THE MAX IV LINAC AND FIRST DESIGN FOR AN UPGRADE TO 5 GeV TO DRIVE AN X-RAY FEL

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Abstract

The installation of the MAX IV linear accelerator is in full progress, and commissioning is planned to start in the second quarter of 2014. The 3 GeV linac will be used as a full energy injector for the two storage rings, and as a high brightness driver for a Short Pulse linac light source. The linac has been deigned to also handle the high demands of an FEL injector. The long term strategic plan for the MAX IV laboratory includes an extension of the linac to 5 GeV and an X-ray FEL.

In this paper we present the both design concept and status of the MAX IV linac along with parameters of the 3 GeV high quality electron pulses. We also present the first design and simulation results of the upgrade to a 5 GeV X-ray FEL driver.

BACKGROUND

The MAX IV facility [1], successor of the MAX-lab accelerators at Lund University, Sweden, was already in the initial plans around year 2000 drawn with the idea that the facility could be extended with a FEL in a later stage. Since then the X-ray FELs LCLS [2] and SACLA [3] have been put into operation as well as the UV machines FLASH [4] and Fermi [5]. The European XFEL [6], the SwissFEL [7] and the PAL-XFEL [8] are currently being constructed, indicating the development of the photon science scene worldwide. The MAX IV facility includes a linear accelerator followed by a short pulse linac light source (SPF) and two storage rings at 3 and 1.5 GeV. The facility is right now being constructed with the installation of the linac structures (up to 3 GeV), waveguides and magnetic systems almost completed (August 2013).

The MAX IV laboratory strategy includes a plan for an extension of the facility with an X-ray FEL starting by a conceptual design in near future, followed by a technical design and a tentative operation in 2021. No funding is at the moment available.

MAX IV LINAC DESIGN CONCEPT

For injection and top up to the storage rings a thermionic gun with a pulse train chopper system is used. In high brightness mode we use a 1.6 cell photo cathode gun capable of producing an emittance of 0.4 mm mrad at a charge of 100 pC [9]. The gun will be operated together with a kHz Ti:sapphire laser at 263 nm. The same laser will be used for timing and synchronisation of the whole accelerator.

The acceleration is done in 39 warm S-band linac sections together with 18 RF units, each consisting of a 35 MW klystron and a solid state modulator. The Klystrons are operated at the lower power of 25 MW which reduces the operational cost and gives a total redundancy in energy of 0.6 GeV. The RF power will be doubled with a SLED

The three first RF units are driven individually by a low level rf system, and the main drive line for the remaining 15 RF units is controlled by extracting power from the last of these LLRF stages. The RF phase can be set individually in the first three stages and power can be set individually for all RF units. The MDL is situated inside the linac tunnel and is attached to the linac in such a way that it will follow the length variations of the linac and help keep the phases stable.

The lattice in the main linac is made with few magnets for simplicity and reduction of vibration sensitivity. Matching is done before each bunch compressor, and the beam is focused with one triplet before each injection extraction point. This means that only 6 quads are used through the whole main linac, about 200 m. This restrictive use of quads leads to a simple, stable and cost effective lattice, that is easy to operate and tune.

The beam is kicked out for injection into the storage rings at 1.5 and 3 GeV. Bunch compression is done in double achromats at 260 MeV and at full energy, 3 GeV, after extraction to the storage ring. A schematic view of the layout can be seen in Figure 1. BC2 is not only used for bunch compression, but also works as a beam distributor for a few beamlines. This is done by letting all electrons pass through the first achromat, and then chose where, in a long transport, to extract the bunch in the second, compressing achromat.The second exit is used for the Short Pulse facility in the current MAX IV plan. The first exit achromat would be used to lead the beam into the linac extension for a possible FEL.

Self Linearising Bunch Compressors

The two magnetic double achromats used as bunch compressors in the MAX IV linac has a positive R56 unlike the commonly used magnetic chicane which has a negative R56. The energy chirp needed for compression is done by accelerating the electrons on the falling slope of the RF voltage. Both types of bunch compressors naturally have a positive T566 and in the case of a BC with positive R56 this has a linearising effect on the longitudinal phase space. We can thus choose the optical parameters in the achromat to get optimal linearisation without needing to have a harmonic linac for this purpose [10].

