ISBN: 978-3-95450-179-3 doi:10.18429/JACoW-FEL2017-TUP013

EXPERIENCE AND INITIAL MEASUREMENTS OF MAGNETIC LINEARISATION IN THE MAX IV LINAC BUNCH COMPRESSORS

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Abstract

The MAX IV Linac is now in routine operation for injection into two storage rings, and as a high-brightness driver for a Short Pulse Facility (SPF). In short-pulse mode the electron bunch is created in a photo cathode gun and compressed in two double achromat bunch compressors that also linearise longitudinal phase space with the second order transfer matrix element T566. T566 in the compressors can be tweaked with weak sextupoles located at high dispersion. In this paper we present the current experience from operating the bunch compressors at MAX IV and results from initial measurements of longitudinal phase space using our version of the the zero-crossing method.

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 still remains, to the most part concerning bunch compression.

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 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 [7] at 260 MeV and at full energy, 3 GeV, after extraction to the storage ring. A schematic view of the linac layout can be seen in Figure 1.

Linearising double achromat compressors

The magnetic double achromats used as bunch compressors in the MAX IV injector has a positive R56 unlike the commonly used magnetic chicane which has a negative R56. We have thus to work on the falling slope of the RF voltage. Both types of bunch compressors naturally have a positive T566 and a positive T566 has a linearising effect in the achromat case. We can thus choose the optical parameters in the achromat to get optimal linearisation without needing to have a harmonic linac for this purpose. A sextupole is needed to minimize the second order dispersion at the end of the achromat. This sextupole, positioned at the achromat middle, is rather weak and could be compared with the chromaticity compensating sextupoles in a storage ring.

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. To achieve full linearisation of longitudinal phase space, the sextupole strength has to be increased. This can be done in such a way that second order dispersion is still closed at the end of the BC, but the energy derivative of dispersion becomes large, leading to increased emittance. For a spontaneous source like the SPF this is however not a problem. But even without over-tuning the sextupoles, a satisfying linearisation can be achieved to produce low emittance pulses, although at a lower peak current.

Table 1: Electron Bunch and Measurement Parameters

Compression energy	265 MeV
Final energy	9.98 GeV
Compression phase	0-50°
Initial electron bunch length rms	3 ps
Charge	100 pC
Dispersion at the screen	0.34 m
Sextupole strength	18/35 m^{-3}

BUNCH LENGTH MEASUREMENT USING A VARIANT OF THE ZERO-CROSSING METHOD

One single achromat will also induce some other second-order effects acting in the transverse direction. Many of the relevant ones are energy-dependent and thus linear in angle or position. The introduction of a double achromat, the

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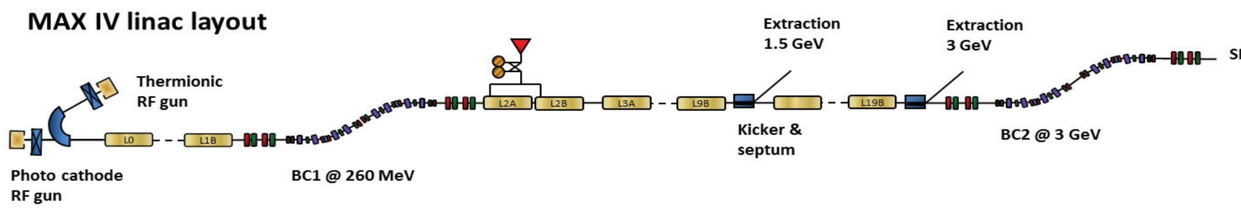

Figure 1: Layout of the MAX IV linac.

