Beam–beam Effects in Superbnch Collision: Weak–strong Model

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Continuous parastic beam-beam effects in superbunch collision have been examined in the weak-strong model. Emittance growth due to nonlinear resonances excited by the space-charge force is extremely large in such shallow-angle crossing as that in the LHC and VLHC. The Hybrid crossing and inclined hybrid crossing can reduce the effects. In addition, PACMAN effects have been studied and its significance is discussed.

1. Introduction

A μsec long superbunch intersects with its counterpart in the superbunch hadron collider (SHC). The SHC is expected to yield a 15 ~ 20 times higher luminosity than that of the conventional RF bunch collider [1] by storing an effectively large number of particles. However, the superbunch is exposed to the space-charge forces created by the counterpart during passing through an interaction region beyond the detector region. The continuous parastic beam–beam effects should be crucial for realizing the SHC. The beam-beam effects in the superbunch collision have been examined by simulation based on the weak-strong model. As an example, the VLHC 1st stage employing the superbunch scheme is considered.

Table I Calculation parameter. T, ε_n, N and β^* are storage energy, RMS normalized emittance, line density and beta function at collision angle, respectively. (ν_x, ν_y) are the combination of bare tunes.

	LHC	VLHC
T [TeV]	7	20
ε_n [π mm mrad]	3.75	1.5
N [particle/m]	5×10^{11}	3.5×10^{11}
β^* [m]	0.5	0.3
(ν_x, ν_y)	(68.28, 63.31)	(218.397, 217.445)[a]

[a]Design value is (218.419, 218.425) in VLHC 1st stage.

The calculations were carried out for 2-D round beams with a Gaussian distribution. Most of the beam/machine parameters are taken from the LHC and VLHC 1st stage. No external nonlinear fields, except for space-charge originated fields, were included in the present calculations. The space-charge electric fields generated by the strong beam is calculated by employing an analytic solution of the round Gaussian beam. The momentum spread was assumed to be zero. It is supposed that the dipole component of the space-charge forces originated by the core region of the superbunch is compensated by the steering magnets distributed along the interaction region.

2. Hybrid Crossing and Inclined Hybrid Crossing

In order to manifest the characteristic of HyC, three types of crossing of horizontal crossing (HC), vertical crossing (VC), and hybrid crossing (HyC) [2] were examined by using the LHC's parameters (see Table I) . In the HC and VC, the superbunchs intersect on the medium plane and the vertical plane, respectively. In the HyC, the HC and VC take place at the north and south IP, respectively. The footprints on the tune diagram are shown in Figure 1, where the collision angle Φ is 200μrad. In order to keep the resonances excited by the space-charge forces low level, the length of interaction region is assumed to be 2m in these calculations, although the designed value in the SHC is 50m. The strong beam is fixed through the calculation. The maximum tune shift of HyC is much smaller than that of HC and VC as theoretically expected [1]. Dependence of the footprints of the HyC in Figure 1 on the particle emittance, ε_x and ε_y, is shown in Figure 2.

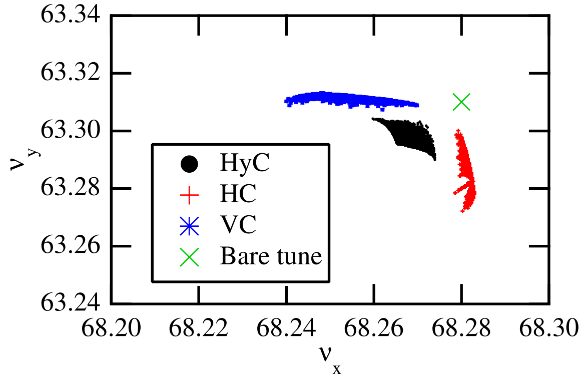

Figure 1: Footprints on the tune diagram in the case of HyC, HC×2 and VC×2.

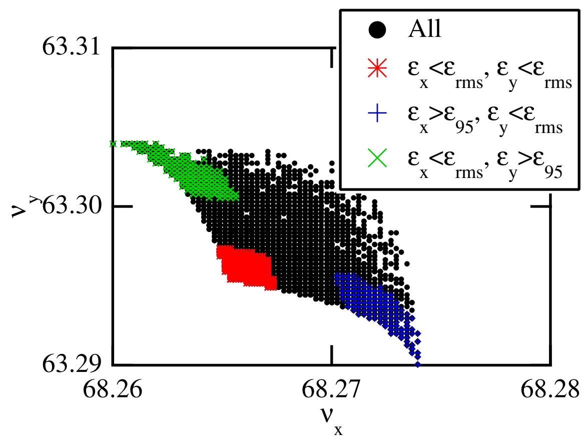

Figure 2: Footprints on the tune diagram. ε_{rms} and ε_{95} are the rms and 95% emittance, respectively.