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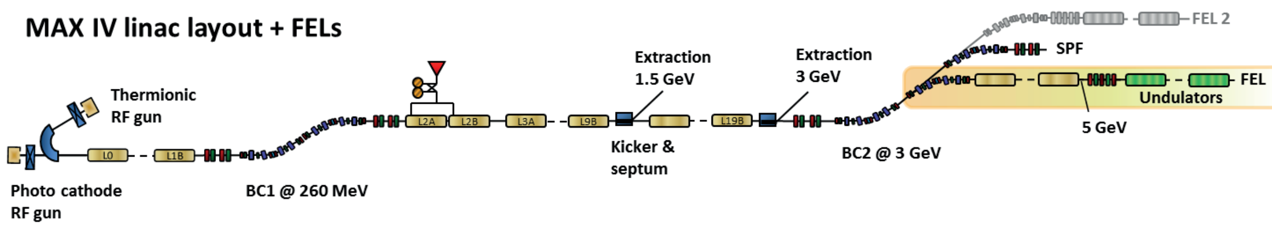

Figure 1: Layout of the MAX IV linac with possible linac extension and FEL undulator section.

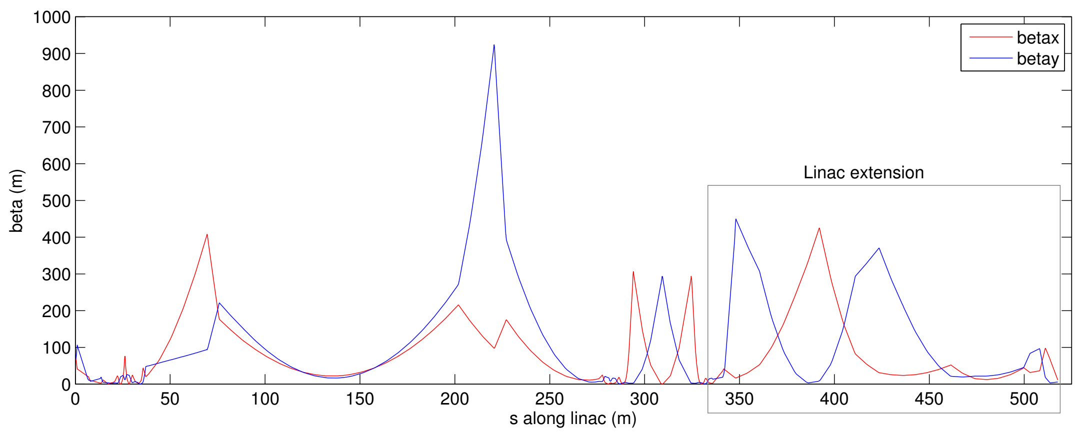

Figure 2: Beta functions through the linac all the way up through the proposed extension. The part of the linac up to the start of the extension is installed and under vacuum.

A sextupole is used in the centre of each achromat to minimize the second order dispersion at the end. This sextupole is rather weak and could be compared with the chromaticity compensating sextupoles in a storage ring. These sextupoles are also used to tweak the linearisation through the bunch compressor. The natural T566 of the double achromats is actually over-linearising the RF induced curvature and the sextupoles work in the opposite direction of the natural T566, to compensate for the over-linearisation.

A schematic view of the layout and optics of bunch compressor 2 can be seen in Figure 3.

Symmetric Achromats to Reduce Chromaticity Effects

If each bunch compressor consisted of only a single achromat we would introduce an increase in transverse chromaticity terms. The symmetry of the two achromats bending in different directions reduces these chromaticity effects substantially and minimize the emittance growth due to chromatic aberrations. It also effectively gives a translation of the electron beam transport instead of a change of angle, which eases the construction of the linac hall.

