Recent Improvements to the Lattices for the MAX IV Storage Rings

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RECENT IMPROVEMENTS TO THE LATTICES FOR THE MAX IV STORAGE RINGS

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Abstract

Construction of the MAX IV facility started early this year. The facility will include two storage rings for the production of synchrotron radiation. The 3 GeV ring will house insertion devices for the production of x-rays while the 1.5 GeV ring will serve UV and IR users. Recently, the lattices for the storage rings in the MAX IV facility were updated. In the 3 GeV storage ring the vertical beam size in the long straights has been reduced. The lattice of the 1.5 GeV storage ring has been updated to take into account first results from detailed magnet and vacuum system designs. Additionally, a new injection method to facilitate commissioning of the storage rings has been studied. This paper summarizes the changes made in the lattices and the effect of these modifications.

INTRODUCTION

The MAX IV facility will use a 3 GeV linac and two storage rings to deliver synchrotron radiation to a broad and international user community across a wide spectral range and covering different temporal scales [1, 2]. Construction of the facility started earlier this year and is progressing swiftly [3, 4]. A facility overview is displayed in Fig. 1.

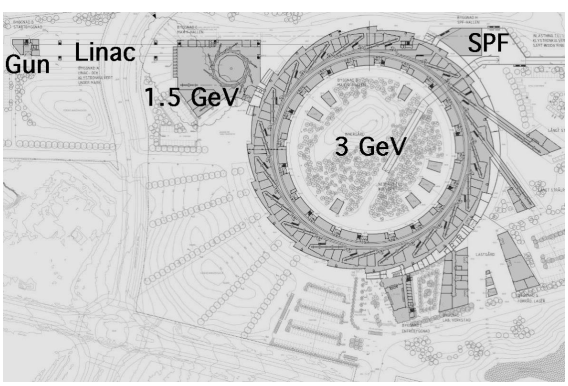

Figure 1: Overview of the MAX IV facility. The gun bunker is at the top left followed by the underground linac tunnel. The 1.5 GeV and 3 GeV storage ring buildings are indicated. The short-pulse facility (SPF) is indicated at the top right.

With facility construction ramping up quickly, detailed designs have to be completed soon so purchasing orders can be sent out on time. This paper summarizes the latest modifications to the lattices for the MAX IV storage rings. The following two sections focus on the 3 GeV and 1.5 GeV storage ring lattices. The final section introduces a new injection scheme intended to facilitate commissioning of the storage rings.

3 GeV OPTICS IMPROVEMENTS

The MAX IV 3 GeV storage ring lattice relies on a multibend achromat (MBA) to achieve ultra-low emittance ($\varepsilon_x < 0.3$ nm rad) while retaining large dynamic aperture and momentum acceptance [5]. The detailed magnet and vacuum system designs for the 3 GeV storage ring [6] are almost complete. Feedback from these design efforts have called for a few changes to the 3 GeV storage ring lattice and optics [7]. The most important optics modification is related to insertion device (ID) compensation.

The ultra-low emittance MBA lattice requires optics to be matched to strong IDs [8]. This is accomplished in two stages: locally using quadrupole doublets installed around the IDs and globally using the main focusing quadrupole family and pole-face strips (PFSs) in the gradient dipoles. One disadvantage of using air-cooled PFSs to compensate for strong IDs is that it limits the number of strong IDs that can be compensated for to about six, whereas 19 long straights are available to users in the 3 GeV storage ring. Another disadvantage is that powering the PFSs gives rise to a considerable dipole component as has been revealed by measurements on the prototype magnet [9]. This is undesirable as dynamic ID compensation then creates varying dipole kicks around the storage ring which have to be compensated by the orbit feedback system [10].

One solution to this problem is lowering the vertical beta function in the long straights, thus reducing the amount of tune shift generated by an ID and hence, relaxing the required compensation strength. In the updated 3 GeV storage ring lattice [7] the vertical beta function at the center of the long straights has therefore been reduced from 4.8 m to 2.0 m (cf. Fig. 2). Because of the reduced amount of tune shift generated by strong IDs with this optics, both local and global optics matching can now be performed using only the quadrupole doublets at the IDs. The PFSs no longer have to be powered dynamically. This reduces the complexity of ID compensation and facilitates operation of the storage ring. The new lattice optics not only reduces the amount of tune shift generated by IDs, it also reduced the beam height in the ID by one third. At the 1 Å diffraction limit, the rms vertical beam size is now 4 μm. Note that due to the ultra-low lattice emittance, this diffraction limit corresponds to a comparably high emittance coupling of about 3%. Dedicated skew quadrupoles will allow a significant reduction of coupling so that vertical source sizes as low as 1 μm should become possible.