Particles with the large emittance for each directions place at the extreme end of the incoherent tune-spread. This is a characteristic of the HC and VC. For the HC, the particles in the weak beam are exposed to the focusing quadrupole component of the space-charge forces in the horizontal plane, but at the same time these particles with small ε_y are exposed to the defocusing space-charge force in the vertical plane through the interaction region. For the VC, the footprints with small ε_x and large ε_y is in contrast to that of above case. For the HyC, this feature still remains; these particles indicate the relatively large incoherent tune shift. It is natural that the incoherent tune shift of these particles becomes larger as the length of the interaction region becomes longer. Therefore, the resonances can be excited by the space-charge forces when the tune crosses the resonance lines. The emittance growth and the footprints for the interaction region of 50m are shown in Figure 3. When Φ is the design value (200μrad), the rms emittance rapidly increases by 100 times of the initial rms emittance in 1000th turns as shown in Figure 3a. This emittance growth seems to be excited by the nonlinear resonances such as the 4th order resonance in horizontal plane and the 3rd order resonance in vertical plane as shown in Figure 3b. Thus, it turns out that the superbunch collision scheme is not realistic with such a shallow crossing angle as that of the present LHC.

In order to realize the SHC, a larger crossing angle may be a possible countermeasure. As shown in Figure 3a, the rms emittance in the cases with less than 350μrad increases rapidly due to the space-charge forces, but the emittance growth is not observed in the case of 400μrad. Certainly, the footprints with 400μrad is smaller than these with 200μrad (see Figure 3b); the magnitude of the tune-spread is tolerable. The luminosity decreases generally with a larger collision angle. Namely, the suppression of emittance growth with a large crossing angle is realized at the expense of luminosity. But the luminosity with 400μrad is still 15 times higher than conventional hadoron collider with 200μrad [1].

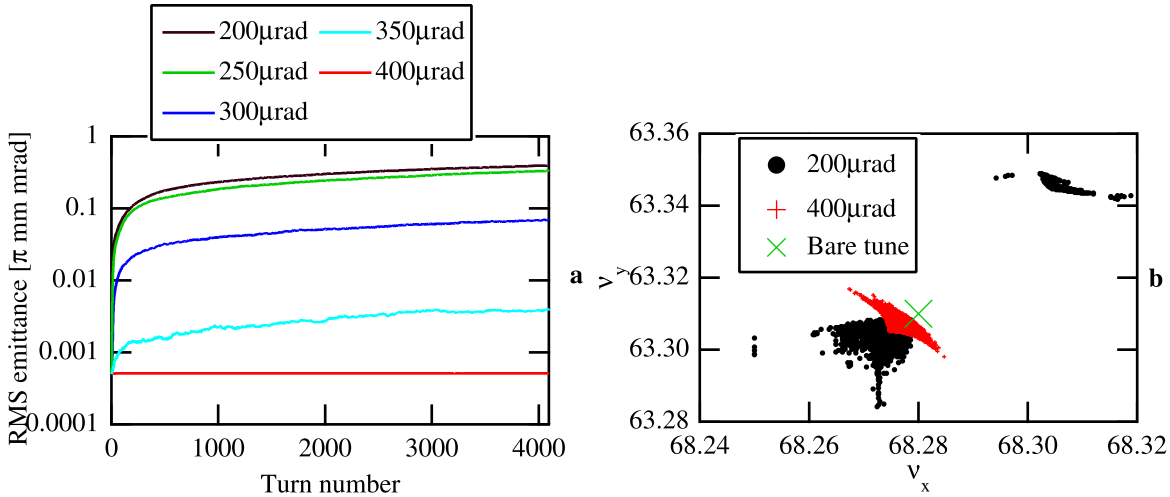

Figure 3: (a) The dependence of vertical emittance growth on collision angle and (b)footprints on the tune diagram, where the length of interaction region is 50m.

As the second countermeasure, another modification of the HyC called the inclined hybrid crossing (IHyC) is proposed [1]. The IHyC consists of the two interaction regions in which two beams cross horizontally and vertically at the same time as shown in Figure 4. The weak beam is horizontally and vertically focused by the quadrupole component of the space-charge forces at the same time. The footprints on the tune diagram of the IHyC with Φ of 400μrad and the length of interaction region of 50m is shown in Figure 5. The tune spread for the IHyC locates in the closer area to the bare tune than that for the HyC. The tune spread closely located to the bare tune may make handling of the nonlinear resonances excited by the space-charge forces much easier.

