BENCHMARK OF ELEGANT AND IMPACT *

L. Wang[#], P. Emma and T. Raubenheimer SLAC, Stanford, CA 94309, USA
J. Qiang, LBNL, Berkeley, CA 94720, USA

Abstract

The beam dynamics codes ELEGANT and IMAPCT have many users. We use these two codes for the design of LCLSII. Both codes use a 1D model for the coherent synchrotron radiation (CSR) in bend magnets. In addition, IMPACT has a 3D space-charge model, while ELEGANT uses a 1D model. To compare the two codes, especially the space-charge effects, we systematically benchmark the two codes with different physics aspects: wakefields, CSR and space-charge forces.

INTRODUCTION

The new LCLS-II high-repetition rate FEL project at SLAC [1] will use a new superconducting linac composed of TESLA-like RF cavities in continuous wave (CW) operation, in order to accelerate a 1-MHz electron beam to 4 GeV. Fig. 1 shows the optics of the hard x-ray beam of LCLS-II linac. The new superconducting linac is driven by a new high-rate injector [2], will replace the existing SLAC copper linac in sectors 1-7 (101.6 m/sector), while the remaining Cu RF structures in sectors 7-10 will be removed and replaced with a simple beam pipe and focusing lattice (the "linac extension"). The existing 2-km PEP-II bypass line (large β section in Fig. 1) will be modified to transport electrons from the linac extension in sector 10 through more than 2.5 km and into either of two undulators in the existing LCLS undulator hall. The overall design of the linac can be found in [3].

We use both ELEGANT and IMPACT codes for the LCLS-II design. The main difference in term of physics included is the space charge: ELEGANT uses 1D longitudinal space charge (LSC) model while IMPACT has 3D model. The long pass beamline at LCLS-II makes the space charge effect stronger compared to LCLS and the beam energy of LCLSII is low. Therefore strong micro-bunching instability is expected. Recently, it is found that the transverse space charge is also important and can add addition energy modulation to the beam [4]. Therefore it is important to check the impact of 3D space charge model compared to the 1D LSC model.

In this benchmark we use LCLS-II Hard X-ray linac as shown in Fig 1. The initial beam energy is 100 MeV and has an ideal Gaussian distribution in longitudinal direction with *rms* beam size of 1.0 *mm* and energy spread of 1 keV. The uncorrelated energy spread is increased downstream by using a 6 keV laser heater. The bunch charge is 100 pC. The particles are tracked through LCLS-II linac to the beginning of the undulator. We did step-by-step comparisons: first step for pure optics, all collective effects are turned off. Then the wakefields, CSR and space charge are added one-by-one.

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#wanglf@SLAC.stanford.edu

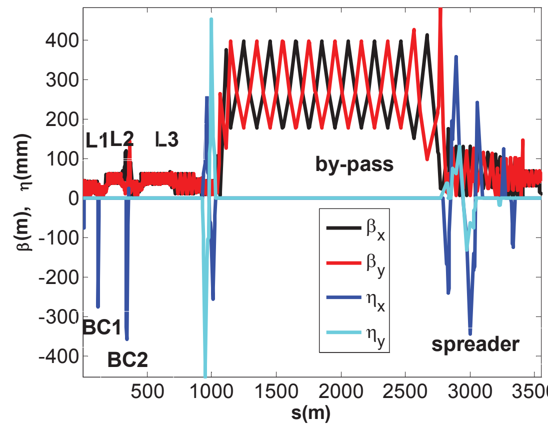

Figure 1: Optics (HXR) of the LCLS-II linac.

PURE OPTICS

To compare different collective effects, it is important to study a case when all collective effects are turned off. This means the wake fields (geometric wake of rf linac and resistive wall wake of the beam pipe), CSR and space charge are not included. The main parameters of the linac set-up are: the rf phase at L1, linearizer and L2 are -12.7^o -150^o and -15.5^o, respectively.

Figure 2 shows the phase space and the current profile before the undulator. There is an excellent agreement between both codes as expected. The peak current is about 1 kA with single spike. If the simulation starts with real injector beam, the final beam usually is flat at core of the beam with double horns at head and tail of the bunch. The beam energies are 250 MeV and 1.647 GeV at BC1 and BC2, respectively. Note that the BC2 beam energy in nominal design is 1.6 GeV. We use slight different beam energy here.

