THE MAX IV LINAC AS X-RAY FEL INJECTOR: COMPARISON OF TWO COMPRESSION SCHEMES

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Abstract

The MAX IV linac will be used for injections and top up of two storage rings and at the same time provide high brightness pulses to a short pulse facility (SPF) and in a second phase an X-ray FEL. Compression in the linac is done in two double achromats which implies a positive R56 unlike the commonly used chicane compressor scheme with negative R56. Compression using the achromat scheme requires the electron bunch to be accelerated on a falling RF slope resulting in an energy chirp that longitudinal wakefields will boost along the linac. This permits a stronger compression.

In this proceeding we will present how the longitudinal wakefields interact with the bunch compression in the double achromat scheme, compared with the chicane compression case. Focus is brought on how the unique MAX IV linac lattice is fully capable to cope with the high demands of an FEL injector. The charge related electron beam jitter in both set-ups will also be investigated.

INTRODUCTION

The new synchrotron facility at MAX IV laboratory [1] is now being constructed in Lund (Sweden). A 300 m long S-band linac, equipped with two guns, will serve as injector for two storage rings and drive a SPF using 3 GeV high brightness pulses to generate short spontaneous X-ray pulses. The linac layout is illustrated in Fig 1. As a second development stage of the facility an X-ray FEL is considered [2].

Double Achromat Compression Scheme

Two double achromats, BC1 at 260 MeV and BC2 at 3 GeV, serve as bunch compressors (BCs) in the linac. More precisely, one achromat structure consists of four bending magnets, a sextupole and a series of quadrupoles forming an arc, see Fig 1. The double achromat scheme gives a positive R56 and consequently the electrons must be accelerated on a falling RF voltage slope to achieve compression. Since the R56 is fixed to 3.2 cm in BC1 and 2.6 cm in BC2, the compression factor is tuned by changing the off-crest RF phase. The BCs in the MAX IV linac are self-linearizing in the longitudinal phase space since they both have a positive T566, which in the achromat case act linearizing while ordinary chicanes have opposite sign on R56 and T566 perturbing the linearization. To compensate for possible over-linearization and to minimize second order dispersion at the end of the BCs, a sextupole is used in the middle of each achromat structure [3].

Longitudinal Wakefields

When a charged particle bunch passes through a geometric varying structure, such as an RF cavity, it will induce wakefields that can act back on the particles and lead to beam instabilities. Only short ranged wakefields i.e. wakes generated by and acting up on particles within the same bunch, are considered in this article since the time between each electron bunch during MAX IV linac operation is sufficient to attenuate all long range wakes. Wakefields affect both the longitudinal and transverse beam dynamics, additional discussion about the transverse wakes in the MAX IV linac can be found in [4]; however it is the longitudinal wakes that are of interest here since they influence the compression. More precisely, the longitudinal wakefields affect the energy spread of the pulse since the particles in the back of the bunch lose energy from the wake generated by the particles in the head. In this way, the wakes will either enhance (achromat scheme) or reduce (chicane scheme) the energy chirp already obtained from the RF slope which is used to vary the compression.

COMPARISON OF COMPRESSOR SCHEMES, TWO CASES

Two compression schemes for the MAX IV linac were set up and compared using Elegant [5]; the original lattice including the double achromats versus a lattice using chicane compressors. Figure 2 illustrates the two setups. The dipole magnets in each BC are identical for both layouts

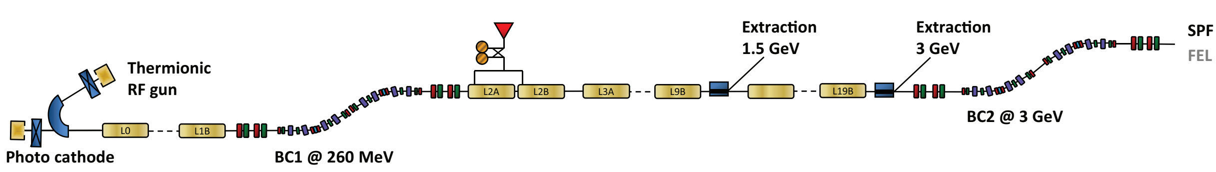

Figure 1: The MAX IV linac layout

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respectively and the absolute value of R56 remains constant. To make a fair comparison, the chicane lattice was matched to the Twiss parameters of the achromatic lattice, ensuring the same beta-function within the linac sections in both schemes. Moreover, an additional section of ten 3rd harmonic cavities was added in the chicane case in order to linearize the bunch, even though this involves a certain energy loss.

