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STATUS OF THE MAX IV STORAGE RINGS

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Abstract

In 2009 the MAX IV facility was granted funding by Swedish authorities. Construction of the facility will begin this summer and user operation is expected by 2015. MAX IV will consist of a 3.4 GeV linac as a driver for a short-pulse radiation facility (with planned upgrade to a seeded/cascaded FEL) as well as an injector for two storage rings at different energies serving user communities in separate spectral ranges. Thanks to a novel compact multibend-achromat design, the 3 GeV ring will deliver a 500 mA electron beam with a horizontal emittance below 0.3 nm rad to x-ray insertion devices located in 19 dispersion-free 5 m straight sections. When the 3 GeV ring goes into operation in 2015 it is expected to become the highest electron-brightness storage ring light source worldwide. The 1.5 GeV ring will serve as a replacement for both present-day MAX II and MAX III storage rings. Its below 6 nm rad horizontal emittance electron beam will be delivered to IR and UV insertion devices in twelve 3.5 m straight sections. We report on design progress for the two new storage rings of the MAX IV facility.

MAX IV FACILITY

The MAX IV facility [1] aims to deliver light to a broad and international user community across a wide spectral range and covering different temporal scales. This goal is achieved by building separate machines to host different types of synchrotron user experiments. In this way each user community is served optimally by a device tailored to their needs without requiring other experiments to compromise.

Users requiring high peak brightness will be able to conduct their experiments at the short-pulse facility (SPF) which produces spontaneous radiation in several undulator branches fed with short and intense pulses from the 3.4 GeV linac [2]. Users interested in fully coherent, highest peak brightness radiation will be served by the FEL branch to be built alongside the SPF in phase two of the project. The FEL will use the same linac, however the design allows for exchange of the gun if necessary. Finally, users who require high average brightness radiation without demands for temporal coherence are served by two storage rings optimized for different wavelength ranges: the ultralow-emittance 3 GeV storage ring delivers spatially coherent x-ray radiation while the 1.5 GeV storage ring houses diffraction-limited IR and UV beamlines. The 1.5 GeV ring will also serve as a replacement for both MAX II [3] and MAX III [4]. Certain beamlines on these two present-day storage rings will move to the new 1.5 GeV ring upon its completion thus preventing a "dark period" at MAX-lab. A facility overview is displayed in Fig. 1.

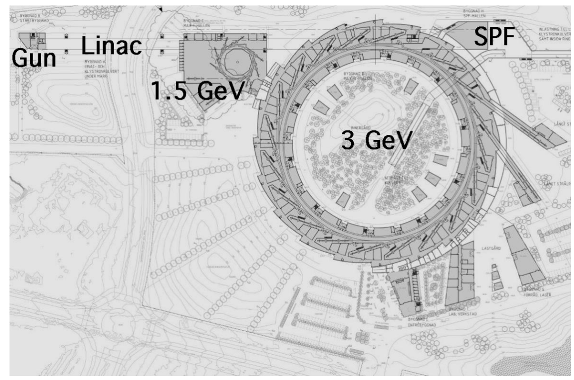

Figure 1: Overview of the MAX IV facility. The gun bunker is at the top left followed by the underground linac tunnel. The 1.5 GeV and 3 GeV storage ring buildings are indicated. The SPF is indicated at the top right.

The use of the 3 GHz drive linac of the SPF and FEL as a full-energy injector for the two storage rings (via low and high-energy transfer line), enables continuous top-up operation of both storage rings. This not only increases the integrated current delivered to users, but also improves stability by reducing thermal load variations. For top-up shots into the storage rings a second gun injects into the linac. While the SPF and FEL use a high-brightness photo-RF gun, storage ring injections come from a high-availability thermionic RF gun optimized for high charge. Injections into the linac for the SPF and FEL occur at up to 100 Hz and are interrupted only for top-up shots to the storage rings (10 Hz, 1 nC/shot). Because of the separation of function between the SPF/FEL and storage rings, the storage rings do not have to serve short-pulse users and can therefore use a 100 MHz main RF system and store long bunches. This counteracts resistive wall instability and thus reduces the need to run at large positive chromaticities which usually restricts the energy acceptance of a storage ring.

3 GEV STORAGE RING

The 3 GeV storage ring was designed to meet the requirements of state-of-the-art insertion devices (IDs) for the generation of high-brightness hard x-rays. It is based on a novel compact multibend achromat (MBA) lattice which delivers a horizontal emittance below 0.3 nm rad (including damping wigglers and IBS) and is diffraction-limited in the vertical plane. Its 528 m circumference houses 20 MBAs

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with 20 5 m straight sections for IDs and 40 short straight sections for RF cavities and diagnostics. Figures 2 and 3 show a schematic of the multibend achromat design and the lattice optics. The detailed design of the 3 GeV storage ring has been completed to a large extent and is described elsewhere [1, 5, 6]. Only modifications made to the previously published design shall be summarized here.

