BUNCH COMPRESSION BY LINEARISING ACHROMATS FOR THE MAX IV INJECTOR

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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) and an FEL (in phase 2) [1]. Compression is done in two double achromats with positive R56. The natural second order momentum compaction, T566, from the achromats is used together with weak sextupoles to linearise longitudinal phase space. In this proceeding we present the design of the achromat compressors and initial results from particle tracking through the MAX IV Injector in high brightness mode.

MAX IV

The MAX IV project [2] at MAX-lab has been funded, and construction has started to build 2 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 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 SPF has relaxed demands on emittance (< 10 mm mrad) and demands a bunch length below 100 fs FWHM. Simulation results, presented later in this paper, show that such pulses are easily obtained with the MAX IV injector. In phase two of the MAX IV project, the injector should also be able to produce low emittance pulses to drive an FEL. Such results have also been produced in simulations.

THE MAX IV INJECTOR

The same photo cathode RF electron gun will be used to drive both ring injection and SPF. It is a copy of the FERMI gun [3]. The acceleration is done in 39 S-band linac sections together with 15 RF units, each consisting of a 35 MW klystron and a solid state modulator. The RF power will be doubled with a SLED. The repetition rate of the injector is 100 Hz, but top up and injection to the rings will be at 10 Hz.

General Layout

The lattice in the main linac is done as a FODO lattice with focusing quadrupole, linac section, defocusing quadrupole, and linac. The beam is kicked out for injection into the rings at 1.5 and 3 GeV. Bunch compression is done in double achromats at approximately 260 MeV and at full energy, 3.6 GeV. A schematic view of the layout can be seen in Figure **1**.

Double Achromat Compression and Linearisation

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 [4]. This can be

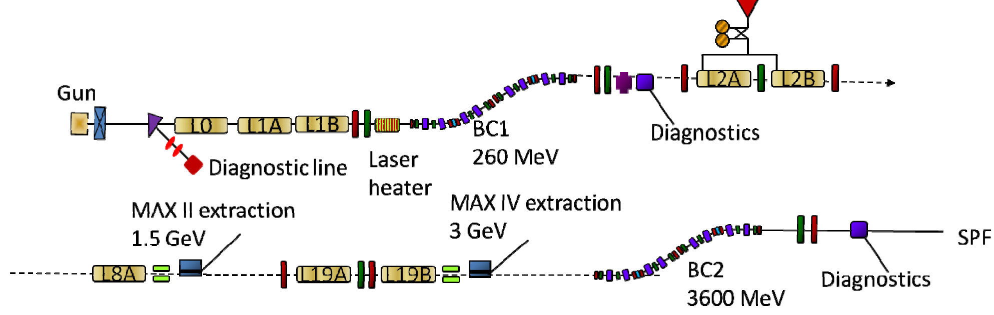

Figure 1: Schematic overall layout of the MAX IV Injector.

done in such a way that second order dispersion still is 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.

One single achromat will also induce some other second-order effects acting in the transverse direction. The relevant ones are energy-dependent and thus linear in angle or position. The introduction of a double achromat, the 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 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. Schematic views, dispersion and optics of the double achromat bunch compressors can be seen in Figure **2** to Figure **5**. Compression and linearisation parameters of the BC's for the SPF optimisation are presented in Table 1 and for the FEL optimisation in Table 2.

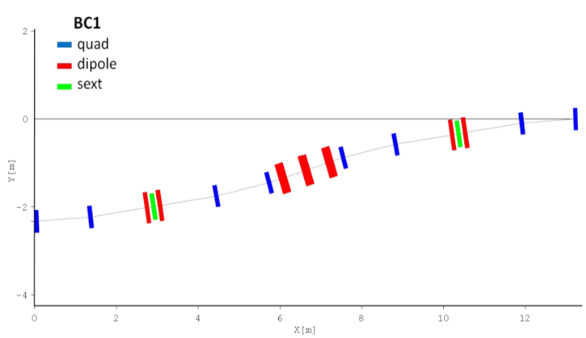

Figure 2: Layout of bunch compressor 1.

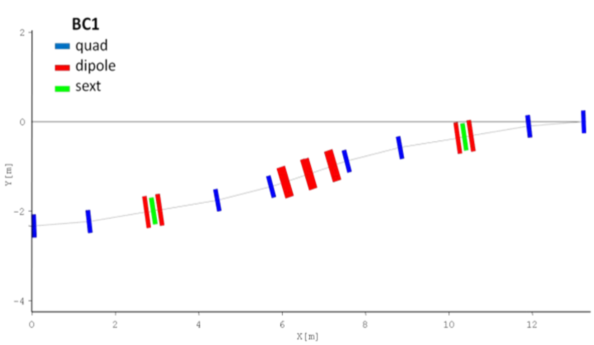

Figure 3: Layout of bunch compressor 2.

