CHALLENGE OF MAX IV TOWARDS A MULTI PURPOSE HIGHLY BRILLIANT LIGHT SOURCE

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Abstract

The MAX IV light source complex is currently being constructed in Lund, Sweden. One of its main sources, a 3 GeV storage ring, is designed to achieve a natural emittance of 0.2 nm rad. A second storage ring operated at 1.5 GeV will broaden the spectral region offered by the facility. The complex will also provide a Short Pulse Facility delivering short X-ray pulses of spontaneous radiation where the 3 GeV injector linac will be used as the electron source.

The speaker will discuss facility targets, the concept of this accelerator design, and show some possibilities of approaching two-dimensional diffraction limited X-ray generation at MAX IV.

DESIGN PHILOSOPHY

When designing the MAX IV facility [1], the following assumptions were made:

- Storage rings will remain the workhorses as light sources for the foreseeable future.
- The ring emittance can be reduced towards the diffraction limit.
- FELs will open up new research areas.

A boundary condition for the design of the MAX IV facility was the staff size at MAX-lab. The technology was thus chosen to fit the former technological development at the laboratory (solid iron ring magnets, 100 MHz RF for the rings, 3 GHz linac etc). A high degree of modularity was necessary to limit the need for additional staff.

The MAX IV facility was thus designed to contain one linear accelerator as the injector for two storage rings operated at 3 and 1.5 GeV respectively to cover different spectral regions. Top-up injection will be used.

Although a linac is somewhat more expensive than a booster synchrotron, it opens up the possibility of producing short, intense X-ray pulses. The linear accelerator will in the first phase feed a spontaneous emitter and may later be extended to say 6 GeV to feed an X-ray SASE FEL. This eventual energy upgrade is prepared for in the building design and land is also allocated to house a longer tunnel.

To reduce electron beam emittance in the 3 GeV ring, the 7-bend achromat concept [2] was followed.

FACILITY OVERVIEW

The overview of the facility is seen in Fig 1. The new facility will be placed at a "green field" site just outside the city of Lund. An S-band linear accelerator equipped with an RF photocathode gun will accelerate electrons up to an energy of 3 GeV. Two bunch compressors are used to shorten the bunches and increase the peak current. Extraction channels are placed at 1.5 GeV and 3 GeV respectively to feed the rings at their operating energies. The linac tunnel is placed below the rings so the electrons are transported vertically to the rings. For injection Lambertson septa and single pulsed multipoles are used to minimize disturbance of the stored beams [3].
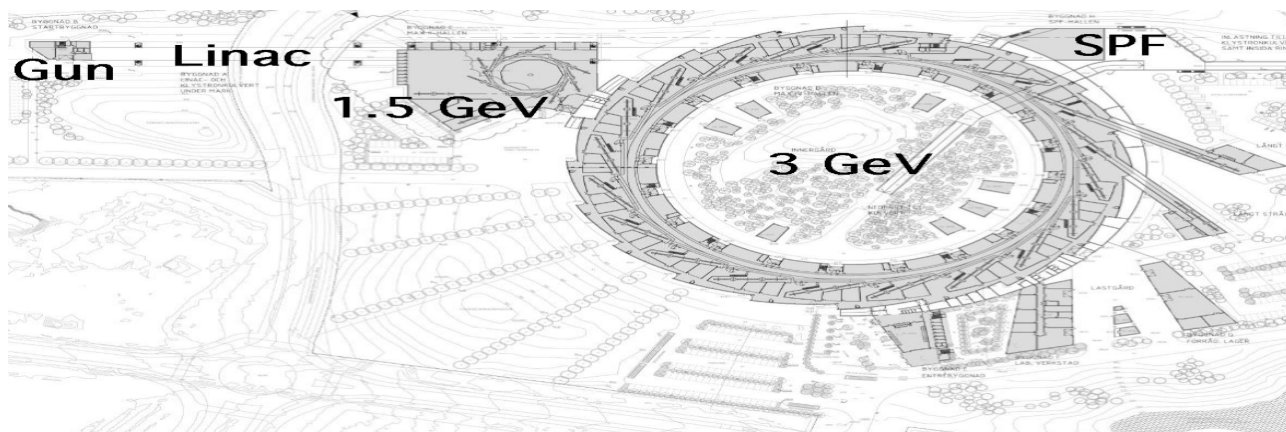

Figure 1: The MAX IV facility.

