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STATUS OF HIGHER BUNCH CHARGE OPERATION IN COMPACT ERL

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Abstract

In the KEK compact ERL (cERL), machine studies toward higher bunch charge operation is one of the most important issues. From January 2015 to April 2015, we carried out a higher bunch charge operation with an bunch charge of 0.5 pC for the experiment of laser compton scattering. After the study of space charge effect and optics tuning, we succeeded in the recirculation operation with the emittance, which was close to the design value. Moreover, a test operation in the injector section with the bunch charge of 7.7 pC was carried out as a preparation toward the recirculation operation with the average current of 10 mA.

INTRODUCTION

The compact ERL (cERL) is a test accelerator to demonstrate beam performance and high average current operation in an energy recovery linac. It consists of a photocathode DC gun, superconducting RF cavities, a recirculation loop, and a beam dump. The layout of the cERL is shown in Fig. 1. Since commissioning of the injector in April 2013, production and transportation of low-emittance beams have been demonstrated with several tens of fC where the space charge effect can be neglected. In the low bunch charge operation, an energy recovery operation through the recirculation loop with an average current of 6.5 μA was also demonstrated.

One of the most important issues in the cERL operation is to obtain low-emittance and short bunch, high-quality beams under the space charge effect. Since June 2013, we have been studying higher-charge operation with bunch charges of up to 7.7 pC which corresponds to a peak current of 10 mA [1]. To minimize emittance growth due to the space charge effect, we have been developing beam tuning methods.

From January 2015, we increased the maximum average current up to 100 μA [2], and carried out a higher bunch charge operation with the bunch charge of 0.5 pC for the experiment of laser compton scattering (LCS) [3,4]. In this operation, we have to control the space charge effect, because we can not neglect the effect in this bunch charge. Our goal for this operation is to achieve a recirculation without emittance growth. Moreover, we carried out a test operation in the injector section with the bunch charge of 7.7 pC to correct a numerical model for higher-charge and low energy beam. In this paper, we report optics design, tuning methods and our results from higher-charge operations of the injector and the recirculation loop.

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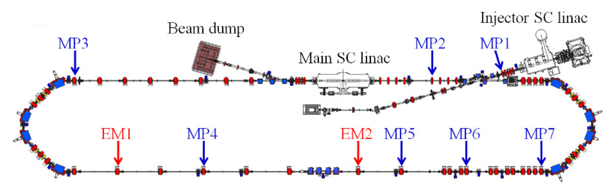

Figure 1: Layout of cERL. MP and EM indicate optics matching point and emittance measurement point, respectively.

RECIRCULATION OPERATION FOR LASER COMPTON SCATTERING

For the LCS operation, the higher bunch charge was required in order to increase the LCS signal power. However, the maximum bunch charge is limited to 77 fC for 1.3 GHz CW operation, in which the maximum average current reaches 100 μA, and it is not enough for the LCS operation. Then, we switched the repetition frequency of the gun excitation laser from 1.3 GHz to 162.5 MHz, and increased the bunch charge to 0.5 pC, in which the average current corresponded to 81μA.

Optics Design

The optics design strategy for the 0.5 pC operation is to use the same RF settings of the injector and main SC linac as the normal operation with several tens of fC to maintain the beam energy, and the same optics parameters at the exit of main SC linac in order to reduce tuning parameters. Under these conditions, we can quickly switch the operation mode from the normal mode to the higher-charge mode. For both operation modes, the beam kinetic energies at the gun, the injector and the main SC linac are 390 keV, 2.4 MeV and 19.4 MeV, respectively, and the distribution of the cathode excitation laser is a gaussian distribution with the rms length of 3 ps.

