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EVALUATION OF 60 pC BEAM PERFORMANCE AT cERL INJECTOR FOR ERL BASED EUV-FEL

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Abstract

In order to compensate for the emittance which is increased by space charge in the low energy region, it is important to transport the beam as designed. Until now, we did not consider couplers in injector superconducting cavities in optics design. But in this study, to improve optics matching and emittance compensation conditions for space charge dominated beam in cERL at KEK, we introduced a new 3D cavity model. We first investigated the influence of the couplers on electromagnetic field distribution. As a result, it was found that an asymmetric focusing force is generated by the influence of the couplers. It also became clear that the influence of the coupler kick on the optics significantly devastated the emittance compensation condition from the calculating including space charge. Furthermore, it was found that by optimizing the optics in consideration of the coupler kick, it is possible to improve the beam control accuracy and reduce the emittance in beam commissioning.

INTRODUCTION

Energy recovery linac (ERL) is the linear accelerator which can supply high average current beam. ERL based EUV-FEL for semiconductor lithography is designed at KEK [1]. EUV-FEL requires a beam with a bunch charge of 60 pC, kinetic energy of 10 MeV, bunch length of 1 ps and emittance of 1 mm.mrad in the injector.

Since the emittance increases due to space charge in the low energy region, the increased emittance must be compensated. In order to compensate the emittance, it is important to transport the beam as well as the designed optics. But, in beam commissioning at cERL in KEK, we found that the influence on the optics caused by coupler kick of injector cavity can not be ignored [2, 3].

We analyzed numerically and experimentally to study the influence of coupler kick on optics and emittance compensation. In this proceedings, we report on these results.

ELECTROMAGNETIC FIELD ANALYSIS

In order to analyze the influence on the electromagnetic field distribution by the couplers, we created two models of cERL injector cavity [4]; model 1 does not have couplers (Fig. 1 top, 2D model), model 2 has couplers (Fig. 1 bottom, 3D model). The electromagnetic field for 2D model is calculated assuming cylinder symmetry by Poisson/Superfish [5], for 3D model is calculated by CST [6]. 3D model has no cylindrical symmetry.

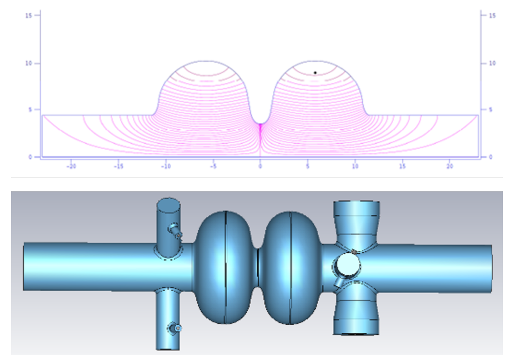

Figure 1: Two models of cERL injector cavity. Top is 2D cavity model and bottom is 3D cavity model.

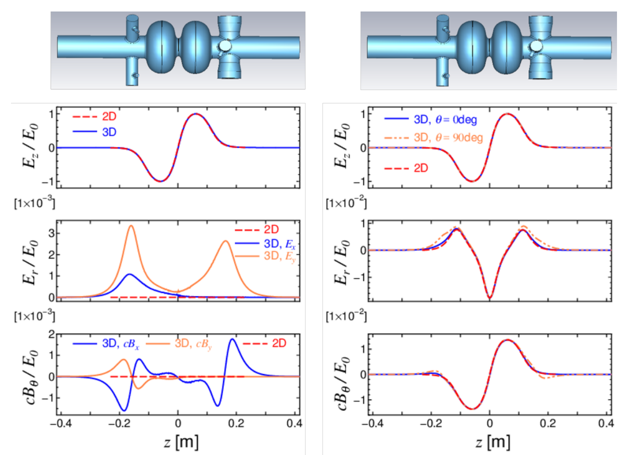

Figure 2: Comparison of electromagnetic field distribution (left: $r = 0$ mm, right: $r = 1$ mm). The red dotted line is the result of 2D model. The blue solid line is the result of 3D model with $\theta = 0$deg. The orange solid line is the result of 3D model with $\theta = 90$deg. The magnitude of the electromagnetic field is normalized by the maximum value of $E_z(r = 0, z)$.

