SESAME **Technical Note**

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Note: **O-4**

SESAME Dynamic Aperture With High Order Multipoles

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Introduction

In this note, we present the effect of high order multipoles on SESAME dynamic aperture. In order to better estimate the dynamic aperture, especially at larger amplitude, we took into account also the vacuum chamber aperture.
Most of the work has been carried out on SESAME optics 1 [1, 2] with β-tunes (Q_x=7.23, Q_z=5.19). The optics 2 with (Q_x=7.23, Q_z=6.19) has also been tested, and it seems to have similar (or better) behavior to multipoles effect.

We have crosschecked the results with two codes BETA and TRACY, which give similar results.

1 - Vacuum chamber limitation

All the dynamic apertures are evaluated for chromaticity corrected to zero value in both planes, with only 2 families of sextupoles. The on-momentum dynamic apertures, with and without chamber limitation, are shown in Fig. 1 for the working point (Q_x = 7.23, Q_z =5.19): we can see the good agreement between BETA and TRACY mainly at small amplitudes.

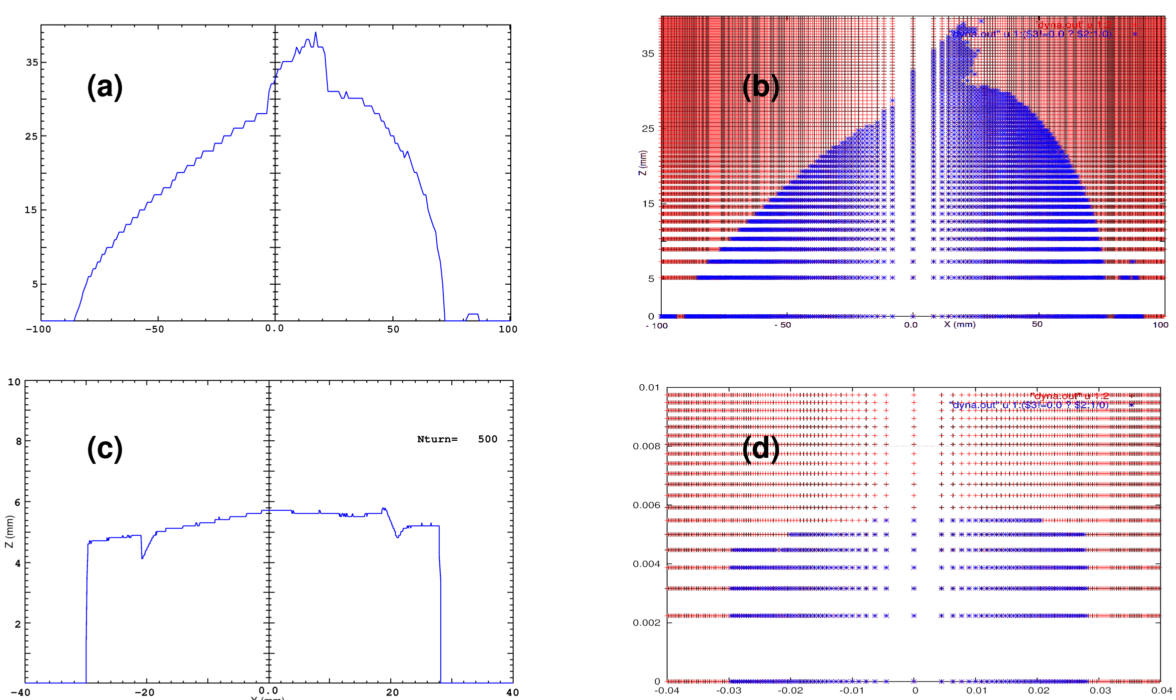


Figure1: (a) & (b) bare Dynamic apertures; (c) & (d) Dynamic apertures with vacuum chamber limitation, as given by BETA and TRACY codes respectively. (Scales are in mm).

The dynamic apertures, in the middle of the *Long straight* (β_x = 12.31m and β_z =3.13 m, while β_{xmax} = 12.807 and β_{zmax} = 21.35m) are obtained by tracking the particles for 500 turns. The vacuum chamber apertures are Δx = ±35mm and Δz = ±15mm, while in the injection straight the horizontal aperture is limited, due to the thin septum position, to -30mm and + 35mm.

