FREQUENCY MAP STUDIES FOR THE ILC DAMPING RINGS*

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Abstract

Designing a lattice with sufficient dynamic aperture for the ILC Damping Rings is very challenging as the lattice needs to provide a small equilibrium emittance and at the same time a large aperture for the injected beam (including a large momentum acceptance). In addition, outside constraints have forced layout changes in the damping ring. Some of the layout changes had an impact on the dynamic aperture. In order to better understand the changes in dynamic aperture, frequency maps are studied. Those studies can help in identifying the reason for the changed dynamic aperture and in finding a good location for the betatron tunes and determining an upper limit for the chromaticities. A summary of recent studies and suggestions for improving the dynamic aperture by choosing a different tune are presented.

INTRODUCTION

Frequency maps have been used for some years to study dynamic aperture and related issues in particle accelerators [1]. They can help in the understanding of loss mechanisms and sources of dynamic aperture restrictions.

The OCS6 lattice

The OCS6 lattice is the baseline version for the ILC Damping Rings. The lattice has four short and two long straight sections. The short straight sections contain the wiggler magnets and rf cavities. One or both long straight sections can be used for injection and extraction depending on the overall layout. All studies presented here assume no machine errors. It is expected that the results with errors will be worse.

Figure 1 shows the frequency map for the lattice. Some resonance lines are visible, particularly the vertical quarter-integer and the horizontal third-integer. It is frayed at the lower left side. Although a large number of particles have a small tune diffusion rate, some particles at larger amplitudes have high tune diffusion rates.

One can see that particles at large vertical amplitude are lost. Large diffusion rates occur at large vertical amplitudes even for small horizontal amplitudes. The area up to $A_x = 30\,\mathrm{mm}$ and $A_y = 20\,\mathrm{mm}$ is very stable. The yellow arc of higher diffusion rates at that amplitude is caused by the vertical fourth-order resonance (see Fig. 1).

The OCS6 lattice clearly suffers from large detuning with amplitude, strong resonances and resulting loss of particles.

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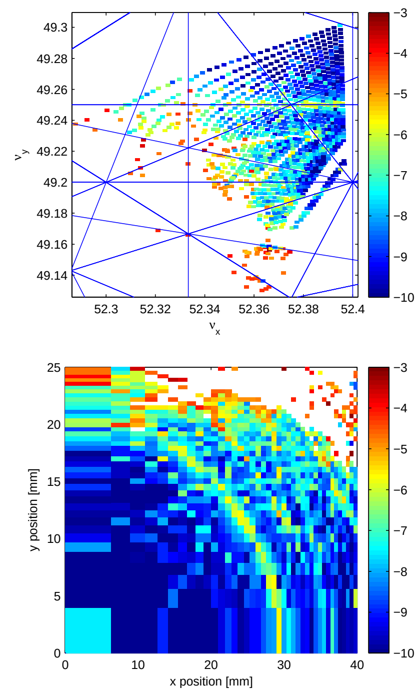

Figure 1: Frequency map for ideal lattice. Resonances up to fifth order are shown.

OFF-MOMENTUM FREQUENCY MAPS

As the injected positron beam has a large energy spread (1% full width) with a fairly flat distribution, it is important that the dynamic aperture is also sufficient for off-momentum particles. As the tracking is done at a chromaticity of $\xi_x = \xi_y = 1$, the tune will be different for the off-momentum particles.

Figure 2 shows the off-momentum frequency maps for the nominal case ($\xi_x = \xi_y = 1$). One can clearly see the problems for negative energy deviations caused by pushing the footprint over the horizontal third-integer resonance. Overall, the diffusion rates are significantly higher than in the on-momentum case (compare to Fig. 1).

Figure 3 shows the diffusion rates plotted versus amplitude. The dynamic aperture is smaller than for the on-momentum case. The area with low tune diffusion rates is now really small, but most resonance lines showing up at lower amplitudes do not increase the diffusion rate too much. Particles at large vertical amplitudes, even at small and moderate horizontal amplitudes, suffer from large tune diffusion rates and a significant fraction of them are lost.

