PREPARATION OF START-TO-END SIMULATION FOR COMPACT ERL

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Abstract

For the preparation of start-to-end simulation (S2E) for a synchrotron light source based on Energy Recovery Linac (ERL), particle tracking simulations were carried in a main super conducting RF cavity (SRF) section and an arc section for the compact ERL (cERL). Since the beam energy after the main SRF section is limited to be 35 MeV for the early stage of the machine commissioning of the cERL, space charge effect after acceleration can not be ignored. To study the space charge effect after acceleration, the particle tracking was carried out using General Particle Tracer (GPT) with mesh based method to calculate space charge effect. As a result of the tracking in the main SRF section and the arc section, the distortion of the betatron function caused by space charge was observed, when the kinetic energy of the bunch was less than 125 MeV.

INTRODUCTION

Start-to-end (S2E) simulation from electron gun to beam dump is required to estimate light source performance and beam loss, which are essential parts in synchrotron light source based on Energy Recovery Linacs (ERL) [1]. The normalized rms emittances less than 1.0 mm mrad and 0.1 mm mrad are required for high current mode with 77 pC /bunch and XFEL-O operation with 20 pC/bunch [2, 3], respectively. Since the beam energy is widely varied from eV to GeV order in the ERL, the S2E simulation have to include many effects, e.g., space charge (SC) effect, coherent synchrotron radiation (CSR), cathode model, wake function, ions and beam break up. In order to carry out the S2E simulation, the preparation of it using General Particle Tracer (GPT) [4], which is a particle tracking code including SC routine, has been started for compact ERL (cERL) beamline. The cERL is a test accelerator to establish accelerator technologies for GeV-class synchrotron light source based on ERL, and consists of an injector with photo cathode DC gun, a merger section, SRF cavities for acceleration and energy recovery, return loops, and a beam dump. In the early stage of the machine commissioning of the cERL, the beam energy after the acceleration by the main SRF cavities is limited to be 35 MeV. In this case, space charge effect can not be ignored after the acceleration, and the distortion of the betatron function arises in the return loop. So far the particle tracking simulation from the gun to the merger section was carried out. In this paper, as a next step for the preparation of the S2E simulation from gun to the beam dump, the results of the tracking simulation with space charge effect in the main SRF section and the arc section are shown. The layout of cERL with a single return loop is shown in Fig. 1.

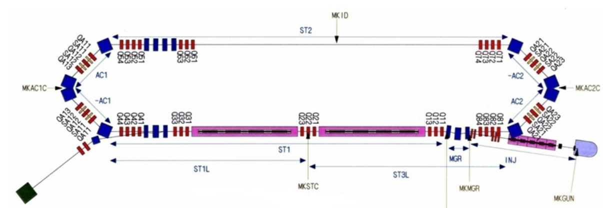

Figure 1: Layout of cERL with a single return loop.

PARTICLE TRACKING SIMULATION

The GPT can include space charge effect and external field map to simulate magnet and RF field. The field map of SRF 9-cell cavity was calculated by POISSON/SUPERFISH. In addition, to calculate CSR effect in the arc section, we developed one dimensional CSR routine for GPT [5]. However, the CSR routine was not used in the simulation to study space charge effect alone. As a space charge routine, a mesh based method is used. Although the GPT has the mash base method routine, we used modified mash based method instead of it to obtain better convergence of a result inside a bending magnet [5].

In order to study the distortion of the betatron function, the bunch with the initial bunch length of 1 ps or 2 ps was tracked in the beam line. The initial particle distribution is a gaussian distribution for both transverse and longitudinal directions with 5000 macro particles. The particle tracking simulation gives the particle distribution in six dimensional phase space, $(x, x', y, y', z, \dot{z})$, where $'$ and $\dot{}$ denote d/dz and d/dt, respectively. Here, x, y and z are the particle coordinates for the horizontal, vertical and longitudinal directions, respectively. When the beam consists of the N macro particles, the particle coordinate of the i-th particle is $(x_i, x'_i, y_i, y'_i, z_i, \dot{z}_i)$. From the particle distribution, the betatron function is defined by

$$\beta_x = \frac{\langle x_c^2 \rangle}{\epsilon_x}, \tag{1}$$

where $x_{c,i} = x_i - \langle x \rangle$, $x'_{c,i} = x'_i - \langle x' \rangle$, and $\epsilon_x = \sqrt{\langle x_c^2 \rangle \langle x_c'^2 \rangle - \langle x_c x'_c \rangle^2}$. Here, $\langle \rangle$ denotes an average, e.g, $\langle x \rangle = \sum x_i / N$. In this paper, the betatron function is calculated by Eq. (1) from the calculated particle distribution. The betatron function with the space charge effect in the main SRF section is shown in next section.

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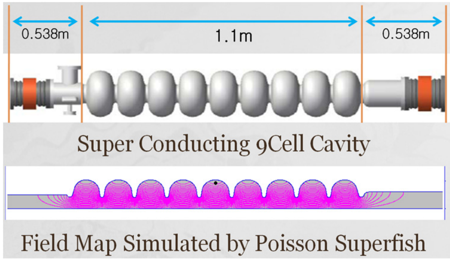

Figure 2: Super conducting 9-cell cavity and field map.