Fig. 1.c and Fig. 1.d show that there are two clear vertical cuts at x = ~ ±22mm. The explanation for these two cuts is that they are an indication of a nonlinearity that the chamber limitation evidentiates. This nonlinearity is due to systematic 5th order resonance.

Another way to look at this nonlinearity is to plot (see Fig. 2) the horizontal tune shift with amplitude at z=4.8mm. We can see, also in this case, a clear discontinuity around x= ±22mm. The nonlinearity seems to be not critically harmful and we can live with it since it exists at high vertical amplitude.

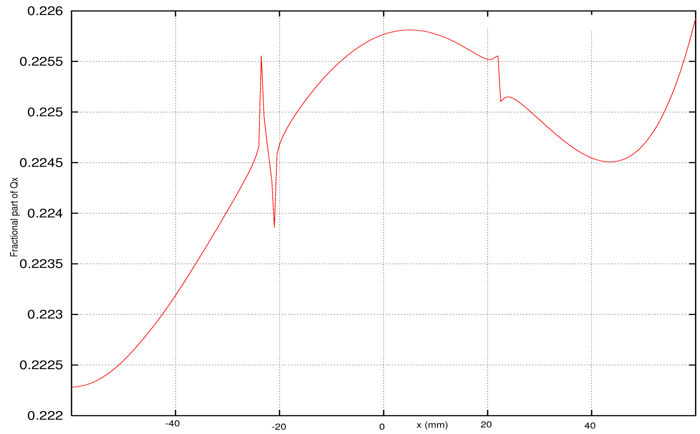


Figure 2: Horizontal tune shift vs. amplitude @ z = 4.8mm.

2 - Bending magnet systematic high order multipoles

We have optimized the pole profile of SESAME dipole [3] by maximizing the dynamic aperture and with the following criteria:

a) $\Delta B/B_0 < 5.10^{-4}$ in a region of ±20mm which is the maximum horizontal amplitude in the bending;
b) We have considered multipoles up to 14-pole;
c) The optimization of the multipoles has been carried out at 2.5GeV and then tested at 800MeV.

In the following, we list the final multipole contents at 2.5GeV, evaluated at 20mm:

-- $(\Delta B/ B_0)_{6\text{-pole}} = 2.42\ 10^{-4}$ -- $(\Delta B/ B_0)_{8\text{-pole}} = 4.7\ 10^{-5}$ -- $(\Delta B/ B_0)_{10\text{-pole}} = -3.09\ 10^{-5}$
-- $(\Delta B/ B_0)_{12\text{-pole}} = -1.36\ 10^{-5}$ -- $(\Delta B/ B_0)_{14\text{-pole}} = -1.17\ 10^{-4}$

which gives the minimum reduction of the dynamic aperture.
The dynamic multipole effect was tested in both codes. The multipoles are continuously distributed in TRACY, while in BETA they are added as thin lens elements distributed in the bending.

Looking at the effect of each individual component, the lattice was too sensitive to the 10-pole component that was reduced, while the 6-pole component had a small destructive effect so it could be relaxed.
The effect of the above multipole configuration on the on-momentum dynamic aperture with and without vacuum chamber is shown in Fig. 3, for optics 1.
Fig. 3, (a) and (b), indicate that the dynamic aperture is still enough larger than the physical one (i.e. the chamber dimensions) while graphs (c) and (d) show that the bending contents, in spite of their small values, amplify the nonlinearity seen in Fig. 1(c) and (d) to a level that cannot be tolerated.
Once again, plotting the horizontal tune shift vs. amplitude (see Fig. 4) evidentiates the multipole effect on the nonlinearity.

Many attempts were made to eliminate these cuts: the only successful one was to change the fractional part of the horizontal tune. Fig. 5 shows the dynamic aperture after the change in tunes from (Q_x = 7.23, Q_z =5.19) to (Q_x = 7.21, Q_z =5.185). The change in the vertical tune was just to keep a reasonable difference in the tunes fractional parts
The enhancement on the dynamic behavior can be seen obviously also from the horizontal tune shift with amplitude shown in Fig. 6. The modified optics 1 (Q_x = 7.21, Q_z =5.185) will be considered in all the next calculations, with the exception of § 2.5.

