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STUDY OF NSLS-II DYNAMIC APERTURE TOLERANCES WITH RESPECT TO FIELD AND ORBIT ERRORS *

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Abstract

As the emittance of synchrotron light sources moves towards diffraction limit, magnet tolerances for reaching dynamic aperture for high injection efficiency and long lifetime become more stringent. Once nonlinear families are designed and the machine is built, a machine operator may ask to which accuracy the linear optics and orbit should be corrected so to achieve reasonable dynamic aperture. We also studied the relations of the non-linear elements and beta-beat to the dynamic apertures by simulating NSLS-II storage ring lattice and the paper shows the results.

INTRODUCTION

As the emittance of synchrotron light sources moves towards diffraction limit, the more and more strong quadrupoles are required. The strong quadrupole field generates high linear chromaticity and to correct the chromaticity, in turn, strong sextupoles are also required. The nonlinearity from the sextupoles can create resonance excitation, and the excitation from the strong sextupoles can critically reduce the dynamic aperture (DA). The poor dynamic aperture directly impact the injection efficiency and lifetime and the normal operation will not be possible. The most traditional strategy is canceling the sextupole effects by making the lattice symmetric. Then the dynamic aperture can be recovered by lattice symmetry restoration [1]. However, as the chromatic sextupole strengths become too big to cancel each other using phase differences, geometric sextupoles are introduced in non-dispersive region to cancel out the effect of chromatic sextupoles [2]. And the symmetry becomes even more important. The usual measure of the symmetry breaking is the beta beating.

Because the dynamic aperture is so an important issue, many efforts are invested to secure it at every step of the lattice design. There are many reviews [3] and studies [4]. Many methods including analytic analysis [5] and simulations are used for the design as well as for improving the running machine. Usually, the simulation is accompanied by the frequency map analysis [6] from which we can see the quality of the DA. Also, the driving terms [7] are used to obtain the good dynamic aperture, and there are some computer tools [8] for this purpose.

Even if the dynamic aperture is good with the given sextupoles, there are many imperfections from magnets and insertion devices are added to the lattice. In general, if the linear lattice is robust, i.e. the twiss parameters are well optimized, the effect of the non-linear disturbance can be far more reduced. Therefore, we not only focus on removing the effect of the sextupoles [9] but, more importantly, we should design and maintain the robust lattice.

As the state of art synchrotron radiation source targeting sub-nanometer emittance with damping wigglers, NSLS-II storage ring is quite a robust lattice [10], as the result of the huge efforts, Still, the dynamic aperture is changing frequently from known as well as unknown reasons. To keep it big enough for the high injection efficiency and long lifetime, the machine parameters should be routinely checked and corrected. Those parameters include beta beating, tune, phase advance, dispersion and chromaticity. Among these parameters, beta beating, which is coming from the symmetry breaking, is primarily corrected for the recovery of the dynamic aperture.

The major linear errors which can break the symmetry is quadrupole field errors and sextuple alignment errors. In this paper, only by simulations, we analyzed the effects of these errors imposed on NSLS-II bare lattice. From the analysis, we want to find the relations between errors, beta beatings, and DA variations.

We'd like to mention that the error numbers in this paper have nothing to do with design specifications nor measured data. They are chosen just for convenience. The design specifications can be found in the design report [10].

QUADRUPOLE FIELD ERROR

The 792 m NSLS-II storage ring have 30 cells and 15 super periods. Each cell has 10 quadrupoles and the total number is 300 with all independent power supplies. We assigned gaussian random errors to these quadrupoles where the rms of the errors are 0.03%, 0.04%,..., 0.09%, 0.1% and, for each rms value, 10 sets of errors are generated. For each simulation, we obtained the area of the dynamic aperture and its ratio to that of the bare lattice is used as the figure of merit. To minimize the distraction, we also assume that the beta beating is corrected to at least 10% and when it is bigger than 10% the points are ignored.

Figure 1 shows the results of those precesses. The marks in Fig. 1(a) are the horizontal and vertical beta beatings of the sampled lattices. The colors of the marks represent the given rms values for the samples. Here, especially when the beta beating is bigger than 2% in the horizontal direction, the beta beating is very loosely related to the rms of the errors. That is, even though beta beating correction is necessary to reduce the field errors, it does not guarantee the reduction of the errors. Similarly, from Fig. 1(b), where the color means the relative dynamic aperture to the bare lattice, the big dynamic aperture does not necessarily mean the low beta beating and vice versa.

