RECENT PROGRESS ON THE MAX IV 1.5 GeV STORAGE RING LATTICE AND OPTICS

S.C. Leemann*, MAX IV Laboratory, Lund University, SE-22100 Lund, Sweden

Abstract

Construction of the MAX IV facility started in 2010 and commissioning is expected to begin in 2014. Once completed, 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 lattice and optics of the 1.5 GeV storage ring have been modified as a result of detailed magnet and vacuum system design. This paper discusses the lattice and optics changes as well as their effects.

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]. A facility overview is displayed in Fig. 1.

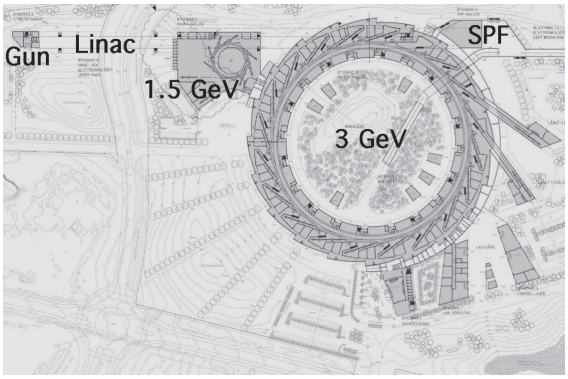

Figure 1: Overview of the MAX IV facility. The gun bunker is at the top left followed by the underground linac tunnel. The 1.5 GeV and 3 GeV storage ring buildings are indicated. The short-pulse facility (SPF) is indicated at the top right.

With facility construction progressing swiftly [3, 4], detailed designs of accelerator subsystems are being completed so purchasing orders can be sent out on time. For the 1.5 GeV storage ring, detailed magnet and vacuum system design efforts are being completed. In this process, feedback from these areas led to changes to the storage ring lattice and optics. This paper summarizes the latest modifications to the storage ring lattice and optics, and demonstrates performance of the updated lattice.

OVERVIEW OF THE 1.5 GeV STORAGE RING

The 1.5 GeV storage ring will replace the present-day storage rings MAX II and MAX III. An identical copy of the MAX IV 1.5 GeV storage ring will be built in Krakow, Poland where it will be the source of synchrotron radiation for the new Solaris facility [5]. An original design report for the 1.5 GeV storage ring was completed in 2010 [1, 6] and recently updated to include an improved lattice model and results of detailed magnet and vacuum system design [7]. This design foresees a simple and robust 12-fold DBA lattice with 96 m circumference and 6 nm rad horizontal emittance. Ten 3.5 m long straight sections are available for insertion devices. In addition, dipole radiation ports off of the first dipole of every DBA cell are foreseen. A schematic of one DBA cell is shown in Fig. 2.

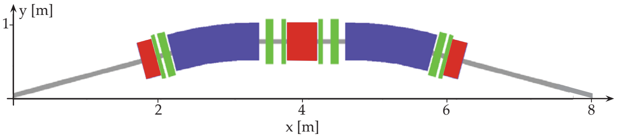

Figure 2: Schematic of one of the twelve DBAs of the MAX IV 1.5 GeV storage ring. Magnets indicated are gradient dipoles (blue), combined quadrupole/sextupole magnets (red), and discrete sextupoles (green).

RECENT 1.5 GeV STORAGE RING MODIFICATIONS

The starting point for detailed magnet and vacuum system designs for the 1.5 GeV storage ring was the lattice provided in the MAX IV Detailed Design Report [1]. Detailed magnet design [8] has however requested more space for sextupole magnet coils and required that magnets adjacent the dipoles be shifted in order to make more space for the dipole field clamps. The magnetic lengths of the trim sextupoles in the lattice have been modified to better match the magnetic length given by the mechanical design. The lattice now also contains slice models for the dipoles (28 slices) and quadrupoles (3 or 4 slices). The slice model includes fringe fields and crosstalk. This is crucial in order to properly model the magnet design as all magnets in the DBA cell are machined from a solid iron block. Such integrated magnet design allows for very compact optics (cf. Fig. 3). This is further enhanced by making use of combined-function magnets: defocusing gradients in the dipoles (adjustable via pole-face strips) and sextupole gradients in the focusing quadrupoles. Other corrections

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* simon.leemann@maxlab.lu.se

(dipole correctors, skew quadrupoles, auxiliary sextupoles) are implemented as extra windings on regular quadrupoles and sextupoles.

