COMMISSIONING OF A LOCALLY ISOCHRONOUS LATTICE AT ALS*

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Abstract

With the advance of the ultra-fast science, manipulating electron beam at the sub-micron and nanometer scale has been actively pursued. A special lattice of the ALS storage ring was conceived to study the sub-micron longitudinal structure of the beam. It contains sections that are isochronous to the first order. Due to the practical constraints of the accelerator, sextupoles have to be off and the dispersion at the injection point is close to 60 cm, which make commissioning a highly nontrivial task. After a few months of tuning, we have been able to store at 40 mA of beam at the lifetime of 1 hour. After a brief introduction to the motivation of the experiment and the design of the lattice, the process and more detailed results of the commissioning will be presented. Future plan will also be discussed.

INTRODUCTION

Lattice is an integral part of every accelerator and beamline and knowledge for lattice design and commissioning had been perfected over the time of accelerator physics development to a highly sophisticated level. Numerous examples suggest that real machine lattices perform according to assumed theoretical designs. However, all evidences collected so far are mostly related to the beam motion in a transverse space. On the contrary, time-of-flight characteristics of lattices, to the best of our knowledge, have not been a subject of serious scrutiny. Perhaps this is because the majority of accelerators and beamlines can tolerate significant errors in the time-of-flight lattice characteristics. However, for new projects such as Optical Stochastic Cooling [1] or Harmonic Cascade Free Electron Lasers [2], the tolerance to the time-of-flight parameter of the lattices is of the order of a fraction of a micron in the former case and even a fraction of a nanometer in some variants of the latter case. Obviously, this poses new challenges for lattice design and commissioning.

In view of that, we have started a new program of lattice studies at the Advanced Light Source (ALS) aiming at finding a suitable lattice solution, implementing it experimentally and exploring new techniques. The details of this program including lattice design and preliminary results of the experimental study are presented in this report.

LATTICE SOLUTION

The near term goal of the study is to find a lattice of the ALS storage ring with a section of it being isochronous to the first order. In order to find a solution that does not require hardware modification, certain symmetry property of the normal lattice has to be maintained. The ALS storage ring consists of 12 sectors; each is a triple bend achromat during user operation. When the insertion devices are open, 9 sectors (1 to 3, 5 to 7 and 9 to 11) are identical. In the remaining 3 sectors (4, 8 and 12), the center bends are superconducting magnets; hence they are called the superbend sectors. The other sectors are called the normal sectors. Optically, each sector is symmetric about its center, although 54 out of 78 quadrupoles are individually powered. What limits the flexibility of the lattice is that all 18 quadrupoles in the arcs of the normal sectors are powered by a single power supply.

From the beam dynamics point of view, it is also advantageous to maintain as high degree of symmetry as possible. Therefore we decided to maintain the mirror symmetry of all sectors. In order to achieve isochronous condition to the first order, R_{51}, R_{52}, and R_{56} have to vanish. R_{56} vanishes when dispersion is negative in the center bend and the difference in path length in the center bend cancels that in the outer bends. In order to zero R_{51} and R_{52}, the section has to be achromatic. Yet it is impossible to achieve achromaticity and isochronicity (in the narrow sense) simultaneously in a sector with only 3 bending magnets and no reverse bend. On the other hand, it is possible to fulfill the achromatic conditions over 3 identical sectors as long as the total phase advance in the horizontal plane is a multiple of 2π. Therefore 2 families of quadrupoles are needed to cancel R_{51}, R_{52}, and R_{56}. In order to maintain the mirror symmetry of each sector, 3 more families are used to match the beta functions and the dispersion between the normal and superbend sectors. Since there 7 families in total, the remaining 2 families are used to adjust the global tunes. The end result is a lattice with 3 isochronous sections: between the beginnings the sectors 1, 5 and 9 and the ends of the sectors 3, 7 and 11, respectively. It happens that, for this lattice, all sextupoles are placed at locations where the dispersion is small and are not very effective for correcting the chromaticites. Furthermore, they generate strong second-order momentum compaction which reduce momentum acceptance in the longitudinal phase space. As a result, the sextupoles are turned off. There are an infinite number of solutions and the one selected for experimental study is shown in Fig. 1. The horizontal and vertical tunes are 8.39 and 7.15; the chromaticities are –11 and –38. Consequently the momentum acceptance is below 0.4%. The first order momentum compaction is -8.3e-4, which is 64% of the nominal value but has the opposite sign. There

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is also a sizable second order term that limits the momentum acceptance to about 1.5%.

