BEAM COMMISSIONING AND INITIAL MEASUREMENTS ON THE MAX IV 3 GeV LINAC

S. Thorin, J. Andersson, F. Curbis, , M. Eriksson, L. Isaksson, O. Karlberg, D. Kumbaro, F. Lindau, E. Mansten, D. Olsson, S. Werin, MAX IV Laboratory, Lund, Sweden

Abstract

The linear accelerator at MAX IV was constructed for injection and top-up to the two storage rings and as a high brightness driver for the Short Pulse Facility. It is also prepared to be used as an injector for a possible future Free Electron Laser.

Installations were completed and beam commissioning started in the early fall of 2014.

In this paper we present the progress during the first phase of commissioning along with results from initial measurements of optics, emittance, beam energy and charge.

BACKGROUND

The MAX IV facility [1] is the successor of the MAX-lab accelerators at Lund University and includes 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.

The first phase of linac commissioning was completed in the beginning of May 2015, and after a few months shutdown for final installations and system tests of the 3 GeV MAX IV storage ring, the linac was recommissioned and started the process of injections for storage ring commissioning.

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 [2]. 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 [3]. 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 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 beam is kicked out for injection into the storage rings at 1.5 and 3 GeV. Bunch compression is done in double achromats [4] 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

Commissioning of the MAX IV linac started in August 2014 using the thermionic RF gun. While high power conditioning was still ongoing in the main linac, the injection system including thermionic gun, chopper and first linac structure was started up and characterised. In November 2014 the hight brightness photo cathode gun produced electrons at MAX IV for the first time. During December we reached both transfer lines to the storage rings (Figure 3) and entered the second bunch compressor where we could measure the electron energy. Full energy, 3 GeV, was reached in February 2015. Beam from the high brightness gun was delivered through the SPF section to the main beam dump in the following month. A first hint of light at MAX IV was detected from an old MAX-lab undulator that is now temporarily installed the SPF [5] (Figure 2).

In the beginning of august 2015, after a few months machine shut-down, the linac was recommissioned with the purpose to start injecting in to the 3 GeV storage ring. The beam reached the first screen in the storage ring on the August 11 (Figure 4).

CHARGE MEASUREMENTS

Beam charge is measured with Current Transformers at several points through the machine and with Faraday Cups at each beam dump (Figure 5). The charge specification for storage ring injection with the thermionic gun is 1 nC within a 100 ns bunch train for each linac shot. This was achieved at the beam dump in the centre of the 3 GeV transferline, but for radiation safety reasons not more than 750 pC is accelerated during normal operation and ring commissioning.

The nominal charge specification for the SPF is 100 pC, which has been achieved and delivered though the undulator section. A charge range from 20 to 200 pC has been accelerated though the whole linac and into the second bunch compressor.

EMITTANCE SCANS

Emittance and twiss parameters are measured before and after both bunch compressors using quad scans. The quad scan station before BC1 is the first point to measure emittance from the electron guns.

Thermionic Gun

For the thermionic gun the measured horizontal normalized emittance is around 30 mm mrad, which is higher than

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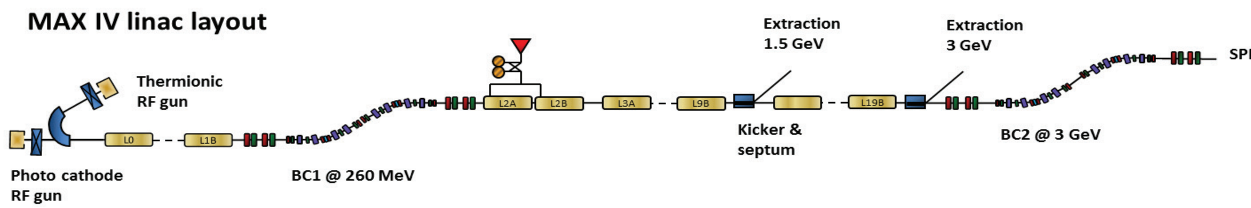

Figure 1: Layout of the MAX IV linac.

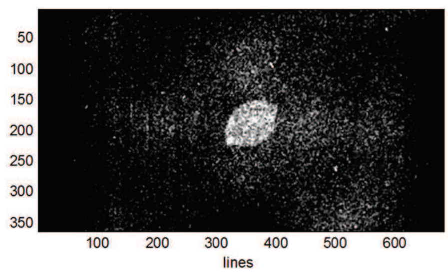

Figure 2: First "‘blip"’ of light detected from an undulator in the Short Pulse Facility.