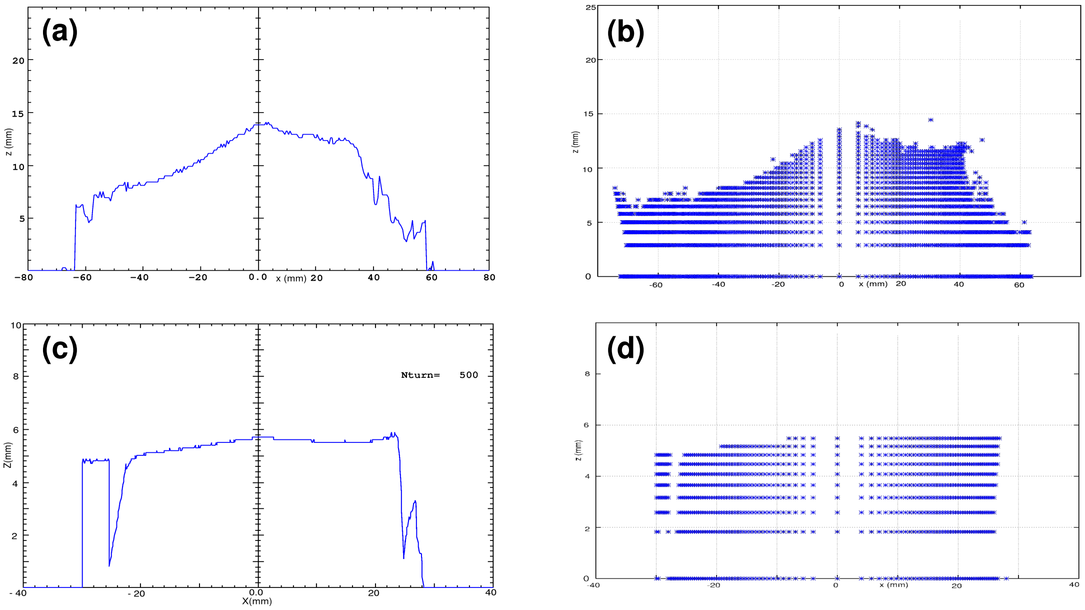


Figure 3: (a) & (b) bare Dynamic apertures; (c) & (d) Dynamic apertures with vacuum chamber limitation, as given by BETA and TRACY codes respectively. (Scales are in mm)

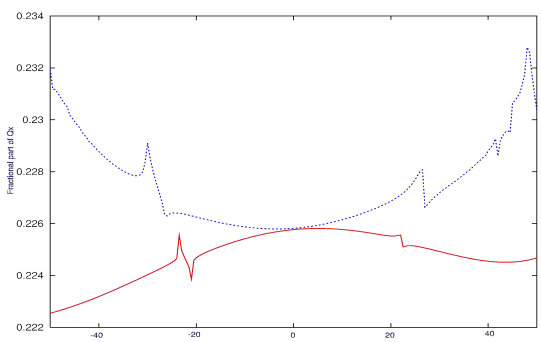


Figure 4: Horizontal tune shift with amplitude at z=4.8mm. The case with no multipoles inside the bending is in red while the one with multipoles is in blue.

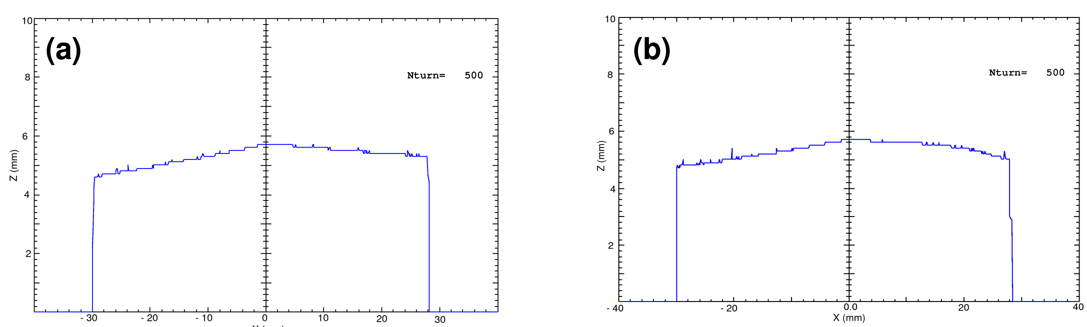


Figure 5: a) The Ideal dynamic aperture with modified tunes. b) Effect of the bending contents on dynamic aperture.