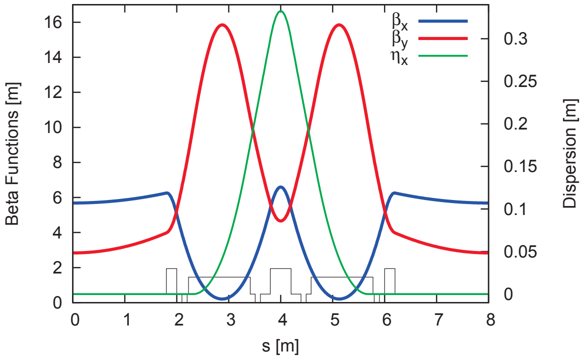

Figure 3: Optics of one DBA cell in the updated MAX IV 1.5 GeV storage ring lattice. The location of the dipoles, combined quadrupole/sextupole magnets, and discrete sextupoles are indicated at the bottom.

Unlike the MAX IV 3 GeV storage ring, the vacuum system for the MAX IV 1.5 GeV storage ring makes use of a conventional stainless steel chamber design with an elliptical cross-section, dipole antechambers, and lumped absorbers. The detailed vacuum design work is well underway. Standard beam-stay clear areas are 20 mm × 10 mm (half-apertures), however, at the center of the DBA cell, where dispersion reaches its maximum of 0.33 m, this area shall be enlarged to ensure sufficient momentum acceptance. An elliptical cross section of 28 mm × 14 mm (half-apertures) throughout the quadrupole at the DBA center and its adjacent correction sextupoles pushes the overall momentum acceptance closer to the maximum RF acceptance of 4.1%.

In addition to magnet and vacuum design improvements, other modifications have been made in the 1.5 GeV storage ring design compared to the original design report [1]. A second harmonic Landau cavity [9] has been included for optimum bunch lengthening. Injection into the storage ring has been entirely redesigned. A pulsed sextupole magnet can capture injected bunches without the need for an injection bump and without perturbing the stored beam [10]. This should make top-up injection transparent to users. During early commissioning a single dipole kicker can be used as a simple and robust method to capture bunches in the storage ring. Later, this device will be used as a horizontal pinger magnet for machine physics studies.

EXPECTED PERFORMANCE OF THE MODIFIED LATTICE

The key parameters of the updated storage ring are given in Table 1. Compared to the original design, the working point has been shifted slightly. Along with the reoptimized nonlinear optics, this results in a very compact tune footprint (cf. Fig 4) in an area that is free of potentially dangerous resonances. This small tune footprint is corroborated by frequency map analysis (FMA): a large continuous area of low diffusion around the design orbit and over a wide energy range can be recognized (cf. Figs. 5 and 6).

Table 1: Parameters for the MAX IV 1.5 GeV Storage Ring

Energy [GeV]	1.5
Main radio frequency [MHz]	99.931
Circulating current [mA]	500
Circumference [m]	96
Number of achromats	12
Length of straight section [m]	3.5
Betatron tunes (H/V)	11.22 / 3.15
Natural chromaticities (H/V)	$-23.0 / -17.1$
Corrected chromaticities (H/V)	$+1.0 / +1.0$
Momentum compaction factor	3.06×10^{-3}
Hor. emittance (bare lattice) [nm rad]	5.982
Radiated power (bare lattice) [keV/turn]	114.1
Natural energy spread (bare lattice)	7.45×10^{-4}
Req. dyn. acceptance (H/V) [mm mrad]	14 / 3
Req. lattice momentum acceptance	$\approx 4\%$

The nonlinear optimization process has resulted in a large dynamic aperture, both on and off momentum, that is stable even after the introduction of strong insertion devices [11] and errors. Figure 7 shows results for the dynamic aperture of the ideal bare lattice (a comparison with FMA results indicates that this ideal lattice DA includes an island at large vertical amplitudes) as well as the realistic machine, i.e. a machine where misalignments as well as field and multipole errors have been included (details of the applied error models are given in [7]).

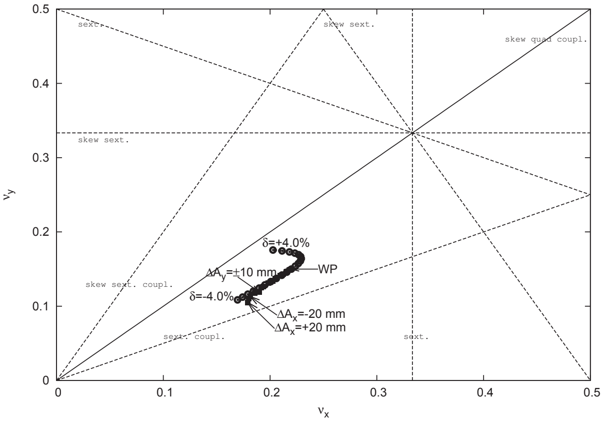

Figure 4: Chromatic and amplitude-dependent tune shifts from the design working point (WP) in fractional tune space. The track point for these studies was at the center of the straight section.

