STUDY OF SOME DESIGN CONCEPTS AND COLLECTIVE EFFECTS IN THE MAX IV LINAC

S. Thorin, F. Curbis, M. Eriksson, O. Karlberg, S. Werin, MAX-lab, Lund, Sweden
D. Angal-Kalinin, P. Williams, STFC/DL/ASTeC, Daresbury, UK

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 (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, leaving no need for a harmonic cavity for linearisation of longitudinal phase space.

In this proceeding we present results from particle tracking through the MAX IV linac in high brightness mode. We also investigate emittance dilution due to CSR, in the achromat compressors, and transverse wakefields in a high beta function lattice. From the light-source point of view, we present preliminary simulation of the expected spontaneous emission in the x-ray range of the SPF electron beam.

THE MAX IV LINAC

The MAX IV project [2] at MAX-lab has been funded and construction has started to build 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 light source, producing sub-ps x-ray pulses. The linac will be flexible enough to drive both injection and top-up for the storage rings and to produce high brightness pulses for the SPF. The SPF has relaxed demands on emittance (less than 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 linac. 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, but won't be presented here.

General Layout

The lattice in the main linac uses only two tripplets to focus the beam onto the ring injection extraction points at 1.5 and 3 GeV. Bunch compression is done in double achromats at 260 MeV and at full energy, 3 GeV. A schematic view of the layout can be seen in Fig. 1.
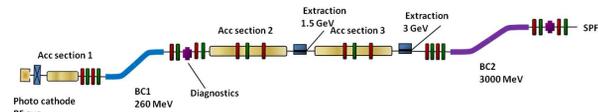
Figure 1: Layout of the MAX IV linac.

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. This means that the electron bunch is accelerated on the falling slope of the RF voltage. Both types of bunch compressors naturally have a positive T566 which 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 [3]. This can be 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. Since the R56 of the double achromats is fixed, the off crest RF phase is used to vary the compression factor.

BEAM DYNAMICS SIMULATIONS

A realistic bunch distribution was generated using AS-TRA [4] to optimise parameters up to the end of the first linac module L0. The bunch was then converted and read into Elegant [5] for tracking through the linac and the bunch compressors. Figure 2 shows simulation results for maximum linearisation and compression where the peak current comes up to almost 20 kA and FWHM pulse length is 10 fs.

02 Synchrotron Light Sources and FELs

T02 Lepton Sources
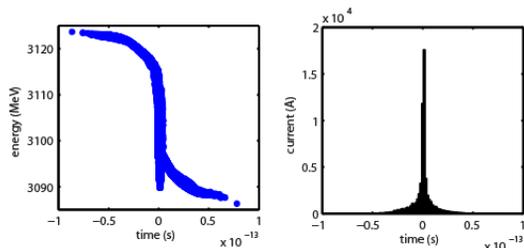
Figure 2: Beam parameters for high compression mode a) longitudinal phase space b) longitudinal profile.

Emittance Dilution

The increase of emittance due to coherent synchrotron radiation at full compression is quite high, more than a factor of 5. However, the effect of transverse wakefields in the main linac has to be investigated too. With just a few quadrupoles in the main linac, the beta functions tend to reach high values, at some points close to 600 m (see Fig. 3).
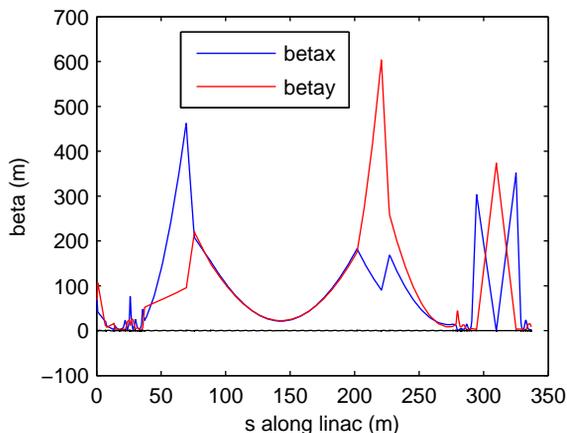
Figure 3: Beta functions.

Figures 4 and 5 show how transverse wakefields influence the horizontal and vertical emittance respectively for the high compression mode. The transverse wakefields have a tendency to kick the beam in a transverse direction and thus reduce the beam quality and increase the emittance. In the MAX IV case the effect from transverse wakefields is small and the highly compressed bunch satisfies the demands on the emittance for SPF operation. The wake model uses data files generated originally for LCLS at SLAC [6] as it resembles the MAX IV linac. Elegant [5] was then used to simulate the effect of the integrated transverse wake of each linac cavity.

