Start-2-End Simulation in FACET Linac

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Abstract

Start-2-end simulations are essential to evaluate various beam dynamic aspects. In this note, start-2-end simulation studies are presented for FACET electron linac accelerator, from the damping ring exit point to the final interaction point.

1 Linear optics

Start-2-end beam dynamics simulation is widely used to optimize the design of modern accelerators. It is also essential in understanding and evaluating various beam dynamics aspects, such as bunch compression, emittance dilution etc..

The energy profile and TWISS parameters of FACET optics Version 31 [1] are shown in Figure 1 below, which are calculated (also designed) by MAD8 [2]. The starting point of this lattice is at the extraction septum of the electron damping ring. It is followed by RTL bunch compressor, a first linac section (LI02-10), a second bunch compressor at LI10, a second linac section (LI11-19), then finally a W-shaped chicane (a third bunch compressor consisting of dipoles, quadrupoles and sextupoles) plus final focus region. The end point of this lattice is the main interaction point (MIP) with plasma wakefield acceleration experiment.

To mitigate the dispersive and chromatic emittance dilution along with a strong linac betatron lattice at lower energy, a gradually increasing staggered RF phase [3] is adopted in LI02-10. As shown in Figure 1, the electron beam energy is accelerated from 1.2 GeV to 9 GeV in LI02-10, then from 9 GeV to 20.35 GeV in LI11-19.

This FACET MAD8 lattice is then converted into Elegant [4] format, by modifying and applying the FORTRAN code MAD2LTE [5]. The modification of the code is mainly in the RF cavity part, which was previously defined and converted by type (for LCLS case, there are only several types of RF cavity), and currently by actual name and length (each RF cavity is defined separately with a unique name and length).

In the RTL bunch compressor, there are two quads (QDI454R and QFI464R) with dipole fields, which has no edge effect. All the dipole magnets has FINT=0.5, denoting an average fringing field. Transverse and longitudinal wake fields are employed in all the SLAC S-band RF cavities. Incoherent and coherent synchrotron radiation (ISR and CSR) effects may be included on all the dipole magnets. Meantime CSR could be included for CSR drifts.

Similarly, the energy profile and TWISS parameters of FACET optics Version 31 are shown in Figure 2 below, which are calculated by Elegant [4]. Observed from a comparison between Figure 1 and Figure 2, also as shown in Table 1, a good agreement is achieved between MAD8 and Elegant calculated energy and TWISS parameters. This is an indication that the conversion from MAD8 to Elegant is successful.

Table 1: Comparison of accelerator parameters calculated by MAD8 and Elegant.

	MAD8	Elegant
Accelerator length [m]	1972.69	1972.69
$\beta_{x,IP}$ [m]	0.018	0.018
$\beta_{y,IP}$ [m]	0.18	0.18
$\alpha_{x,IP}$	-0.001	-0.001
$\alpha_{y,IP}$	0	-0.002
$D_{x,IP}$ [m]	0	0
$D_{y,IP}$ [m]	0	0
ν_x (to dump point)	25.3378	25.3362
ν_y (to dump point)	23.8107	23.8087

2 Start-2-end simulation

The initial electron beam out of the damping ring is represented by 200k macro particles. The normalised horizontal and vertical emittance are $33 \mu\text{m}$ and $3.4 \mu\text{m}$ respectively, which are the best guess from measurement. The initial uncorrelated energy spread is 7.9×10^{-4} and the RMS bunch length is 5.6 mm . Gaussian distribution is employed for either dimension, with a cutoff at 4 sigma. An asymmetry factor of -0.245 is adopted in generating the longitudinal coordinates, which reflects the potential-well distortion effect in the damping ring.

This electron beam is tracked through the FACET linac, with acceleration, bunch compression and wake fields effects included. The RMS bunch length is compressed by a factor of 5 in the RTL bunch compressor, then a factor of 20 in the sector 10 chicane, and finally a factor of 3 in the W-chicane. The final RMS bunch length is $83 \mu\text{m}$, while the Gaussian fit is $22 \mu\text{m}$. The bunch length and energy spread evolution along the linac are shown in Figure 3.

The transverse emittance is well preserved, and the design transverse beam size is achieved at MIP, as shown in Figure 4. The longitudinal phase space at the entrance and exit of each bunch compressor is shown in Figure 5. Over-compression is employed in a first and second stage bunch compression, while full-compression is adopted in the third stage bunch compression (in W-chicane). The electron beam current profile at the entrance and exit of each bunch compressor is shown in Figure 6. The beam current is 4 kA out of sector 10 chicane, and it is pushed up to 16 kA after W-chicane.

Figure 1: FACET linac TWISS parameters (left) and beam energy (right), calculated from MAD8.

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Figure 2: FACET linac TWISS parameters (left) and beam energy (right), calculated from Elegant.

Figure 3: Bunch length (left) and energy spread (right) evolution along FACET linac.

Figure 4: Transverse RMS beam size (left) and projected emittance (right) evolution along FACET linac.

Figure 5: Longitudinal phase space at different locations. From left top to right bottom: RTL bunch compressor entrance; RTL end; sector 10 chicane entrance; sector 10 chicane end; W-chicane entrance; W-chicane end.

Figure 6: Beam current profile at different locations. From left top to right bottom: RTL bunch compressor entrance; RTL end; sector 10 chicane entrance; sector 10 chicane end; W-chicane entrance; W-chicane end.