal	Low Emittance
SF	14.98	24.79
SD	10.16	16.54

However, there is no space to install new sextupole magnets around the ring. We explore possibilities of modifying magnets in the straight sections to have sextupole components.

Two options have been found and are described below. In either case, the extra integrated sextupole strengths of 1~3 T/m reduce the values of SF and SD to reasonable range as shown in Fig.5.

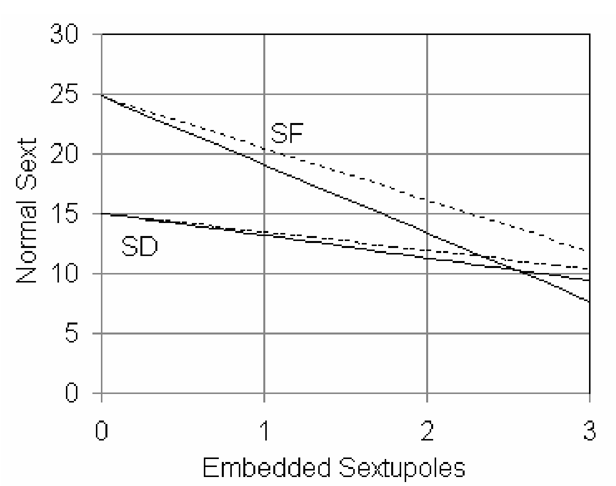

Figure 5. Reduction of normal sextupole strengths for chromaticity correction in presence of embedded sextupoles. Solid lines are for Option 1, and dotted for 2. The values are integrated K values [T/m].

Option 1: Sextupoles in Steering Magnets

The existing sextupole magnets, SF and SD in Fig.4, are originally equipped with extra coils to give horizontal and vertical steering. Therefore, the existing steering magnets in the straight sections can be replaced with such sextupoles with steering capabilities. The outer HCMs are for focusing sextupoles, and inner HCMs are for defocusing. Beam dynamics wise, this is a simple solution but is more costly than the second option. The actual settings of the 4 sextupole families are to be determined by dynamic apertures studies including frequency map analysis.

Since frequency map analysis calculates diffusion rates for every initial condition it provides a quantitative tool to compare how regular the dynamics is for different settings of the 4 sextupole families. To find an optimum setting, a scan was carried out varying the settings of the additional sextupoles. In the scan, the chromaticity was kept constant (at 0.4 and 0.8, horizontally and vertically), using the 2 original sextupole families do to the chromaticity fit. Figure 6 shows the Sum of all frequency map diffusion rates (defined as change in betatron tune calculated for two subsequent periods of 512 turns) for 500 initial conditions between 0 and 15 mm horizontally and 0 and 4 mm vertically. For particles that were lost in tracking the diffusion rate was set artificially to 0.1, a value larger than that of all particles that survived the 1024 turns. Using frequency map analysis and diffusion rates allows to not just search for the settings with the largest area of particles surviving for a given number of turns, but simultaneously allows to search for settings with the most regular particle behavior within this short term dynamic aperture boundary. This usually means that the solution is more robust with regards to machine errors.

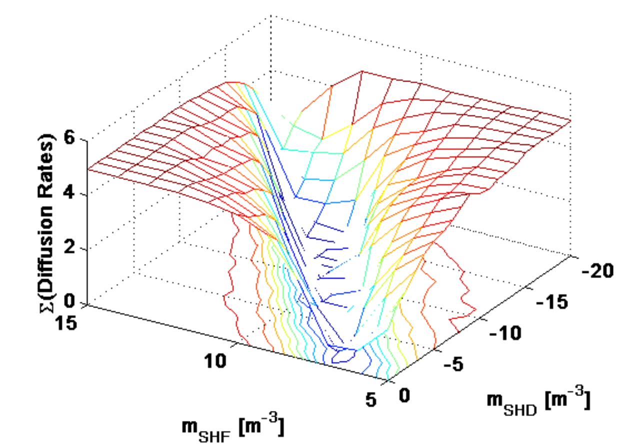

Figure 6. Sum of all frequency map diffusion rates for 500 initial conditions versus the strength of the 2 additional sextupole families. One can see a fairly extended area of small diffusion rates with a broad minimum.

