

HIGH-CHROMATICITY OPTICS FOR THE MAX IV 1.5 GeV STORAGE RING

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Abstract

The MAX IV facility currently under construction in Lund, Sweden will include a 1.5 GeV storage ring. To prevent head-tail instability, the negative natural chromaticities of the MAX IV 1.5 GeV storage ring have been corrected to positive values using sextupole gradients in the focusing quadrupoles along with dedicated sextupole magnets. To allow adjustment of the chromaticity correction, weak correction sextupoles have been inserted into the lattice. A high-chromaticity optics has been developed for the MAX IV 1.5 GeV storage ring in case instability issues arise during commissioning. Two chromatic sextupole families were used to correct the linear chromaticity. The tune footprint was then tailored using the remaining two sextupole families with the goal of maximizing dynamic aperture and Touschek lifetime. This paper describes the recently developed high-chromaticity optics for the MAX IV 1.5 GeV storage ring and discusses performance limitations of the optics constrained by available gradient strength in the sextupoles.

INTRODUCTION

The MAX IV facility is a third generation synchrotron light source currently under construction in Lund, Sweden. The facility will include two storage rings operated at 3 GeV and 1.5 GeV, respectively. The MAX IV 3 GeV storage ring employs a multibend achromat lattice for ultralow emittance, whereas the MAX IV 1.5 GeV storage ring is based on a double-bend achromat lattice [1]. To prevent head-tail instability the negative natural chromaticities of the MAX IV storage rings have been corrected to positive values. In case instability issues arise during commissioning, operating the storage rings at higher chromaticity than foreseen in the design optics could become desirable. A high-chromaticity optics had previously been developed for the MAX IV 3 GeV storage ring [2] and this has now also been studied for the MAX IV 1.5 GeV storage ring. The performance of an optics with linear chromaticity +4 in both transverse planes and the possibility to operate this optics in the real machine have been studied and are summarized in this paper.

CHROMATICITY CORRECTION IN THE MAX IV 1.5 GeV STORAGE RING

To make the lattice of the MAX IV 1.5 GeV storage ring more compact, a focusing sextupole component has been integrated into the focusing quadrupole magnets. The defocusing sextupoles are dedicated magnets. In order to allow adjustment of the chromaticity, small focusing correction sextupoles have been inserted into the lattice. Since most

of the focusing sextupole strength is implemented in iron it is only possible to adjust the chromaticity within a certain range depending on the gradients that the focusing correction sextupoles are able to produce [3]. The fixed sextupole strengths in the quadrupoles have been designed to correct the natural linear chromaticity of the lattice to +2 in both transverse planes. In the design optics the linear chromaticity is then corrected to +1 in both planes using the dedicated sextupole magnets [4].

To study the performance of an optics with linear chromaticity +4 in both transverse planes, a candidate for a high-chromaticity optics was developed [5]. This candidate was achieved by correcting the linear chromaticities to +4 with the chromatic sextupoles, followed by small adjustments of the chromatic tune footprint with the other sextupoles to avoid the resonances assumed to be most dangerous. By evaluating the performance of this optics the need for a more thorough optimization can be evaluated.

TUNE SHIFTS

The chromatic tune footprint over the desired energy acceptance is displayed in Fig. 1. The optimization of the chromatic tune footprint focused on avoiding the upright sextupole resonances.

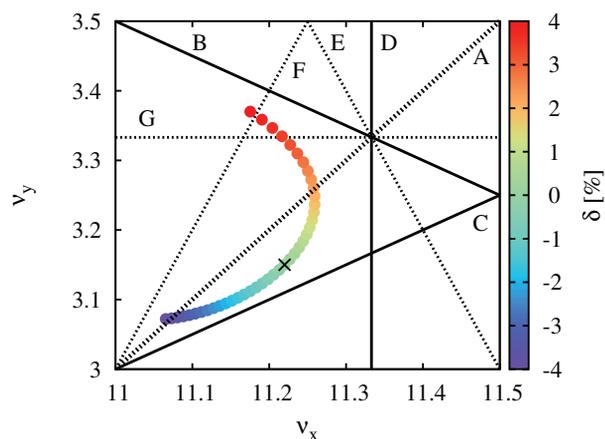


Figure 1: Chromatic tune footprint calculated with TRACY-3. The resonances up to third order are displayed. A: $\nu_x - \nu_y = 8$, B: $\nu_x + 2\nu_y = 18$, C: $\nu_x - 2\nu_y = 5$, D: $3\nu_x = 34$, E: $2\nu_x + \nu_y = 26$, F: $2\nu_x - \nu_y = 19$ and G: $3\nu_y = 10$. The working point is marked with a black cross.

