SINGLE AND MULTI-BUNCH END-TO-END TRACKING IN THE LHeC

D. Pellegrini, EPFL, Lausanne, Switzerland and CERN, Geneva, Switzerland
A. Bogacz, JLab, Newport News, VA 23606, USA
A. Latina, D. Schulte, CERN, Geneva, Switzerland

Abstract

The LHeC study aims at delivering an electron beam for collision with the LHC proton beam. The current baseline design consists of a multi-pass superconductive energy-recovery linac operating in a continuous wave mode. The high current beam (~100 mA) in the linacs excites long-range wake-fields between bunches of different turns, which induce instabilities and might cause beam losses. PLACET2, a novel version of the tracking code PLACET, capable to handle recirculation and time dependencies, has been employed to perform the first LHeC end-to-end tracking. The impact of long-range wake-fields, synchrotron radiation, and beam-beam effects has been assessed. The simulation results and recent improvements in the lattice design are presented and discussed in this paper.

INTRODUCTION

The current baseline design for the LHeC electron is sketched in Fig. 1. Each of the two 1 km long superconducting linacs provide a total acceleration of 10 GeV. The injection energy is 500 MeV. In order to reach the collision energy of 60 GeV, the electrons are recirculated three times. This is accomplished employing beam spreaders and recombiners placed at each end of the linacs. They allow to vertically separate the beams at the different energies routing them to the corresponding arcs. Arc2 and Arc4 are equipped with bypasses to avoid the interference with the detector. After the collision with the LHC proton or ion beam, the electron beam is decelerated in further three turns, allowing to increase the beam current and luminosity while limiting the power consumption [1]. The machine is operated continuously and bunches at different turns are interleaved in the linacs. An up-to-date beam parameter list can be found in [2].

The full LHeC lattice consisting of the two linacs and the six arcs has been imported into PLACET2 which allows to simulate recirculating machines [3]. A single-bunch end-to-end tracking simulation has been set up to evaluate the impact of synchrotron radiation and beam-beam effect. We verified the beam transport to the dump and we identified the lattice sections that could be improved. Moreover, since PLACET2 natively supports simultaneous multibunch tracking, it has been possible to investigate the impact of the transverse long range wakefields.

Progress has also been made with the machine design including the detector bypasses in Arc2 and Arc4. Details of the design will be presented.

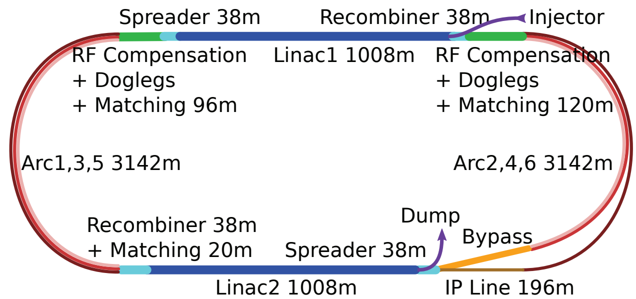

Figure 1: Scheme of the LHeC electron facility.

MACHINE MODELLING

The two linacs and the six arcs, properly connected together, have been imported in PLACET2. This code implements the recirculation in a realistic way. Each element is defined only once and its phase is computed accordingly to the beam time of flight. Although progress is being made, a complete, detailed design of the whole machine is not yet available and small footprint variations are still expected. For this reasons and for convenience the lengths of the arcs are adjusted artificially. Another simplification was applied to the IR, where the squeezing is implemented with a matrix, the beam-beam effect is then computed by GUINEA-PIG [4]. It has been found that the synchrotron radiation has a big impact in the spreader and recombiner sections and in the doglegs for path length adjustments. For the time being, in order to proceed with this study, the above effects have been ignored. The second harmonic RF, required to re-integrate the synchrotron radiation energy loss, is currently modelled as a thin element. No multipolar magnets are currently in the lattice, however higher order beam dynamics arise both from RF cavities and from the fringe fields in the dipole magnets.

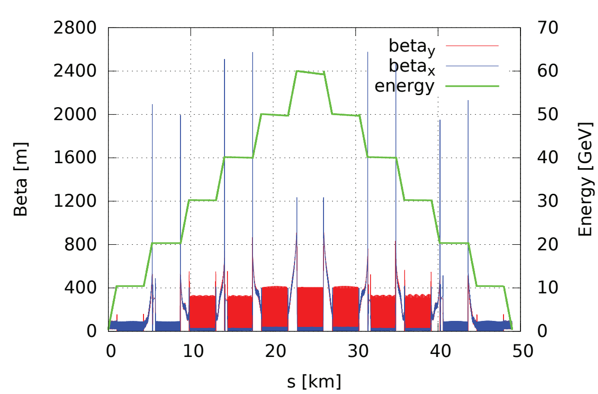

Figure 2: Beta functions and energy profile obtained following a bunch in the whole LHeC lattice.

