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CROSSTALK OF BEAM-BEAM EFFECT AND LONGITUDINAL IMPEDANCE AT CEPC *

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Abstract

In conventional e+e- storage ring colliders, we only use lengthend bunch length in beam-beam simulation instead of considering impedance directly. It is no problem since the longitudinal dynamics is not sensitive to beam-beam interaction. But it is different since the bunch will also be lengthend during beam-beam interaction by beamstrahlung effect. It is very natural and more self-consistent to consider the longitudinal impedance in the beam-beam simulation. The simulation shows that the working point region of stable collision is slightly shifted by the longitudinal impedance. It is found that the vertical coherent oscillation may decreases the beam-beam limit with impedance at some working point.

INTRODUCTION

The circular Electron Positron Collider(CEPC) is a large international scientific project initiated and housed by China. It was presented for the first time to the international community at the ICFA Workshop “Accelerators for a Higgs Factory: Linear vs. Circular”(HF2012) in November 2012 at Fermilab. The Conceptual Design Report (CDR, the Blue Report) was published in September 2018 [1]. The CEPC is a circular e+e- collider located in a 100-km circumference underground tunnel. The CEPC center-of-mass energy is 240 GeV, and at that collision energy will server as a Higgs factory, generating more than one million Higgs particles. The design also allows operation at 91 GeV for a Z factory and at 160GeV for a W factory. The number of Z particles will be close to one trillion, and W^+W^- pairs about 15 million. Theses unprecedented large number of particles make the CEPC a powerful instrument not only for precision measurments on these important particles, but also in the search for new physics.

Beam-beam interactions are one of the most important limitation to luminosity. Beamstrahlung is synchrotron radiation excited by the beam-beam force, which is a new phenomenon in such high energy storage ring based e+e- collider. It will increase the energy spread, lengthen the bunch and may reduce the beam lifetime due to the long tail of photon spectrum [2,3]. In this paper, we’ll first briefly show some impedance data of CEPC. And then some initial result of longitudinal wakefield influence on beam-beam interaction is shown.

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LONGITUDINAL IMPEDANCE

In conventional e+e- storage ring colliders, we only use lengthend bunch length in beam-beam simulation instead fo considering impedance directly. It is no problem since the longitudianl dynamics is not sensitive to beam-beam interaction. But it is different since the bunch will also be lengthend during beam-beam interaction by beamstrahlung effect. The longitudinal dynamics should have an important impact on the transverse motion in collision with a finite crossing angle. It is very natural and more self-consistent to include the longitudinal impedance in the beam-beam simulation. The longitudinal kick along the bunch $V(t)$ is calculated each turn [4],

$$I(t) = \int_{-\infty}^{\infty} \frac{d\omega}{2\pi} e^{-i\omega t} \tilde{I}_{\|}(\omega), \quad \tilde{V}(\omega) = -\tilde{I}(\omega)\tilde{Z}_{\|}(\omega) \quad (1)$$

where $I(t)$ is the bunch distribution.

Impedance Model

The impedance are calculated both with formulas as well as simulations with ABCI and CST. The longitudinal wake contributions of different impedance objects at a bunch length of 3mm are shown in Fig. 1. The longitudinal impedances are dominated by the resistive wall and elements of which there is a large quantity. The longitudinal loss factor is mainly contributed by the resistive all and the RF cavities.

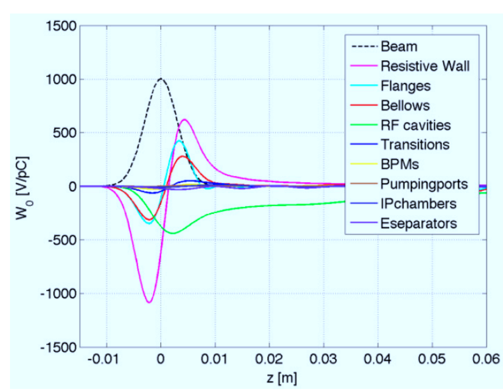

Figure 1: Longitudinal wake potential with rms bunch length of 3mm.

To suppress the electron cloud instability, the vacuum chamber of e+ ring will be coated 0.2μm NEG on copper. And the material of e- ring vacuum changer is almunium. Figure 2 shows the total longitudinal impedance of the two rings. The real part impedance of Al is greater than that of

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coated copper, while the imaginary part of the prior is less. In this paper, it is supposed that the impedance of the two rings are both that of NEG coated in most cases.