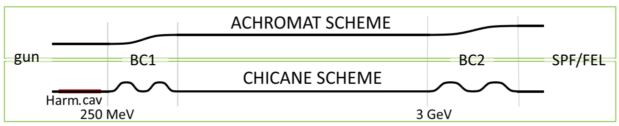

Figure 2: Achromat and Chicane schemes

Two cases involving different final compression of the electron bunch have been studied. Identical initial beam distribution with a hundred thousand particles was used and the total charge of the bunch was 0.1 nC. The RF phases of the cavities were adjusted such that the pulse was linearized and had a final pulse length, σ_{rms} , of 30 fs in case 1, which corresponds to a rather relaxed compression. A more compressed pulse was studied in case 2, where the current peak defines as the average current within a time span of 5 fs, was 2.5 kA. Simulation results of the longitudinal phase space of the beam as well as its slice emittance and current are presented in Fig. 3 for case 1 and Fig. 4 for case 2. The analysis of the two cases will be done separately.

Case 1

The achromat scheme gives the particles higher beam energy compared to the chicane scheme as can be seen in Fig. 3. The final energy difference between the setups is around 260 MeV. This is due to the fact that in the chicane scheme the bunch is accelerated on a rising RF slope giving the electrons an energy chirp that the longitudinal wakefields will attenuate along the linac. Thus, to achieve the requested compression in the chicane scheme the particles need to be further off-crest in RF phase that results in a less efficient acceleration. However, in the achromat scheme the wakefields emphasize the given energy chirp leading to a stronger compression without increasing the RF off-crest. For example, in the achromat scheme the RF phase off-crest in the main linac is roughly 15 degrees less than in the chicane schemes, which partially motivate its higher beam energy of 3.14 GeV vs. 2.88 GeV. In the chicane setup, there are also energy losses in the harmonic cavities that increase the gap in beam energy between the schemes.

There is a notable difference in the current profiles resulting from the different setups. One of the advantages with the double achromat compression scheme is that the central part of the bunch includes most of the particles, leaving the head and tail rather unpopulated [6]. The result is a cone shaped current profile where a higher peak current can be obtained with relatively less compression. Using the achromat scheme, a mean current of 1.4 kA and an emittance of 0.38 mm mRad within the 30 fs covering the peak current was obtained.

The current profile in the chicane setup resembles in overall a top hat. The current profile reveals a rather regularly populated bunch which together with the 30 fs rms pulse length requirement justifies its shorter appearance in longitudinal phase space. The current and emittance in the central part of the bunch is here 1.0 kA and 0.32 mm mRad respectively, slightly lower values than the corresponding results from the achromat setup.