The optics for the higher-charge operation was designed by the following two steps. In the fist step, we adjusted the strengths of the two solenoid magnets in the injector section to satisfy a condition of emittance compensation. In the second step, based on these solenoid settings, we adjust quadrupole magnets between the injector and the main SC linac to satisfy a optics matching condition at the exit of the main SC linac for recirculation operation, whose values are β_x = 2.67 m, β_y = 2.12 m, α_x = −0.6 and α_y = −0.18. Figure 2 shows the design optics from the gun to the main SC linac for the 0.5 pC recirculation operation. At the exit of the main SC linac, the design horizontal and

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vertical normalized emittances and bunch length are 0.26, 0.24 mm·mrad and 3 ps. The Twiss parameters satisfy the optics matching condition for the recirculation operation. Therefore, we basically do not require the modification of the recirculation loop optics. From the middle of February 2015, we switched the injector optics and the repetition frequency of the gun cathode laser from the normal operation to the 0.5 pC operation, and began optics tuning.

Space Charge Effect

In the normal operation, we usually use the bunch charge of several tens fC. In this case, we can neglect space charge effect. However, for the 0.5 pC operation, we have to include space charge effect. After the switch of the operation mode, we confirmed space charge effect in the injector section by solenoid scan method. In the solenoid scan, we measured the beam size response on a screen monitor, when we scanned solenoid strength. Figure 3 shows the layout of the solenoid, SL1, and the screen monitor, MS1.

Figure 4 shows simulated and measured solenoid scan results. The simulated results were calculated by General Particle Tracer (GPT) with 100 k macro-particles and a 3D mesh based space charge routine. The numerical model of the photocathode DC gun was corrected to reproduce the measurement result without space charge effect [5]. As shown in Fig. 4, space charge effect for 0.5 pC operation is

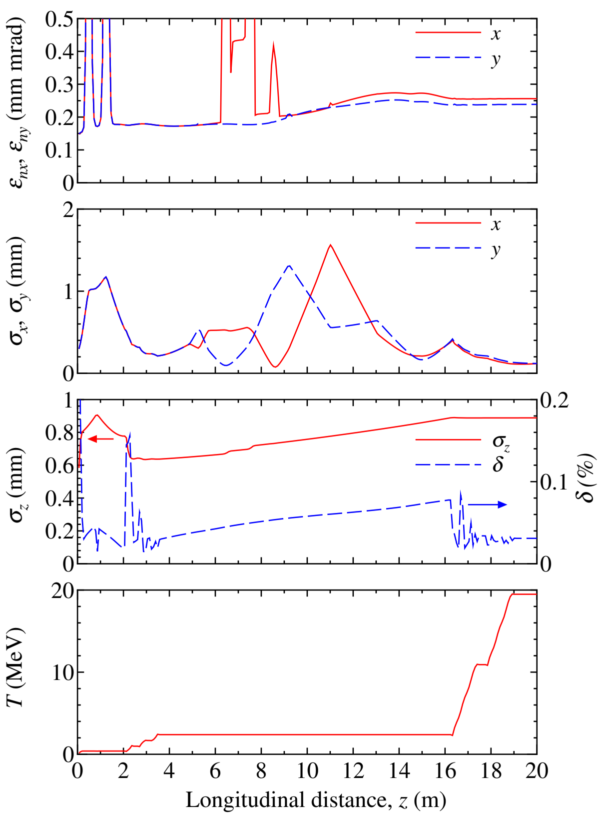

Figure 2: Design optics parameters from a gun to main SC linac for 0.5 pC recirculation operation.

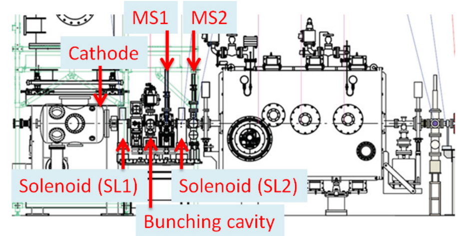

Figure 3: Layout of injector beamline, which consists of a gun, solenoids (SL1 and SL2), a bunching cavity, and screen monitors (MS1 and MS2).

