High-Chromaticity Optics for the MAX IV 3 GeV Storage Ring

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HIGH-CHROMATICITY OPTICS FOR THE MAX IV 3 GeV STORAGE RING

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Abstract

The ultralow emittance lattice of the MAX IV 3 GeV storage ring has a large negative natural chromaticity. This has to be corrected to positive values to prevent head-tail instabilities. On the other hand, high linear chromaticity can lead to a large tune footprint which limits Touschek lifetime. Therefore, the linear chromaticity is corrected to +1 in both planes with sextupoles while octupoles are used to further reduce the tune footprint. Studies indicate this design leads to threshold currents for resistive wall and transverse mode coupling instabilities beyond what is expected during regular user operation. However, since these are only preliminary studies based on approximations, the possibility of instability issues during commissioning needs to be considered. A short term solution is to operate the storage ring at a higher chromaticity. This paper describes the developed high-chromaticity optics for the MAX IV 3 GeV storage ring. It focuses on reduction of chromatic and amplitude-dependent tune shifts to maximize dynamic aperture and Touschek lifetime. A comparison between the performance of the new high-chromaticity optics and the design optics is also presented.

INTRODUCTION

The MAX IV facility is a 3rd generation state-of-the-art synchrotron light source currently under construction in Lund, Sweden [1]. The MAX IV 3 GeV storage ring has an ultralow emittance lattice with a large negative natural chromaticity in both planes [2]. To avoid head-tail instabilities, the linear chromaticity has to be corrected to positive values. On the other hand, a large linear chromaticity can lead to proximity to, or crossing of, potentially dangerous resonances, which can limit dynamic aperture and Touschek lifetime. To satisfy both constraints, the linear chromaticity in the design optics of the MAX IV 3 GeV storage ring has been corrected to +1 in both planes [2]. Initial instability studies indicate this design leads to threshold currents for resisitive wall instability and transverse mode coupling instability beyond what is expected during user operation [3]. However, since these are only preliminary studies based on initial estimates of the impedance budget the possibility of instability issues occurring during commissioning needs to be considered. The instability studies indicate that the threshold currents increase with chromaticity. A short term solution is therefore to operate the storage ring at a higher chromaticity. An alternate optics for the MAX IV 3 GeV storage ring with linear chromaticity +4 in both planes has therefore been developed [4]. This paper presents the performance of the newly developed high-chromaticity optics in comparison to the design optics. The challenges to achieve a high-chromaticity optics with sufficient performance are also described.

NONLINEAR OPTICS OPTIMIZATION

The MAX IV 3 GeV storage ring make use of strong sextupoles to correct the linear chromaticity, minimize chromatic tune shifts and tailor the chromatic tune footprint while minimizing first-order resonance driving terms. Octupoles are employed to minimize the amplitude-dependent tune shifts and further tailor the tune footprint. This approach is detailed in [5]. The same approach was used during the development of a high-chromaticity optics.

OPA [6] was used to correct the linear chromaticity to +4 in both planes using the two strongest chromatic sextupoles. All five sextupole families were then adjusted to optimize the chromatic tune footprint while constraining the linear chromaticities to +4.

The chromatic tune shifts for the high-chromaticity optics are displayed in Fig. 1. For both planes, the resulting chromatic tune shifts for the high-chromaticity optics are not unexpectedly larger than the corresponding tune shifts for the design optics across the entire range of interest.

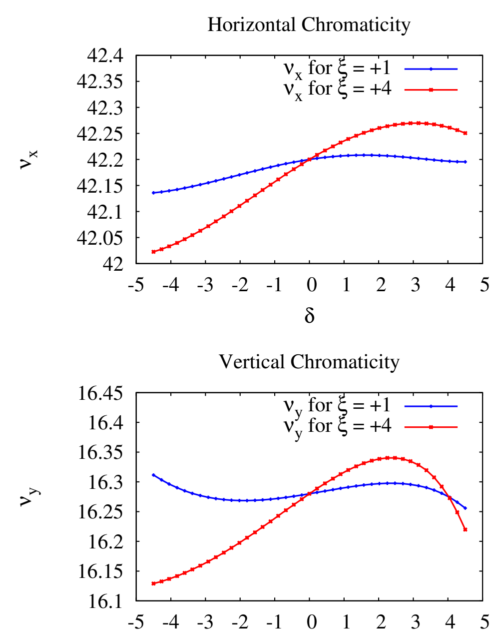

Figure 1: Chromatic tune shifts for the high-chromaticity optics calculated by TRACY-3 [7]. The chromatic tune shifts for the design optics are displayed for comparison.