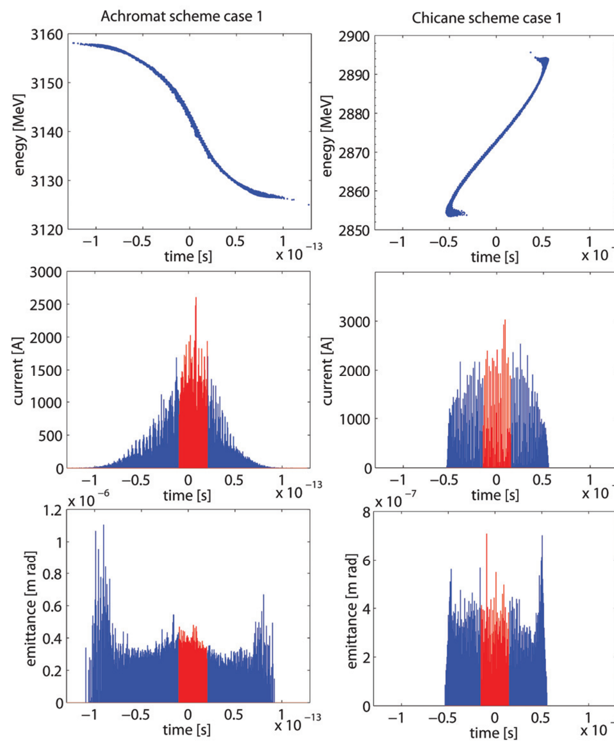

Figure 3: Case 1: Longitudinal phase space(upper-row), slice current(middle-row) and slice emittance(lower-row) of the achromat scheme(left) and chicane scheme(right)

Case 2

With the achromat scheme, the requested peak current of 2.5kA is easily obtained by a slight increase in the compression. In the chicane scheme however, the bunch needs to be fully compressed to obtain the wanted current within the central part of the pulse, where the emittance is kept low. But at full compression extremely high current spikes rise in the extremities of the pulses. Therefore, to avoid this and in order to make a fairer comparison, a less linearized chicane pulse is used resulting in a more comparable peak current to the one seen in the achromat scheme, see Fig. 4.

The following bunch lengths: $\sigma_{achr} = 22.5$ fs and $\sigma_{chi} = 37.5$ fs are obtained. In the achromat setup, the overall shapes of the slice parameters are comparable to the ones observed in case 1 and despite the current increase, the emittance is preserved low at 0.40 mm mRad. In the chicane scheme the current profile reveals that the head have a high electron density but the emittance is still kept rel-

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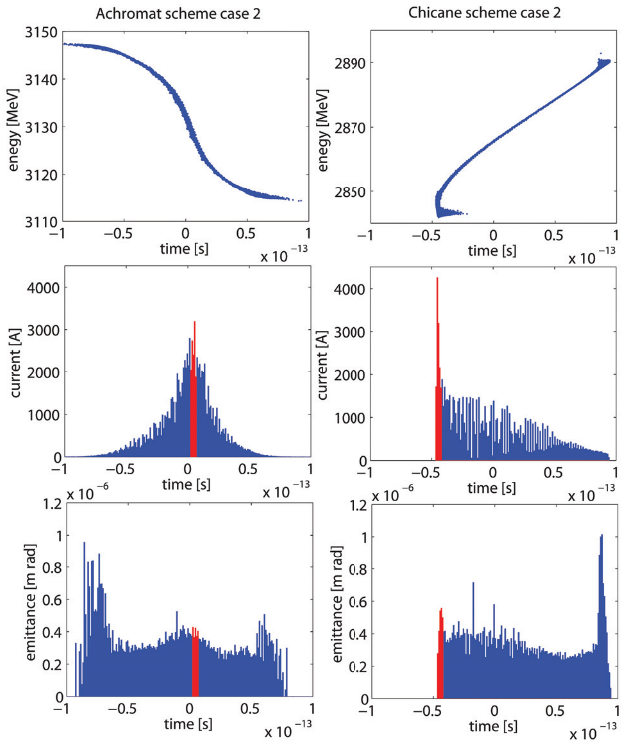

Figure 4: Case 2: Longitudinal phase space(upper-row), slice current(middle-row) and slice emittance(lower-row) of the achromat scheme(left) and chicane scheme(right)

atively low at 0.45 mm mRad. As in the previous case, the longitudinal wakefields diminish the energy chirp attained from the RF curvature and hence the final beam energy from the chicane lattice is 260 MeV lower than the one from the achromat.

Charge Jitter in Case 2

In a second part of this study, the charge related electron beam jitter in case 2 is investigated for the same specific beam distribution as used earlier. All parameters are fixed except for the total charge of the beam which we let vary $\pm$ 15% around the nominal charge of 0.1nC. The variation of the peak current and the emittance, defined as the average current and emittance within the 5 fs highlighted in Fig. 4, can be observed in Fig 5. The deviations are calculated in percentage from the corresponding slice parameters obtained in the previous section.