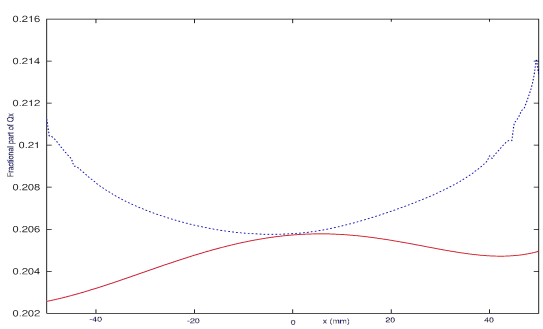
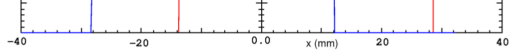


Figure 6: Horizontal tune shift with amplitude at z = 4.8mm. The ideal case is in red while the one with bending field error is in blue.



2.1 - The bending contents effect on the off-momentum dynamics

Fig. 7 shows the ideal dynamic aperture of modified optics 1 for ±1.5 % of momentum deviations with and without chamber.

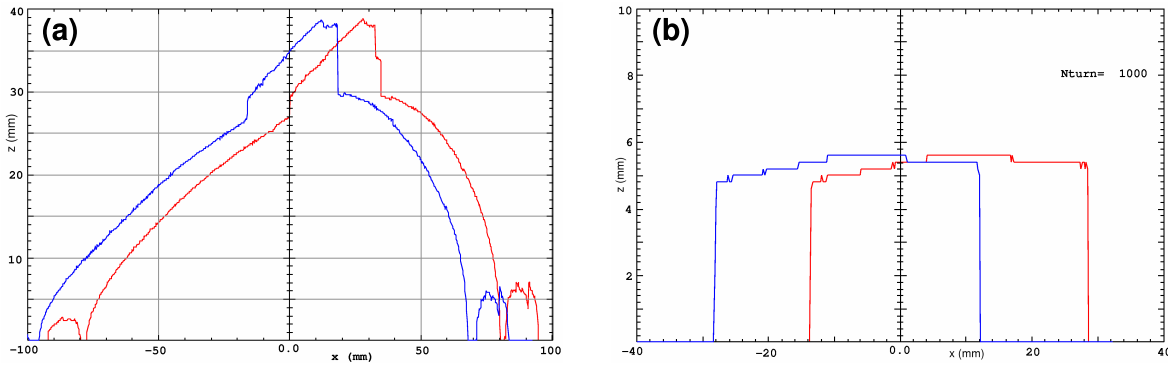


Fig. 7: Off-momentum dynamic apertures: a) without chamber and b) with chamber

Touschek lifetime is the main criterion to be considered about the tolerance of field error impact on off-momentum dynamics. Off-momentum dynamic apertures can also indicate the level of that impact.

Using the above chamber dimensions, Touschek lifetime has been calculated, by BETA code, under the following conditions:

- The longitudinal and transverse spaces have been divided into 10cm and 0.1mm steps.
- A coupling of 1% and bunch current of 2mA.
- A zero-current bunch length = 3.8693e-11s (11.6mm) and RF acceptance=1.459%.

It was 99.797h in both the ideal case and the field error affected one. Furthermore, the momentum aperture was calculated, by TRACY, and was the same in both cases.

2.2 - The bending multipole effect at 800 MeV

Because SESAME will be ramped from the injection energy of 800MeV up to the working energy of 2.5GeV, the effect of the multipoles at 800MeV has also been checked.

The field errors at 800MeV for the above bending design are:

-- $(\Delta B/B_0)_{6\text{-pole}} = 6.65\ 10^{-4}$ -- $(\Delta B/B_0)_{8\text{-pole}} = 1.36\ 10^{-5}$ -- $(\Delta B/B_0)_{10\text{-pole}} = -2.63\ 10^{-5}$
-- $(\Delta B/B_0)_{12\text{-pole}} = -1.1\ 10^{-5}$ -- $(\Delta B/B_0)_{14\text{-pole}} = -1.169\ 10^{-4}$

Their effect on the dynamic aperture, of the modified optics 1, is shown in Fig.8. The multipole error at the injection energy were also acceptable.