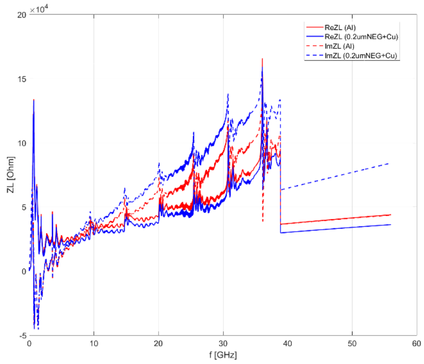


Figure 2: Total longitudinal impedance of the two rings.

Crosscheck

The beam-beam simulation code (IBB) was first developed for BEPCII [5], which is a self-consitent strong-strong code. The beamstrahlung effect during collision has been considered so far [3]. In order to study the effect of longitudinal impedance on beam-beam performance, the longitudinal kick coming from the wakefield was implemented in the code. Figure 3 shows the longitudinal bunch distribution simulated by Elegant [6] and IBB, where collision is turned off. The result coincides very well between the two codes.

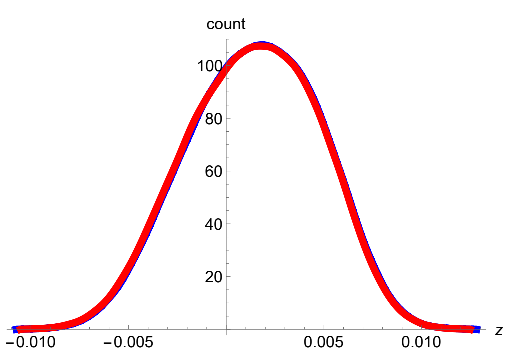


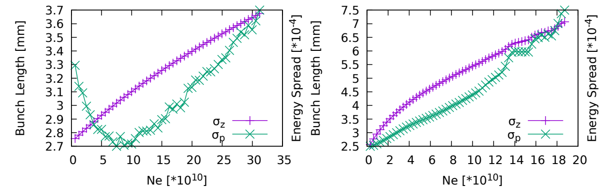
Figure 3: Longitudianl distribution obtained with Elegant and IBB.

SIMULATION RESULTS

Figure 4 shows the longitudinal distortion coming from wakefield without collision. The design bunch population is about 12×10^{10}. As we can see, the distortion at Higgs mode is not very serious. Howevere the effect at Z is very strong, both bunch length and energy spread is distroted.

With beam-beam, we simulate 2 cases:

- the conventional method, the bunch equilibrium distribtuion without beam-beam is assumed gaussian but lengthed by wakefield.
- self-consistent method, initialize the bunch using the zero-current natural bunch length, considering the longitudianl impedance during tracking.



(a) Higgs (b) Z

Figure 4: Longitudinal distortion casued by wake field(simulated by Elegant).

Higgs

With CDR paramters but different bunch population(20×10^{10}), it is found that the optimzed working point is closer to half integer with impedance in Fig. 5. There is no longitudinal tune shift. It is not related with the so called X-Z coherent beam-beam instability [7]. Instead it is related with the coherent oscillation in vertical direction, see Fig. 6. It is also found there exist <xy> moment oscillation with impedance, but no <x> oscillation. We change the impedance data by a factor of 0.8-1.2 manually, The beam-beam performance at Higgs is not sensitive to the longitudinal impedance budget.

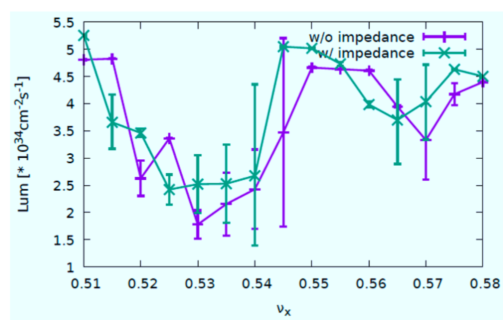
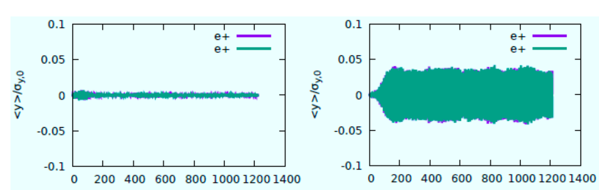


Figure 5: Luminosity versus horizontal tune at Higgs. The errorbar shows the turn-by-turn luminosity evolution.