Since the R56 of the double achromats is fixed, the off crest RF phase is used to vary the compression factor.

Simulation of the MAX IV linac have been performed using ASTRA [11] for the gun and first linac unit and ELEGANT [12] for the linac. Results and parameters for an electron pulse reaching the SPF specifications can be seen in Table 1 and Figure 4.

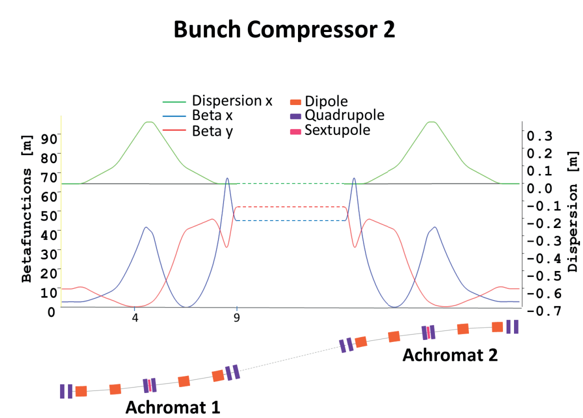

Figure 3: Schematic view and optics of the second bunch compressor.

The scheme of compressing with a positive R56 and a positive RF chirp means that the longitudinal wakefields in the linac works in the same direction as the RF induced chirp. Studies has been performed to see how this affects the compression sensitivity to charge jitter, compared to a case with chicane compressors [13].

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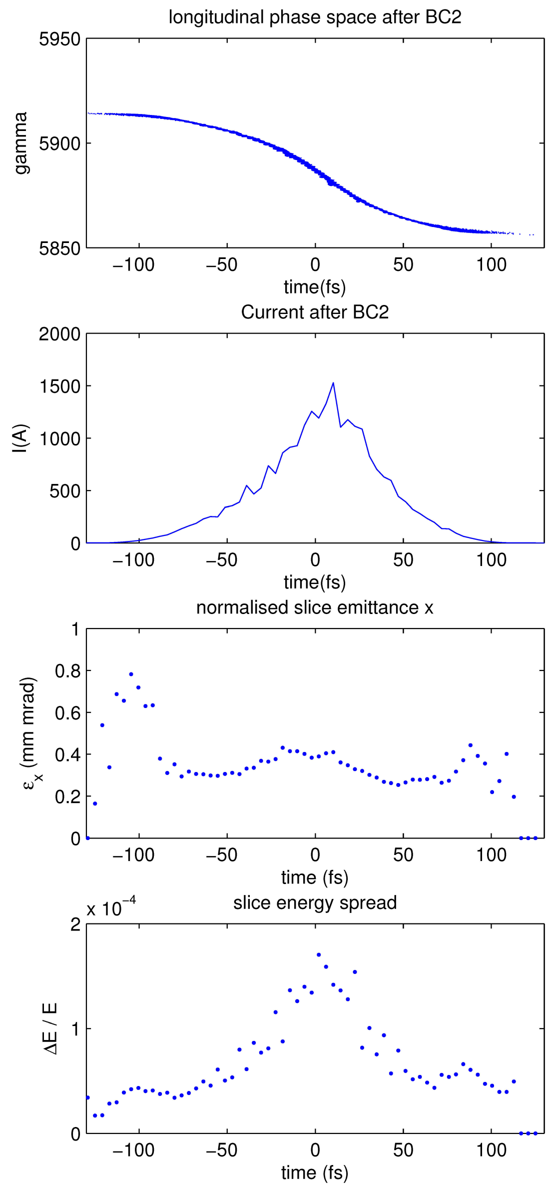

Figure 4: Result from simulations of the pulse optimised for the Short Pulse Facility.

STATUS OF THE CURRENT MAX IV LINAC (AUGUST 2013)

The acceleration structures are all installed and under vacuum in the MAX IV linac tunnel. The first bunch compressor is in place, and all other optics except for BC2 have been installed. The magnets for BC 2 will be delivered during the autumn. The next steps in the installation process will be putting the modulators and klystrons in place, and testing them. During autumn and early winter all cabling and plumbing are planned to be completed, and the various subsystems of the linac will be tested. According to the current time plan, linac commissioning will start in mid march 2014.