The amplitude-dependent tune shifts (ADTSs) over the required aperture (cf. next section) are displayed in Fig. 2. In order to study the performance of an optics with only chromatic corrections no additional optimization of the ADTSs was performed. Therefore the ADTSs are rather large, but still substantially smaller than the chromatic tune shifts.

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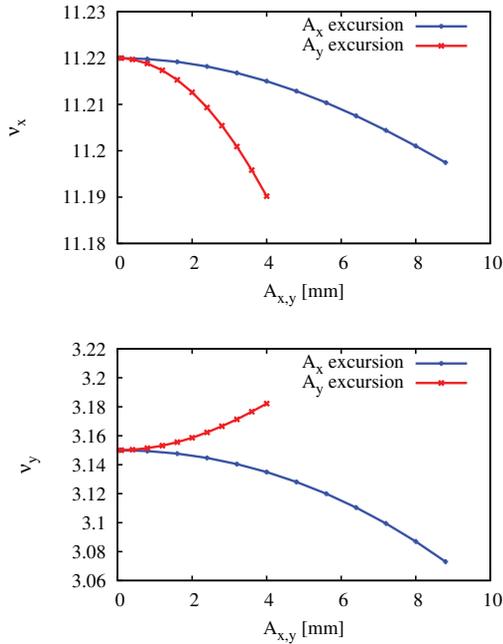


Figure 2: Amplitude-dependent tune shifts calculated with TRACY-3.

DYNAMIC APERTURE

The dynamic aperture is displayed in Fig. 3. The required aperture in the horizontal plane is given by the requirements for the injection process and in the vertical plane by constraints from insertion device chambers. Frequency map analysis reveals low diffusion inside the required aperture.

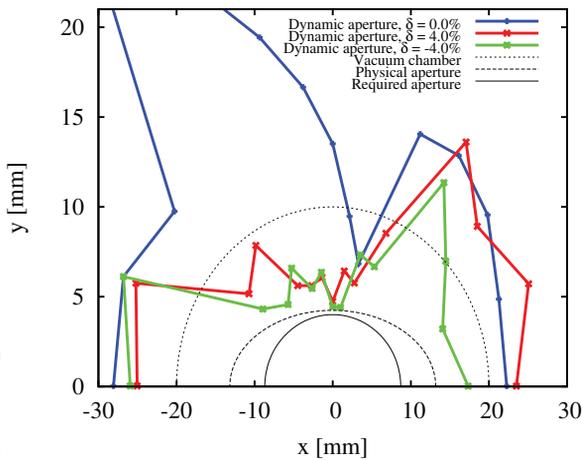


Figure 3: Dynamic aperture at the centre of the straight sections calculated with TRACY-3 by tracking 512 turns (~1.2 synchrotron periods).

MOMENTUM ACCEPTANCE

The off-momentum diffusion map over the desired momentum acceptance $\pm 4\%$ is displayed in Fig. 4. The area with elevated diffusion around $\delta = -1.5\%$ is caused by cross-

ing $6\nu_x = 67$ and around $\delta = 1-3\%$ by crossing $4\nu_x = 45$, $4\nu_y = 13$, $\nu_x - \nu_y = 8$ and finally $4\nu_x = 45$ again.

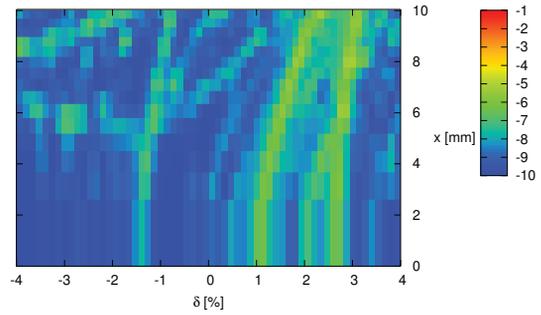


Figure 4: Diffusion map at the centre of the straight sections calculated with TRACY-3.

ERROR STUDIES

To study the performance of the real machine, errors were added to the lattice. The error model includes random alignment, field and multipole errors as well as systematic multipole errors [5]. On-momentum the studies reveal that the reduction of dynamic aperture caused by imperfections takes place beyond the physical aperture. Hence, the required aperture is still achieved and no problems with the injection process are to be expected. Off-momentum the reduction of dynamic aperture is of greater importance for $\delta < 0$ than for $\delta > 0$ since the ideal dynamic aperture is already smaller for $\delta < 0$. However, the dynamic aperture reduction is not severe in either case.