The chromatic tune footprint for the high-chromaticity optics is displayed in Fig. 2. The chromatic tune shifts were tailored with OPA to avoid the $\nu_x + 2\nu_y = 75$ resonance which is assumed to be potentially strongly driven. The resonances $\nu_x - \nu_y = 26$, $2\nu_x - \nu_y = 68$ and $3\nu_y = 49$ are all skew resonances. They were assumed to be weaker driven and less focus was put on avoiding them. The resulting chromatic tune footprint although not large, is not as compact as the chromatic tune footprint of the design optics detailed in [8].

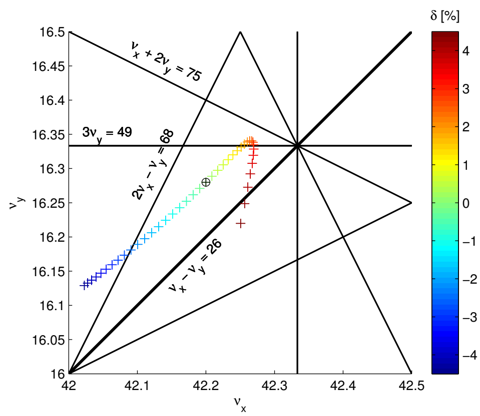

Figure 2: The chromatic tune footprint for the high-chromaticity optics calculated by OPA. Resonances up to third order are displayed.

The three families of octupoles were then used to tailor the amplitude-dependent tune shifts. The resulting amplitude-dependent tune shifts for the high-chromaticity optics are displayed in Fig. 3. It is evident that the amplitude-dependent tune shifts are larger for the high-chromaticity optics than for the design optics.

DYNAMIC APERTURE

The dynamic aperture for the high-chromaticity optics is displayed in Fig. 4. Comparison with the dynamic aperture for the design optics presented in [8] reveals that the dynamic aperture for the high-chromaticity optics is smaller. However, the required on-momentum dynamic aperture is achieved. The off-momentum dynamic aperture is smaller for $\delta = -4.5\%$ than for $\delta = +4.5\%$ which is a consequence of the chromatic tune shifts.

MOMENTUM ACCEPTANCE

The off-momentum diffusion map is displayed in Fig. 5. The momentum acceptance appears to be limited to within $\delta = -7\%$ and $\delta = +9\%$. Within the required momentum acceptance $\delta = \pm 4.5\%$ several areas with somewhat elevated diffusion and some bands and ring-shaped structures possibly indicating resonant behavior are visible. From frequency map analysis two resonances can be recognised, $4\nu_x = 169$ and $4\nu_y = 65$. These are both upright octupole resonances that are not expected to be driven strongly. For

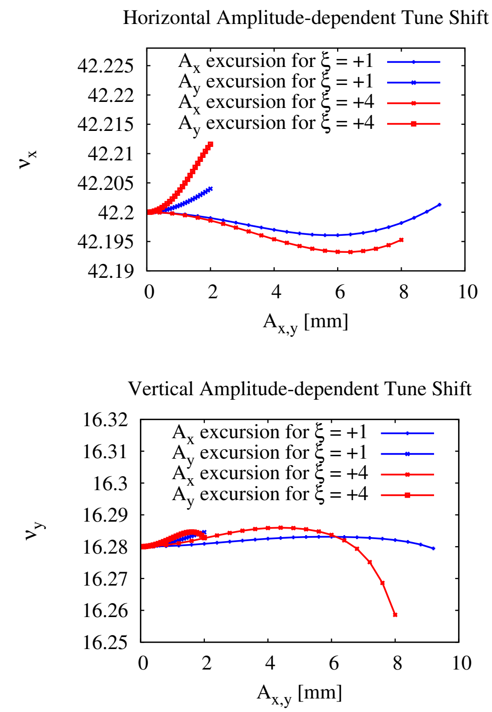

Figure 3: Amplitude-dependent tune shifts for the high-chromaticity optics calculated by TRACY-3. The amplitude-dependent tune shifts for the design optics are displayed for comparison.

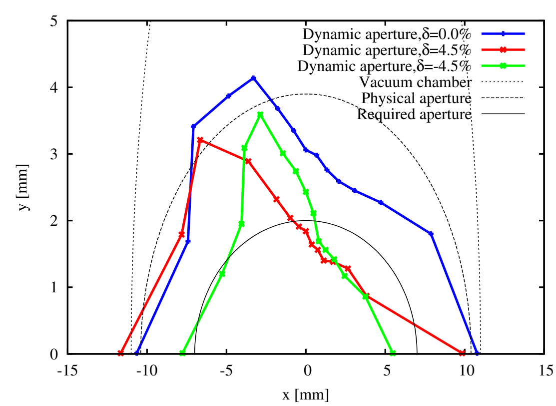

Figure 4: Dynamic aperture at the centre of the long straight sections for the high-chromaticity optics calculated by TRACY-3. The physical aperture originating from the vacuum chamber and the aperture required for injection and lifetime reasons are also shown.