For particles with momentum deviation, the dynamic aperture is clearly reduced further, more so for negative momentum deviation than for positive. The problems are

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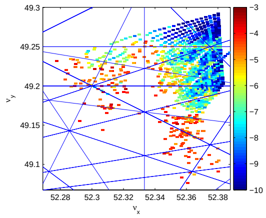
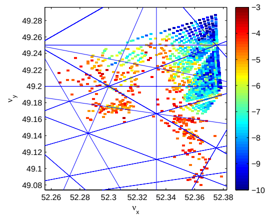
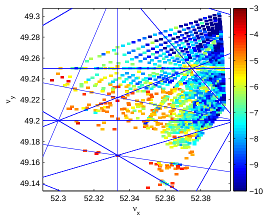


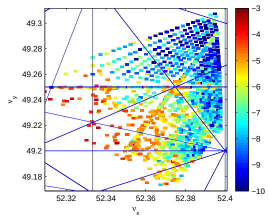
(a) $\frac{\Delta p}{p} = -0.5\%$



(b) $\frac{\Delta p}{p} = -1.0\%$

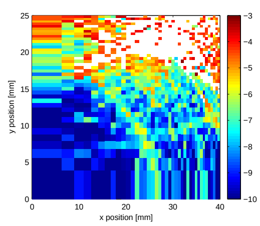


(c) $\frac{\Delta p}{p} = +0.5\%$

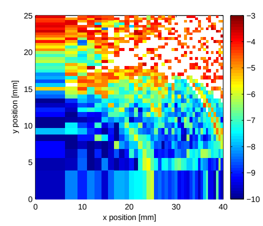


(d) $\frac{\Delta p}{p} = +1.0\%$

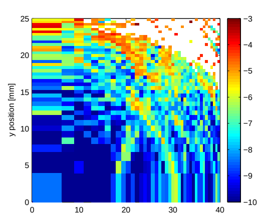
Figure 2: Off-momentum frequency maps for the nominal lattice.



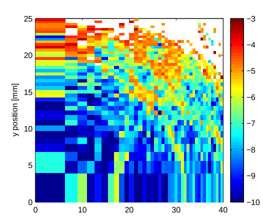
(a) $\frac{\Delta p}{p} = -0.5\%$



(b) $\frac{\Delta p}{p} = -1.0\%$



(c) $\frac{\Delta p}{p} = +0.5\%$



(d) $\frac{\Delta p}{p} = +1.0\%$

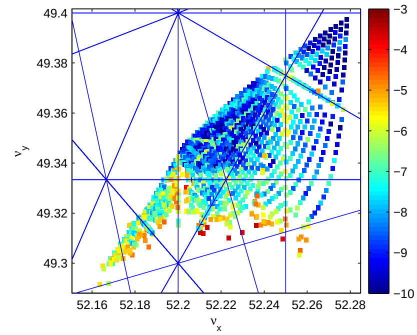
Figure 3: Off-momentum tune diffusion versus amplitude for the nominal lattice.

mainly in the vertical plane, where large horizontal detuning with vertical amplitude pushes particles over the horizontal third-order resonance. In addition to losing many particles, surviving particles exhibit large detuning with amplitude.

CHANGING THE TUNE OF THE OCS6 LATTICE

OCS6 with OCS5 tunes

A previous version of the lattice, OCS5, had larger dynamic aperture. The arc cells are the same for both lattices; only the straight sections and their number are different.



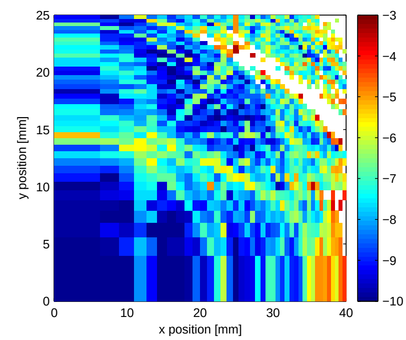


Figure 4: Frequency map for a tune of $Q_x = 52.2810$ and $Q_y = 49.4012$. Resonances up to fifth order are shown.

The OCS5 lattice has a significantly larger dynamic aperture compared to OCS6. As the tunes of the two lattices are different, it was assumed that this might be at least part of the cause. Therefore the OCS6 lattice was retuned to the tunes of the OCS5 lattice.

This was done in two different ways:

- Using one straight section as a tune trombone: This reduced the dynamic aperture even further.
- Changing the phase advance in the arc cells: This method was more successful. Results are described below.

The arc has one string of focusing and defocusing quadrupoles each. As the sextupole magnets used to correct the chromaticity are located in the arc as well, changing the tune with the arc quadrupoles changes the phase advance between the sextupoles. This can reduce the dynamic aperture, which is the drawback of this method. The advantage is that the correct setting of the quadrupoles for the desired tune can easily be calculated and no matching is required. The change in quadrupole strength is rather small, as is the change in phase advance between sextupole magnets. Figure 4 shows the frequency map for the adjusted tune.

It shows that some particle losses at high amplitude occur mainly due to the horizontal fifth-order resonance. From this, it looks like the tune is at least partly responsible the reduced dynamic aperture (with the larger detuning with amplitude being the other cause). The large detuning with amplitude could be decreased by using additional sextupole magnet families (harmonic sextupoles). This is currently under study.