THE LINEAR ACCELERATOR

As mentioned above, the first phase tasks for the linac are to feed the rings and the SPF, which implies less tight demands than those for FEL A later FEL might very well call for an upgrade of critical parts. At the time being, the tight time.schedule calls for simple and robust design solutions.

When economically optimizing the linear accelerator, a relatively low accelerator gradient of some 15 MeV/m was chosen to reduce the operational cost. Each accelerating unit consists of a 35 MW klystron operated at a lower power of 25 MW to introduce energy redundancy.

Initially, two common Main Drive Lines (MDLs) are feeding all the klystrons except for the first two ones. The MDLs are placed in the linac tunnel to get an automatic compensation for linac tunnel length variations.

Linearization at the bunch compression uses the natural second order matrix terms of a Four Bend Achromat (FBA) where the dipoles are deflecting in the same direction. Contrary to a chicane, the second order T_{566} term is positive in such an achromat and the parameters of the achromat can be chosen for an optimum linearization. Because of symmetry, two FBAs, bending in opposite directions, will cancel second order terms which are odd in horizontal angle or position.

The choice of this type of bunch compressor was motivated by our limited resources to handle additional types of RF systems and a short time-schedule.
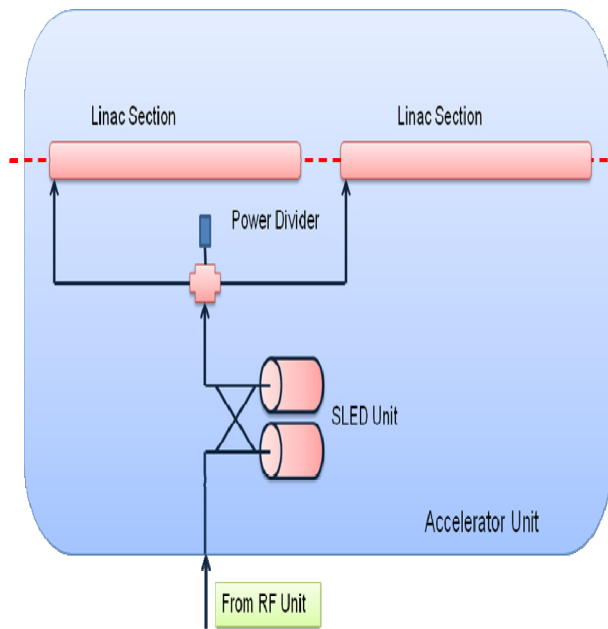

Figure 2: Linac accelerator unit.

One accelerator unit is seen in Fig 2. It consists of a klystron feeding a pair of SLED cavities to boost the RF power. Each pair of SLED cavities feeds two linac sections of 5.2 m length, except for the last two RF units, which feed four linac sections each.

The modulators for the klystrons are of the solid state type. The main reason for this choice was the pulse to pulse stability offered by this modulator type which reduces the linac phase jitter.

The linac is described in more detail in ref. [4].

Table 1: Linac Parameters (SPF/injector)

Operating energy	3.0 GeV
Max energy	3.7 GeV
Charge/bunch	0.1 nC
Bunches/train	1/3
Max rep rate	100 Hz
Bunch length (FWHM)	30-100 fs/3 ps
Peak current	3 kA/30 A