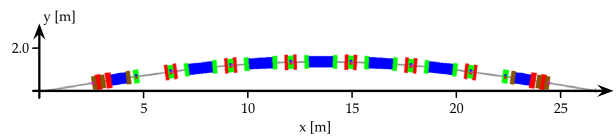

Figure 2: Schematic of one of the 20 achromats of the MAX IV 3 GeV storage ring. Magnets indicated are gradient dipoles (blue), focusing quadrupoles (red), sextupoles (green), and octupoles (brown). The basic structure of five unit cells flanked on either side by a matching cell can be recognized.

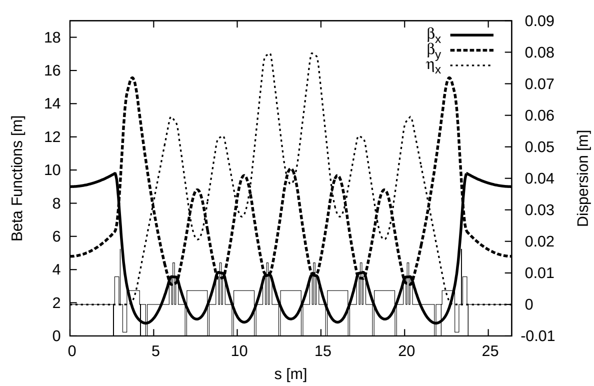

Figure 3: Beta functions β_x, β_y and dispersion η_x for one achromat of the MAX IV 3 GeV storage ring. The position of the dipoles, quadrupoles, sextupoles, and octupoles are indicated at the bottom.

All magnets within a unit cell (five per MBA) or matching cell (two per MBA) will be machined into a solid iron magnet block. This integrated magnet design allows for a very compact lattice and facilitates alignment of the magnets on massive but inexpensive concrete supports (cf. Fig. 4). The block consists of two halves; the top half is lowered onto the bottom half after the vacuum chamber is installed. The mounting plate on top of the support has three adjustment points which allow alignment of the magnet block.

The vacuum chamber is a circular copper pipe (24 mm outer diameter) which is NEG-coated on the inside to allow for distributed pumping. A cooling channel is brazed to the outside of the vacuum chamber at the locations of the dipoles. In this way lumped absorbers are avoided and fewer pumps are required. Very good experience has been made with prototype chambers installed in MAX II [7].

Recent studies have shown that a single pulsed sextupole magnet (PSM) could be used for injection into the 3 GeV

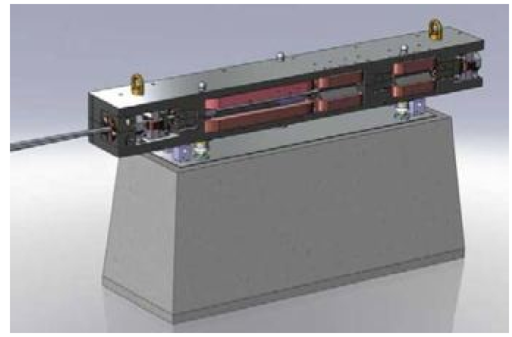

Figure 4: Illustration of the solid iron block out of which the magnets for one complete cell of the MAX IV 3 GeV storage ring have been machined. The example here shows the matching cell upstream of the long straight section. Note the massive concrete support with mounting plate.

storage ring [8]. This method does not require kicking the stored beam onto an injection bump and hence synchronizing four fast kicker magnets as in conventional injection. Residual orbit oscillations during injection which can lead to photon intensity fluctuations at the experiment can thus be avoided. Ultimately, such a PSM injection could enable very frequent low-charge top-up injections which should further increase stability.

Ongoing work includes the design and optimization of IDs [9], detailed design of the vacuum and RF systems, orbit feedback studies, as well as investigations into coupling correction and suppression of vertical dispersion [1].

1.5 GEV STORAGE RING

The 1.5 GeV storage ring will replace the present-day storage rings MAX II and MAX III. It is being designed so insertion devices and beamlines can be moved to the new MAX IV facility. Detailed design efforts for the 1.5 GeV storage ring components have just begun. The lattice design of the 1.5 GeV storage ring is presently being completed [1] after which the detailed design of the magnets will commence. The 1.5 GeV storage ring lattice in its current state is presented here.