6D tracking studies performed with Tracy-3 confirm that the modified optics along with the updated vacuum

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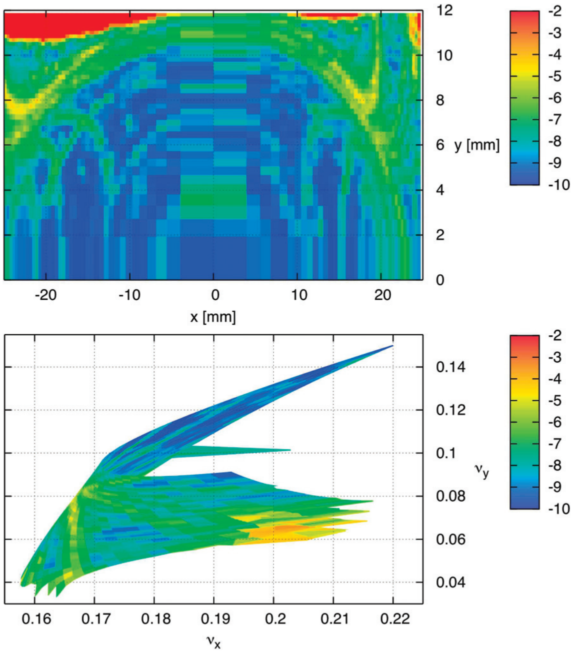

Figure 5: On-momentum FMA performed with Tracy-3. Diffusion is displayed in configuration space around the design orbit (top) and in tune space (bottom).

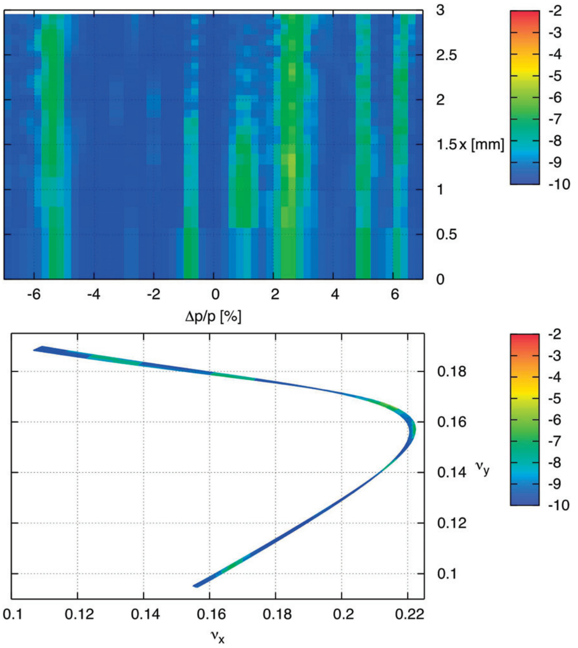

Figure 6: Off-momentum FMA performed with Tracy-3. Diffusion is displayed for different momenta close to the beam's center (top) and in tune space (bottom).

apertures achieve an overall momentum acceptance above 3.5%. This translates to a Touschek lifetime (including bunch lengthening from the Landau cavities) beyond 20 hours at 500 mA stored current held constant by top-up shots from the MAX IV linac. Overall lifetime in the 1.5 GeV storage ring should therefore be around 10 hours.

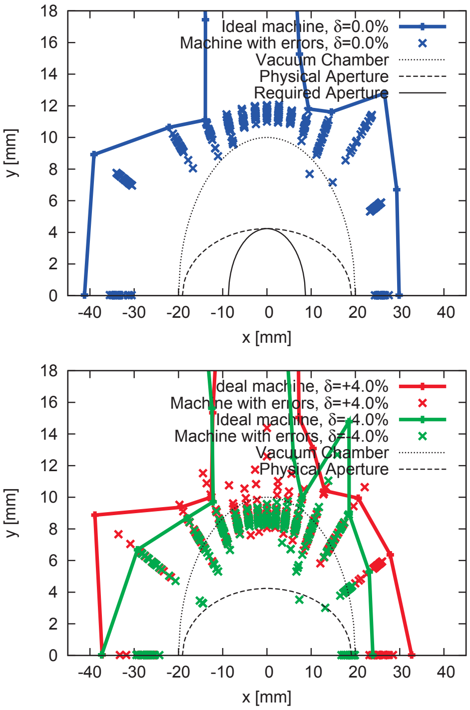

Figure 7: Dynamic aperture on energy (top) and off energy (bottom) calculated with Tracy-3 in 6D. The plots show 20 error seeds. The "required aperture" reflects requirements derived from injection and lifetime studies.

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