TOUSCHEK LIFETIME

The Toushek lifetime of the high-chromaticity optics for the ideal machine was calculated by tracking 800 turns to 8.54 hours at 1% coupling, not including bunch lengthening from the harmonic cavities in the storage ring. The Toushek lifetime with imperfections was then calculated for 20 seeds, again by tracking 800 turns. This resulted in a Toushek lifetime of 7.87 ± 0.35 hours at 1% coupling, corresponding to a reduction of roughly 4–12%.

PERFORMANCE OF THE SEXTUPOLE MAGNETS

A comparison of the sextupole gradients given by the technical specification of the MAX IV 1.5 GeV storage ring magnets [6] and the sextupole gradients required by the high-chromaticity optics is displayed in Table 1. The required gradients are lower than the technical specification for all magnets except the SDi family.

Initial studies reveal that the required gradients of the SDi magnets are on the limit of what can be achieved with the present power supplies. Further studies, including measurement data from real magnets, have to be undertaken before a final conclusion can be reached. From the studies performed

Table 1: Sextupole gradients for the high-chromaticity optics compared to technical specifications.

Family	Compared to technical specification
SDi	115%
SDo	78%
SCi	-97%
SCo	42%

so far, it is expected that the magnets will be able to produce the gradients required by the high-chromaticity optics, possibly with an exchange of power supplies. Alternatively, it is possible to reduce the gradient of the SDi magnets and achieve an optics with a chromaticity close to +4 in both transverse planes. This might be a solution if a chromaticity slightly lower than +4 is sufficient to resolve the instability issues.

COMPARISON TO THE DESIGN OPTICS

The design optics of the MAX IV 1.5 GeV storage ring has a linear chromaticity of +1 in both transverse planes [4]. Due to the lower linear chromaticity, the design optics has a smaller chromatic tune footprint than the high-chromaticity optics, which influences the performance of the optics. The performance of the design optics was evaluated similarly to the high-chromaticity optics. This results in a Touschek lifetime of 8.65 hours at 1% coupling. Hence, the Touschek lifetime of the ideal machine is reduced by only roughly 1.3% for the high-chromaticity optics compared to the design optics. The Touschek lifetime for the design optics with imperfections was then calculated for 20 seeds to 8.55 ± 0.02 hours with 1% coupling. This corresponds to a reduction of roughly 0.9–1.4%, revealing that the design optics are less sensitive to imperfections than the high-chromaticity optics.

NONLINEAR OPTIMIZATION OF THE MAX IV STORAGE RINGS

There are substantial differences between the two MAX IV storage rings which affect the optimization of their optics. Some of these differences are of interest since they give insight into where difficulties in the optimization process might arise for different machines.

The optimization challenges for the MAX IV 3 GeV storage ring arise from strong sextupole magnets and the lattice including octupole magnets to optimize ADTSs to first order. The performance of a high-chromaticity optics for the MAX IV 3 GeV storage ring is mainly constrained by the dynamic and not the physical aperture [2]. All sextupole families are chromatic which gives much freedom to optimize. However, when the gradients of the octupoles are considerably enlarged they start to affect the chromatic tune shifts through higher order dispersion. This makes the optimization process of the MAX IV 3 GeV storage ring rather complex since all higher order magnets need to be optimized simultaneously [2].

The focusing strength of the MAX IV 1.5 GeV storage ring is weaker, leading to larger dispersion and therefore weaker sextupole magnets can be employed. Since most of the focusing sextupole strength is implemented in iron the lattice only allows for small adjustments of the chromaticity. The nonlinear optimization is performed with four dedicated sextupole families, two chromatic and two harmonic. This leads to fewer degrees of freedom in the optimization process, but at the same time the process of finding satisfactory solutions becomes less complex. On the other hand, the MAX IV 1.5 GeV storage ring lattice does not include any octupoles which means the ADTSs cannot be optimized to first order. The performance of a high-chromaticity optics for the MAX IV 1.5 GeV storage ring is constrained to a larger degree than the MAX IV 3 GeV storage ring by the physical aperture and the gradients the magnets are able to produce. Also, since not all sextupole families are chromatic a too weak gradient in one of the chromatic families cannot be compensated by the others.

CONCLUSIONS

The performance of the studied candidate for high-chromaticity optics is considered satisfactory. No problems with the injection process are anticipated despite imperfections expected in the real machine. The reduction of Touschek lifetime compared to the design optics is small. Considering that the candidate was achieved with only limited optimization there exist possibilities to further increase the performance. However, the performance of the present candidate is sufficient for application in the real machine should instability issues arise during commissioning.

The performance of the sextupole magnets in the MAX IV 1.5 GeV storage ring remains to be studied in detail, but they are expected to be able to produce the gradients required for the high-chromaticity optics. However, if in the future a more in-depth optimization of the high-chromaticity optics is desired the performance of the sextupole magnets has to be studied in greater detail to verify that they can actually produce the required gradients.

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