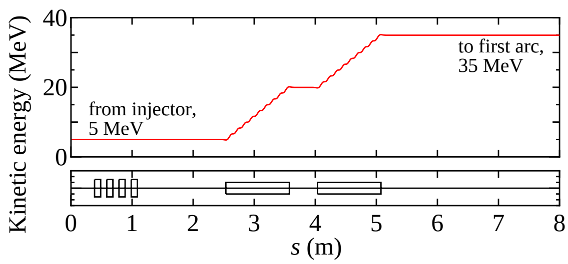

Figure 3: Kinetic energy in main SRF section.

BEAM DYNAMICS IN MAIN SRF SECTION

In order to study the space charge and RF focusing effects, the particle tracking simulations from the exit of merger section to the entrance of the 1st arc section were carried out. The figure of the SRF 9-cell cavity and the field map are shown in Fig. 2. The main SRF section, which is used in the simulation, consists of four quadrupole magnets, two SRF cavities and drift space. The injected beam with 5 MeV is accelerated by the two SRF cavities to be 35 MeV. The variation of the energy in the main SRF section is shown in Fig. 3.

The initial Courant-Snyder parameters are $\alpha_x = 2.7168$, $\beta_x = 0.79858$ m, $\alpha_y = -1.1307$ and $\beta_y = 10.9564$ m. In the tracking simulation, the bunch charge was varied from 10 pC to 80 pC with 10 pC step. In addition, the simulation with out space charge effect was carried out to compare the linear beam optics, which calculated by elegant. Typically, the cERL will be operated with 80 pC and 20 pC for high current mode and for XFEL-O operation, respectively.

Figure 4 shows the space charge effect on the betatron function with the bunch length of 1 ps in the main SRF section. This graph shows that the space charge effect causes the distortion of the betatron function for any bunch charge. Figures 5 shows the space charge effect on the betatron function with the bunch length of 2 ps in the main SRF section. These graphs show that the distortion of the betatron function for the bunch length of 1 ps is larger than for the bunch length of 2 ps. Since the charge density with shorter bunch length becomes higher, the space charge effect with 1 ps bunch length becomes stronger compared with 2 ps bunch length. These results show that the space charge effect can not be ignored in this section, and the beam optics

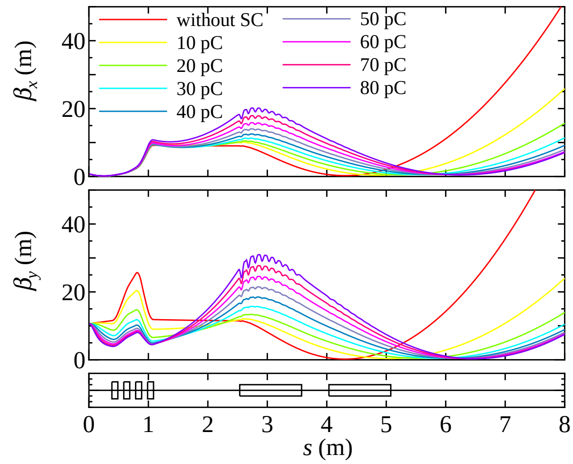

Figure 4: Space charge effect on betatron function with the bunch length of 1 ps in main SRF section.

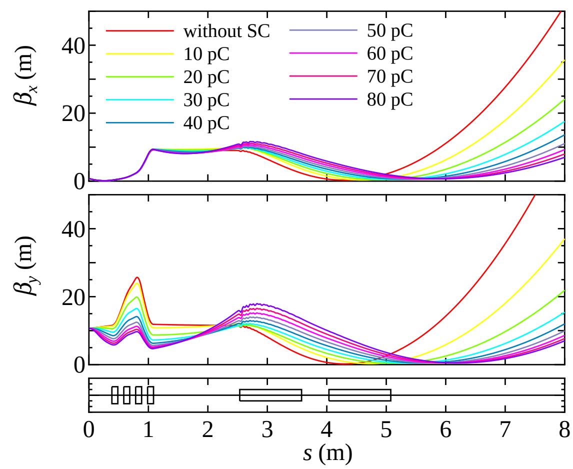

Figure 5: Space charge effect on betatron function with the bunch length of 2 ps in main SRF section.

matching is required to match the optics between the main SRF section and the 1st arc section. The betatron function with the space charge effect in the 1st arc section, which is located behind the main SRF section, is shown in next section.

BEAM DYNAMICS IN ARC SECTION

In order to study the space effect, the particle tracking simulations from the entrance to the exit of the 1st arc section were carried out. The layout of the 1st arc section is shown in Fig. 6. The 1st arc section consists of three bending magnets, six quadrupole magnets and four sextupole magnets. The input file for GPT was checked compared with the linear beam optics calculated by elegant.

