STATUS OF MAX IV LINAC BEAM COMMISSIONING AND PERFORMANCE

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Abstract

The MAX IV linac is used both for injection into a 3 GeV storage ring, and as a high brightness driver for a Short Pulse Facility (SPF). It has also been deigned to handle the high demands of an FEL injector.

The linac is now routinely injecting into the two storagerings, and commissioning work is focused towards delivering high brightness pulses to the SPF. In this paper we present results from characterisation of the linac in ring injection mode, as well as results from measurements of key parameters for the SPF such as bunch length and emittance.

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) [2]. The rings are operated at 1.5 and 3 GeV. The SPF is a single pass linac lightsource, producing sub-ps spontaneous X-ray pulses. The linac injector is flexible enough to drive both injection and top-up for the storage rings, and produce high brightness pulses for the SPF. Recently plans for a soft X-ray FEL has developed [3] and the long term strategic plan for the facility include an X-ray FEL. The linac was developed to be fully prepared to handle the high demands for an FEL driver.

The MAX IV linac is now operating mainly to deliver beam to both storage rings and to the Short Pulse Facility. Some commissioning work is still remain mainly in the areas of bunch compression and emittance optimization.

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 [4]. 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 [5]. The gun is operated together with a kHz Ti:sapphire laser at 263 nm [6]. The same laser is used for timing and synchronisation of the whole accelerator and the SPF.

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 is doubled with a SLED.

The beam is kicked out for injection into the storage rings at 1.5 and 3 GeV. Bunch compression is done in double achromats [6] 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.

STATUS OF BEAM COMMISSIONING

The MAX IV linac has now been in commissioning and operation for over 2.5 years. It is routinely delivering beam to both storage rings for full energy injection and top-up with open gaps and closed front ends. In between full injections or machine top-ups the mode is switched to high brightness mode for SPF. Switching is done using a state machine that keeps track of all setting for the different linac and ring configurations. To meet exactly the right energy required for each light source, 1.5 GeV for the small storage ring, 3 GeV for the big storage ring and SPF, the fill-time to the energy doubling SLED units is used. This instantaneously sets the right energy at a specific point in the linac.

Injection to Storage Rings

From the thermionic RF gun a train of 10 100 MHz RF buckets are injected into the two storage rings at 1.5 and 3 GeV during each shot. For the 3 GeV ring 300 pC are transported through the transfer line and an injection efficiency of up to 95% has been observed. In the 1.5 GeV ring, 175 pC of charge reaches the end of the transferline for each shot, but no reliable injection efficiency has been calculated yet. At the moment both rings are injected with a repetition rate of 2 Hz, but work to get radiation safety permission for the design value of 10 Hz is ongoing. Table 1 shows the current status of some beam parameters for the linac in ring injection mode.

Table 1: Some Beam Parameters for Injection into the two Storage Ring

	1.5 GeV ring	**3 GeV ring**
Charge/shot	300 pC	175 pC
Rep rate	2 Hz	2 Hz
100 MHz pulses/shot	10	10
Injection efficiency	95 %	
$\epsilon_{Nx,y}$	4 μm rad	4 μm rad
ΔE/E in bunch train	1%	1%

High Brightness Mode for SPF

For driving the SPF the linac switches mode to use the photo cathode gun. At the moment the bunches are not compressed when delivering to the FemtoMAX beamline as the scientists at the beamline prioritize high charge during

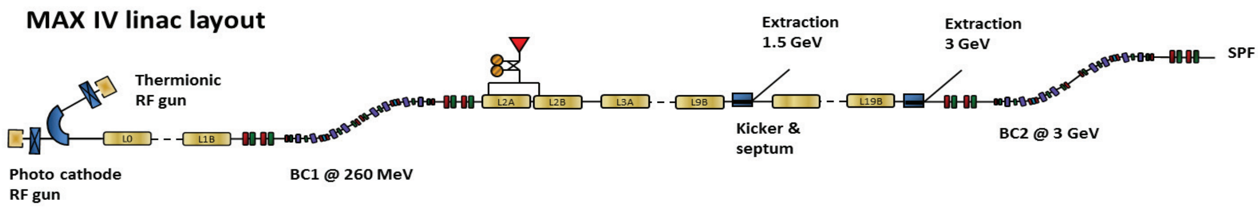

Figure 1: Layout of the MAX IV linac.

the initial commissioning phase. Routinely 260 pC bunches with 3 ps bunch length are delivered to the beamline at 2 Hz. For the design repetition rate 100 Hz a new gun is needed and the design process is ongoing. The current gun system could handle 30 Hz, but also in this case we are awaiting radiation safety permission to go above 2 Hz. Beam parameters for both delivery to the FemtoMAX beamline and during optimized measurements can be found in Table 2.

Table 2: Beam Parameters for the Linac when Used in High Brightness Mode

	Delivery	Measured
Charge per shot	250 pC	30-300 pC
Rep rate	2 Hz	2 Hz
Bunch length	3 ps	300 fs
$\epsilon_{Nx,y}$	3 μm rad	0.91 μm rad (100 pC)
Δ E/E	0.35%	0.3%

EMITTANCE FROM THE PHOTO CATHODE GUN

The emittance of the beam delivered to FemtoMAX is measured to 3-4 mm mrad. Efforts are being made to minimize emittance from the current gun and at present values of just below 1 mm mrad has been achieved at 100 pC [7]. A number of projects are working towards improving emittance even further and to make sure the 100 Hz gun can produce optimal emittance for driving a soft X-ray FEL. The copper cathode will be exchanged for a polished version and a new RF power divider will be installed this summer to give more power in the gun cavities. A lot of effort is being put into longitudinal pulse shaping of the gun laser [8]. To both develop and optimize the low emittance gun, a Gun Test Facility is being installed at MAX IV [9]. The first measurements from the Gun Test are expected before the end of the year.