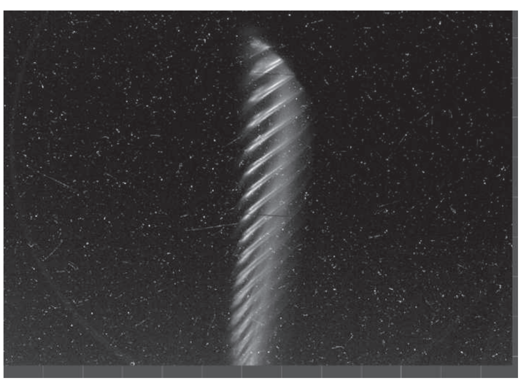

Figure 3: In the dispersive maximum in the 3 GeV transfer-line it is possible to resolve individual S-band pulses in the 500 MHz structure created by the gun and chopper.

the design value. The vertical emittance is at the same point below 7 mm mrad, which corresponds to simulations. A typical quadscan plot can be seen in Figure 6.

Photo Cathode Gun

For the photo cathode gun a normalised emittance down to 1.5 mm mrad has been measured before BC1 at 100 pC. This is a factor 3 higher than the design value of 0.5 mm mrad. It has later been discovered that the length of the laser pulse is below 2 ps which in combination with slightly too low RF power to the gun can be a reasonable explanation to the large emittance. Activities to stretch the laser pulse and increase the RF power to the gun are in progress.

More information about commissioning of the MAX IV electron guns can be found in [6].

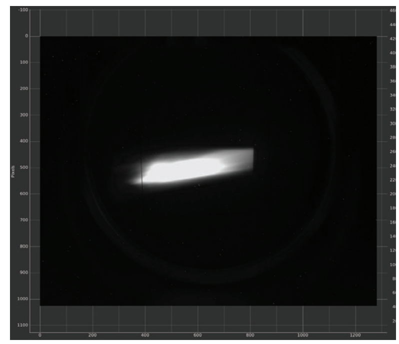

Figure 4: Image of the electron beam at the first screen in the 3 GeV storage ring.

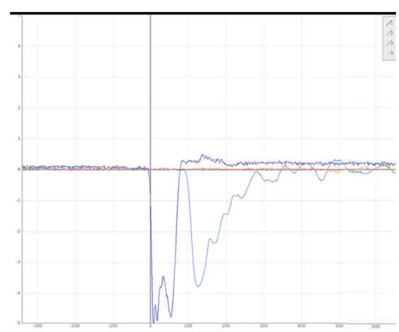

Figure 5: Trace on oscilloscope from the current transformer (dark blue) and Faraday cup (light blue) at the extraction to the 3 GeV storage ring.

At the quad scan station before the second compressor emittances as low as 0.8 mm mrad at 50 pC has been measured after using scrapers inside BC2 to get rid of some unwanted transverse beam halo.

BUNCH COMPRESSION

The two magnetic double achromats used as bunch compressors in the MAX IV linac have 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 achieve linearisation without needing a harmonic cavity for this purpose.

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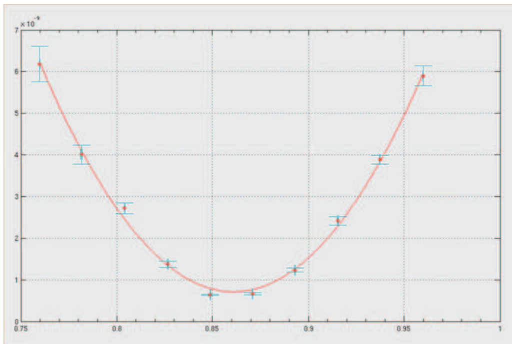

Figure 6: Typical plot from a quad scan emittance measurement just before BC2.

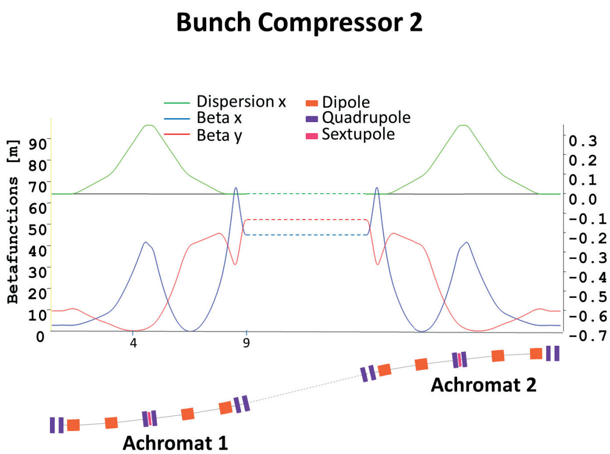

Figure 7: Layout and optics of the second bunch compressor. BC1 is very similar.

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 7.

Relative Bunch Length Measurements

A relative bunch length measurement using horn antennas [7] was carried out with the beam from the photo gun after only compressing in BC1. The antennas were placed outside a ceramic gap after the compressor and a phase scan indicated full compression at around 26o which agrees with simulations.

