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BEAM-BEAM STUDIES FOR SUPER PROTON-PROTON COLLIDER

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Abstract

A future circular collider project has been proposed in China. CEPC (Circular Electron Positron Collider) that aims to study the Higgs physics will be first considered and SPPC (Super Proton-Proton Collider) that aims to explore new physics beyond standard model will be an upgrade. Due to the higher energy and current, the major issue of SPPC is becoming the effects of 164 long-range beam-beam interactions. We look at luminosity decrement and beam lifetime considering different bunch population, dynamic aperture and crossing scheme under weak-strong beam-beam simulation to get the beam beam limit of SPPC. Long-range interaction can cause closed orbit distortion. Resonance analysis that is related to emittance growth is also presented in this report.

INTRODUCTION

The 100 km circumference tunnel has been mutually defined by CEPC and SPPC. For SPPC, the centre of mass collision energy is 75 TeV. A number of 10080 bunches each beam is distributed in 90 trains of 112 bunches. Particles can be accelerated using four stages which are a proton linac (p-Linac), a rapid cycling synchrotron (p-RCS), a medium-stage synchrotron (MSS) and the final stage synchrotron (SS). The two beams are separately accelerated in their individual ring except for 2 collision areas where they will meet in a common vacuum chamber which is about 310 m. Bunch separation is 25 ns and the crossing angle is 110 μrad. Fig.1 shows the layout of CEPC-SPPC [1]. The main beam parameters of SPPC are listed in Table 1. Luminosity is one of the most important factors of high energy colliders. But with higher current and higher energy, the Beam beam effect is becoming increasingly a significant limiting factor of luminosity improvement. The beam-beam limit is that the collider can accept the maximum tune shift induced by the beam-beam interaction.

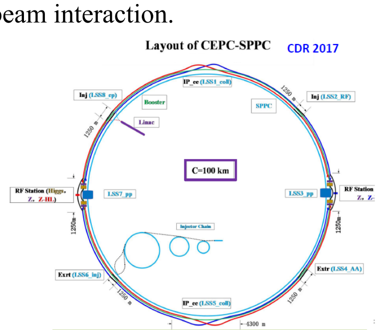

Figure 1: Layout of CEPC-SPPC.

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Table 1: Beam Parameter for SPPC

Parameter	Value	Unit
Circumference	100	km
CM energy	75	TeV
Peak luminosity	1.20×10^{35}	$cm^{-2}s^{-1}$
Number of IPs	2	
Bunch intensity	1.5×10^{11}	
Crossing angle	110	μrad
Normalized rms transverse emittance	2.4	μm
β^*	0.75	m
Bunch spacing	25	ns
Beam beam limit	0.0076	

WEAK-STRONG SIMULATION

When two beams collide, any one of them will experience an electromagnetic field from each other. In this report, we only discuss weak-strong model which means particles in a (weak) beam would go through another counter-rotating (strong) beam, affected by its electromagnetic force. However, particles in a (strong) beam can't be influenced by the electromagnetic field of weak beam [2]. A round Gaussian distribution is assumed for the colliding strong beam. We initialize 131072 particles with random number generator and track particles in 10^6 revolutions for 4 different cases. The luminosity degradation will be fitted with function f(x)=a+b*x/100. The particles are basically injected once a day. Thus, we use one day as a key factor to evaluate how fast luminosity will decay and how much the beam-beam limit will be. Luminosity decay rate each day is estimated using revolution frequency and fitting parameters.

HH (Horizontal-Horizontal) Crossing and Head on Without Long Range Interactions

For 2 IP (Interaction point), tune of (121.31, 118.32) is used. The luminosity decay rate per day is summarized in the Table 2 below. Np represents bunch population. ξ is the beam beam parameter.

We can easily discover that as the bunch population increases, so does its beam-beam parameter. Obviously, the luminosity decay rate is also becoming progressively faster whatever the crossing angle is taken into account or not. The luminosity decay rate is faster than 1, which corresponds to a luminosity lifetime smaller than one day. After the crossing angle is included, the beam-beam limit

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decreases from 0.15266 to 0.07633. Therefore, the crossing angle deteriorates the beam beam effect.

