DYNAMIC APERTURE STUDIES FOR THE SRRC STORAGE RING WITH GAUSSIAN SEXTUPOLES

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Abstract

In an attempt to maximize the dynamic aperture at the SRRC storage ring the effect of Gaussian sextupoles were studied to replace the normal sextupole families. In Gaussian sextupoles the fields are partially truncated at large distance from the axis to reduce destabilizing, nonlinear effects on particles with large betatron amplitudes. The results of these studies will be described including the improvement on dynamic aperture for on-momentum particles in an unperturbed lattice. Furthermore, tracking results in the presence of magnet multipole errors will be presented as well as those involving tracking of off-energy particles.

1 INTRODUCTION

For a small emittance storage ring, strong focusing schemes are required. Sextupoles are employed to cancel natural chromaticities from quadrupoles. Hence strong sextupoles can be expected from the strong focusing scheme lattice. The nonlinear field of sextupoles cause instabilities for example with large betatron amplitude leading to a reduction of dynamic aperture.

One way to improve the dynamic aperture is to insert additional sextupole families in dispersion free regions to correct effects of the geometric driving terms from chromatic correction families. Another method was proposed by M. Cornacchia and K. Halbach[1]. They introduced the idea of modified sextupoles with the field approximate to the normal chromatic correction sextupoles at small betatron amplitude, while it is damped off at large betatron amplitude and results in smaller nonlinear driving forces.

Since the SRRC storage ring is a small ring and there is not much space in dispersion free regions, the modified sextupole scheme is appealing. In this paper, the Gaussian type of modified sextupoles are chosen for the study.

The Gaussian sextupole field[1] is

$$\begin{aligned} B_y &= \frac{m}{2} exp[K(x^2-y^2)] \\ &\quad [(x^2-y^2)cos(2Kxy) - 2xysin(2Kxy)] \quad (1) \end{aligned}$$

$$\begin{aligned} B_x &= \frac{m}{2} exp[K(x^2-y^2)] \\ &\quad [(x^2-y^2)sin(2Kxy) + 2xycos(2Kxy)] \quad (2) \end{aligned}$$

in which m is sextupole strength used for chromatic correction and K is the damping coefficient to taper off the field at large betatron amplitude. As x and y approach zero, equations (1) and (2) approximate to normal sextupole fields of $\frac{1}{2}m(x^2-y^2)$ for vertical and mxy for horizontal. From the exp$[K(x^2-y^2)]$ term, it indicates the field can't taper off in both planes at the same location. But for the chromatic correction sextupoles, the focusing ones are putting at the location where $x > y$. On the contrary, the defocusing sextupoles are inserted in the location of which $x < y$. Therefore if the damping coefficient K is negative for F-sextupole and is positive for D-sextupole, a resultant effect of tapered off sextupole field at large amplitude could be obtained.

There are additional off-energy driven terms when the Gaussian sextupoles replacing the normal ones. As an illustration the horizontal equation of motions is given in equation (3), with the additional terms shown in braces.

$$\begin{aligned} x_\beta^{''} + K_0 x_\beta &= (K_0 - m\eta_x)x_\beta\delta - B_y(x_\beta, y_\beta) \\ &\quad + K_0\eta_x\delta - \frac{m}{2}\eta_x^2\delta^2 + \frac{m}{2}\{ \\ &\quad 4Kx_\beta^3\eta_x\delta + 4Kx_\beta y_\beta^2\eta_x\delta + ...\} \quad (3) \end{aligned}$$

where K_0 is the quadrupole focusing strength, η_x horizontal dispersion, δ energy deviation and $B_y(x_\beta, y_\beta)$ the Gaussian sextupole field at betatron amplitude of x_β and y_β. From equations (1) to (3), it implies the good locations for Gaussian sextupole are a) where has big beta-function difference in horizontal and vertical to achieve large tapper off field effects, and b)small eta function to reduce the off-energy driven forces.

2 PARAMETERS SEARCHING FOR GAUSSIAN SEXTUPOLE

Due to hardware and space considerations, the same locations are assumed for the Gaussian sextupoles to replace the normal ones. For the SRRC storage ring, two families of chromatic correction sextupoles are used. Figure 1 shows the optics function in one of six symmetrical superperiods with β_x=5.6m, β_y=2.6m at the F-sextupole and β_x=2.2m, β_y=5.8m at the D-sextupole.