(a) Conventional Method (b) With Impedance

Figure 6: Coherent oscillation in vertical direction caused by impedance at ν_x=0.555.

Z

The luminostiy performance at Z is limited by HOM of RF cavity and electrong cloud instability instead of beam-beam interaction. Using the conventional method, we still

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simulate the beam-beam interaction at different bunch intensity, shown in Fig. 7. With same beam current, comparing to 3T detector solenoid, weaker solenoid (2T) reduces the verticla emittance and allowing to squeze β_y^*, luminsoty increase by a factor of 2. If we increase the bunch population from 8×10^{10}(CDR design value) to 12×10^{10} and keep the beam current constant, the luminosity will increase 20%.

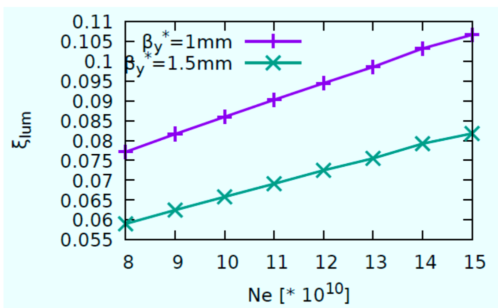


Figure 7: Beam-beam performance at Z (β_y^* = 1.5mm for 3T and 1mm for 2T). No impedance is considered directly.

With CDR paramters(β_y^*=1mm) but different bunch population(12×10^{10}), the effect of impedance on beam-beam perfomance with different horizontal tune is shown in Fig. 8. With same vertical tune(0.61), the beam-beam parameter is lower considering longitudinal wakefield. More important, the stable working point space is much narrower. Two dimensional tune scan should be done to check if there exist large enough stable region.

Figure 9 shows the turn-by-turn rms size evolution with and without impedance. It is clear that there exist strong 3-D flip-flop instablity with impedance. Even though the luminosity is nearly same (about 10% difference), but the dynamics is totaly different. The influence of the wakefiled on beam-beam interaction is very strong. With asymmetric impedance of the two rings, the phenomenon is similar.

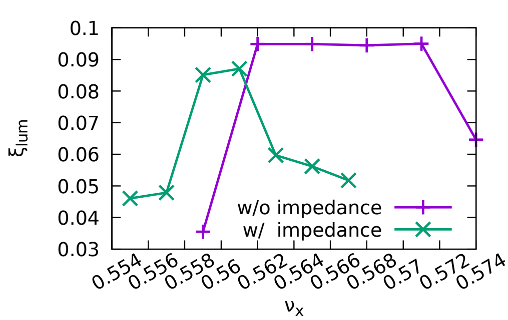
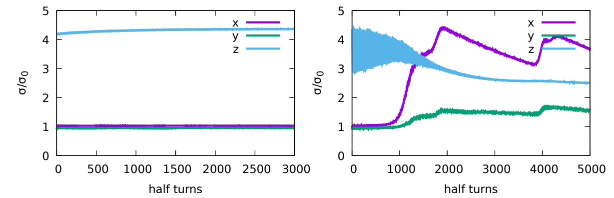


Figure 8: Influence of impedance on beam-beam performance at Z (β_y^*=1mm).



(a) Conventional Method (b) With Impedance

Figure 9: RMS size evolution during collision at optimized working point (Z).

SUMMARY

The very initial simulation shows that the beam-beam performance is influenced by longitudinal wakefield at Z-mode of CEPC. Further crosscheck and more detailed study is necessary.

The influence of transverse wake field is also an interesting topic, which will be studied in near future.

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REFERENCES

[1] arXiv:1809.00285 [physics.acc-ph]

[2] V.I. Telnov, *Phys. Rev. Lett.*, 110, 114801, 2013.

[3] Y. Zhang, K. Ohmi, D. Zhou, and D. N. Shatilov, "Beam-beam Simulation Study for CEPC", in *Proc. 5th Int. Particle Accelerator Conf. (IPAC'14)*, Dresden, Germany, Jun. 2014, pp. 3763–3765. doi:10.18429/JACoW-IPAC2014-THPRI003

[4] A. Chao, "Physics of collective beam instabilities in High Energy Accelerators", 1993.

[5] Y. Zhang, K. Ohmi, *et al.*, *Phys. Rev. ST-AB.*, 8, 074402, 2005.

[6] ELEGANT, https://ops.aps.anl.gov/elegant.html

[7] K. Ohmi, *et al.*, *Phys. Rev. Lett.*, 119, 134801, 2017.