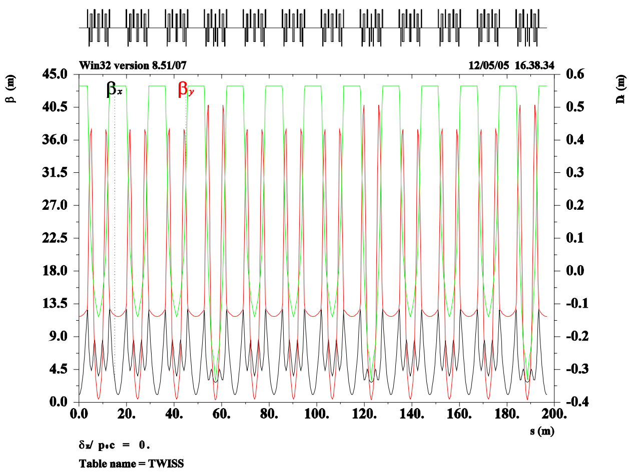

Figure 1: Lattice functions of the ideal solution

THE COMMISSIONING PROCESS

Getting beam to store in the lattice was a slow and tedious process. Initial attempts at storing beam were not successful and there was uncertainty whether it was even possible. The first turns came with injection trajectory and orbit (most sensitive correctors) adjustments. As additional parameters were scanned, it became evident that the match between beam energy and lattice parameters was extremely critical, which is consistent with the choice of tunes and the large chromaticities. Quadrupole strengths are critical as well, reflecting the fact that the horizontal tune is rather close to the half integer. A current change of 0.1% can make the difference between stored and no stored beam. The large dispersion (57 cm) and small horizontal beta function at the injection point may also have contributed to the difficulty of storing beam. Since the sextupoles are turned off, the tune change induced by the closed orbit distortion (COD) is less than that of the normal lattice. Nonetheless, there is a fairly large sextupole component (45.4 1/m^3 in MAD unit) in the superconducting magnets (each ~25 cm long). Since the horizontal and vertical beta functions are 2.76 m and 0.33 m, respectively, an average offset of 5 mm, which was the case before the orbit could be corrected, would cause the tunes to change 0.04 horizontally and 0.005 vertically. While the vertical tune shift is small, the size of the horizontal tune shift helps to explain the need to tune the closed orbit and the quadrupoles interdependently.

Early on, while still counting turns and attempting to get a sense of the effect of the RF on the beam, we found that less RF power in the cavities was better and, in fact, by reducing the voltage across the two cavities from the nominal 1.3 to 0.5 MW, the beam survived for more turns. A full account for the underlying physics may be rather involved. One of the factors is that the change in energy is smaller at a given phase. This causes the increase in the bucket width, which has been confirmed by tracking in the longitudinal phase space. Then, by optimizing the RF frequency with small incremental changes, the first breakthrough came, when a beam of 1 mA surviving for few milliseconds was increased to surviving for many seconds.

The next milestone resulted from flattening the vertical orbit, which has to be tightly controlled due to the presence of two narrow gap insertion device chambers. The flattening technique involves using standard lattices and the COD to estimate the effective misalignments of the lattice magnets, and then using these misalignments in a linear model of the locally isochronous lattice to generate a set of corrector strengths that correct the vertical orbit [3]. Using the calculated strengths as a starting point and making fine adjustments around them, it ultimately became possible to store up to 45 mA of beam with a lifetime of 1.5 hr. With reasonable beam intensity and lifetime, the COD has been corrected to peak-to-peak about 3 mm in the horizontal plane and 1.5 mm in the vertical plane. It is also possible to use beam-based measurements to optimize the lattice setup.