THE 3 GEV RING

The 7-bend achromat was chosen to get a small horizontal emittance. This type of magnet lattice is highly stable since the driving terms, introduced by the chromaticity correcting sextupoles, can be almost cancelled within the achromat itself, despite the strong sextupoles necessary to correct the chromaticity in a lattice with small dispersion functions. There is a sufficient number of sextupole families with proper betatron phaseshifts between the sextupoles to carry out this minimisation process, which is greatly simplified by the usage of the lattice code OPA [5]. The situation is further improved by the introduction of octupole magnets, which decrease amplitude-dependent tune-shifts [6].
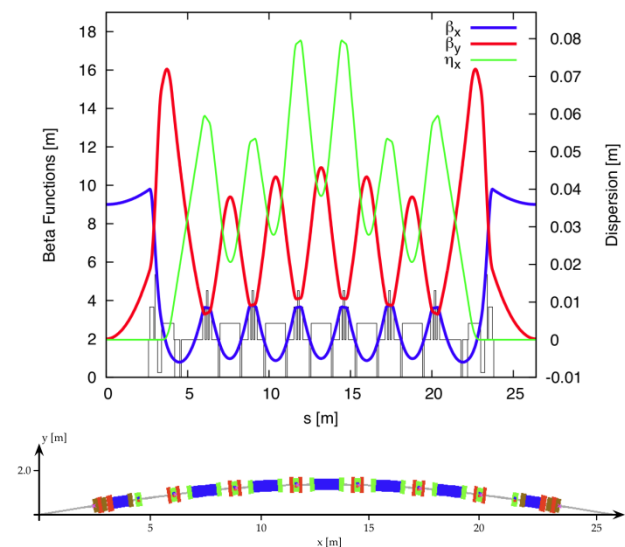

Figure 3: 3 GeV ring achromat and machine functions.

20 achromats are used for achieving a sufficient number of straight sections for the insertion devices (IDs) and to get an ultralow electron beam emittance. Since the

dipole fields are weak, the IDs reduce the lattice emittance considerably.

It should be noted that the drawback of this kind of lattice is that the total length of ID straights easily becomes small compared to the total ring circumference if a compact magnet lattice is not chosen.

The required aperture is however small since the dispersion functions are small due to the large number of lattice cells. A small vacuum chamber bore, favouring small magnet dimensions, is thus possible.

This will however exclude a conventional ion pump vacuum system, since the vacuum conductance becomes poor.

The main parameters of the 3 GeV storage ring are displayed in Table 2.

Table 2: 3 GeV Ring Parameters

Operating energy	3 GeV
Circulating current	0.5 A
Circumference	528 m
Horizontal emittance naked lattice	0.33 nm rad
Horizontal emittance incl IDs	0.23 nm rad
Coupling	0.5-3%
Beam total lifetime	10 h
Qx, Qy	42.20, 14.28
ξx, ξy (natural)	-50.0, -50.2
Mom comp factor	3.07×10^{-4}
Momentum acceptance	4.5 %

The emittance coupling can be kept rather high since there is only little to be gained from getting below the diffraction limit at 1Å in the vertical direction.

The small transverse dimensions of the electron beam call for a harmonic RF system to stretch the bunches in order to achieve a decent Touschek lifetime. It is interesting to note that the Touschek lifetime, after passing a minimum (which lies above the achieved 0.33 nm rad), increases with decreasing beam dimensions.

Magnets

The same magnet technology as applied in the MAX III ring [7] is used for the both MAX IV rings. Several magnets functions are machined from the same solid iron block as seen in Fig 4. This method allows for a high degree of compactness and internal alignment precision.

The iron magnets blocks are mounted on concrete girders as seen in Fig 4. These concrete girders will be positioned within 5 mm and the fine positional adjustment is done at the suspension between the iron block and the concrete girder.

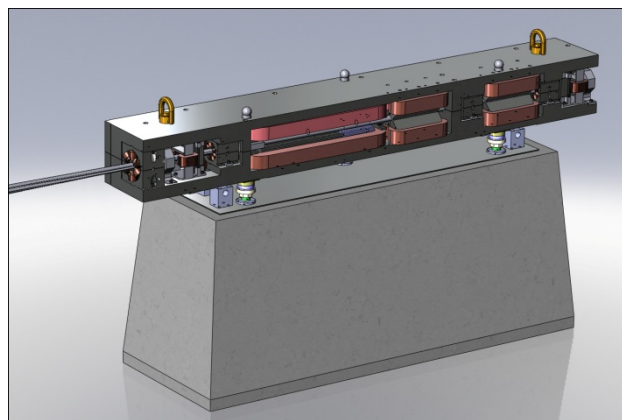Prototypes for the magnet blocks have been manufactured and characterized.