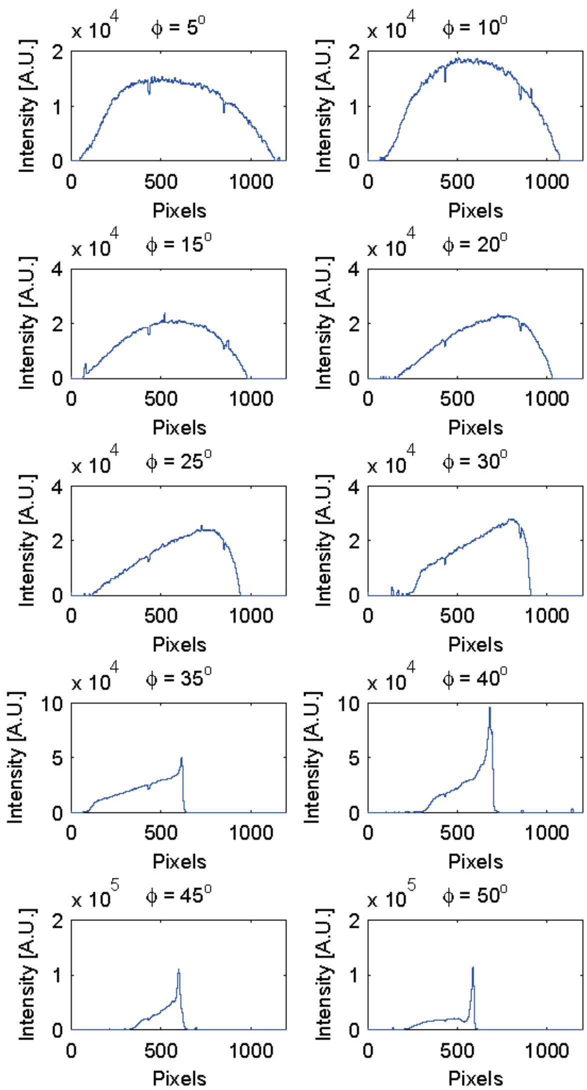

Figure 2: The x-projection of the electron bunch measured on a screen in BC2 while scanning the compression phase before BC1.

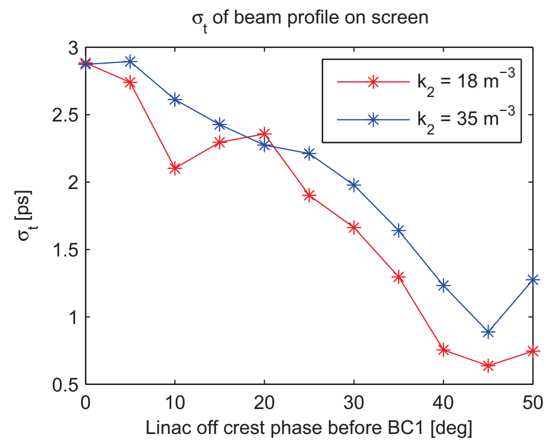

Figure 3: The RMS bunchlength of the electron bunch when the compression phase is scanned from 0 to 50°.

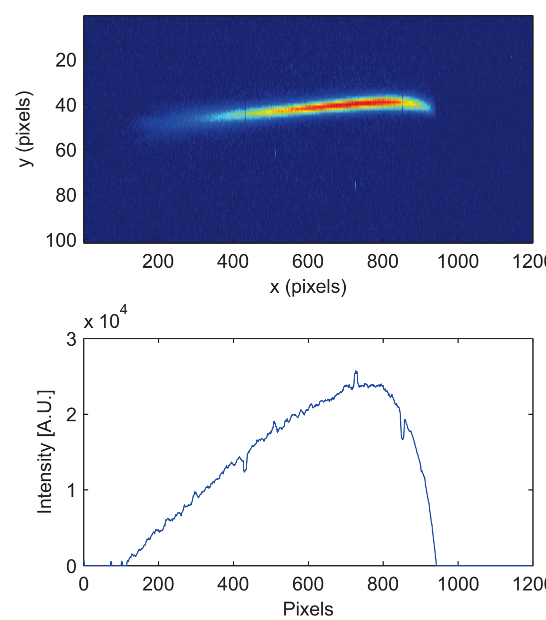

Figure 4: Ramped current shape with a compression factor of 3 and sextupole value 35 m^{-3}.

achromats bending in opposite directions, will cancel these terms. We will also effectively get a translation of the beam instead of a change of angle, which eased 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. By optimizing the combination of sextupole settings and compression RF phase the longitudinal profile of the beam can be shaped to give both a very high spike of peak current or a ramped triangular shaped current profile.

The nature of the MAX IV compressors has also shown useful for letting double pulses with in one RF bucket to be simultaneously compressed giving two short bunches with around 100 fs separation [8].

