THE MAX IV LINAC

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Abstract

The MAX IV linac will be used both for injection and top up into two storage rings, and as a high brightness injector for a Short Pulse Facility (SPF). The linac has also been designed to handle the high demands of an FEL injector. In the storage ring injection mode, the linac is operated at 10 Hz with a thermionic RF gun and the electron bunches are kicked out from the linac at either 3 GeV or 1.5 GeV to reach the respective storage ring. For the Short Pulse mode the linac will operate at 100 Hz with a high brightness photo cathode gun. Compression is done in two double achromats with positive R56 and the natural second order momentum compaction, T566, from the achromats is used together with weak sextupoles to linearise longitudinal phase space, leaving no need for a linearising harmonic cavity. The achromat design for bunch compression produces very short, high peak power electron pulses, while minimizing emittance increase. In this paper we present the MAX IV linac design and the status of commissioning which started in March 2014.

BACKGROUND

The MAX IV facility [1] is the successor of the MAX-lab accelerators at Lund University and include two storage rings, a full energy linac and a Short Pulse Facility (SPF). The rings will be operated at 1.5 and 3 GeV. The SPF will be a single pass spontaneous linac lightsource, producing sub-ps spontaneous X-ray pulses. The injector will be flexible enough to drive both injection and top-up for the storage rings, and produce high brightness pulses for the SPF. The long term strategic plan for the facility include an X-ray FEL, and the linac was developed to be fully prepared to handle the high demands for an FEL driver.

Currently the linac system is completely installed and under commissioning while the storage ring building is being finalized and magnet delivery has commenced.

MAX IV LINAC GENERAL DESIGN

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 [2]. 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 [3].

A sextupole is used in the center 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

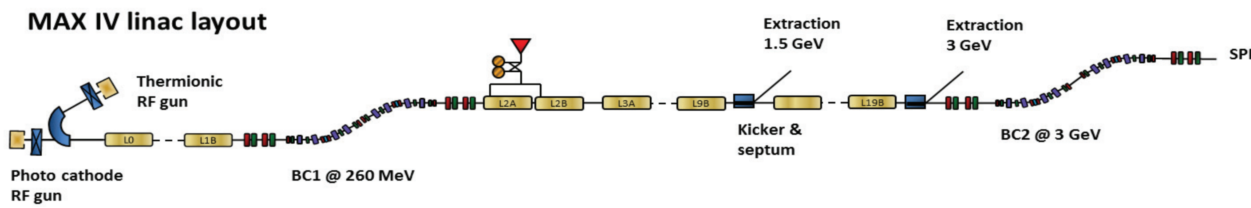

Figure 1: Layout of the MAX IV linac.

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 2.

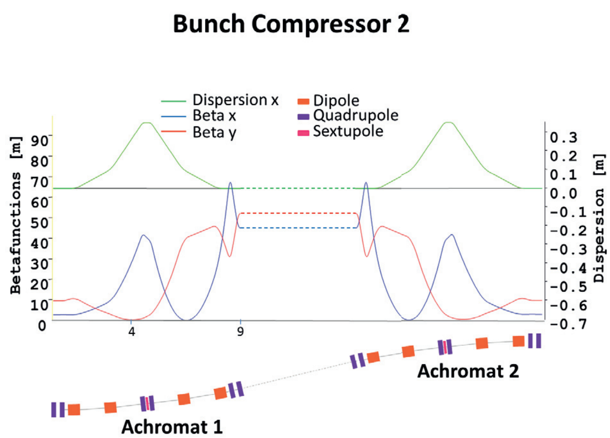

Figure 2: Schematic view and optics of the second bunch compressor.

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 [4] for the gun and first linac unit and ELEGANT [5] for the linac. Results and parameters for an electron pulse reaching the SPF specifications can be seen in table 1 and figure 3.

Table 1: Bunch Compression Parameters

	BC1	BC2
R_{56}	2.23 cm	2.89 mm
T_{566}	8.05 cm	6.76 μm
linac phase (off crest)	33 degrees	10 degrees

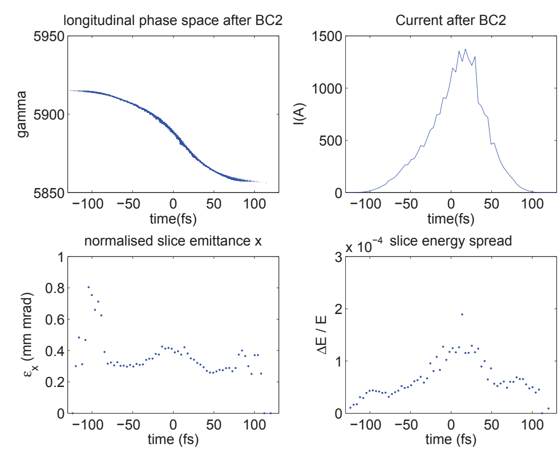

Figure 3: Result from simulations of the pulse optimised for the Short Pulse Facility.