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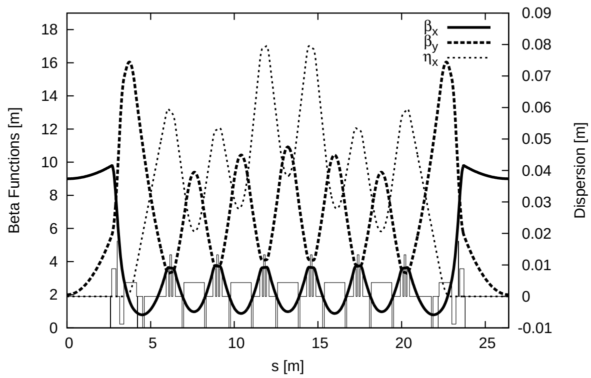

Figure 2: Optics in one of the 20 MBAs of the 3 GeV storage ring. Note the vertical beta function in the long straights has been reduced from 4.8 m to 2.0 m.

In order to limit the impact of this reduction of the vertical beta function in the long straights, the optics were retuned in such a way that the fractional vertical tune was preserved. The integer was increased by two units giving a new vertical tune of $\nu_y = 16.28$. As a result, the changes in required gradient strength for the various quadrupole families in the lattice are small and well within previously established tuning ranges. However, as a consequence of the increased vertical tune, the natural vertical chromaticity grew by six units which called for a re-optimization of the nonlinear optics. Following the previously applied nonlinear optics compensation scheme [11], an updated nonlinear optics has been generated. This nonlinear optics again gives a very compact tune footprint both for off-momentum and large-amplitude particles. Consequently, performance is comparable to the previous lattice despite the one-third reduction of beam height in all long straights. In addition, the revised ID matching shows less residual impact on nonlinear optics compared to the previous scheme. This gives better dynamic aperture and momentum acceptance for lattices with strong IDs and hence, Touschek lifetime has been improved. For the 3 GeV storage ring with ten strong in-vacuum undulators at minimum gap, a Touschek lifetime of up to 50 h (including harmonic Landau cavities) is expected for 500 mA stored current [7].

1.5 GeV STORAGE RING MODIFICATIONS

For the 1.5 GeV storage ring, detailed magnet and vacuum system design efforts have started to ramp up. So far, these studies indicate the previously presented lattice for the 1.5 GeV storage ring [1, 12] is feasible. It uses a simple and robust double bend achromat (DBA) to realize twelve 3.5 m long straight sections of which ten are available to users. Detailed magnet design [13] has however requested more space for sextupole magnet coils. This can be realized by moving the correction sextupoles SCi/o away from the main sextupoles SQFi/o by roughly 20 mm. No substantial change in dynamics is expected from this modification as the correction sextupoles are only powered if the chromaticity has to be shifted from its design value of +2.0. In addition, it is being investigated if the defocusing sextupole family SDo needs to be moved away from the dipole by a few mm in order to allow for some yoke tapering at the dipole end to prevent saturation. Again, such a change is not expected to have a significant impact on dynamic performance of the lattice. A 3D rendering of the lower half of a DBA magnet block is shown Fig. 3.

This 1.5 GeV storage ring will be built twice: once at the MAX IV facility in Lund, Sweden and once in Krakow, Poland as part of the Solaris facility [14]. While the 1.5 GeV storage ring at MAX IV will be operated in top-up mode using the 3 GeV MAX IV linac as a continuous full-energy injector, the 1.5 GeV storage ring at Solaris will be injected from a 550 MeV linac, ramped to full energy, and then operated in decaying beam mode [15]. Therefore, excellent Touschek lifetime has become an important design goal for the 1.5 GeV storage ring. The original MAX IV 1.5 GeV storage ring was designed for 3.0% momentum acceptance. The RF specifications and standard vacuum chamber cross section of 40 mm × 20 mm (elliptical) were chosen accordingly.