Figure 4: A MAX IV 3 GeV magnet cell. This cell contains 1 dipole, 2 quadrupole, 1 sextupole and 3 octupole magnets plus two dipole corrector pairs and two BPM heads. The iron block length is 1.8 m.

Vacuum system

The vacuum system is of the NEG-coated type. It therefore pumps linearly and performance is thus not hampered by the poor vacuum conductance imposed by the small vacuum chamber bore. In principle, the vacuum system consists of a NEG-coated Cu tube with a bore radius of 11 mm and a cooling channel attached on its outside. The heat absorber design is furthermore simplified since the dipole synchrotron radiation is distributed along the tube so only a few lumped absorbers are needed.
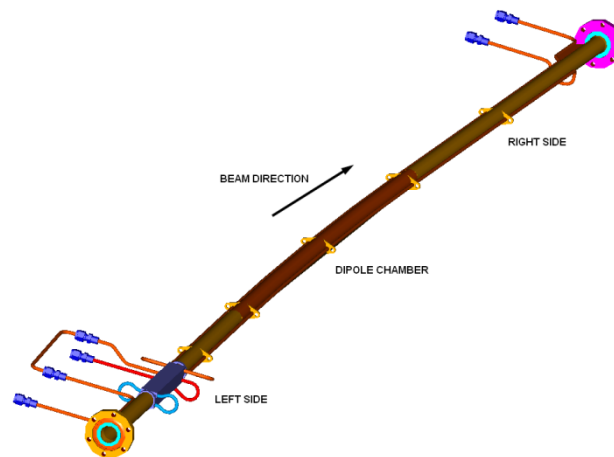

Figure 5: Dipole vacuum chamber.

RF

The same type of 100 MHz RF system as used in MAX II and III [8] will be used. The relatively low frequency favours a large bucket height, narrows the bunch power spectrum and offers the possibility of using high-efficiency and cheap tetrode amplifiers.
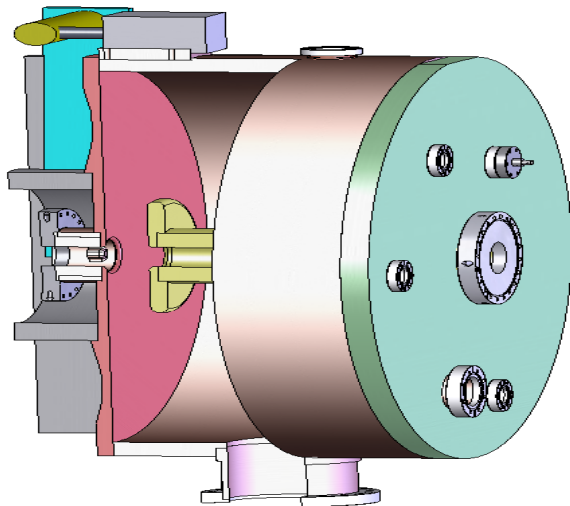
Figure 6: 100 MHz capacity-loaded cavity.

The cavities are of the capacity-loaded type where the Higher Order Modes (HOMs) have a relatively high frequency compared to pill-box cavities, so only few are excited by the long bunches. These HOMs are coupled out by special loops.

Two commercial FM-transmitters of 60 kW each feed one cavity. A total of six cavities are needed to get the 4.5% bucket height (including IDs) and drive the electron beam.

The main RF parameters are seen in Table 3.

Table 3: RF Parameters

Operating frequency	100 MHz
Number of cavities	6
Cavity shunt impedance (linac def)	3.2 MΩ
Cavity Cu losses	28 kW
Toatal RF power	720 kW
Harmonic RF	300 MHz
Total RF voltage	1.8 MV
Total synch rad losses	0.36 MV (bare), 1.0 MV (with IDs)
Bunch length (with harm system), rms	5.6 cm
Bucket height	4.5%