Figure 2 shows the electromagnetic field distribution of $r = 0$ mm (left) and $r = 1$ mm (right) for each model. This indicates that the transverse electromagnetic field is generated on the central axis of the cavity by the couplers. In addition, it can be seen that the transverse electromagnetic field distribution becomes angle dependent by the coupler.

FOCUSING FORCE FROM CAVITY

In order to quantitatively evaluate the influence of coupler on beam dynamics, we tracked the single particle trajectory. The schematic layout is shown in Fig. 3. In this case, the lens whose focusing force is measured is a cavity. The kinetic

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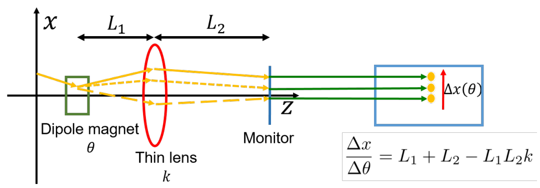

Figure 3: Schematic layout of single particle tracking.

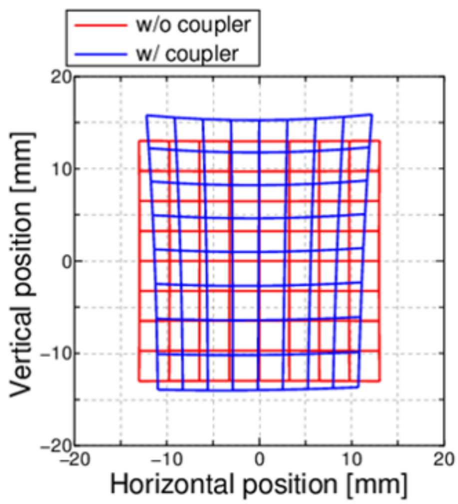

Figure 4: Tracking result. The red line is result of 2D model. The blue line is result of 3D model.

energy of injection particle is 0.5 MeV and after passing through the cavity is 1.7 MeV. The phase of cavity matches the maximum acceleration phase.

We tracked the particle trajectory while changing the dipole kick angle. Figure 4 is a plot of the transverse position of the particle at a certain z position after passing through the cavity. The result of the 2D model shows that the lattice is square. On the other hand, the result of 3D model shows that the lattice is vertically long.

In order to further evaluate quantitatively, the amount of movement of the particle with respect to the dipole kick angle θ were obtained from the linear fit of the scan result in the x-axis direction and y-axis direction. The result of the 2D model is $\Delta x/\Delta\theta = \Delta y/\Delta\theta = 1.16$ m/rad. The result of the 3D model is $\Delta x/\Delta\theta = 1.02$ m/rad, $\Delta y/\Delta\theta = 1.32$ m/rad.

OPTICS AND EMITTANCE MEASUREMENT

In order to evaluate the influence on optics and emittance compensation, we performed multistage calculation including space charge effect. The tracking code is General Particle Tracer (GPT) [7].

The results optimized to minimize the emittance at the final position using the 3D cavity model are shown in Fig. 5. Figure 5 also shows the evolution of beam size and emittance when only the cavity model is changed to 2D model. Since the focusing force from cavity varies depending on the cavity model, the beam size at the downstream is different.

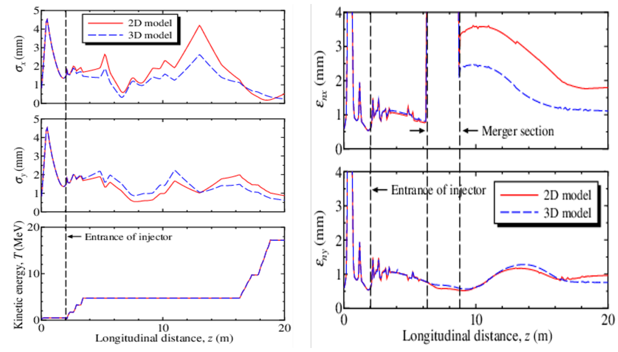

Figure 5: The evolution of RMS beam size (left) and normalized emittance (right). The red solid line is the result of 2D model. The blue dotted line is the result of 3D model.