The scan method using frequency map analysis can also be applied to other parameters (such as tune) and the computation time required for a reasonable sized grid and two parameters is reasonably short (using AT on a typical PC it requires a few hours CPU time). One can then study the solution in more detail for example using frequency map analysis with a finer grid of initial conditions and different seeds of machine errors. Figure 7 shows a frequency map in configuration space for the optimum settings of the additional sextupoles with realistic machine errors (gradient and skew gradient) as they would be present in a well corrected machine but without insertion devices. The stable area appears large enough both for injection as well as for reasonable lifetime.

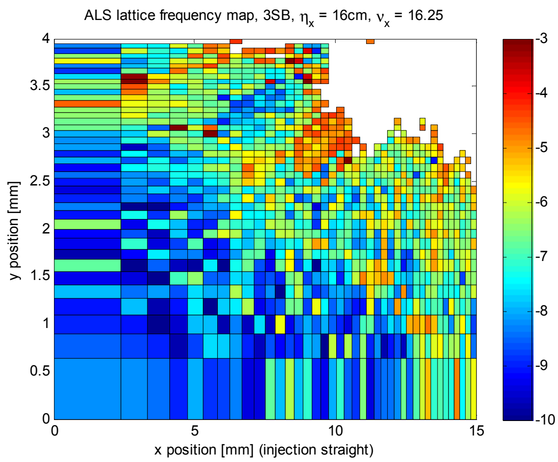

Figure 7. Frequency map calculated with realistic gradient and skew gradient machine errors, a vertical physical aperture of 4 mm and optimized settings for the additional sextupole families. The color code indicates diffusion rates on a logarithmic scale.

Option 2: Sextupole in Quadrupole Magnets

A quadrupole can have a sextupole component by adding extra coils that give the same polarity to the upper poles, and the opposite to the lower. As these coils do not have to be strong, this scheme can be very effective. However, it comes with the extra horizontal dipole kicks which is 1.34 mrad per 1.0 T/m of integrated sextupole strength.

This dipole kick can be locally compensated by using the steering magnets (2 HCM) to 2.1 mad and -1.1 mrad to have the maximum excursion of 1.2 mm. Here the kick of 2.1 mrad by HCM is close to its maximum; therefore it is reasonable to shift the reference orbit in QF and/or QD to reduce this value.

Here is an example of the dynamic aperture for this option. We took SQF=2 and SQD=3, which gives manageable values of SF= 16.1 and SD = 9.8.

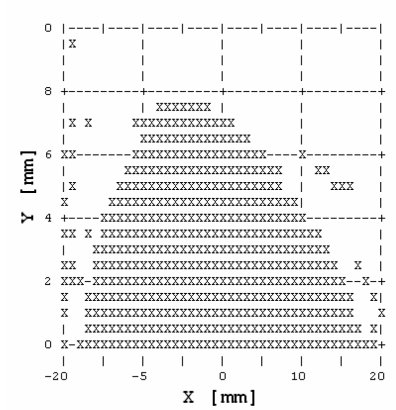

Figure 8. Dynamic aperture of Option 2, 400 turns.

DISCUSSION

We find that there are still ways that we can significantly improve the performance of the ALS storage ring lattice. Our preliminary studies indicate that it is possible to tune the ALS lattice for increased brightness by increasing the horizontal tune and raising the dispersion in the straight section. The emittance is reduced by a factor of 3 down to nearly 2 nm-rad. Preliminary dynamic aperture studies indicate that including additional sextupole components in the straight section correctors or quadrupoles will provide the ALS with a sufficiently large dynamic aperture. This new lattice would significantly improve the performance of many beamlines – particularly those using the central bends (such as the protein crystallography Superbend beamlines.) The necessary hardware modifications to provide sextupole components in the lattice appear to be feasible and could be done in typical yearly shutdowns. Therefore this appears as an attractive option for an evolutionary upgrade of the ALS.

REFERENCES

[1] LBL PUB-5172 Rev. LBL, 1986.
A. Jackson, PAC'93, Washington D.C, May 1993, P.1432.