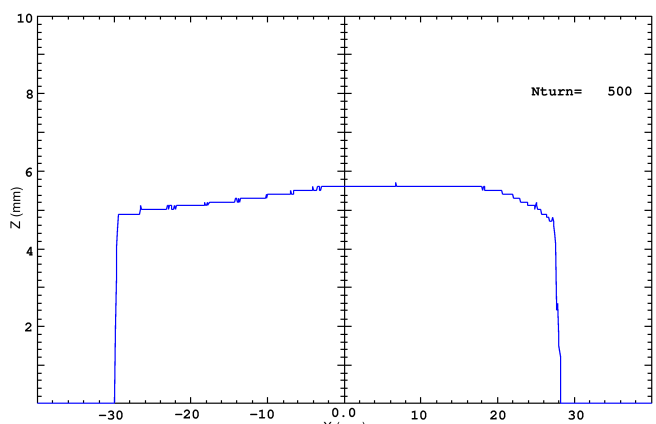


Figure 8: The multipole effect on the modified optics 1 dynamic aperture at injection energy.

2.3 - The multipole contents of the deformed bending

The magnetic force on the bending pole faces, at 2.5GeV, is expected to cause some deformation in the bending (the central full height could be decreased by about 12μm). This effect was taken into account. Due to the above simulated deformation, the changes in the multipoles were small:

-- $(\Delta B/B_0)_{6\text{-pole}} = 2.543\ 10^{-4}$ -- $(\Delta B/B_0)_{8\text{-pole}} = 4.5435\ 10^{-5}$ -- $(\Delta B/B_0)_{10\text{-pole}} = -3.6\ 10^{-5}$
-- $(\Delta B/B_0)_{12\text{-pole}} = -1.417\ 10^{-5}$ -- $(\Delta B/B_0)_{14\text{-pole}} = -1.1519\ 10^{-4}$

and no dynamical effect was seen.

2.4 - The effect of random high order multipoles:

The manufacturing errors modify the systematic high order multipoles by some error values and create new multipoles that are not present among the systematic ones. These modifying errors and new created multipoles are called random multipoles. The effect of these random values could be harmful for the beam dynamics, so a tolerance on these values has to be determined too. Due to the above systematic bending contents up to 14-pole one, there is no chance for new contents to be created but modifications to the systematic ones are expected.

The 1 σ tolerable values are listed below:

-- $(\Delta B/B_0)_{6\text{-pole}} = 1.21\ 10^{-4}$ -- $(\Delta B/B_0)_{8\text{-pole}} = 4.7\ 10^{-5}$ -- $(\Delta B/B_0)_{10\text{-pole}} = 1.545\ 10^{-5}$
-- $(\Delta B/B_0)_{12\text{-pole}} = 1.36\ 10^{-5}$ -- $(\Delta B/B_0)_{14\text{-pole}} = 3.9\ 10^{-4}$

The dynamical effect of the random multipoles was tested by tracking 10-20 different samples for 500-1000 turns. Tt is shown in Fig. 9, for the dynamic aperture with and without chamber limitation.

The probable effect of these random multipoles on the off-momentum dynamic apertures can be seen in figure (10) where the chamber was taken into account.

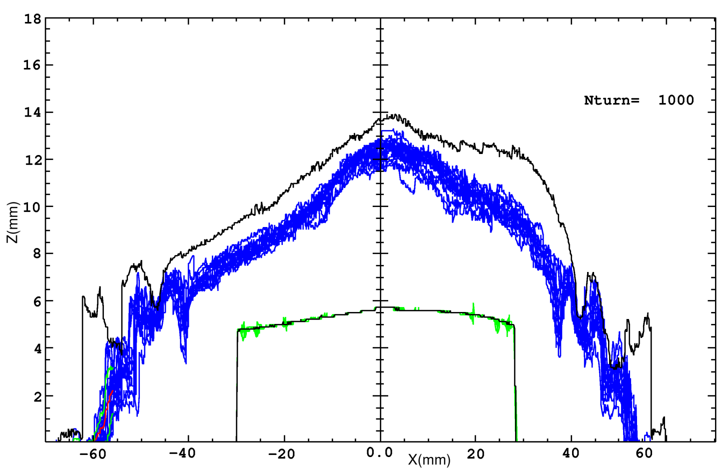
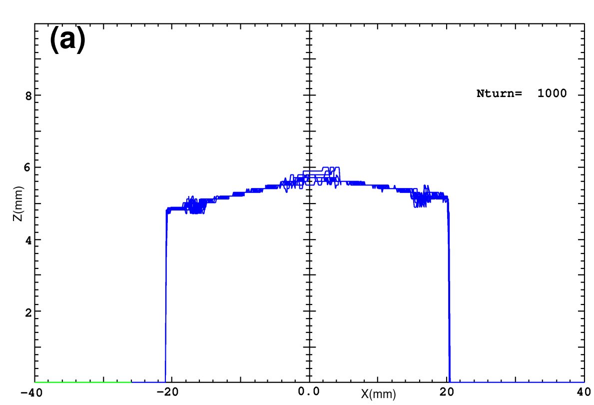


Figure 9: Effect of random high order multipoles on the dynamic aperture. 15 samples were tracked.