BUNCH COMPRESSION

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

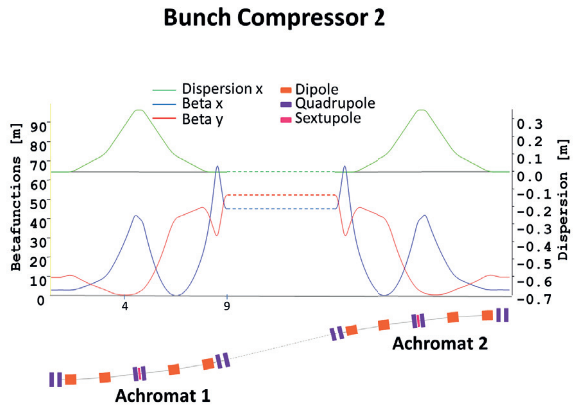

Figure 2: Layout and optics of the second bunch compressor. BC1 is very similar.

a linearising effect on the longitudinal phase space. We can thus choose the optical parameters in the achromat to achieve linearisation without needing a harmonic cavity for this purpose [10].

A sextupole is used in the centre of each achromat to minimize the second order dispersion at the end of the linac. 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. R56 of the achromats is fixed and the compression is varied using the RF phase in the linac.

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

Horn Antenna Measurements

A relative bunch length measurement using horn antennas was carried out with the beam from the photo gun after only compressing in BC1. One antenna was placed after BC1 and the other one after BC2 outside a ceramic gap. The phase in the linac section before BC1 was scanned and the response from the antenna + diode recorded [11].

A plot of a recent initial measurement can be seen in Figure 3. The response after BC1 saturates at 35 degrees, which according to simulations of horn response indicates a bunch length of 300 fs. This corresponds well to simulations. It can also be seen that the horn antenna signal after BC2 starts to decrease at around 30 degrees which indicates that the beam gets over compressed. This is due to the influence of wakefields in the linac that, because of the positive R56 in our compressors, increase the chirp in the beam. This measurements method will be developed further and calibrated with other bunch length measurements.

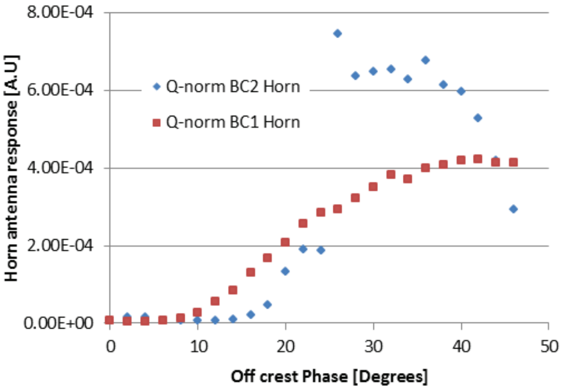

Figure 3: Response from the two horn antennas placed after BC1 and BC2.

Sextupole Influence on Bunch Length

A measurement of the sextupole influence on bunch length and longitudinal profile was performed. The beam was accelerated off crest in the main linac, between BC1 and BC2, and viewed on a screen at maximum dispersion in BC2 [12]. This induces a correlated energy spread in the beam, and the dispersive region in BC2 will streak the beam horizontally, making the profile along the x-axis on the screen proportional to the longitudinal profile of the beam. The phase of the linacs before BC1 was set for maximum compression, and the sextupoles in BC1 varied from 0 to maximum current. A clear influence of the sextupoles on the profile can be seen. Figure 4 shows a projection of the horizontal plane on screen images with sextupoles off and on. Both the RMS and FWHM beam size decreases with increasing sextupole strength, and has a minimum at k3 = 52 m^{-3}. This corresponds very well with simulations. We did not have enough control of the optics of the beam at the screen to make assumptions about the absolute bunch length. Work is however ongoing with an online machine model [13] that will make it possible to draw better conclusions from several measurements and make it possible to set up the machine automatically in pre-specified configurations.

SUMMARY AND OUTLOOK

The MAX IV Linear Accelerator is now routinely delivering beam to two storage rings and the linac based lightsource SPF. Preliminary measurements using horn antennas and diodes after the bunch compressors indicate that we can reach 300 fs after BC1 and that around this compression the beam gets over compressed after BC2.

The plan for coming steps for MAX IV linac commissioning include increasing repetition rate to 10 Hz, running in top-up mode for both storage rings and achieving an absolute measurement of bunch length for the compressed high brightness beam for the SPF.

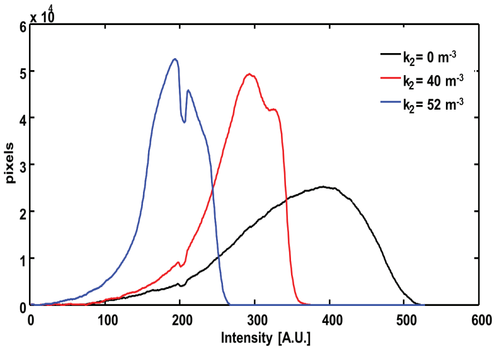

Figure 4: The longitudinal profile of the beam depends on strength of the bunch compressor sextupoles.

Another interesting topic, part of a possible future for the MAX IV linac, is as a driver for plasma wakefield acceleration. More about the linac suitability for this purpose can be found in [14].

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