The MAX IV Facility

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Abstract. The MAX IV synchrotron radiation facility is currently being constructed in Lund, Sweden. The accelerator park consists of a 3 GeV linac injector and 2 storage rings operated at 1.5 and 3 GeV respectively. The linac injector will also be used for the generation of short X-ray pulses. Close to 30 straight sections will be available for IDs at the rings. The three machines mentioned above are described below with some emphasis on the effort to create a very small emittance in the 3 GeV ring. Some unconventional technical solutions imposed by the emittance minimisation are discussed.

1. Design Philosophy
The design of the MAX IV facility started in 2002 and originates from the following assumptions:

- Storage rings will remain the light source workhorses for the foreseeable future.
- The ring emittance can be reduced towards the diffraction limit.
- Free Electron Lasers (FELs) will become invaluable complements to the ring sources and open up new research areas.

The base-line design [1] includes the following accelerators:

- A 3 GeV injector linac
- A 3 GeV low emittance hard X-ray ring
- A 1.5 GeV medium emittance soft X-ray ring

The injector linac will, apart from being an injector for the storage rings, also act as an electron source for a Short Pulse Facility (SPF) providing fs X-ray pulses of spontaneous undulator radiation. This linac system is also prepared for an eventual future FEL extension.

Two storage rings, operated at different electron energies, were chosen to cover a broad spectral range of high quality synchrotron radiation from optimized undulator sources. The two rings share the infrastructures in terms of injector, building, control systems, media etc. Two copies of the 1.5 GeV ring will be built, one will be placed in Lund and the other will be placed in Krakow [2] and constructed in cooperation with the Solaris staff.

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The 3 GeV ring emittance was minimized following the multi-bend achromat concept [3] within given economy and space boundaries.

2. The linear accelerator
The S-band injector linac operates at a relatively low accelerating gradient of some 15 MV/m to reduce the operational cost and to achieve a high level of electron energy redundancy. There are 18 RF stations, each consisting of a modulator and klystron feeding two or four 5.2 m long linac sections. SLED cavities are introduced to reduce the number of RF stations.

| Table 1. Linac parameter values. |
|----------------------------------|
| Operating energy                | 3.0 GeV     |
| Maximum energy                  | 3.7 GeV     |
| RF                               | 3 GHz       |
| Linac length                     | 300 m       |
| Charge/bunch                     | 100 pC      |
| Bunches/pulse SPF               | 1           |
| Bunches/pulse (injector)        | 30          |
| Max rep rate (inj)              | 100 Hz      |
| Bunch length (FWHM)             | 30-100 fs   |

Each RF unit consists of one solid state modulator feeding a 37 MW klystron. The RF pulse, with a maximum length of 4.5 μs, feeds a SLED cavity, where the RF pulse is compressed to 0.7 μs with a resulting electron energy gain factor of 1.8.
3. The 3 GeV ring

3.1. System integration
To obtain a small emittance, the MAX IV 3 GeV ring will be equipped with more than 1000 magnets of various kinds. A high degree of miniaturisation is thus mandatory to prevent the ring to grow beyond space and economy limits. Small magnet implies limited vacuum conductance with a need for a linear pumping scheme. The RF system should be chosen to restrict Touschek losses and Intra Beam Scattering (IBS) effects which else should be pronounced in this small emittance ring.

The technical design thus calls for system integration where technologies are chosen to match the challenges implied by small emittance request.

An integrated magnet design housing several magnet elements within the same solid steel magnet block was then developed. Several magnets are then machined out from this magnet block. All cabling and piping of these blocks are carried out by the magnet supplier.

3.2. Magnet lattice
A 7 bend achromat lattice was chosen to get a sufficiently small horizontal emittance. This type of lattice is characterized by a large number of dipole magnets and an emittance reduction is due to this large number. Our lattice modelling indicates a high level of stability for the type of lattice chosen.

20 achromats yields a naked lattice emittance of 330 pm rad. The low dipole field value of 0.5 T, will introduce a significant emittance reduction when Insertion Devices (IDs) are introduced. A fully armed ring with 19 straight sections equipped with IDs, will result in an emittance decrement towards 200 pm rad including elastic scattering effects. The dynamic aperture is 10*4 mm² in the long straights.