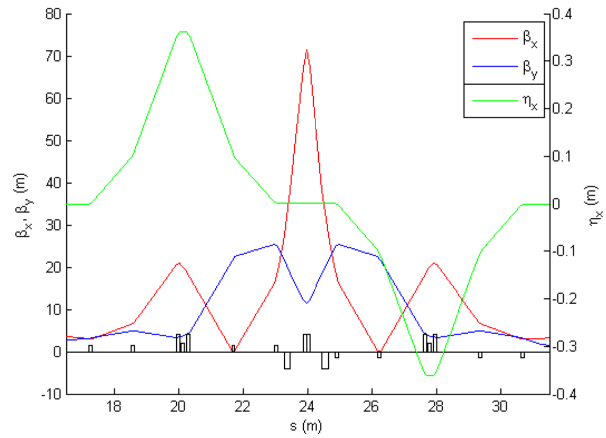

Figure 4: Optics and dispersion in bunch compressor 1.

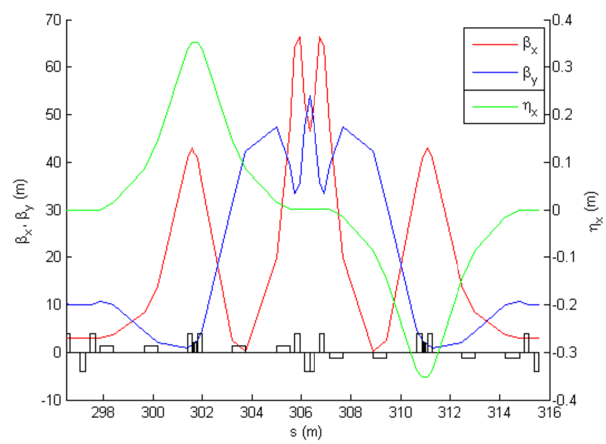

Figure 5: Optics and dispersion in bunch compressor 2.

Table 1: Compression and linearisation parameters in the high peak current optimisation

	BC1	**BC2**
R_{56}	3.23 cm	2.6 cm
T_{566}	9.26 cm	-17.8 cm
Energy	275 MeV	3700 MeV
Linac phase	32°	17.5°
Integrated sextupole strength	± 10 m^{-2}	± 10 m^{-2}

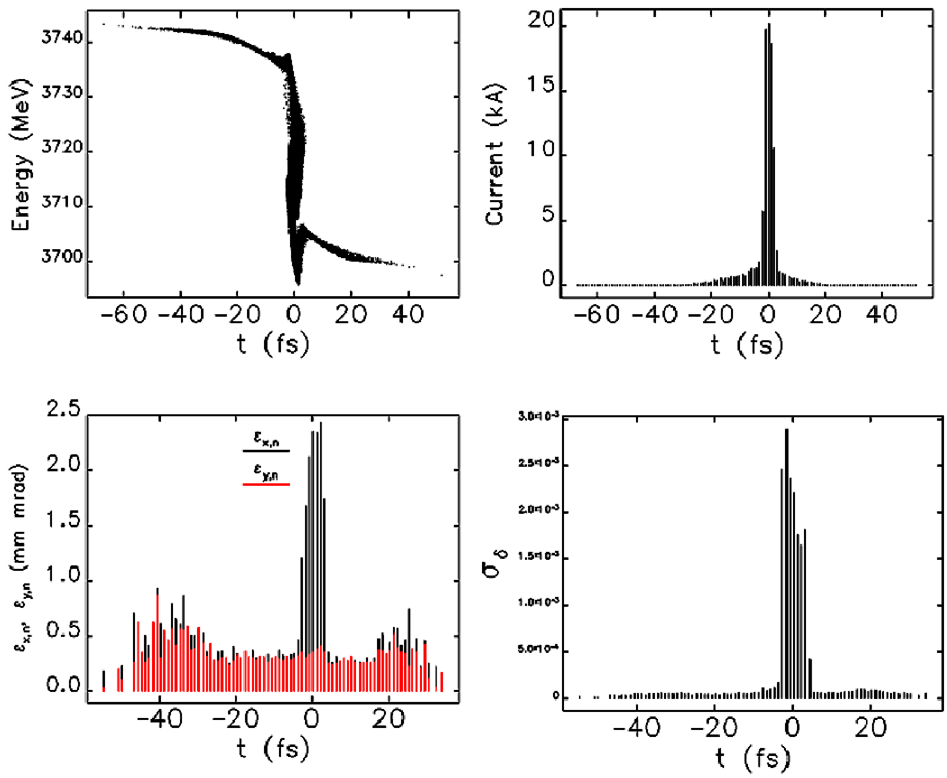

Figure 6: Simulation results for the high peak current optimisation for the SPF.