FIRST DESIGN OF THE FEL LINAC EXTENSION

The currently funded short pulse facility follows the second exit from BC 2. A possible extension of the linac is prepared for the first exit from BC2. An addition of 26 accelerator structures would give a total energy of about 5 GeV at the entrance to the FEL undulators (see Figure 1).

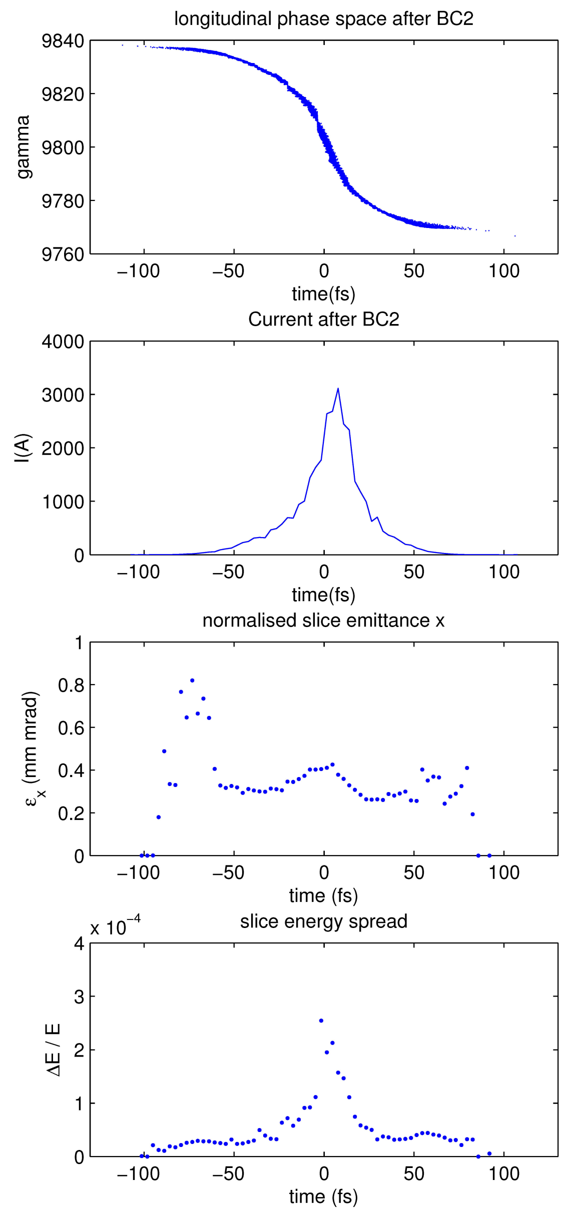

Figure 5: Result from simulations of the pulse optimised for the proposed linac extension and FEL.

A simulation of the extended linac up to the FEL undulators have been performed in ELEGANT. Simulation results and parameters for an FEL optimized pulse can be seen in Figure 5 and Table 1. The output from this calculation was then used in a time dependent GENESIS simulation to get an idea of the FEL output we could expect [14].

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Table 1: MAX IV Linac Parameters

	SPF	FEL extension
Operating energy	3 GeV	5 GeV
Charge/bunch	100 pC	100 pC
Rep rate	100 Hz	100 Hz
Bunch length (FWHM)	50 fs	25 fs
Peak current	1.6 kA	3.2
Normalised slice emittance	0.4 µmrad	0.42 µmrad
Slice energy spread	0.018 %	0.025 %

SUMMARY

The MAX IV 3 GeV linac, providing electrons for two storage rings and a short pulse linac light source is currently being installed in Lund, Sweden. Future plans for the MAX IV Laboratory includes an extension of the linac to 5 GeV and an FEL. The linac design is already prepared to handle the high demands off an FEL injector, and with an addition of about 2 GeV the MAX IV facility could be upgraded with an X-ray FEL.

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