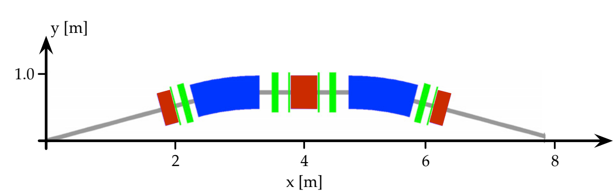

Figure 5: Schematic of one of the twelve DBAs of the MAX IV 1.5 GeV storage ring. Magnets indicated are gradient dipoles (blue), combined quadrupole/sextupole magnets (red), and discrete sextupoles (green).

The lattice for the 1.5 GeV storage ring is based on a compact double-bend achromat (DBA) delivering 6 nm rad horizontal emittance (cf. Fig. 5). The 96 m circumference allows for twelve DBAs with 3.5 m straights for IDs. As in the 3 GeV storage ring, integrated magnet blocks allow for very compact optics (cf. Fig. 6). This is further enhanced by making use of combined-function magnets: defocusing gradients in the dipoles (DIP), and sextupole gradients in the focusing quadrupoles (SQF). As a result, the 1.5 GeV storage ring offers two ID straights more than MAX II which was also based on a DBA and has almost the same circumference.

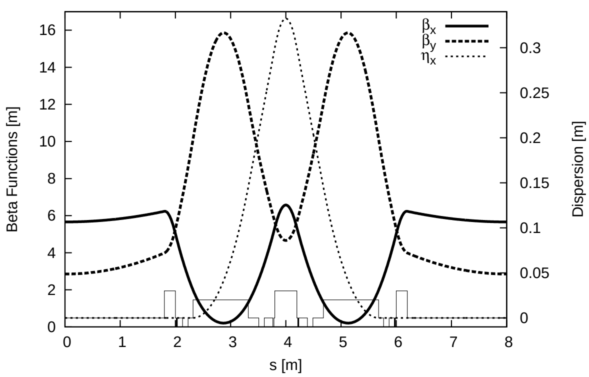

Figure 6: Beta functions β_x, β_y and dispersion η_x for one achromat of the MAX IV 1.5 GeV storage ring. The position of the dipoles, combined quadrupole/sextupole magnets, and discrete sextupoles are indicated at the bottom.

The combined-function quadrupole/sextupole magnets (SQF) are being designed so that the built-in sextupole gradient together with the dedicated defocusing sextupole magnets (SD) correct the natural chromaticity to $\xi_{x,y} = +2.0$. An additional correction sextupole (SC) allows adjustment of the chromaticities within 0.0 to +4.0 (cf. Table 1). The option to compensate for a single superconducting wiggler is included in the design. The overall defocusing gradient (and hence the working point) can be shifted by powering pole face strips in the dipoles. Parameters of the 1.5 GeV storage ring are shown in Table 2.

Table 1: Strengths of the magnets in the MAX IV 1.5 GeV storage ring. The gradients have been normalized. The settings shown here are for chromaticity $\xi_{x,y} = +1.0$.

Family	B_{bend} [T]	b_2 [m^{-1}]	b_3 [m^{-2}]
DIP	1.31	−1.35	—
SQFi	—	5.00	28.04
SQFo	—	5.74	36.68
SDi	—	—	−68.18
SDo	—	—	−84.76
SCi	—	—	−20.16
SCo	—	—	−30.00

Two 100 MHz RF cavities and a third-harmonic Landau cavity similar to those used in the 3 GeV storage ring will be installed in one straight. Overall lifetime is expected to be above 10 hours. The vacuum chamber will be a NEG-coated copper tube with elliptical cross-section; the increased horizontal aperture will accommodate for the larger dispersion in the 1.5 GeV ring. The stored current will be held constant at 500 mA with top-up shots from the MAX IV linac extracted through the low-energy transfer line. Orbit correction will be performed with three BPM/corrector pairs (similar to those used in the 3 GeV storage ring) per achromat: two pairs flanking each straight and one pair is installed next to the center SQF magnet. The detailed design of these systems is an ongoing effort.

Table 2: Parameters for the MAX IV 1.5 GeV storage ring.

Energy [GeV]	1.5
Main radio frequency [MHz]	99.931
Harmonic number	32
Circulating current [mA]	500
Circumference [m]	96
Number of achromats	12
Length of straight section [m]	3.5
Betatron tunes (hor / ver)	11.22 / 3.14
Natural chromaticities (hor / ver)	−22.9 / −17.1
Corrected chromaticities (hor / ver)	+1.0 / +1.0
Momentum compaction factor	3.04×10^{-3}
Hor. emittance (bare lattice) [nm rad]	6.00
Radiated power (bare lattice) [keV/turn]	117.2
Natural energy spread (bare lattice)	7.51×10^{-4}
Req. dyn. acc. (hor / ver) [mm mrad]	61 / 6
Req. lattice mom. acceptance	±3.0%

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