This type of lattice is highly stable since the driving terms, introduced by the strong chromaticity correcting sextupoles, are almost cancelled within an achromat. Octupole magnets are introduced to minimize the amplitude-dependent tuneshifts. The lattice optimisation was carried out with the OPA [5] and TRACY 3 [6] codes [7,8,9].

![Figure 2. The 3 GeV ring lattice functions (above) and magnet lattice (below).](image-url)
### Table 2. 3 GeV ring parameters.

| Parameter                              | Value            |
|----------------------------------------|------------------|
| Operating energy                       | 3.0 GeV          |
| Circulating current                    | 0.5 A            |
| Circumference                          | 528 m            |
| Straight section length                | 4.6 m            |
| Hor emittance, naked lattice           | 0.33 nm rad      |
| Hor emittance incl IDs                 | 0.23 nm rad      |
| Coupling                               | 0.5-3 %          |
| Total beam life-time                   | 10 h             |
| RF                                     | 100 MHz          |
| $Q_x/Q_y$                              | 42.2/16.28       |
| $\xi_x/\xi_y$                         | -50.0/-50.2      |

#### 3.3. Magnet design

One example of a magnet block is seen below. The magnet technology is further described in ref [10].

![One flanking cell magnet block.](image)

The block shown above houses one dipole magnet, two quadrupoles, one sextupoles, three octupoles and two pairs of dipole correctors. Two BPM heads supported in a symmetrical way to avoid movements due to heat load are also integrated.

The concrete magnet girder is equipped with magnet block adjustment means. This stiff concrete girder design is most favourable from a vibration point of view.

#### 3.4. Vacuum system

The small magnet bore radius of 13 mm allows for a vacuum chamber bore radius of 11 mm only. Despite this limited aperture, the vacuum chamber can still house and momentum acceptance of 4.5% due to small lattice dispersion function. A NEG-coated CuS tube will handle almost all pumping needed as well as the synchrotron radiation heat-load [11]. Only a few lumped heat absorbers are needed.

One example of a vacuum chamber is seen below.
3.5. RF
A 100 MHz RF system, similar to the ones used in the MAX II and MAX III rings are used for both rings [12]. The relatively low frequency favours a high bucket height in medium energy rings and standard FM transmitters can be used as RF sources.

Passive cavities, operated at the third harmonic, are used to stretch the electron buckets. Their action results in an improved Touschek lifetime and increased RF-related instability thresholds as well as a reduction of the IBS effect.

4. The 1.5 GeV ring
Two identical storage rings are built; one will be placed at the MAX IV Laboratory in Lund, the other at Solaris in Krakow, Poland. A 12 Double Bend Achromat (DBA) lattice is chosen and a similar magnet technology as in the 3 GeV ring will be used.

The magnet lattice is seen below and the most important machine parameters are shown in table 3.

Figure 5. One vacuum chamber section.

Figure 6. 1.5 GeV ring machine functions and lattice.
Table 3. 1.5 GeV ring parameters.

| Parameter                                      | Value       |
|------------------------------------------------|-------------|
| Operating energy                               | 1.5 GeV     |
| Circulating current                           | 0.5 A       |
| Circumference                                 | 96 m        |
| Straight section length                        | 3.5 m       |
| Hor emittance, naked lattice                   | 6 nm rad    |
| Coupling                                       | 0.5-5 %     |
| Total beam life-time                           | 10 h        |
| RF                                            | 100 MHz     |
| $Q_x/Q_y$                                      | 11.22/3.15  |
| $\xi_x/\xi_y$                                  | -22.9/-17.1 |

5. Status
The linac tunnel is now almost finished and linac installation should start April 2013. The 3 GeV ring follows one year later and operation should start up end 2015-early 2016. The 1.5 GeV ring follows half a year after the 3 GeV one.

Acknowledgements
The MAX IV facility is constructed with a solid support from our colleague laboratories. Special thanks to ALBA, taking a heavy load of the design work of the vacuum system. Valuable cooperation has been established with BINP, CERN, CLS, DESY, Elettra, ESRF, NSLS II, PSI and Soleil to mention a few. The Solaris team is working side by side with the MAX staff.

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