In light of the Solaris requirement of improved Touschek lifetime, the momentum acceptance of the 1.5 GeV storage ring was re-evaluated. By operating two main cavities at a gap voltage of 280 kV, 4.0% RF acceptance can be ensured [16]. If the vacuum chamber cross section is enlarged at the center of the DBA cell where dispersion reaches its peak value of $\eta_x = 0.33$ m, the lattice momentum acceptance can be increased accordingly. An elliptical cross section of 56 mm × 20 mm throughout the SQFI magnet ensures that the lattice momentum acceptance can match the RF acceptance of 4.0%. In this way a Touschek lifetime (at natural bunch length) of about 9 h can be achieved for 500 mA stored current, representing a 30% increase over the previous design. Together with the bunch lengthening from the harmonic Landau cavity (almost a factor five should be possible), the overall lifetime can be pushed to about 13 h which is considered sufficient for decaying beam operation.

As magnet and vacuum chamber design progress, additional feedback will likely call for continued modification of the lattice. Such iterations between magnet, vacuum, and lattice design should finally converge in a frozen 1.5 GeV storage ring lattice. So far, it appears lattice modifications required by magnet and vacuum design are limited and the overall lattice paradigm remains feasible. It is therefore expected that the lattice can be frozen in the near future.

DIPOLE KICKER INJECTION FOR COMMISSIONING

Both MAX IV storage rings have been designed to rely exclusively on pulsed sextupole magnet (PSM) injection

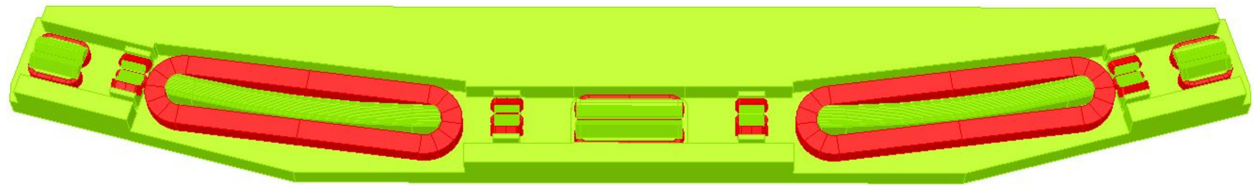

Figure 3: 3D rendering of the lower half of a 1.5 GeV magnet block [13] with coils (red). All magnets contained in the DBA cell are machined from two 4.5 m long iron blocks (green). The correction sextupoles, field clamps, and conduits have not been included in this drawing.

from the start [17]. This injection scheme has several advantages over conventional injection with a closed four-kicker bump. The potential to make top-up injection entirely transparent to users is certainly the main motivation behind this decision. However, despite the great performance expected from PSM injection, commissioning a new storage ring with this injection scheme is non-trivial. During early commissioning the exact beam position is possibly not known and at least a few magnets with erroneous strengths or inverted polarity have to be assumed. Additionally, the injected bunches have to be transported from the injection septum through a fairly long magnet section successfully before reaching the PSM where they can be captured within the storage ring acceptance. If, due to unforeseeable errors, this transport is not successful, a lack of stored beam makes diagnosing and correcting the errors very difficult.

In order to facilitate early commissioning, it has therefore been decided to install a single dipole injection kicker as close as possible to the injection septum in both storage rings. This will allow injecting beam into the storage ring even before exact beam positions and optics are known and have been corrected. Although the dipole kickers cannot be installed directly at cross-over locations (which would allow for on-axis injection), the amplitude of the injected beam at the dipole kicker is sufficiently low so that an appropriate dipole kick will knock the injected particles to well within the storage ring acceptance.

For both rings, an ideal kick strength has been calculated in order to minimize the reduced invariant of the injected particles (3.5 mrad in the 3 GeV ring, 2.2 mrad in the 1.5 GeV ring). Furthermore, if this strength is reduced somewhat, injected particles are captured within the storage ring acceptance (albeit not at the minimum reduced invariant) while any particles previously stored in the machine are not kicked out of the acceptance. Operated at such a setting, the dipole kickers can be used to accumulate small amounts of beam in the storage ring. Once some beam can be stored, magnet errors can be detected, corrections to the optics can be made, and beam positions can be more accurately determined. The commissioning team is then in a much better position to commission injection with the PSM. In this way, the dipole kickers reduce the risk of relying exclusively on a novel injection scheme in both storage rings from the start.

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