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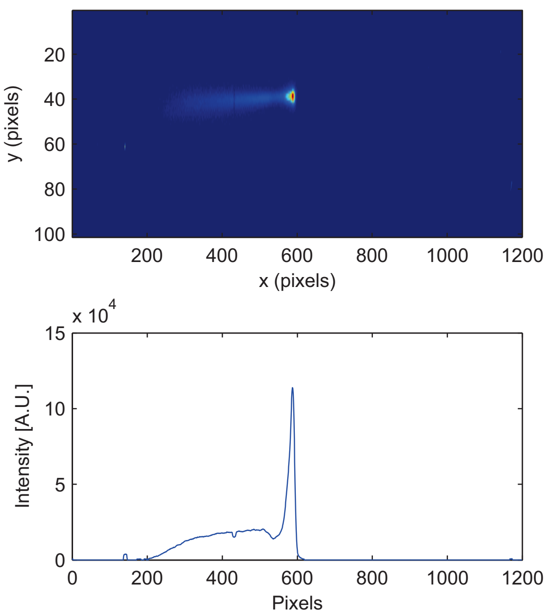

Figure 5: FWHM bunch lent of the beam is 160 fs in the narrow peak.

Lacking a transverse deflecting cavity, measurements of longitudinal phase space has been made using our version of the zero-crossing method [9]. The beam was accelerated 20° off crest in the main linac, between BC1 and BC2, and viewed on a screen at maximum dispersion in BC2 [10]. 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 scanned between 0 and 50° off crest. With the known dispersion of 0.32 m at the screen the width of the pulse on the screen could be related to the energy spread of the beam. With the known off crest phase in the main linac, this could then be converted to bunch length. Beam and compression parameters for the measurement can be found in table 1. Images from the screen and the projection along the x-axis for a sextupole setting of 35 m^{-3} can be seen in figure 2. In figure 3 the RMS bunch lengths for sextupole strength 18 and 35 m^{-3} are plotted.

Using this method we could see that the current profile of the beam will get a triangular shape for certain sextupole settings and compression factors (see figure4). It is also possible to achieve a very high peak current at full compression where even though the RMS bunch length is in the order of 500 fs due to a charge plateau, the fwhm bunchlength in the peak comes down to 160 fs (see figure5). This results was obtained using only one bunch compressor.

SUMMARY AND OUTLOOK

The MAX IV linac uses 2 double achromat bunch compressors where the linearisation of longitudinal phase space is done through the T566 in the compressors. Weak sextupoles can be used to tweak the linearisation and with that also the shape of the electron bunch. By accelerating the electron bunch off crest in the main linac after compressing it in BC1 we could use a screen at high dispersion in BC2 to image the longitudinal bunch distribution. Using this method we were able to measure bunch lengths down to 160 fs in the sharp peak of a fully compressed bunch.

REFERENCES

[1] *Detailed Design Report-MAX IV facility* (2010) Lund, Sweden.

[2] S. Werin, *et al.*, "Short pulse facility for MAX-lab", *Nucl. Instr. and Meth. in Phys. Res. A* 601, pp. 98- 107, (2009).

[3] S. Werin *et al.*, "The Soft X-ray Laser Project at MAX IV", WEPAB077, IPAC2017.

[4] D. Olsson *et al.*, *Nuclear Instruments and Methods in Physics Research A*, 759, p. 29–35 (2014).

[5] E. Elafifi *et al.*, "An Electron Gun Test Stand to Prepare for the MAX IV Project", TUPPD065, IPAC2012.

[6] F. Lindau *et al.*, "MAXIV Photocathode Gun Laser System Specification and Diagnostics", TUPAB097, IPAC2017.

[7] S. Thorin *et al.*, "Bunch Compression by Linearising Achromats for the MAX IV Injector", WEPB34, FEL2010.

[8] J. Björklund Svensson *et al.*, "Double-Bunches for Two-Color Soft X-Ray Free-Electron Laser at the MAX IV Laboratory", TUP010, These proceeding.

[9] WANG, D. X *et al.*, "Measurement of femtosecond electron bunches using a rf zero-phasing method", *Physical Review E*, 1998, 57.2: 2283.

[10] F. Curbis *et al.*, "Prospects for Longitudinal Phase-space Measurements at the MAX IV Linac" THPME170, IPAC14.