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SINGLE-BUNCH TRACKING

The single bunch tracking allows to verify the beam transport. Fig. 2 shows the Twiss parameters obtained following a bunch along its path along the whole machine. The linacs are easily identifiable by looking at the energy variation. In the arcs the energy stays almost constant, the only variation being caused by the synchrotron radiation. A small beta beating can be barely noted in the arcs: it is caused by the different model of the RF-focussing in the linacs between PLACET2 and OptiM, the program used for the matchings.

While the lattice footprint is common to all the arcs, the beta functions and the dispersion (not showed) display different patterns. The arc cells are indeed flexible momentum compaction and are adjusted to mitigate the synchrotron radiation effect at different energy scales. At the highest energies it is important to contain the emittance growth, while at lower energies we can compensate for the bunch elongation due to non-zero momentum compaction. For this reasons: Arc1 and Arc2 are tuned to a negative momentum compaction lattice, Arc3 and Arc4 are tuned to a DBA-like lattice, Arc5 and Arc6 are tuned to a TME-like lattice.

The beam parameters are collected in Table 1 and Table 2 respectively at the IP and at the dump (after the deceleration). The beam is transported to the IP with a reasonable emittance growth. The impacts of beam-beam and SR in Arc6 are evident, but not detrimental to the deceleration. The beam envelop remains well within the aperture even at the end of the deceleration.

Table 1: Initial Beam Parameters Compared to the Ones at the IP in Presence of Synchrotron Radiation

	initial/CDR	IP
ε_x [μm]	50	57.4
ε_y [μm]	50	50.8
δ	0.0020	0.0026
RMS x [μm]	7.20	7.66
RMS y [μm]	7.20	7.21
RMS z [mm]	0.600	0.601
RMS e [MeV]	1.00	15.4

Table 2: Beam Parameters at the Dump, the Columns Shows the Values for SR Only, SR and Beam-Beam, SR and Beam-Beam with High Lumi Parameters. The List of the Parameters can be found in [2]

	Final SR	SR + BB	SR + BB-HL
ε_x [μm]	107	133	165
ε_y [μm]	87	125	158
δ	0.059	0.059	0.059
RMS x [mm]	1.52	1.67	1.86
RMS x' [mrad]	0.08	0.09	0.10
RMS y [mm]	2.42	3.03	3.15
RMS y' [mrad]	0.07	0.09	0.09
RMS z [mm]	0.66	0.66	0.66
RMS e [MeV]	29.7	29.5	29.6

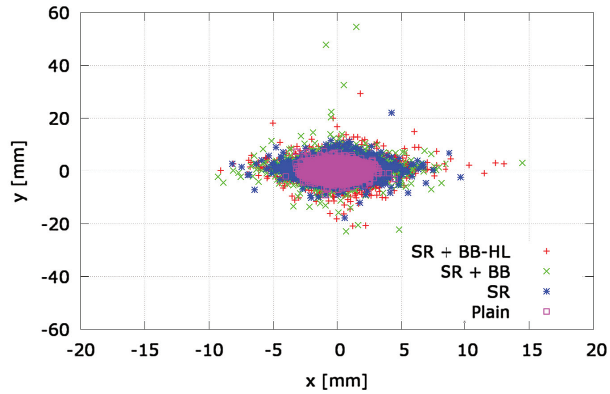

Figure 3: Beam transverse section at the end of the last linac, after the deceleration, including different Synchrotron Radiation and Beam-Beam with standard and High Luminosity parameters. The beam contains 5000 macroparticles and the initial distribution is gaussian with no cuts.

MULTI-BUNCH EFFECTS

PLACET2 allows to set up a train of bunches for tracking. It simultaneously propagates all the bunches in the machine preserving their time sequence in each beamline. This allows to compute multi-bunch effects even with complex lattice topologies. A model of transverse long-range wakefields (LRW) is currently implemented in PLACET2. LRW take place when a bunch passing through a cavity excites higher order modes (HOMs) of oscillation of the electromagnetic field; if the Q-value is big enough, the HOMs kick the subsequent bunches. High current and strong HOMs can establish a positive feedback leading to beam break up. The operation of the LHeC as an Higgs Factory requires high currents, up to 150 mA in the linacs [2], this posed a concern for the beam stability.

For the multi-bunch simulation the same setup, as described before, was used. The tracking was performed using single particle bunches. The beam-beam computation GUINEA-PIG was substituted by an amplitude-dependent kick. The simplified beam-beam calculation overestimates the beam-beam effect as in reality the electrons oscillate around the proton beam and receive a smaller kick. The HOMs considered are the transverse dipole modes of the SPL cavity design, scaled to 802 MHz.