STORAGE RING INJECTION

For injection and top up to the two storage rings, the same kind of thermionic RF gun that is in operation at current MAX-lab was chosen. It is a 1.5 cavity RF gun with a BaO cathode and an energy filter and it has proven to be a simple and reliable injection system [6].

For MAX IV a chopper system [7] was added between the gun and the energy filter in order to create the bunch structure for ring injections, see table 2. The chopper consists of two planar stripline electrodes that sweep the beam across an aperture, letting only the desired electron bunches through. Although the final goal is to transmit pulses at 100 MHz for injection into the storage rings [8], we are using 500 MHz for the chopper during commissioning since this maximises the BPM signal levels.

The thermionic gun with chopper system and energy filter was first commissioned at the gun test at MAX-lab, and is now installed and running at MAX IV. (Figure 4)

COMMISSIONING

In June this year (2014) the thermionic gun produced the first electrons at MAX IV. After a summer shut down the commissioning of the linac has now commenced again, and

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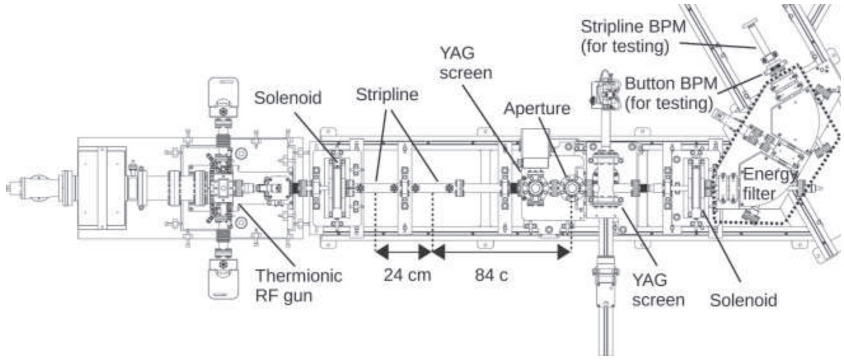

Figure 4: Drawing of the MAX IV thermionic gun with chopper system and energy filter.

Table 2: Design parameters of the MAX IV thermionic pre-injector.

Beam kinetic energy	2-2.5 MeV
Bunch frequency before chopper	2.9985 GHz
Bunch train frequency	99.931 ± 0.5 MHz
Number of bunches per bunch train	3
Number of bunch trains per LINAC shot	1 or 10
LINAC shot repetition frequency	10 Hz
Total injected charge per top-up injection	9 nC

electrons are accelerated to an energy of about 250 MeV and transported into the first bunch compressor.

We choose only one of the six 3 GHz bunches that is produced during a 500 MHz sweep. The low energy part of this pulse is then scraped of in the energy filter. Images from YAG screens showing the electron beam in the gun area and inside BC1 can be seen in figure 5. The top part of figure 5 shows the beam after the chopper without the aperture inserted. The top and bottom spots contains electrons from one RF bucket, while the center spots contain two each. The aperture is inserted so that the electrons that hit the top spot is selected for acceleration.

The first goal for the MAX IV linac is to deliver a beam according to specification to both storage ring transfer lines. When this is achieved, commissioning of the photo cathode gun and and bunch compressors will begin to deliver compressed, low emittance electron pulses to the SPF. The linac should be fully commissioned by June of 2015.

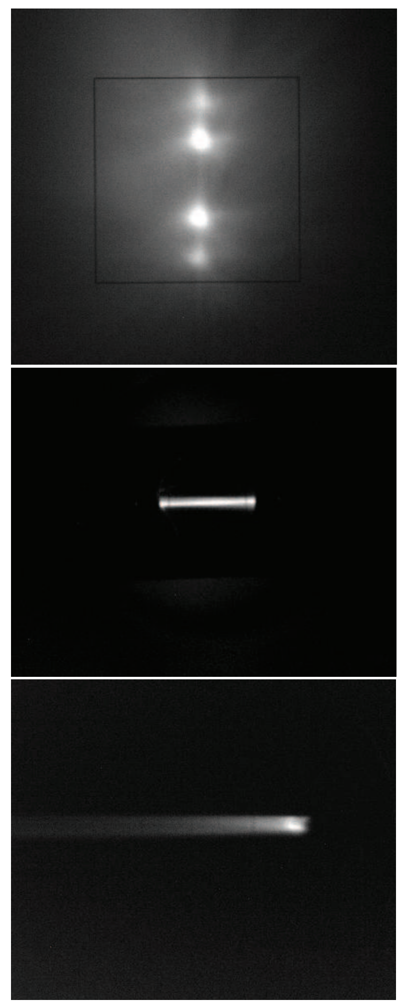

Figure 5: *Top:* The beam efter the chopper without the aperture inserted. *Middle:* The beam in the dispersive section inside the energy filter. *Bottom:* The beam after two dipoles in the first bunch compressor. This is at the maximum dispersion point.

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