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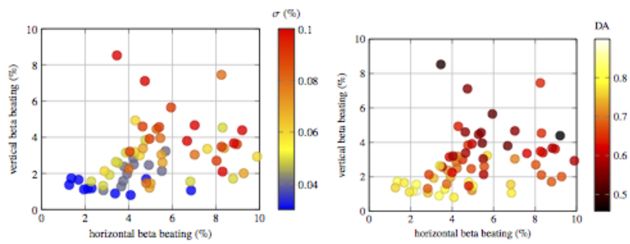
Figure 2 is the tune distribution of the samples where the resonance lines up to order 4 are shown. Considering the design tune is (33.216, 16.261), only very limited area around the design tune guarantee the large dynamic apertures.

From Figs. 1 and 2, where the beta beating is coming from the quadrupole field errors, even if we reduce the beta beating to some extent, it does not mean the error situation or dynamic aperture is improved. Only when the beatings become lower than about 1.5%, we can say that the machine is improved. Figure 3 shows the amplitude dependent tune shifts and driving terms. They show very general reduction with large dynamic aperture.



(a) (b)

Figure 1: (a) Beta beating depending on quadrupole errors and (b) Corresponding dynamic apertures.

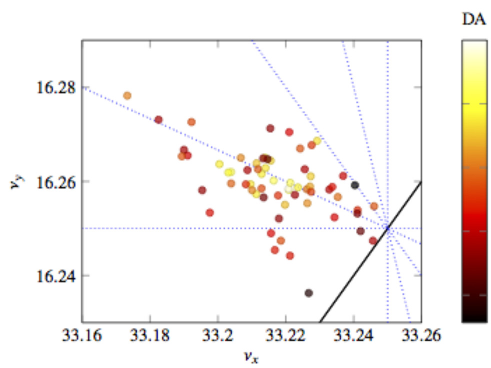
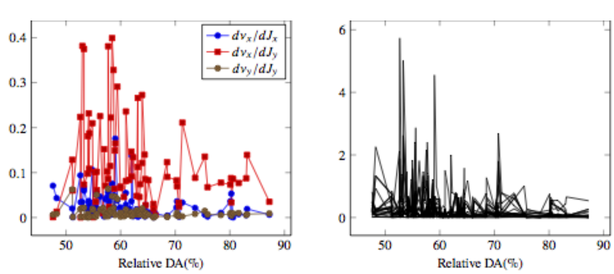


Figure 2: Tune distribution of the quadrupole field error samples where horizontal and vertical beta beatings are less than 10%.



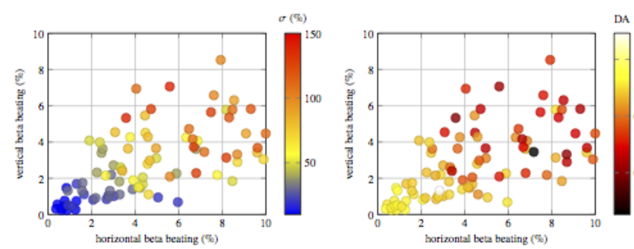
(a) (b)

Figure 3: (a) Amplitude dependent tune shifts and (b) driving terms depending on DA for the quadrupole field errors.

SEXTUPOLE ALIGNMENT ERROR

Sextupole alignment errors give rise to the focussing or defocussing of the lattice and have impact on the linear properties. There are 9 sextupoles in each cell and the total number of the sextupoles is 270. We made 10 gaussian errors sets of alignment errors with each of rms values of (10μm, 20μm, ..., 150μm) and assigned the errors to the sextupole as the horizontal and vertical displacements.

Figure 4 shows the relations between magnitude of errors, beta beatings and the dynamic aperture and Fig. 5 shows the distribution of the samples in the tune diagram. Compared to Figs. 1 and 2, the dependencies are very regular and expectable. If there are only sextupole alignment errors, by correcting the beta beating or only correcting the tunes, we can be sure that the dynamic aperture will be improved. Unfortunately, however, the alignment cannot be controlled at NSLS-II storage ring, and we can only identify the misalignments and correct them during the maintenance period. Also, as can be seen in Fig. 6, driving terms show quite different patterns from those of the quadrupole field error case.



(a) (b)

Figure 4: (a) Beta beating depending on sextupole alignment errors and (b) Corresponding dynamic apertures.