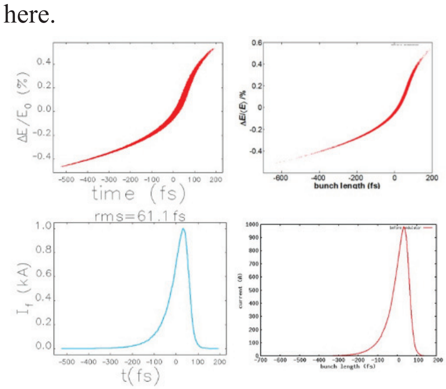

Figure 2: Longitudinal phase space (top) and current profile (bottom) at the beginning of undulator without collective effects from ELEGANT (left) and IMPACT (right).

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EFFECT OF WAKE FIELDS

In this case the geometric wake of RF structure and the resistive wall wake of the beam pipe are included. These wakefields de-chirp the bunch and therefore reduce the beam energy chirp and peak current as shown in Fig. 3. The final peak current reduces from 1kA to 0.8kA. There is same current profile and similar phase space. IMPACT shows slightly stronger effect of wakefield.

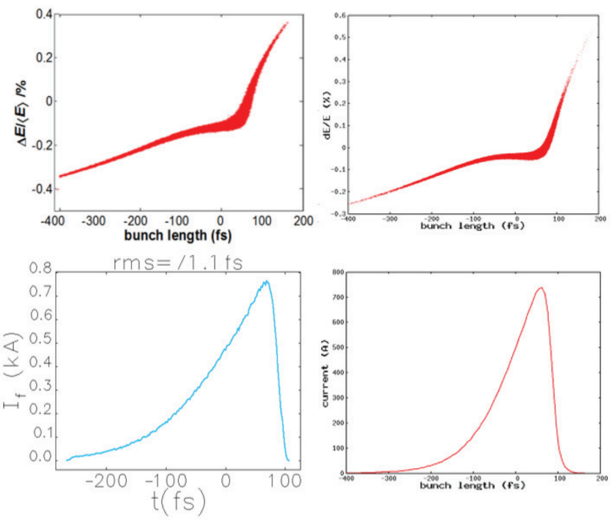

Figure 3: Longitudinal phase space at the end of BC2 with geometric wake and resistive wall wake effects: ELEGANT (left) and IMPACT (right).

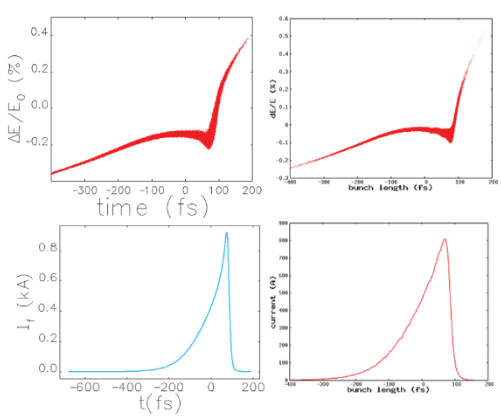

Figure 4: Longitudinal phase space with geometric wake, resistive wall wake and CSR: ELEGANT (left) and IMPACT (right).

WITH WAKEFIELD AND CSR

1D CSR is used in both codes. Similar as wake field effect, the CSR can de-chirper the beam in the longitudinal phase space. Figure 4 shows the comparisons. The phase space is hard to compare due to the different centroid in energy.

One noticeable difference is the peak current: ELEGNAT gives a larger peak current (0.9 kA vs 0.8 kA). Apparently it is caused by CSR. Detail study shows that the CSR in the 2nd bunch compressor (BC2) increases the peak current in ELEGNAT. This is typical CSR effect in LCLSII. The CSR in the 3rd bend of BC2 de-chirp the bunch and change the peak current due to the non-zero dispersion there. Although the last bend has stronger CSR and therefore larger energy kicker, it has negligible effect on the current profile due to the very small dispersion there.

Another benchmark is done with ideal Gaussian beam right before the BC2. There is good agreement for the beams at the end of BC2. So we are unable to identify the causes of the difference in previous case. The CSR may interplay with other things. It seems that the CSR in ELEGNAT play important role for sharp current profile.

WITH WAKE AND SPACE CHARGE

Wakefields and space charge are included in this comparison. IMPACT uses 3D space charge model while ELEGNAT uses 1D LSC. Figure 5 shows the comparison with the same numerical parameters for both codes: 50 million particles and 1024 slices in the space charge computation. The overall current profile is similar although it is spikier for Impact. The scale in the phase plot is quite different. IMPACT shows stronger overall de-chirper effect (smaller energy chirp near peak current center). Detail comparison shows similar energy modulation near the peak current: 0.15% for ELEGNAT and 0.14% for IMPACT. The modulation wavelength is also similar: 3 μm for ELEGANT and 2.3 μm for IMPACT. Actually the wavelength of modulation in ELEGNAT ranges from 2–3 μm if we look at the bunching result.