In order to evaluate the LRW impact the machine is completely filled with approximately 6000 bunches perfectly aligned. One misaligned bunch is then injected followed by many bunches again perfectly aligned. The perturbation introduced by the misaligned bunch is propagated to the others, as can be seen in Fig. 4. There are two important parameters: the slope of the tail, which determines if and how fast the perturbation is damped; and the F parameter that represents the total amplification of the beam action, defined as the squared sum of all the amplitudes [5]. This sum is convergent and mostly driven by the bunches that are close to the exciting one.

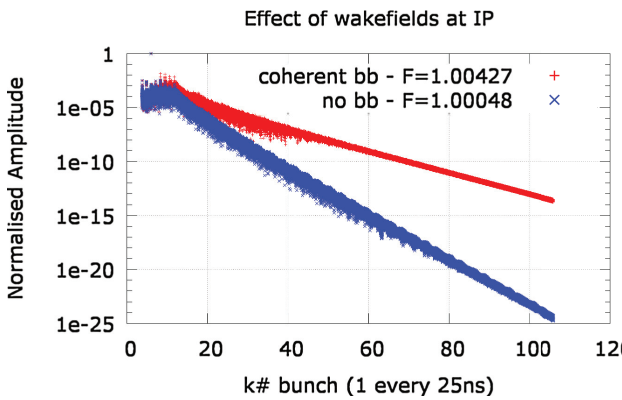

Figure 4: Normalised actions of the bunches at the IP. Only the bunch with action 1 carries an initial misalignment. All the other bunches are excited by LRW. The bunches contains 4×10^9 electrons.

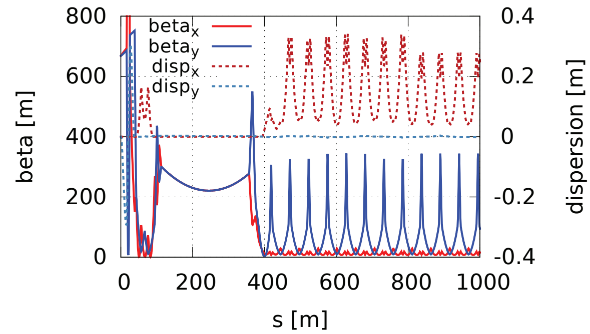

Figure 5: Beta functions and dispersion at the beginning of Arc4 with the detector bypass included. We see the vertical spreader, the initial horizontal bending, the straight section, the modified dispersion suppressor, seven junction cells, and four regular cells.

BYPASS DESIGN

After the linac2 spreader, that provides vertical separation, the 60 GeV beam goes straight to the IP. However the lower energy beams need to be further separated to avoid the detector. This is accomplished by the bypass section that applies to Arc2 and Arc4. As shown in Fig. 1, the separation takes place in the horizontal plain, towards the inside the racetrack. This allow to minimise the required extra bending and so the impact of synchrotron radiation.

Ten arc-like dipoles, placed very close to the spreader, provide the initial bending, resulting in 10 m separation from the detector 150 m downstream. The straight section of the bypass is approximately 300 m long and may have many applications as diagnostic and path length adjustments. To connect with Arc6, ten of the sixty standard cells in Arc2 and Arc4, are replaced with seven higher field cells. This is a compromise between the field strength and length of the tunnel in which the three arcs are superimposed and combined magnets can be employed [6].

Figure 5 shows the Twiss functions at the beginning of Arc4. We chose to keep the same quadrupolar strengths in the junction and in the arc cells, this creates a little mismatch in the junction cells that is removed in the dispersion suppressor. In Arc2 the mismatch is more evident and it has been cured by adjusting the quadrupoles in the last junction cell and in the first regular cell.

CONCLUSIONS AND OUTLOOK

PLACET2, a new version of the tracking code PLACET, has been developed in order to handle recirculating lattices. A model of the LHeC electron facility has been set up in PLACET2. Single and multi-bunch tracking simulations have been performed. The single bunch tracking verified the transport of the beam down to the dump in presence of synchrotron radiation and beam-beam effect. The multi-bunch tracking shows that the current beam parameters do not lead to beam break up. Even in the highest current scenario and in presence of beam-beam, we are still well below the threshold current. Future investigation with increased number of particles in the bunches should reveal the additional damping expected from the energy spread and chromaticity.

The machine model will be improved in the near future adding the recently designed detector bypass for Arc2 and Arc4 and the losses compensating sections. We noted that the spreader/recombiner sections are heavily affected by synchrotron radiation. New designs aimed at alleviating the issue are under investigation.

ACKNOWLEDGMENT

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