A search for optimum of damping coefficients K_F and K_D were done by running PATPET[2] for 1000 turns, with the on-momentum dynamic aperture at the insertion middle as the judging parameter. In this run, K_F and K_D are equal value but opposite sign. The biggest enlargement on dynamic aperture appears as the K value near 200 and 400 m^{-2}. While the negative horizontal aperture of K=400

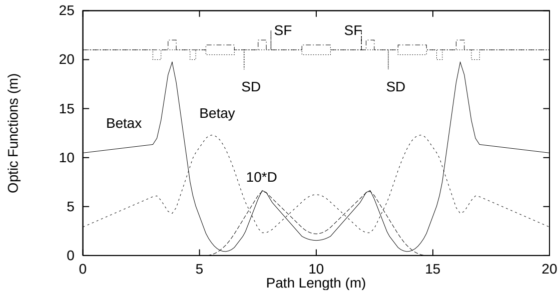

Figure 1: Optic functions in one of the six symmetrical superperiods of the SRRC storage ring.

m^{-2} is much smaller than that of 200 m^{-2}. Hence more searchings were done for K around 200 m^{-2} by different K_F and K_D. But no further improvement was found. Hence K_F is chosen to be -200 m^{-2} and K_D 200 m^{-2} for the following study. Figure 2 shows the vertical field component along the horizontal axis for the chosen Gaussian sextupole compared with that of the normal one. From this plot, the consistence of field in small amplitude and a reduction at large horizontal amplitude are clearly shown.

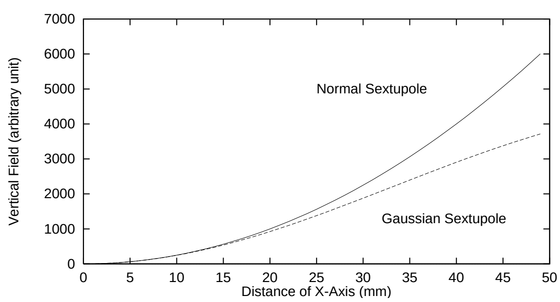

Figure 2: Vertical magnetic field along the horizontal axis for the normal and Gaussian sextupoles with K = 200 m^{-2}.

3 TUNE VARIATION WITH AMPLITUDE

Tune variation with betatron amplitude was studied for both planes. Figure 3 shows the on-momentum horizontal tune variation with horizontal amplitude. A smaller tune variation with horizontal amplitude for the chosen Gaussian sextupole is clearly shown. While for the vertical plane, there is no significant change between the chosen Gaussian and normal sextupoles up to 55 σ_y, about 9 mm, for the on-momentum particles.

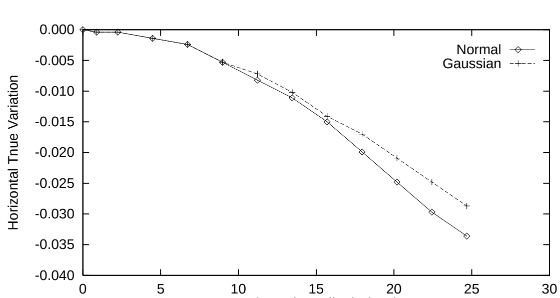

Figure 3: Horizontal tune variation versus horizontal amplitude for on-momentum particles.

In order to simulate the effects for the off-energy particles, tune variation with amplitude for off-energy, 1% and 2%, were performed. These results are given in figure 4. From figure 4, the 1% off-energy particles also get benefit from Gaussian sextupole. While as the energy is up to 2%, a larger horizontal tune shift is seen for the Gaussian sextupole as the horizontal amplitude increased up to 13.5mm (around 30 σ_x). Within 11mm (around 25 σ_x), Gaussian sextupoles give small horizontal tune variation with horizontal amplitude. For the vertical plane, not much improvement is found for 1% off-momentum. But for the 2% off-momentum the improvement is obvious, especially at the large vertical amplitude. As the vertical amplitude increased to larger than 7mm (around 45 σ_y), the vertical tune shift for 2% off-momentum is reduced.

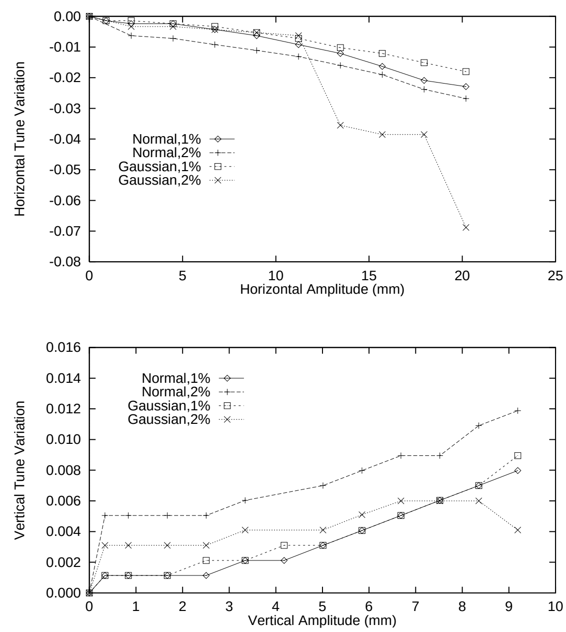

Figure 4: Tune variation versus amplitude for off-momentum particles.

4 DYNAMIC APERTURE TRACKING

In the following study, the dynamic aperture tracking was performed at the insertion middle with 1000 turns by PATPET[2].

The tracking was first performed for on-momentum particles with the bare lattice. Figure 5 shows this tracking results for the chosen Gaussian sextupole compared with that of the normal one. From figure 5, improvement on dynamic aperture is apparent, especially in the horizontal axis, around 66%, and in the region of positive horizontal amplitude, around 20% to 60%. The improvement in vertical axis is around 8%.