We are able to run IMPACT with real number particles to reduce the numerical noise. Figure 6 shows the IMPACT results with 624 million particles and 2048 slices. There are fine spikes in the current profile compared to the 50 million particles case. And the energy modulation has the same wavelength with smaller modulation (0.10% compared to 0.14%).

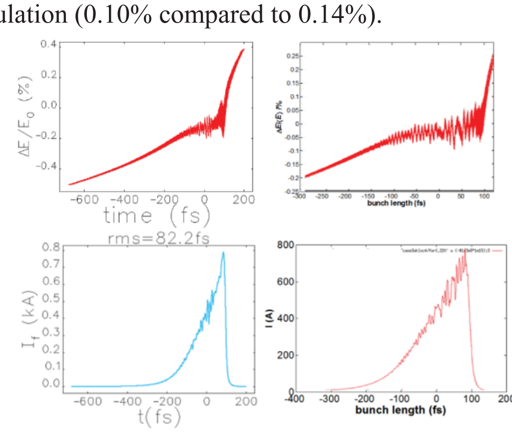

Figure 5: Both ELEGANT (left) and IMPACT (right) use 50 million particles and 1024 slices. Wake fields and space charge are included.

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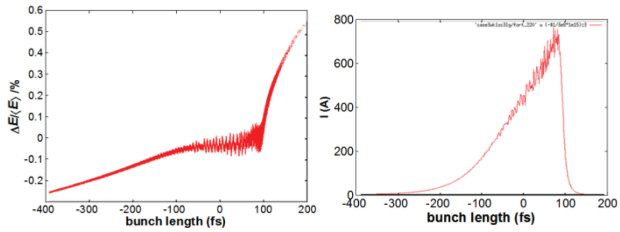

Figure 6: IMPACT with 624 million particles and 2048 slices.

WITH WAKE, CSR AND SPACE CHARGE

Wakefields, CSR and space charge are included in this comparison. Again, we run both codes using the same numerical parameters: 50 million particles and 1024 slices. The results are shown in Fig. 7. For both codes, the energy modulation wavelength and amplitude are very close to the previous case (with wake and space charge). The peak current increases compared to the previous case when the CSR is added in both codes. ELEGNAT gives a larger peak current. The IMPACT result with real number of particles is shown in Fig. 8. The results are quite close to that of 50 million particles case. For instance, the energy modulation reduces from 0.16% to 0.15%. The modulation wavelength doesn't change with the number of particles.

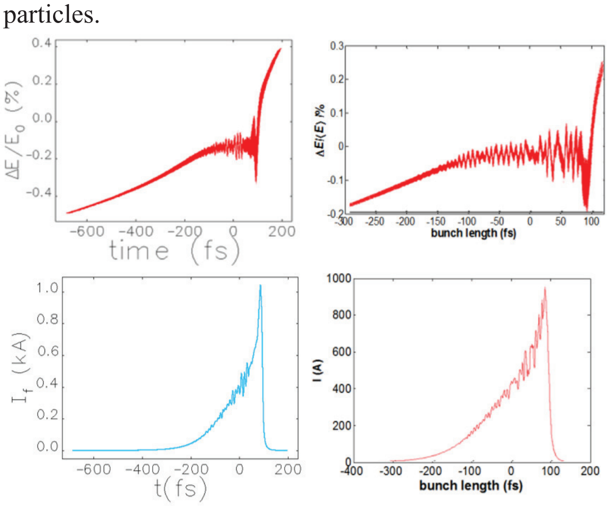

Figure 7: Wakefield, CSR and space charge are included. Both ELEGANT (left) and IMPACT (right) use 50 million particles and 1024 slices.

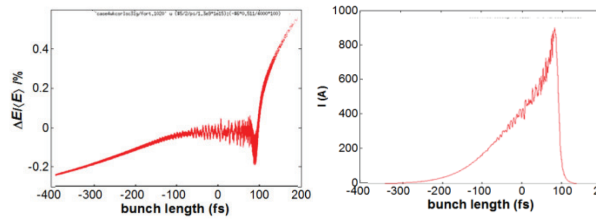

Figure 8: IMPACT with 624 million particles and 2048 slices. Wakefield, CSR and space charge are included

SUMMARY

We have done step-by-step benchmark for ELEGNAT and IMPACT. The overall agreements are good between ELEGANT and IMPACT codes for different effects: pure optics, wake and space charge. One noticeable effect is CSR on the peak current.

The most important to us is the space charge effects. Although the difference in the space charge model (3D in IMPACT compared to 1D in ELEGNAT), the results (such as the amplitude and wavelength of the energy modulation) are quite similar. The IMPACT with real number of particles shows similar result as 50 million particles with smoother current profile and smaller energy modulation.

ACKNOWLEDGEMENTS

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