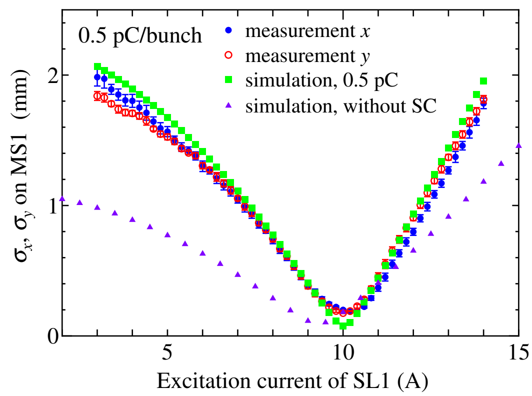

Figure 4: Solenoid scan results for 0.5 pC operation. The initial laser pulse is 3 ps gaussian distribution. The rms beam size were measured at a screen monitor, MS1.

not negligible, because the beam size for 0.5 pC is increased by it comparing with no space charge case.

The measured horizontal and vertical responses for 0.5 pC in Fig. 4 almost correspond to the simulated results. It shows that the measured beam maintains cylindrical symmetry, and the numerical model is correct to reproduce space charge dominant beam. From these results, we confirmed the space charge effect in the injector section for the 0.5 pC operation mode.

Optics Tuning

After the study about space charge effect in the low energy region, we accelerated the beam up to the kinetic energy of 2.4 MeV by the injector SC linac with the same RF settings, acceleration field and phase, as the normal operation mode. The next step is optics matching to the entrance of the main SC linac. We carried out the optics matching at two matching point, MP1 and MP2, as shown in Fig. 1.

To measure the optics, we scan quadrupole strength and measure beam size response on a screen monitor. To adjust the optics, we use other four quadrupole magnets, which are located on the upper stream of the scanned quadrupole magnet. The optics matching has the following four steps. In the first step, we calculate a target quadrupole response from the design optics. In the second step, we measure the Q-scan response, and calculate the difference between the target and measured responses. In the third step, we

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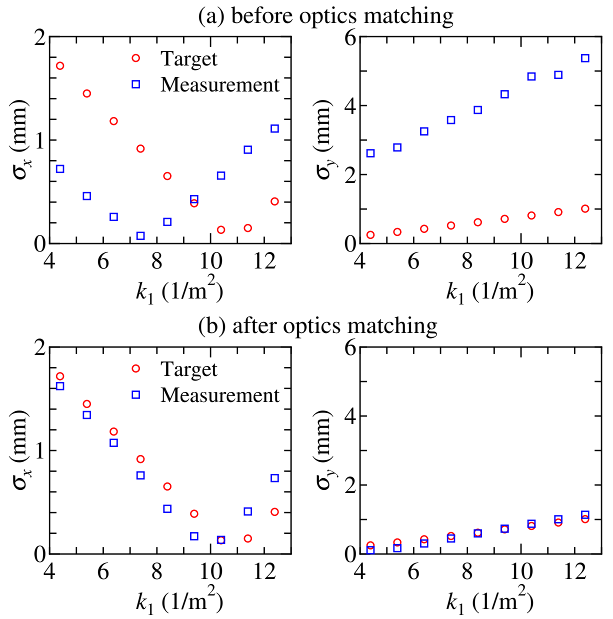

Figure 5: Quadrupole scan results before and after optics matching at a matching point, MP2.

measure a response matrix about the Q-scan response, when we individually vary the other four quadrupole magnets. In the fourth step, we calculate the correction values for the four quadrupole magnet by solving the inverse measured response matrix.

Figure 5 shows the optics matching results at the matching point, MP2, as shown in Fig. 1. As shown in Fig. 5, the measured response before optics matching differs from the target. It seems that additional unwanted environment magnetic field causes the difference. After optics matching, we succeeded in the optics correction, and obtained the almost same response as the target.