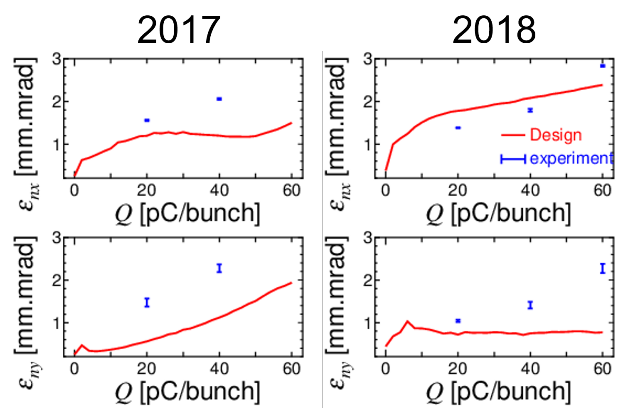

Figure 6: Emittance measurement result (left: 2017, right: 2018). The red line shows designed emittance value.

Although the horizontal emittance up to merger has hardly changed, it turns out that the emittance at the merger exit is greatly changed.

We measured the emittance at the merger exit by Q-scan method in beam commissioning using optics optimized considering coupler kick. To clarify the effect of coupler kick, the results of 2017 measured with optics optimized using 2D model are also shown in Fig. 6. From the comparison of the results it turns out that the emittance is lower in 2018 than in 2017. Moreover, it is understood that the amount of deviation from the designed value is smaller in 2018 than in 2017.

DISCUSSION

From the result of the electromagnetic field analysis, it was found that the influence of the couplers causes a non-zero electromagnetic field in the transverse direction on the central axis of the cavity. The transverse electromagnetic field on the central axis gives a dipole kick to the beam. It was also found that the distribution of the transverse electromagnetic field has circumferential dependence due to the presence of the coupler. This shows that the transverse electromagnetic field gives a beam the focusing force that is asymmetrical in

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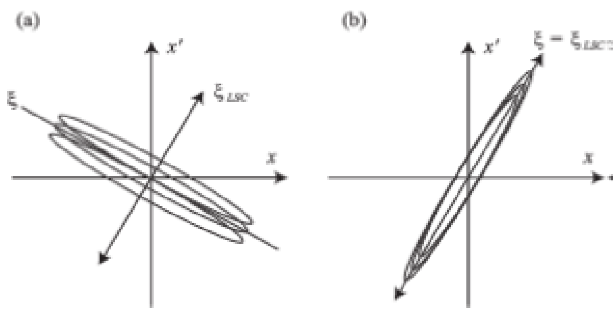

Figure 7: Diagram for compensating the emittance increased in the dispersion region by longitudinal space charge. (a) When the emittance deterioration amount becomes the maximum. (b) When the emittance deterioration amount becomes the minimum.

the horizontal and vertical direction. Therefore, this directly affects beam optics.

The asymmetry of focusing force was quantitatively evaluated from single particle tracking. It was found that the beam movement amount ratio was distorted by 1.3 times, and it was shown that the focusing force in the horizontal direction is stronger than vertical direction. It is consistent with the result of electromagnetic field analysis that the focusing force becomes asymmetric.

In order to investigate the influence on beam transport optics and emittance compensation, multiparticle tracking considering space charge effect was performed. Depending on the model of the cavity, that is, the presence or absence of couplers, it was shown that the downstream beam size is different. This is due to the change in the focusing force from the cavity due to the influence of the couplers. It was also shown that the emittance after passing through the dispersion region (merger) greatly varies depending on the model. This is because compensation of the horizontal emittance increase in the horizontal dispersion region due to the longitudinal space charge effect is determined by the upstream optics [8,9]. Figure 7 shows a diagram for compensating the emittance increased by longitudinal space charge effect at the dispersion region. Emittance at the merger exit can be reduced by aligning the major axis directions of the ellipses in the direction aligned by the longitudinal space charge effect, that is, matching with the optics of emittance compensation. Therefore, it is considered that the emittance at the merger exit was increased due to the influence of upstream optics change (cavity model change). And we guess that the actual emittance value has been brought close to the designed value since we designed an optics to compensate the emittance using the 3D cavity model.

CONCLUSION

We numerically and experimentally analyzed the influence optics and emittance compensation due to coupler kick. We showed that the electromagnetic field distribution is distorted due to the existence of the couplers, the distorted electromagnetic field distribution gives dipole kick and asymmetric focusing force. An increase in horizontal emittance at the dispersion region by longitudinal space charge is known. Since the change in the focusing force by the couplers directly affects the optics, it can not be ignored against the compensation of the increased emittance. But, by optimizing the optics including the contribution of the coupler kick, the emittance could be brought close to the designed value.

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