$\delta < -5\%$ there appears to be an area with chaotic motion. Frequency map analysis indicates that this occurs close to the integer resonance.

TOUSCHEK LIFETIME

The Touschek lifetime of the high-chromaticity optics was determined by 6D tracking with TRACY-3 using actual

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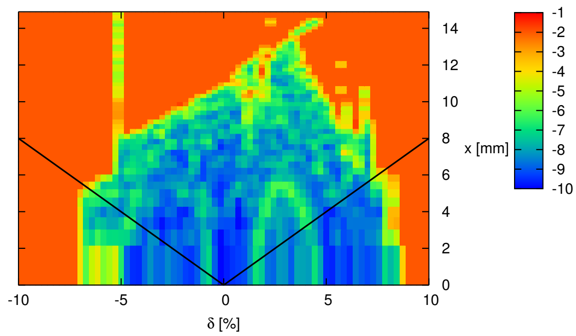

Figure 5: Diffusion map for off-momentum particles at the centre of the long straight sections for the high-chromaticity optics calculated by TRACY-3. Blue areas show low diffusion and red areas high diffusion. The vertical amplitude was set to +0.1 mm. The black line is an approximation of the maximum dispersive orbit.

vacuum chamber apertures. For the maximum stored beam current of 500 mA, vertical emittance 8 pm rad and maximum cavity voltage 1.8 MV, the Touschek lifetime was determined to be 8.98 hours. Neither the effects of IBS nor the Landau cavities present in the MAX IV 3 GeV lattice were included in this calculation. This is a reduction of roughly 5 hours compared to the corresponding Touschek lifetime of the design optics [8].

ERROR STUDIES

Initial error studies have been performed. These studies indicate that a lattice momentum acceptance of $\pm 4.5\%$ will not be achievable with the high-chromaticity optics, however an overall momentum acceptance of roughly $\pm 3.5\%$ is ensured. This will considerably reduce the Touschek lifetime. Initial estimates for the reduction of Touschek lifetime caused by magnet and alignment imperfections indicate that the Touschek lifetime could still be sufficient to allow the high-chromaticity optics to be used in the MAX IV 3 GeV storage ring as a short term solution should instability issues occur during commissioning. Further studies of the reduction of Touschek lifetime with errors need to be performed to fully validate this conclusion.

CHALLENGES FOR A HIGH-CHROMATICITY OPTICS

The correction of the linear chromaticity to +4 in both planes sets high demands on the nonlinear optics to achieve sufficiently large dynamic aperture to ensure an efficient injection process and sufficiently large Touschek lifetime. Since the linear chromaticity is set to +4 there is a need for strong sextupole magnets and skillful optimization of the chromatic tune footprint to accomplish small chromatic tune shifts which do not approach dangerous resonances. Because of the enlarged chromatic tune footprint caused by the increased linear chromaticity, the demand for small amplitude-dependent tune shifts is further increased.

The strong sextupole magnets and the need for small amplitude-dependent tune shifts call for strong octupole magnets. When the gradients of the octupole magnets are considerably enlarged they start to have a substantial effect on the chromatic tune shifts through higher order dispersion. Therefore, the chromatic tune shifts and the amplitude-dependent tune shifts have to be optimized with regard to each other. This results in a more complex design process. Several iterations and skillful design are required to achieve good performance. A possible alternative is to apply MOGA [9] to find a high-chromaticity optics with further improved performance.

CONCLUSIONS

A high-chromaticity optics with linear chromaticity +4 in both planes has been developed for the MAX IV 3 GeV storage ring. The high-chromaticity optics has a smaller dynamic aperture than the design optics, especially for off-momentum particles. The momentum acceptance of the high-chromaticity optics is therefore lower compared to the design optics. No major effect on the efficiency of the injection process is expected since the dynamic aperture requirements are fulfilled on-momentum. However, the reduction of momentum acceptance will result in a considerable reduction of Touschek lifetime. Initial estimates for the reduction of Touschek lifetime caused by errors indicate that the performance of the high-chromaticity optics should be sufficient to allow the optics to be applied in the MAX IV 3 GeV storage ring as a short term solution if instability issues occur during commissioning. Further studies are necessary to validate this conclusion. There also exist opportunities to revise the high-chromaticity optics and perhaps further improve its performance.

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