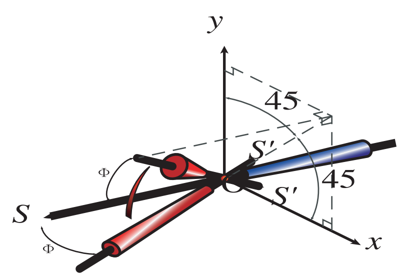

Figure 4: Scheme of inclined hybrid crossing.

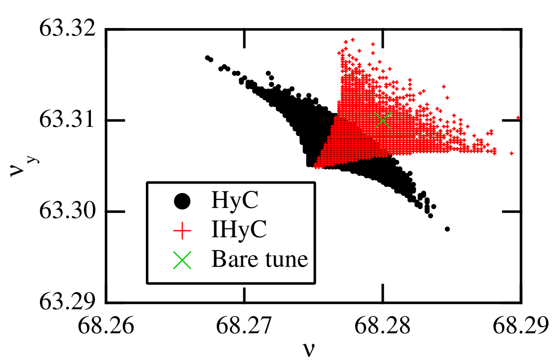

Figure 5: Footprints on the tune diagram in the case of HyC and IHyC.

3. PACMAN effects

Head and tail parts of the superbunch have no counterparts in the upstream and downstream of collision, respectively. However, member particles in both parts gradually change with a slow synchrotron oscillation. From this reasons, PACMAN effects in the SHC are different from that in the conventional hadron collider, where the bunches subjected to PACMAN effects are never replaced by others. For studying an extreme case of PACMAN effects, the behavior of the beam-slice locating at the head of the weak beam are simulated. The results are shown in Figures 6. As mentioned early, the steering magnetic field is assumed for compensating the dipole component of the space-charge forces by the strong beam. Since the strong beam does not exist through the upper half region for the particles of interest, they are directly exposed to the force from the steering magnet. Since the direct steering-forces through the upper half interaction region is a source of COD through the interaction region, the head of the weak beam has its own COD deviating from the designed orbit for the superbunch core. Thus, the beam-slice oscillates coherently around its own COD if the head places on the designed orbit for the core at first. In this case, the rms emittance of this beam-slice grows because of the filamentetion induced by the nonlinear space-charge forces from the strong beam as shown in Figures 6. However, this result seems to be an extreme case because this simulation is equivalent to the case that the beam-slice abruptly moves from the core to the head. This effect must be suppressed where the particles adiabatically move from the head to the core.

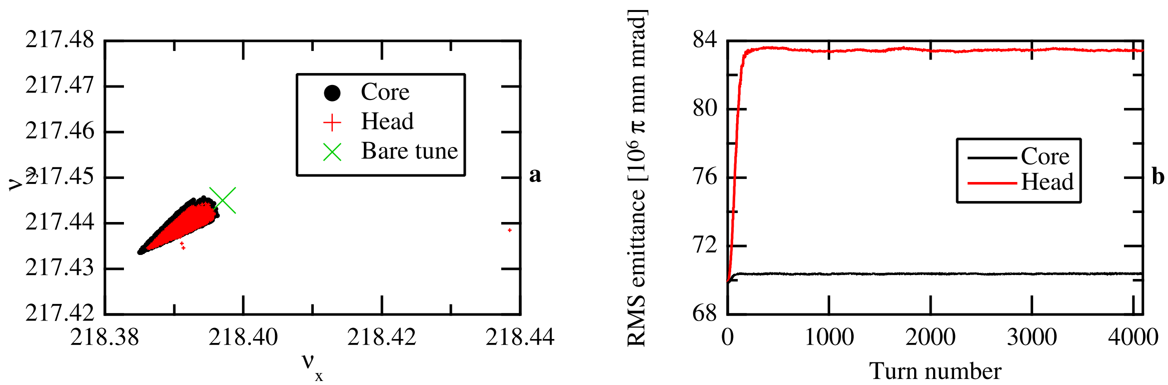

Figure 6: (a) Footprints on the tune diagram and (b) emittance growth of the head and core of the superbunch. Φ = 400 μrad and the length of interaction region is 42m. The resonance is not excited in Figures 6a.

4. Summary

Beam–beam effects in superbunch collision have been examined by simulation using the weak–strong model. The SHC does not work with the shallow crossing angle chosen in the LHC and VLHC even if hybrid crossing is employed. For suppressing a tune spread, the collision angle should be more than 400μrad. The inclined hybrid crossing seems to work for avoiding the resonances excited by the space-charge forces. The steering magnetic field, which compensates the COD for the core region of the superbunch, generates the COD of the head/tail regions. This COD induces the emittance growth in the head/tail regions. Longitudinal motion in the superbunch should be included for more precise estimation .

References

[1] K.Takayama, *The superbunch vlhc* (2001), in this proceedings.

[2] *Proceedings of the workshop on beam-beam effects in Large Hadron Collider* (J.Poole and F.Zimmermann, Geneva, Switzerland, 1999).