After the optics matchings at MP1 and MP2, we accelerated the beam up to 19.4 MeV by the main SC linac. And then, we carried out the optics matchings in the recirculation loop at the matching points, MP3 to MP4, as shown in Fig. 1. As a result of the optics corrections, we obtained preliminary measured emittances at EM1 and EM2, as shown in Fig. 1. The measured horizontal and vertical normalized emittances at EM1 are 0.32±0.02 and 0.28±0.01 mm·mrad, respectively. And, the measured horizontal and vertical normalized emittances at EM2 are 0.41±0.1 and 0.3±0.02 mm·mrad, respectively. These measured emittances are close to the design values, whose horizontal and vertical emittances are 0.26 and 0.24 mm·mrad, respectively.

HIGHER BUNCH CHARGE OPERATION

Since June 2013, we have been studying space charge effect for 7.7pC. One of the important parameters about space charge effect is the initial distribution of the gun cathode excitation laser. In June 2014, we studied eight stacked gaussian pulse as the laser distribution, whose length is 32 ps FWHM. However, the analysis of the measured result

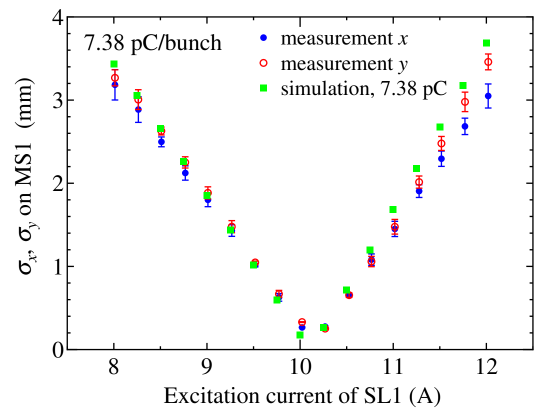

Figure 6: Solenoid scan results for 7.38 pC operation. The initial laser pulse is 3 ps gaussian distribution. The rms beam size were measured at a screen monitor, MS1.

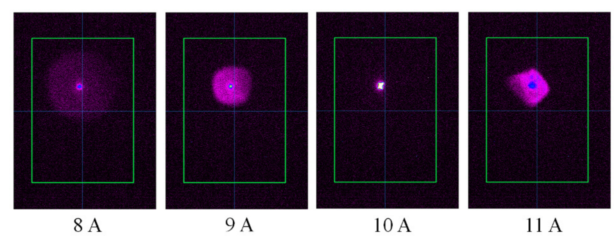

Figure 7: Transverse beam profiles on a screen monitor, MS1, for 7.38 pC operation.

was slightly complicated, because the measured result after acceleration by the injector linac was sensitive the initial laser distribution and the RF cavity settings. To simplify the situation, we used 3 ps rms gaussian as the laser distribution, and measured solenoid scan response.

Figure 6 shows the solenoid scan result with 7.38 pC. The measured horizontal and vertical responses for 7.38 pC in Fig. 6 almost correspond to the simulated results. However, the difference between the horizontal and vertical beam sizes appears for lager beam size, I_{SL1} > 11 A. It indicates that the cylindrical symmetry is slightly broken. Figure. 7 shows transverse beam profiles on MS1. The profile at 11 A in Fig. 7 is not circular distribution. In order to decrease emittance growth caused by space charge effect, we are investigating the source for the symmetry breaking. Based on this result, we plan recirculation operation of low emittance beam with 7.7 pC from May 2015 to June 2015.

SUMMARY

For laser compton scattering experiment, we operated the KEK compact ERL with higher bunch charge of 0.5 pC from January 2015 to April 2015. After the study of space charge effect and optics tuning, we succeeded in the recirculation operation with the emittance, which was close to the design value. Moreover, a test operation in the injector section with the bunch charge of 7.7 pC was carried out. In the next operation period from May 2015 to June 2015, we plan machine studies toward higher bunch charge recirculation.

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