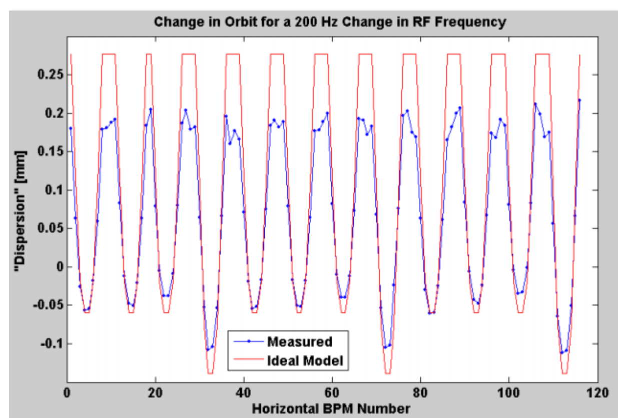

Figure 2: Horizontal dispersion function; note the factor of 2 scaling from Fig. 1.

RESPONSE MATRIX ANALYSIS

Using measured response matrices, it is possible to calibrate the model. The code LOCO (Linear Optics from Closed Orbits) was used to accomplish this [4], which, in the past few years, has been routinely used at many synchrotron light sources. By measuring the orbit response matrix, dispersion, and BPM noise of the actual accelerator, one can fit various parameters of the model until they agree within the noise of the measurement. The fits included 118 BPM gains & coupling, 94 horizontal corrector gains & coupling, 70 vertical corrector gains & coupling, 58 quadrupole strengths and the quadrupole component in the normal conducting bending magnets (33 identical ones). The dispersion measurement in Fig. 2 shows that the discrepancy from the ideal model is still rather large. After the LOCO run, the model is fitted to the measured dispersion. The beta function of this fitted model is shown in Fig. 3-4. The LOCO fit model predicts up to a 20% beta beat in both planes and tunes of 8.58 and

7.19. Compared to the ideal lattice, the horizontal tune is almost 0.2 too high. By applying the LOCO correction to the accelerator the beta functions, phase advance, tunes, etc should be restored close to the design values.

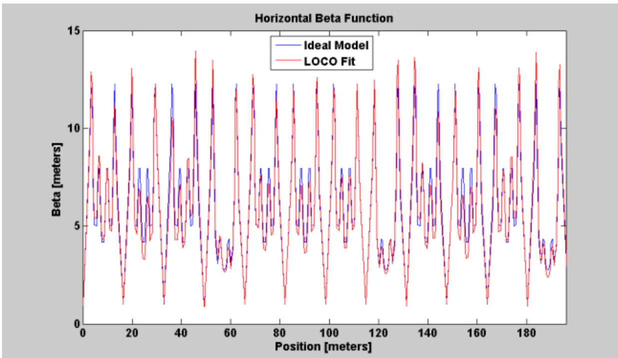

Figure 3: Horizontal beta function

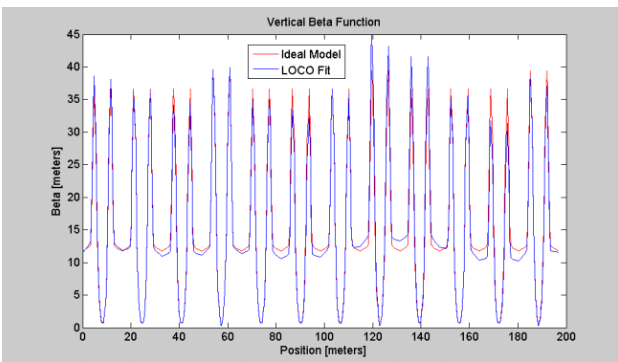

Figure 4: Vertical beta function

SUMMARY

Over the past year, we have started program to study a locally isochronous lattice. A family of lattice solutions has been found at the ALS without hardware modification. One of the lattices has been successfully commissioned and is close to ready for direct measurement of the longitudinal profile of the beam. Qualitative agreement between the ideal lattice and the calibrated model has been found. A lot of valuable experience has been gained in handling a lattice with large chromaticities and running close to the half integer resonance. One lesson is that the importance of the half-integer should not be under estimated. Work to be done next is to validate the LOCO calibrated model and try to obtain a lattice that agrees with the design quantitatively. Recently, a lattice solution with the fractional tunes of the normal lattice (0.25 and 0.20) has been found. Since the tunes are no longer close to the half integer, it will be interesting to test this lattice experimentally. Meanwhile, various options to measure the bunch profile longitudinally down to the nanometer scale are being evaluated. We believe that this is an exciting area waiting to be explored.

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