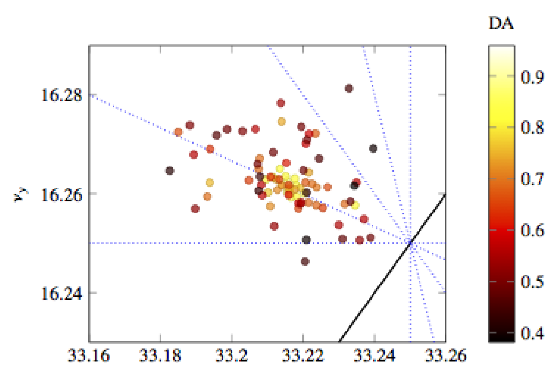


Figure 5: Tune distribution of the sextuple alignment error samples where horizontal and vertical beta beatings are less than 10%.

SEXTUPOLE FIELD ERROR

In this section, we simulated the impact of sextupole field errors on dynamic aperture. Because the pure sextupole component does not change the linear property of the lattice,

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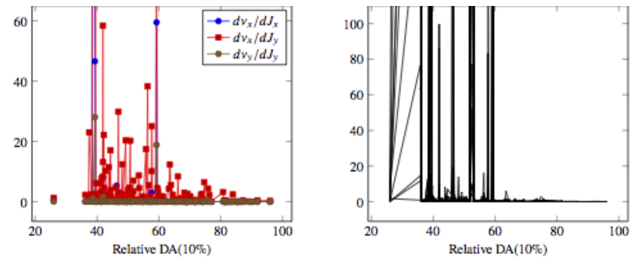


(a) (b)

Figure 6: (a) Amplitude dependent tune shifts and (b) driving terms depending on DA for the sextupole alignment errors. Vertical maximum scale is arbitrarily chosen for the visual convenience.

tune and the Twiss parameters are same as the design lattice. As briefly mentioned in the introduction, with well designed linear lattice, the multipole effect should be small compared to that from the linear imperfections.

The gaussian errors with the same rms values as for the quadrupole case (0.03% to 0.1%) are distributed to all 270 sextupoles around the ring. Figure 7 shows the dynamic aperture dependency on the rms values for the errors. As expected, compared to Fig. 1, the figure shows that the impact of the sextupole errors on dynamic aperture is weak and the dependency is quite regular. Also, from Fig. 8 we can see the driving terms are weak and hard to find the reduction with the bigger dynamic apertures.

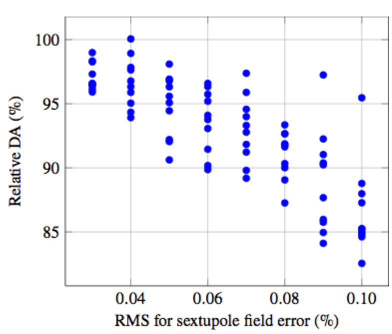
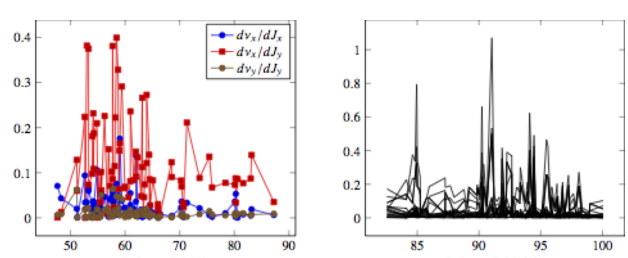


Figure 7: Variation of dynamic aperture with sextupole field errors.



(a) (b)

Figure 8: (a) Amplitude dependent tune shifts and (b) driving terms depending on DA for the sextupole field errors.

SUMMARY

The study in this paper assumed the perfect machine only except for the given errors. Therefore, considering the all realistic errors and measurement limitations, the requirement for the beta beating correction suggested by this paper will become far more stringent. Both the quadrupole field errors and the sextupole alignment errors change the linear optics. However, the dynamic aperture reduction from the sextupole alignment errors are very regular compared to the reduction from the quadpole field errors.

Driving terms for the sextupole alignment errors shows dramatic dependences on the dynamic aperture while they show some general trend for the quadrupole errors. When we correct the machine, we include the desired parameters all together. But some parameters cannot be easily included or including some parameters can prevent the correction. The correction is usually achieved by iteration. If all the parameters cannot be included, we need to check all the parameters at every step of iteration to make it sure that the machine is going to the right direction. If we carefully choose the direction with the measured parameters at every step, including, e.g., driving terms [11], performing only the beta beating correction can also improve the dynamic aperture and we can even obtain the information about the error sources.

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