Table 2: Luminosity Decay Rate for HH Head-on and Crossing

$Np(10^{11})$	ξ/IP	dL/L0 (0mrad)	dL/L0 (110mrad)
1.5	0.007633	0	0
3.0	0.015266	0	0
7.5	0.038165	0	0
15	0.076330	-0.26	-6.66
30	0.152660	-2.36	-210
75	0.381650	-380	-494
150	0.763300	-552	-436

HV (Horizontal-Vertical) Crossing Without Long Range Interactions

In this case, tune of (121.31, 118.32) is used. The luminosity decay rate per day is summarized in the Table 3 below. The crossing angle keeps the same.

Table 3: Luminosity Decay Rate for HV Crossing

$Np(10^{11})$	ξ/IP	dL/L0 (per day)
1.5	0.007633	0
3.0	0.015266	0
7.5	0.038165	-14.5
15	0.076330	-203
30	0.152660	-309
75	0.381650	-231
150	0.763300	-215

The same result can be concluded for HV crossing collision. The more bunch population we use, the higher beam beam parameter will become. In this case, the beam beam limit is 0.038165 and the luminosity decay rate is over 2 times than its value for HH crossing. This result shows the beam beam effect from HV crossing is more serious than HH crossing. Thus, if the long-range interaction is not considered, HH crossing or VV crossing is better than HV crossing.

HH (Horizontal-Horizontal) Crossing with Long Range Interactions

Long range interactions are from two completely H crossing. Since the closed orbit distortion will occur due to long-range interactions, we need to re-initialize 131072 particles with random number generator at the closed orbit with taking into account of closed orbit distortion, otherwise the beam size will obviously increase. Beam life time is evaluated for the dynamic aperture 5σ or 7σ.

The luminosity decay rate and beam lifetime are summarized in the Table 4 below with tune of (121.31, 118.32). The beam beam parameter increases with the increasement of bunch intensity. But beam lifetime and luminosity decay rate seem not to perform like the way the beam beam parameter behaves. The bunch population 3.0×10^{11} is the most serious case among 3 different bunch populations. Actually, the third resonance line exists in last two cases. For the tune of (121.31, 118.32), the third resonance remarkably accelerates the luminosity decrement. Then the tune of (120.31, 117.32) which is similar with LHC will be used. The luminosity decay rate and beam lifetime are summarized in the Table 5 below with tune of (120.31, 117.32). As we expect, the much better simulation result finally shows and the beam beam limit is between 0.015 and 0.023

Table 4: Luminosity Decay Rate and Beam Lifetime at HH Crossing

$Np(10^{11})$/ξ	Beam lifetime[h](R=7)	Beam lifetime[h](R=5)	dL/L0
1.5/0.0152	137.9	27.2	0
3.0/0.0305	0.08	0.08	-12.1
4.5/0.0457	23.6	0.08	-5.10

Table 5: Luminosity Decay Rate and Beam Lifetime at HH Crossing

$Np(10^{11})$/ξ	Beam lifetime[h](R=7)	Beam lifetime[h](R=5)	dL/L0
1.5/0.0152	no lost	148	0
3.0/0.0305	no lost	21.52	-0.12
4.5/0.0457	2.14	1.35	-2.26

HV (Horizontal-Vertical) Crossing With Long Range Interactions

Long range interactions are from H crossing and V crossing in this case. Tune of (120.31, 117.32) is used. And the horizontal closed orbit distortion at the vertical collision point and vertical closed orbit distortion at the horizontal collision point will simultaneously appear. Thus, it is pretty necessary to correct closed orbit distortion at 2 IP. Figure 2 shows the x-px phase space plot without and with correcting closed orbit distortion. No complex chaotic and regular phase space structure is seen after correcting closed orbit distortion. The simulation results are summarized in table 6 and 7 below without and with correcting closed orbit distortion.

Table 6: Luminosity Decay Rate and Beam Lifetime at HV Crossing

$Np(10^{11})$/ξ	Beam lifetime[h](R=7)	Beam lifetime[h](R=5)	dL/L0
1.5/0.0152	no lost	216.72	0
3.0/0.0305	58.91	13.95	-0.14
4.5/0.0457	1.03	0.93	-11.5

Table 7: Luminosity Decay Rate and Beam Lifetime at HV Crossing

$Np(10^{11})$/ξ	Beam lifetime[h](R=7)	Beam lifetime[h](R=5)	dL/L0
1.5/0.0152	no lost	220.66	0
3.0/0.0305	263.8	17.46	-0.09
4.5/0.0457	8.76	3.15	-2.22

Obviously, the luminosity decay rate becomes much slower than without correcting closed orbit distortion. Comparing with HH crossing collision, HH crossing or VV crossing are almost similar with HV crossing after the long-range interaction is considered. And the beam beam limit is between 0.015 and 0.023.