Dynamic aperture

The dynamic aperture is crucial for all small-emittance rings. As explained above, both the dynamic aperture and the momentum acceptance are favoured by the 7-bend achromat lattice [9]. The nonlinear dynamics have been optimized with five sextupole and three octupole families [6,9]. In this process tune shifts are limited and chosen so

that the overall tune footprint is minimized. The sextupoles correct chromaticity to +1.0 in both planes and minimize the first-order resonance driving terms. Second-order chromaticity is adjusted so that the resulting chromatic tune spread within the desired momentum acceptance is minimized. The octupole families are adjusted so the three first-order driving terms for amplitude-dependent tune shift give a minimum tune spread for amplitudes within the acceptance of the storage ring. In this way, the dynamic aperture can be increased, ultimately covering the entire physical aperture of the machine including alignment, field and multipole errors. Overall, the optimization of momentum acceptance and dynamic aperture will ensure good Touschek lifetime and high injection efficiency.
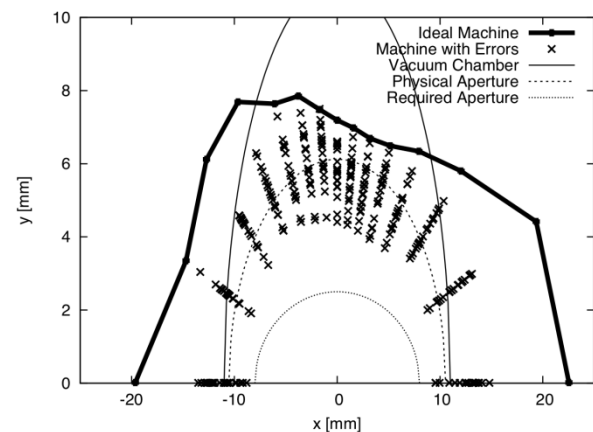

Figure 7: On-momentum dynamic aperture calculated with Tracy-3 at the center of the 5 m long straight section for the MAX IV 3 GeV storage ring. The crosses show results for 20 seeds with random error distributions, mis-alignments, field errors, and multipole errors) and applied orbit correction (for details of the error model see [1]).

THE 1.5 GEV RING

Two identical 1.5 GeV storage rings are being built, one will be placed at MAX IV [10] and one will be placed at Solaris in Krakow.

There will be 12 Double Bend Achromats (DBAs) in each of the 1.5 GeV rings. The machine functions for one DBA are displayed in Fig 8. Three quadrupoles take care of the horizontal focusing while focusing in the vertical direction is handled by gradients in the dipoles.

The technology chosen for the 3 GeV ring is followed for the 1.5 GeV ring as well. The ring parameters are given in Table 4.

Table 4: 1.5 GeV Ring Parameters

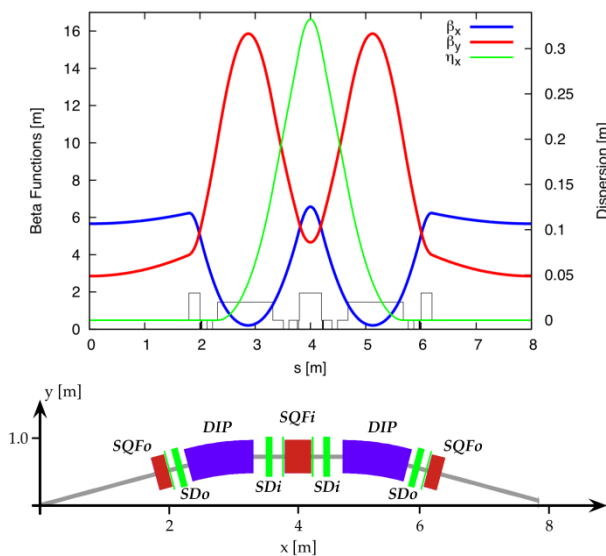|	
Operating energy	1.5 GeV
Circulating current	0.5 A
Circumpherence	96 m
Horizontal emittance (bare lattice)	6 nm rad
Coupling	0.5-5%
Qx, Qy	11.22, 3.14
ξx, ξy (natural)	-22.9, -17.1
Mom comp factor	3.04×10^{-3}
Momentum acceptance	3%

Figure 8: Machine functions and achromat for the 1.5 GeV ring.

STATUS

The first phase of the MAX IV facility covering the building construction, a 3 GeV linear accelerator and two synchrotron radiation storage rings has started. The Detailed Design Report was completed in August 2010 and funding was released September 2010.

The purchasing process is underway and excavation for the linac tunnel will commence in April 2011.

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