Table 2: Compression and linearisation parameters in the low emittance optimisation

	BC1	BC2
R_{56}	3.23 cm	2.6 cm
T_{566}	33 cm	8.5 cm
Energy	275 MeV	3700 MeV
Linac phase	32°	15.5°
Integrated sextupole strength	± 5 m^{-2}	± 4 m^{-2}

BEAM DYNAMICS SIMULATIONS

A realistic bunch distribution was generated using ASTRA [5] to optimise parameters up to the end of the first linac module L0. The bunch was then converted and read into Elegant [6] for tracking through the linac and the bunch compressors. The effects of transverse and longitudinal wakefields were included, as was longitudinal space charge and coherent synchrotron radiation. Beam parameters after the electron gun can be found in Table 3.

Table 3: Beam parameters after the gun and first linac module

Energy	105 MeV
ΔE/E	1.5 % (FW)
Norm. emittance	0.4 mm mrad

High Peak Current Optimisation

Sextupoles in the achromats were tuned such that longitudinal phase space curvature was minimised, this set up is optimal for the short pulse facility where emittance degradation is not of great concern. Figure **6** shows the properties of the bunch at the exit of the second compressor. It can be seen that compression and linearisation is effective and that a peak current of 20kA is achieved. This is done at the expense of both projected and slice emittance. Coherent synchrotron radiation has the effect of shifting trailing particles transversely with respect leading particles, giving the final horizontal emittance value of 2.5 mm mrad. This is still a very acceptable number for the SPF, which needs an emittance below 10 mm mrad.

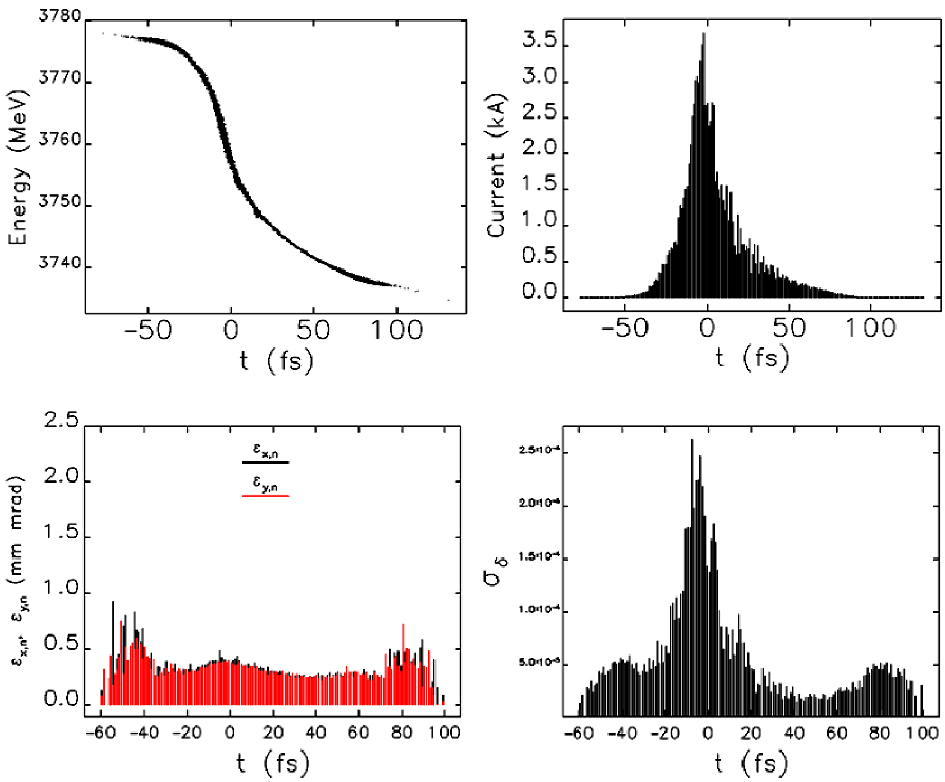

Figure 7: Simulation results from the low emittance optimisation.

Low Emittance Optimisation

In order to provide a bunch suitable to drive a free-electron laser we must suppress transverse emittance degradation as much as practicable. This is achieved by tuning the sextupoles in bunch compressor 2 to minimise the chromatic amplitude functions and chromatic derivative of dispersion, in exchange for relaxing the longitudinal linearisation of the bunch. In addition we do not compress as aggressively, thereby trading peak current against final projected and slice emittance. Figure **7** shows the bunch properties at the exit of bunch compressor 2. We see that the bunch slice properties are well preserved. The peak current is reduced, however studies at similar facilities suggest that 3kA would be sufficient to drive an FEL.

Outlook

In order to make the double achromat bunch compressors more flexible to tune T566 without disturbing the energy derivative of dispersion, an extra sextupole family could be added. This possibility will be examined before the final design of the bunch compressors is decided.

Many options to use the MAX IV Injector as an FEL driver are available. Examples of upgrades are adding extra linac sections to reach higher electron energies, and changing the second bunch compressor for a negative R56 chicane. More about this can be found here [7].

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