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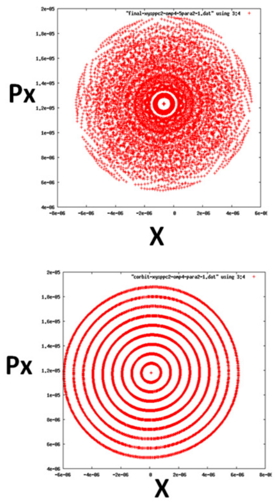

Figure 2: The top and below picture respectively show phase space plot at HV crossing without and with correcting closed orbit distortion.

RESONANCE ANALYSIS

To carefully analyze the transverse resonance in horizontal crossing for 1IP, we calculate the resonance width from the resonance driving terms and the detuning with amplitude [3]. FMA (frequency map analysis) is performed to get diffusion index which measure the tune fluctuation. We initialize particles on an 8σ × 8σ area with both x, y grid steps of 0.2σ in transverse amplitude space and are tracked for 4096 turns [2]. The synchrotron motion is not considered, where z=0.

According to FMA analysis, Figure 3 presents diffusion index in amplitude space for different bunch population. The resonance lines that are distinguished by different colours and their widths in amplitude space are given in Figure 4.

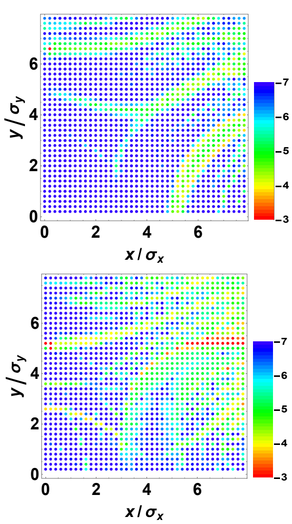

Figure 3: Diffusion index for horizontal crossing in single collision. The top and below picture respectively show bunch population of 1.5×10^{11} and 3.0×10^{11}.

As we can see from Figure 3 and 4, when the bunch population increases, some lower-order resonances lines come out and tune fluctuation becomes more serious especially when it comes to large amplitude particles. Emittance growth can be caused by the lower-order resonance lines, more serious tune fluctuation and their large widths. In general the location of resonance lines on Figure 3 and 4 completely coincide and the resonance widths are not exactly same but similar. The resonance analysis including synchrotron motion need more progress.

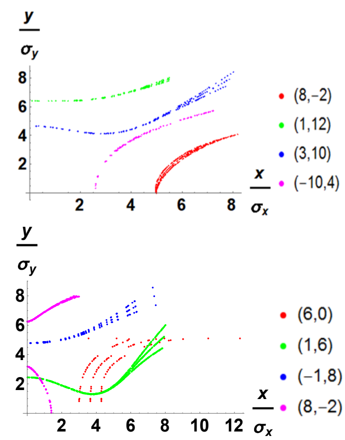

Figure 4: Resonance lines and widths in the amplitude space for H crossing. The top and below picture respectively show bunch population of 1.5×10^{11} and 3.0×10^{11}.

CONCLUSION

Beam-beam limit of each IP for H/V collision without crossing and long-range interactions is 0.15, for HH crossing without long-range interactions is 0.076 and for HV crossing without long-range interactions is 0.038. After the long-range interactions are included, closed orbit distortion appears. The third resonance exists due to the combined effects of long-range effects and working point for H crossing. Closed orbit distortion can cause complex chaotic of phase space for HV crossing. Whether it is resonance or complex chaotic, they both deteriorate the luminosity decrement. Finally beam beam limit of each IP is between 0.015 and 0.023 both for HH and HV crossing. Thus, the beam beam design parameter of SPPC (0.0076 each IP) is reasonable.

The emittance growth can be caused by the diffusion index and the resonance width.

REFERENCES

[1] X. C. Lou, "CEPC-SPPC Overview & Objectives", in *International Workshop on High Energy Circular Electron Positron Collider*, Beijing, China, Nov 2017.

[2] K. Ohmi and F. Zimmermann, "Fundamental Beam-Beam Limit from Head-On Interaction in the Large Hadron Collider," in *Phys. Rev. ST Accel. Beams 18, 121003,* Dec 2015.

[3] T. Sen *et al*, "Beam-Beam Effects at the Fermilab Tevatron: Theory", in *Phys. Rev. ST Accel. Beams 7, 041001, Apr* 2004.