To check chromatic effects, off-momentum tracking at 1% and 2% were also performed with the bare lattice. Figure 6 gives the results for this tracking. From figure 6 it is found that the 1% off-momentum dynamic aperture for the

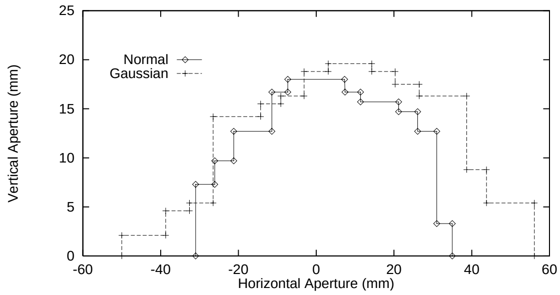

Figure 5: Comparison of on-momentum dynamic aperture of bare lattice for the normal and the chosen Gaussian sextupoles.

chosen Gaussian sextupole is worse than that for the normal one in the horizontal axis as well as in the coupled field region, which are improved for the on-momentum case as that shown in figure 5. But there is no obvious shrinkage about the vertical axis. The reason of the dynamic aperture shrinkage for off-momentum particles is understood from equation (3) by the competition of the advantage of tappered off field effects and the additional off-energy driven terms. It is clear that the additional off-energy terms overcome the tappered off field effects for off-momentum, especially in 1% case. For 2% off-momentum, the energy deviation is too large such that the original off-energy forces play dominate parts as compared with the additional terms of which the octupole term as the leading one. This can explain why there is no big difference for 2% off-momentum cases except a little reduction in vertical for the Gaussian sextupole.

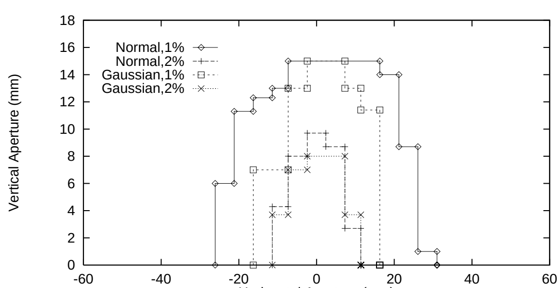

Figure 6: Comparison of off-momentum dynamic aperture of bare lattice for the normal and the chosen Gaussian sextupoles.

For more checking, the multipole errors were included in the study. The multipole errors are coming from the measurement and specification and are taking as systematic errors in the tracking. Results are given in figure 7 for on-momentum particles. It is seen in figure 7 that there is no big difference for two type of sextupoles except a little improvement in vertical for the Gaussian one. This indicates the dynamic aperture shrinkage for on-momentum particles is mainly from the multipole errors and Gaussian sextupole can't help to improve it. For off-momentum particles with the presence of multipole errors, similar results of figure 6 are found except the small reduction on dynamic aperture, which also reveals the dominate effects of multipole errors. The study also included corrected closed orbit with multipole errors. The results are similar to that shown in figures 7 except a further reduction in the horizontal and a little increasing in the vertical were obtained.

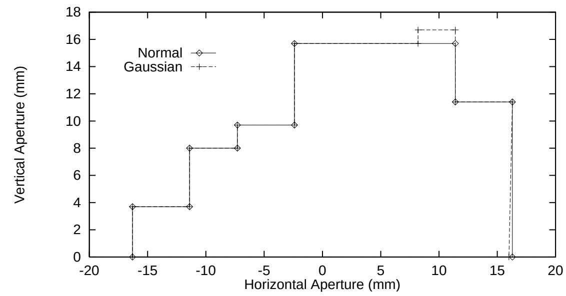

Figure 7: Comparison of on-momentum dynamic aperture with the bare lattice included multipole errors for the normal and the chosen Gaussian sextupoles.

5 DISCUSSION AND CONCLUSION

In these studies, the normal sextupoles are replaced by the Gaussian ones in the same locations with the chosen coefficients. Due to the limitations of the difference of horizontal and vertical beta-functions and of η functions in the locations for sextupoles, it is not the best conditions for Gaussian sextupoles. While the chosen Gaussian sextupole indeed enlarge the on-momentum dynamic aperture, especially in the area of positive horizontal amplitude, as the bare lattice considered. Including multipole errors in magnets, the trackings show the shrinkage of dynamic aperture in the ring is mainly from multipole errors and the chosen Gaussian sextupole can't help the improvement. From the off-momentum trackings, it reveals the improvement on on-momentum dynamic aperture is canceled and deteriorated by additional off-energy driven terms as Gaussian replacing the normal sextupoles. From the tune variation versus amplitude studies, the chosen Gaussian sextupoles also benefits in some extend. The studies also show the vertical aperture get less changing when compared with the horizontal for the off-momentum cases. This effect is explained from equation (3) by the dispersion in vertical chromatic correction sextupoles is smaller than those in the horizontal correction ones[1].

6 ACKNOWLEDGEMENT

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7 REFERENCES

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