Sextupole Influence on Bunch Length

Although it was not yet possible to determine the absolute bunch lengths of the compressed photo cathode beam, a measurement of the sextupole influence on bunch length and longitudinal profile was performed. The beam was accelerated at zero crossing in the last 8 linac structures, and viewed on a screen at maximum dispersion in BC2 [8]. 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. Figures 9 shows a projection of the horizontal plane on screen images (Figure 8) with sextupoles off and on. Both the RMS and FWHM beam size decreases with increasing sextupole strength, and has a minimum at k2 = 50 m^{-3}, see Figure 10. 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.

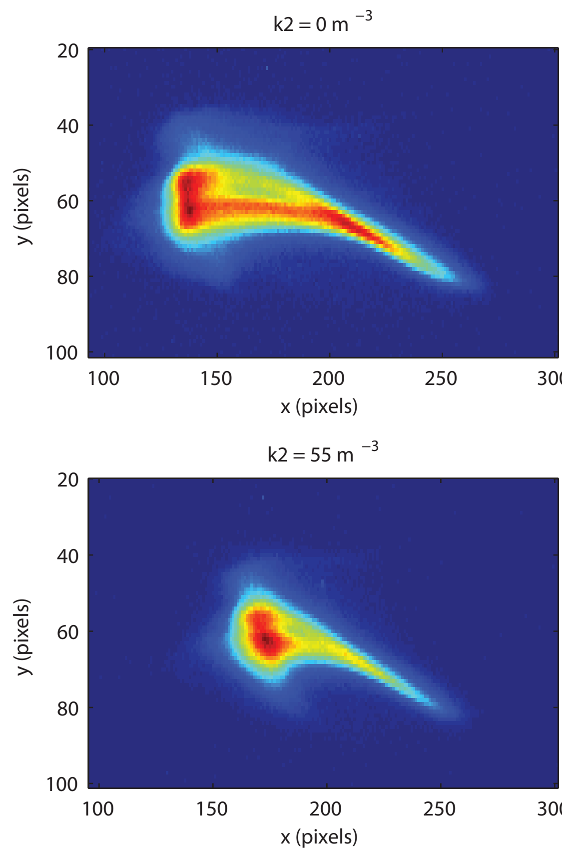

Figure 8: The electron beam from the photogun in the maximum dispersion section of BC2 for two different settings of the BC1 sextupoles. The bunch was at maximum compression in BC1 and the 8 last linac structures phased to zero crossing.

SUMMARY AND OUTLOOK

Phase one of the MAX IV linac commissioning was completed early May 2015. The linac had then delivered elec-

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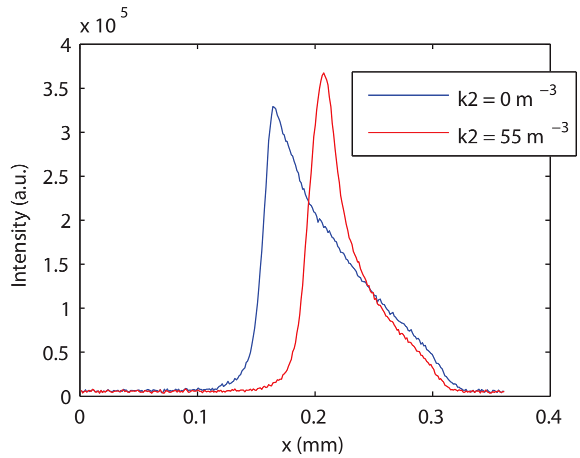

Figure 9: The longitudinal profile of the beam depends on strength of the bunch compressor sextupoles.

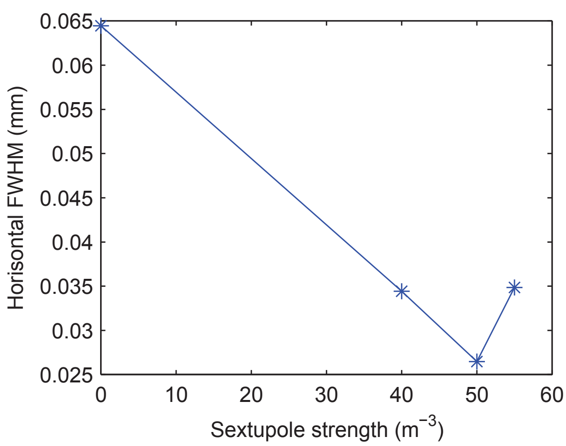

Figure 10: Bunch length dependence of the bunch compressor sextupoles which help to linearise longitudinal phase space and increase peak current.

trons from a thermionic RF gun into transfer lines to both MAX IV storage rings, and electron from a photocathode gun to a Short Pulse facility. In the beginning of August 2015 the linac delivered the first electrons into the 3 GeV storage ring and will now operate for storage ring injection.

The plan for coming steps for MAX IV linac commissioning include improving beam quality from both electron guns, achieving an absolute measurement of bunch length for the compressed high brightness beam and top up injection to the storage rings.

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