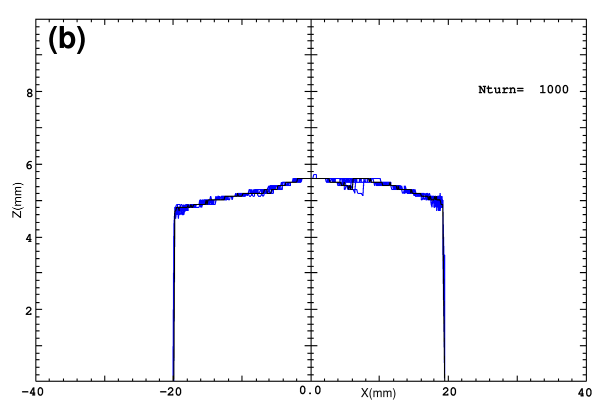


Figure 10: The effect of random multipoles on a) 1.5% and b) –1.5% off-momentum dynamic apertures. The black one is free of random components. Dynamic apertures were plotted around the off-momentum closed orbit

2.5 - The bending multipoles effect on optics 2

The behavior of optics 2, with the bending multipole, was also checked at full and injection energies, for the on-momentum case. Although the field error destruction on the dynamics was much less than the case of optics 1, a similar general behavior was seen by modifying the tunes to (7.21, 6.185), where better results have beenobtained. This can be seen from Fig. 11.

Due to the low sensitivity of optics 2 to the multipole effect, the above random multipole errors are also expected to be valid for this optics.