In order to make the results realistic Figures 4 and 5 show simulations of the mean sliced emittance for 20 arbitrary chosen machines. Each linac set includes a random misalignment in the horizontal and vertical position

Figure 4: Mean sliced horizontal emittance.
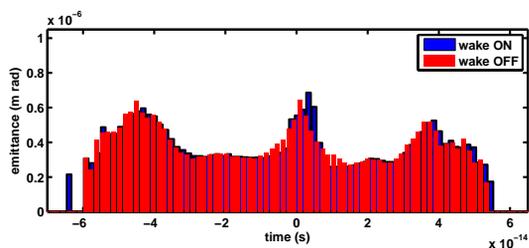
Figure 5: Mean sliced vertical emittance.

of the magnets and the cavities. The mean value of the maximal central deviation of the beam in the x-direction is 1.26×10^{-3} m and the mean value of the central deviation in this same direction is 2.35×10^{-4} m. The misalignment conditions are the same in Fig. 4 to 6, but Fig. 6 shows how the transverse wakefield effects a specific machine setup. Compatible to previous simulation results the impact caused by the transverse wakefield is minor. The maximum central deviation of the beam along this particular machine is 5.70×10^{-4} m in the x-direction. The mean value of the deviation is 7.75×10^{-5} m.
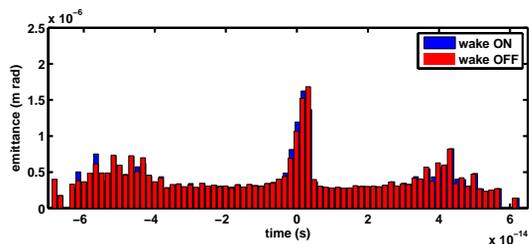
Figure 6: Sliced horizontal emittance for one specific machine.

PRODUCTION OF ULTRA-SHORT PULSES

The requirements for the SPF is a pulse length of about 100 fs FWHM where 90 % of the pulse is within 200 fs. The electron pulse therefore does not have to be fully compressed which also decreases emittance and energy spread. After the tracking through the linac, the optimized-SPF electron bunch has been divided in nine slices of about 12.6 fs and the most important parameters (emit-

tance, energy-spread, peak current, etc.) have been extracted for each slice (see Fig. 7). For the hypothetical undulator, two possible scenarios have been chosen: an insertion device with 65 mm period length to produce radiation at 10 nm and an undulator with 18 mm period length to produce 0.3 nm radiation. Due to the available space for the SPF, it is possible to accommodate a 10 m long undulator, which will result in 153 periods for the soft x-rays case and 555 periods for the hard x-rays case.
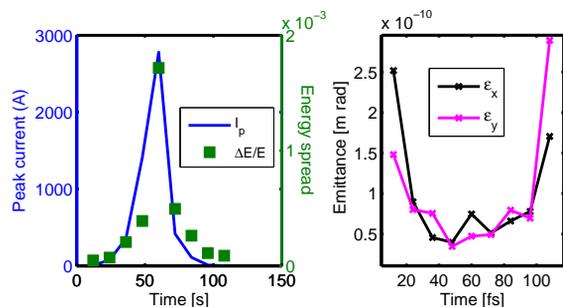
Figure 7: Beam slice parameters used in the simulation for the optimized SPF electron bunch. On the left side, the peak current and the energy spread. On the right side, the horizontal and vertical emittance.

Using SPECTRA [7], the optimized pulse gives the results in Fig. 8. The observation point is 20 m from the center of the undulator. As expected, the peak current plays a major role: despite also the energy spread is bigger for the central slices, they produce more flux. It is worth mentioning that, unlike synchrotron light sources, this radiation output refers to a machine with a repetition rate of 100 Hz.
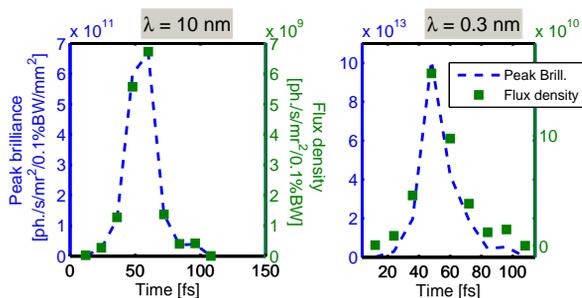
Figure 8: Peak brilliance and flux density of each slice for the two wavelengths: 10 nm and 0.3 nm. The repetition rate of the linac is 100 Hz.

Conclusions

The simulations show that transverse wakefields have a negligible effect on the beam quality despite the fact that the beta functions are rather big along the linac. The SPF will be able to deliver ultra-short (about 100 fs) pulses and different undulator options could be studied in order to cover the soft – hard x-rays range.

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 [8].

REFERENCES

[1] S. Werin et al., "Short pulse facility for MAX-lab", Nuclear Instruments and Methods in Physics Research A 601 (2009) 98-107.

[2] MAX IV conceptual design report (2006);
http://www.maxlab.lu.se/maxlab/publications/
max4/MAX-IV-CDR.pdf

[3] R. J. England et al., "Sextupole correction of the longitudinal transport of relativistic beams in dispersionless translating sections", Physical Review Special Topics-Accelerators And Beams 8 (2005).

[4] K. Flöttman, ASTRA User Manual (2000);
www.desy.de/~mpyflo

[5] M. Borland, Elegant: A flexible SDDS-Compliant Code for Accelerator Simulation, APS LS-287 (2000).

[6] Linac Coherent Light Source at SLAC national acceleration laboratory, Stanford, USA;
http://ssrl.slac.stanford.edu/lcls/s2e/.

[7] T. Tanaka and H. Kitamura, "SPECTRA - a synchrotron radiation calculation code", Journal of Synchrotron Radiation, 1221-1228, 8, (2001).

[8] S. Werin et al., "The MAX IV Injector as a Soft X-Ray FEL Driver", WEPA11, Proceedings of FEL2010, Malmö, Sweden.