Tune scan for the OCS6 *lattice*

In order to explore whether better areas in tune space exist, a tune scan using the quadrupole magnets in the arcs was done. The only optimization done at each step was setting the chromaticities back to $\xi_x = \xi_y = 1$. The tunes are scanned in steps and at each step a frequency map is calculated. All diffusion rates in a frequency map are summed up into a total diffusion rate which is then recorded. Results are plotted in Fig. 5. The locations of the nominal tunes of OCS5 and OCS6 are marked.

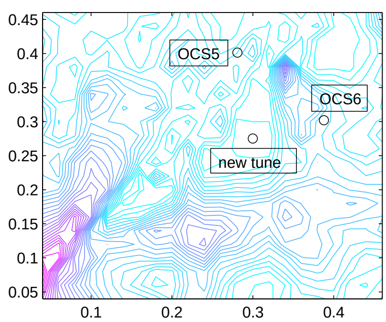


Figure 5: Tune diffusion rates for different tunes.

The lowest diffusion rate occurs in the region around $\nu_x = \nu_y = 0.3$. As this area is close to the coupling resonance, a tune was chosen for further study such that the footprint would not intersect the coupling resonance. The tune used for further study is $Q_x = 52.300$ and $Q_y = 49.275$. The footprint is significantly smaller, and this is not caused by particle losses. It looks like the cross detuning terms are smaller at this tune. The footprint stays below the coupling resonance, as intended.

Figure 6 shows the frequency map for the new tune location. Some resonances are visible but they are not very strong. The strongest one is the one below the vertical fifth-order resonance which corresponds to $\nu_x + 4\nu_y = N$. The vertical fourth-order resonance causes only slightly increased diffusion rates.

One can see that with the new tunes, the dynamic aperture is significantly larger than for the nominal case. However some resonances are visible at fairly small amplitude, especially the vertical fourth order resonance at $A_x = 20\,\mathrm{mm}$ and $A_y = 13\,\mathrm{mm}$. Up to vertical amplitudes of around $A_y = 15\,\mathrm{mm}$ the diffusion rates are low. However above that they are high in some areas.

The dynamic properties at the new tune look significantly better than the nominal case for the OCS6 lattice, but are still worse than the OCS5 lattice, mainly for large vertical amplitudes. However, one must keep in mind that no optimization was done beyond choosing a random tune in a good area from the tune scan (only making sure the footprint stays below the coupling resonance) and keeping the

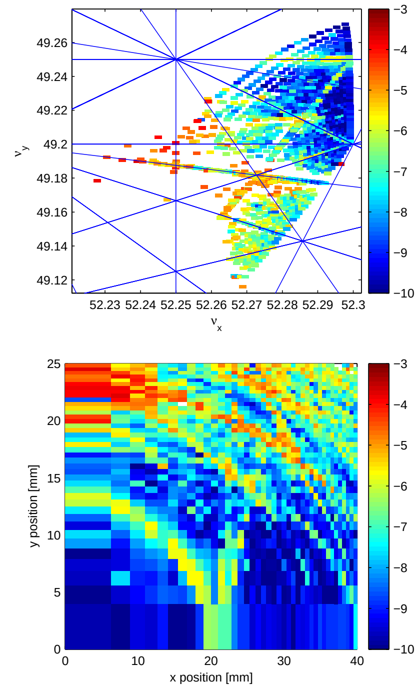


Figure 6: Frequency map for $Q_x = 52.300$ and $Q_y = 49.275$. Resonances up to fifth order are shown.

chromaticities at $\xi_x = \xi_y = 1$. So a more thorough study of that area might yield a good tune with a more optimized dynamic aperture. Harmonic sextupoles might improve the dynamic aperture even more by lowering the detuning with amplitude. This is currently under study.

CONCLUSION

Frequency maps are a useful tool in understanding dynamic aperture. They clearly showed that the reduced dynamic aperture of the OCS6 lattice is caused by a combination of a large (cross-)detuning with amplitude and an unfortunate choice of working point.

All studies were done using no errors. Including machine errors like alignment, strength or multipole errors is likely to decrease the dynamic aperture. So studies of the final lattice should include the influence of those errors on the dynamic aperture.

REFERENCES

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[2] A. Terebilo, Accelerator Toolbox for MATLAB [3], SLAC-PUB-8732 and www-ssrl.slac.stanford.edu/at/.

[3] Matlab [3], The Language of Technical Computing, Programming, Version 7. MATLAB is a registered trademark of The MathWorks, Inc.