In the achromat scheme, the current fluctuates slightly more than in the chicane setup. Within the observed charge span the current deviation ranges from -38% to +62% (corresponding to 2.4 kA) in the achromat scheme, compared to -26% to +43% (corresponding to 1.7 kA) in the chicane scheme. Even though the current depends strongly on the charge in the achromat setup, the emittance stays rather stable altering from -3.6% to 8.4% (a total of 0.05 mm mRad) compared to -13% to +17% (a total of 0.14 mm mRad) in the chicane case.

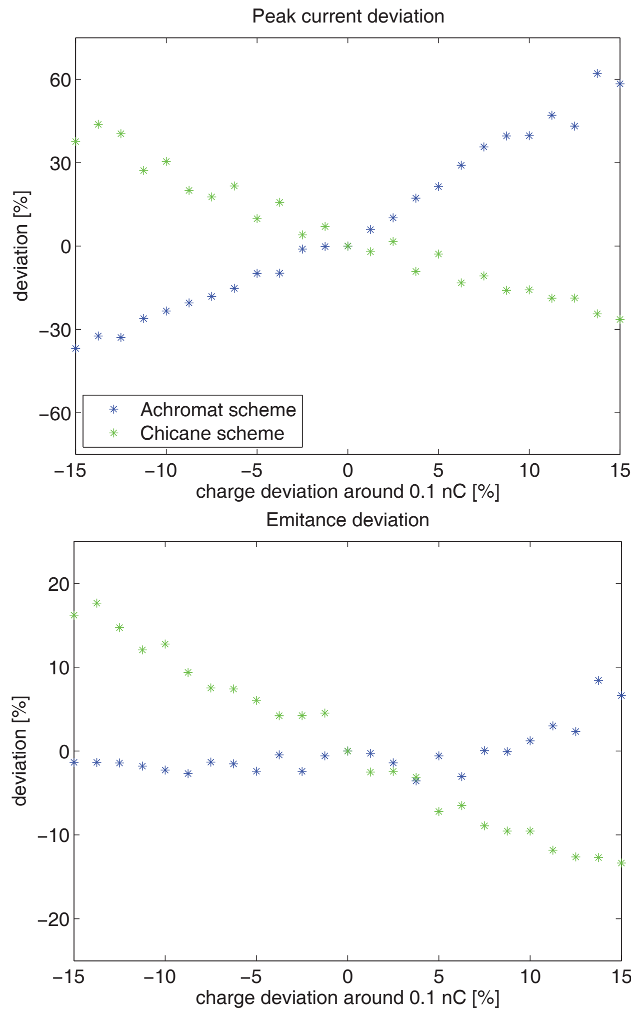

Figure 5: Deviation of peak current(top) and emittance(bottom) due to charge jitter

CONCLUSION

The simulations show that the longitudinal wakefields contributes to the compression when using the double achromat scheme by enhancing the energy spread and hence a higher beam energy is obtained compared to the chicane scheme. Furthermore, since the double achromat scheme is self-linearizing there is no need for harmonic cavities which in the chicane scheme causes an additional the energy loss.

For a relaxed compression, such as in case 1, the two schemes give comparable results. However, for highly compressed beams, a less linearized pulse in the chicane scheme had to be used in order to obtain a comparable peak current and beam quality to the ones in the achromat scheme. The variation of the sliced parameters from case 2 shows that the both schemes are sensitive to charge jitter. As the charge is altered the current deviation is somewhat larger in the achromat setup. Despite this, the emittance stays low and stable which is not the case in the chicane scheme. Exactly how this will influence the FEL process

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has to be investigated more rigorously. Nevertheless, according to this study the double achromat scheme seems to be comparable to an ordinary chicane. The emittance of the beam is preserved low despite charge jitter, which makes it suitable as an FEL injector. However, the charge jitter should be minimized in order to reduce current variations as much as possible.

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