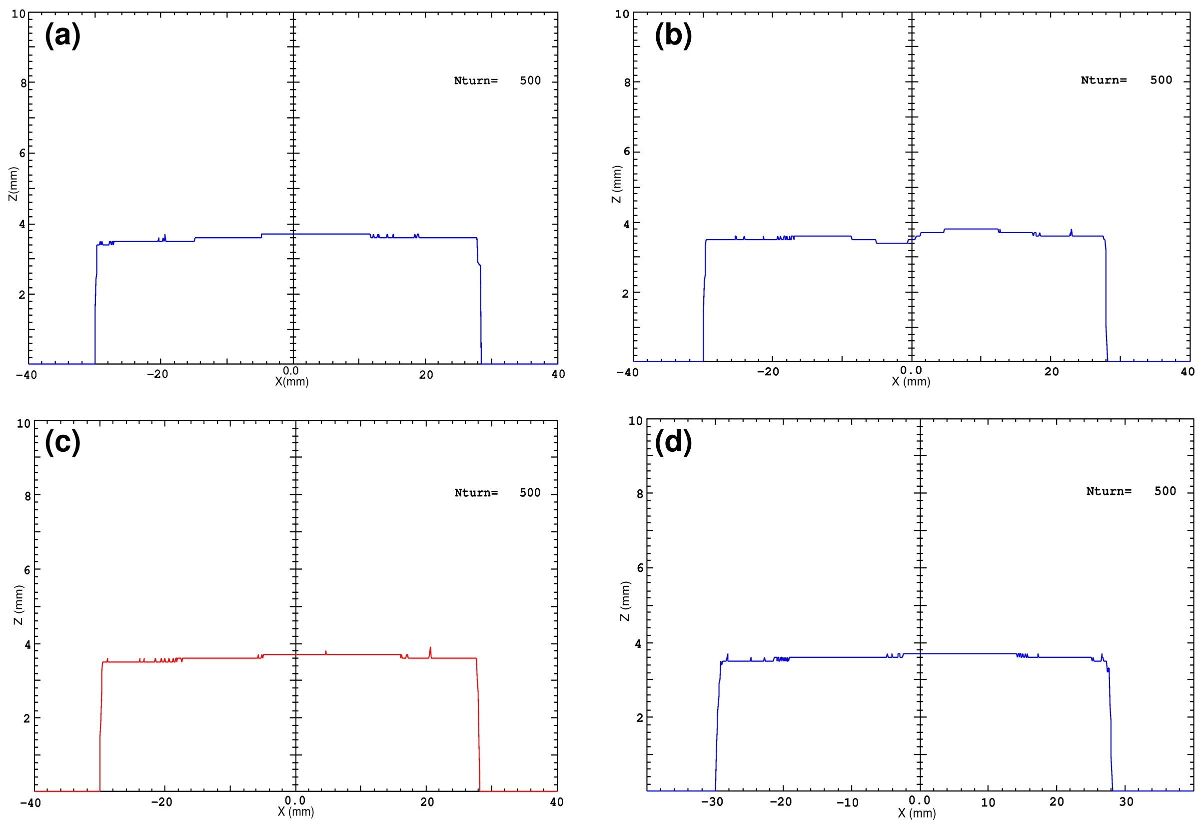


Figure 11: a) The ideal dynamic aperture with chamber. b) The effect of the above systematic bending contents on the dynamic aperture. c) The effect of the bending contents after modifying the tunes. d) the effect of the bending contents on the modified optics at injection energy.

3 - Quadrupole high order multipoles

For the quadrupole contents we used those used for ANKA dynamics simulations. They have been taken from ALS measurements and transformed according to ANKA quadrupole geometry. We used them with the proper transformation to SESAME quadrupole integrated strength.

These multipoles are considered at x =35mm. They represent the average values of the systematic 12-pole and 20-pole components and the random 8-pole, 10-pole, 14-pole, 16-pole and 18-pole ones:

-- $(\Delta B/B_0)_{6\text{-pole}} = 2.048\ 10^{-4}$ -- $(\Delta B/B_0)_{8\text{-pole}} = 1.203\ 10^{-4}$ -- $(\Delta B/B_0)_{10\text{-pole}} = -3.191\ 10^{-4}$
-- $(\Delta B/B_0)_{12\text{-pole}} = 8.072\ 10^{-4}$ -- $(\Delta B/B_0)_{14\text{-pole}} = 1.151\ 10^{-4}$ -- $(\Delta B/B_0)_{16\text{-pole}} = -5.972\ 10^{-4}$
-- $(\Delta B/B_0)_{18\text{-pole}} = 5.788\ 10^{-5}$ -- $(\Delta B/B_0)_{20\text{-pole}} = 7.741\ 10^{-4}$

The multipoles were introduced in BETA as thin lens elements in the mid of the quadrupole. Their effect on absolute and chamber limited dynamic apertures (modified optics 1) is shown in Fig. 12.

The destruction is mainly in the horizontal plane but the chamber limited dynamic aperture is not affected. These multipole errors are within the tolerable range.

Behavior of the off-momentum dynamics is shown in Fig. 13. The dynamic apertures and Touschek lifetime were also not affected.

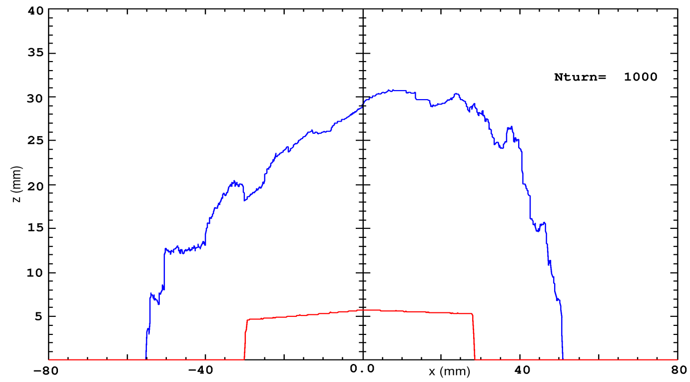


Figure 12: Absolute dynamic aperture is in blue and chamber limited one is in red.

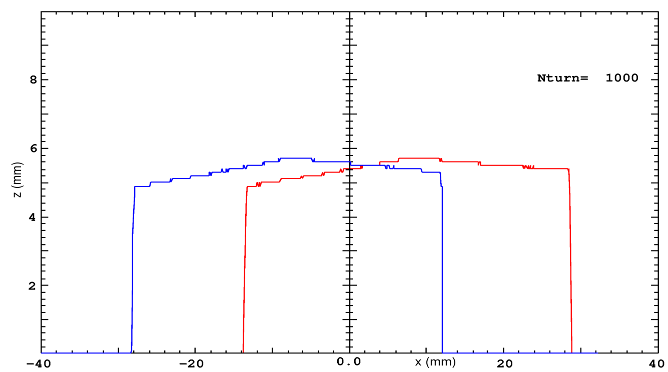


Figure 13: 1.5% off-momentum dynamic aperture is in red and the –1.5% one is in blue.