The initial Courant-Snyder parameters are $\alpha_x = 1.3177$, $\beta_x = 0.9863$ m, $\alpha_y = 12.9075$ and $\beta_y = 16.2181$ m. In the simulation, the bunch charge and the beam energy were varied. Figures 7 and 8 show the space charge effect on the

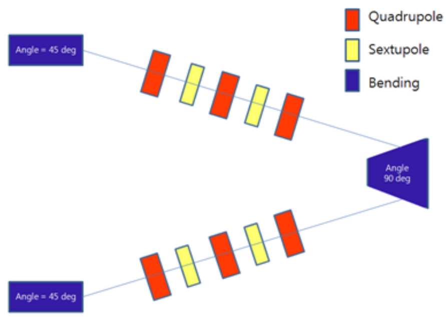

Figure 6: Layout of 1st arc section.

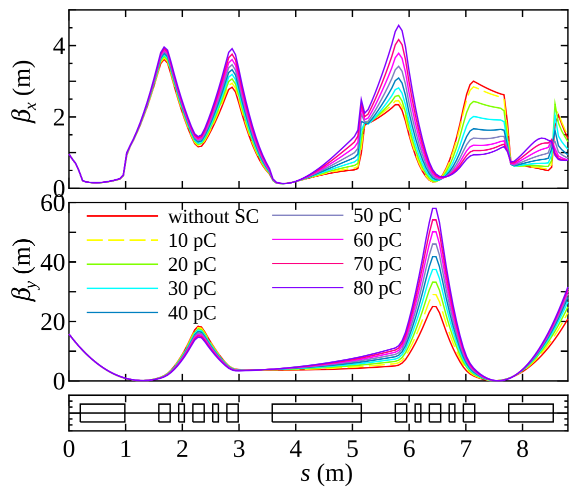

Figure 7: Space charge effect on betatron function with the bunch length of 1 ps in 1st arc section. Beam energy is 35 MeV.

betatron function with the bunch lengths of 1 ps and 2 ps, respectively, when the bunch charge varies from 10 pC to 80 pC with 10 pC step. Comparing the results of 1 ps and 2 ps, the distortion of the betatron function with the bunch length of 1 ps is larger than one with the bunch length of 2 ps. The both cases shows that the distortion of the betatron function can not be ignored for the beam energy of 35 MeV.

Figure 9 shows the space charge effect on the betatron function with the bunch lengths of 2 ps, when the beam energy varies from 35 MeV to 185 MeV with 30 MeV step. This graph shows that the beam energy, which is larger than 125 MeV, is required in order to ignore the space charge effect in the 1st arc section. Therefore, for the early stage of cERL machine commissioning with 35 MeV, the correction of the betatron function is required.

SUMMARY

As the preparation of the S2E simulation in the ERL, the particle tracking simulations with space charge effect in the main SRF section and the 1st arc section were carried out using the particle tracking code, GPT. As a result of the tracking in the main SRF section and the arc section, the distortion of the betatron function caused by space

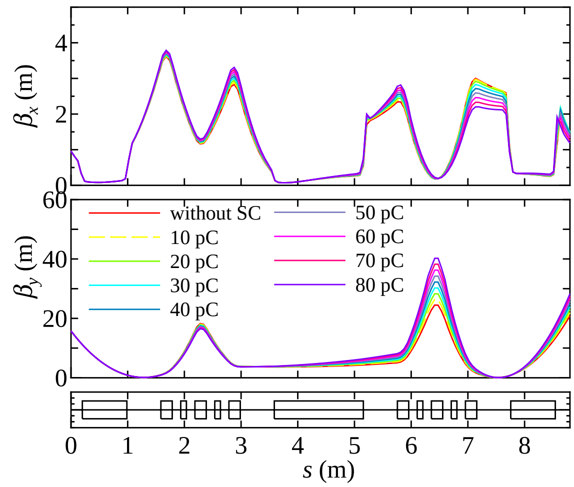

Figure 8: Space charge effect on betatron function with the bunch length of 2 ps in 1st arc section. Beam energy is 35 MeV

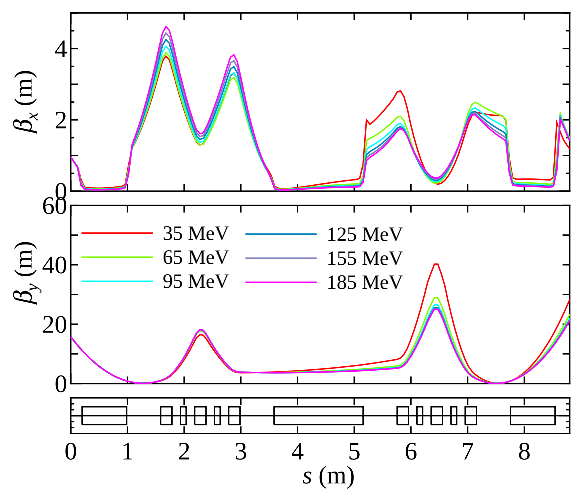

Figure 9: The effect of beam energy on betatron function with the bunch length of 2 ps in 1st arc section. Bunch charge is 80 pC.

charge was observed, when the kinetic energy of the bunch was less than 125 MeV. In the future, we will developed the matching method to connect the each section based on these results, and carry out the S2E simulation from the gun to the exit of the 1st arc. In addition, the CSR effect in the arc section will be studied.

REFERENCES

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