4 - Sextupole high order multipoles

Concerning the sextupole contents, we have used the systematic values taken from the ones used in the ASP calculations, BESSY II and ANKA sextupole measurements at x =32mm. After transforming them to x =35mm, they had the values:

-- $(\Delta B/B_0)_{18\text{-pole}} = 1.712\ 10^{-2}$ -- $(\Delta B/B_0)_{30\text{-pole}} = 2.93\ 10^{-2}$

-- $(\Delta B/B_0)_{42\text{-pole}} = 5.03\ 10^{-3}$ -- $(\Delta B/B_0)_{54\text{-pole}} = 4.295\ 10^{-3}$

Their effect on the dynamic aperture can be seen in Fig. 14. In spite of the strong horizontal impact on the absolute dynamic aperture, the chamber limited one looks unaffected. Nevertheless, we believe that we used conservative multipole values.

Impact of these errors on the off-momentum dynamics was tested also. Touschek lifetime has not been affected.

The random multipole values were small compared to the systematic ones, so they were expected to have no noticeable dynamic effect.

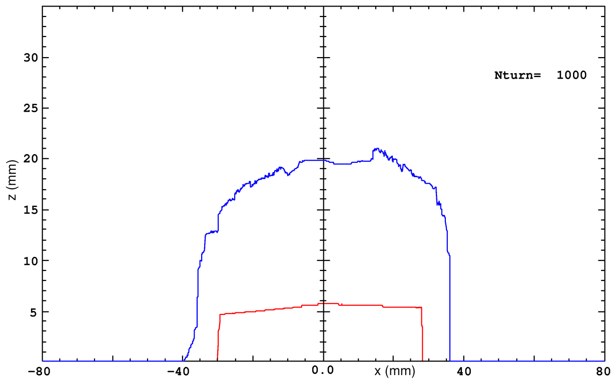


Figure 14: Absolute dynamic aperture is in blue and chamber limited one is in red.

4 – All the magnetic high order multipoles

To see the overall multipole effect, the bending, quadrupole and sextupole multipoles have been introduced together to the lattice. The total effect can be seen in Fig. 15.

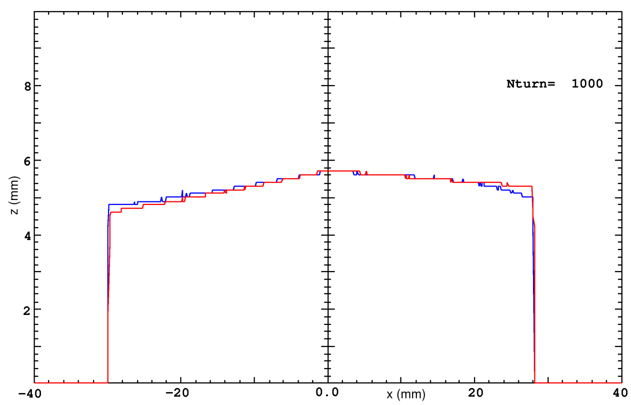


Figure 15: The ideal dynamic aperture is in red and the multipole affected one is in blue.

Conclusion

Including the chamber limitations in the dynamic aperture calculations has the advantage of revealing some nonlinearity not seen in the absolute dynamic aperture case.

The chamber limitation and field error effects gave an indication that optics 2 nonlinear dynamics has better performance than that of optics 1; nevertheless, the tune modification enhances both of them and reduces their sensitivity to the field error effect. So this modification is highly recommended for SESAME optics. More future investigations will be done on this point

According to the transverse beam dynamics, the above high order multipoles are tolerable by SESAME optics but we hope to get more optimistic measured values in SESAME magnets.

REFERENCES

[1] G. Vignola, M. Attal – SESAME Technical Note **O-1** – Dec. 2004
[2] G. Vignola et al. - SESAME in Jordan, PAC 2005 Proceedings
[3] S. Varnasseri – SESAME Technical Note **M-1** – Aug. 2005