MULTIBUNCH COLLISION SCHEME IN BEPC

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Abstract

The multibunch collision by means of pretzel scheme to enhance the luminosity in BEPC have been studied. The modification of the lattice is carried out, the solenoid compensation and chromaticity correction are studied, the physical aperture is examined, the long range beam-beam interaction and coupled bunch instabilities are investigated. The results show that the pretzel scheme with six bunches per beam is feasible.

1 LATTICE MODIFICATION

The purpose of pretzel scheme is to enhance luminosity by increasing the number of bunches N_b beyond the present N_b=1. Since N_b evenly spaced bunches encounter each other in 2 N_b points around the ring and collision is desired only at the south interaction point (IP) in BEPC. Multibunch collision can give rise to unwanted destructive beam-beam interactions at parasitic encounters unless something can be done to separate the beams there. As the operating betatron tunes are ν_x=5.84 and ν_y=6.76, six bunches are allowed with the pretzel, which is generated in horizontal direction by three separators. Two separators are placed on each side of south IP, and the third one is placed at the north IP. Only one separator, i.e. the north one is used when beams are injected to generate the pretzel orbits, (see Figure 1). As shown in Figure 2, three separators are applied when two beams are brought onto collision. The main parameters of multibunch collision scheme are list in Table 1. The results presented in the following sections are based on these data.

Table 1 The parameters of multibunch collision in BEPC

Energy	E(GeV)	2.0
Betatron function at IP	β_x(m)	1.2
	β_y(m)	0.05
Betatron tune	ν_x	5.84
	ν_y	6.76
Natural emittance	ε_0(rad·m)	3.23×10^{-7}
Bunch number per beam	N_b	6
Natural Bunch length	σ_l(cm)	5
Bunch current	I_b(mA)	25.3
Luminosity	L($cm^{-2}s^{-1}$)	5.5×10^{31}

The superperiodicity number of pretzel scheme lattice is one with mirror symmetry in comparison with the superperiodicity number of two in the present lattice. Additional twenty quadrupole and fourteen sextupole power supplies are required.

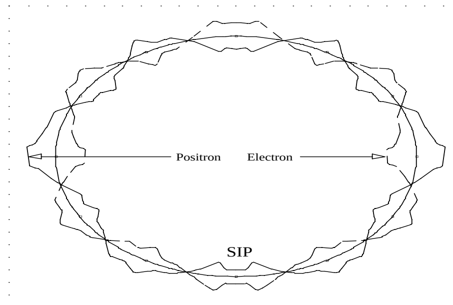

Figure 1: Pretzel orbit of injection mode

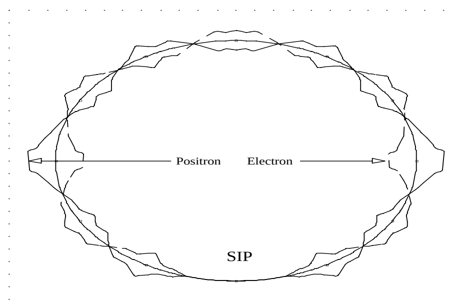

Figure 2: Pretzel orbits of Collision Mode

2 SOLENOID COMPENSATION

Global correction for detector solenoid field with skew quadrupole applied in BEPC now is not suitable for the pretzel scheme. The skew quadrupole where electron and positron beams have no-zero horizontal pretzel orbits of opposite sign can produce vertical orbit separation with opposite sign for two beams. Furthermore, the vertical orbits $y_c^{\pm}$ in the sextupole then give rise to an equivalent skew quadrupole components of opposite sign for the two beams:

$$(\tilde{k_1})_{eff} = k_2 y_c^{\pm}, \qquad (1)$$

where k_2 is the sextupole strength. The different equivalent skew quadrupole components will make two beam have different coupling, so the simultaneous coupling compensation for both beams gets difficult.

The rotating frame method is adopted in our pretzel scheme. Two quadrupoles on each side of south IP are rotated by 3.0825°, following by one compensator solenoid. The coupling is compensated locally in the interaction region where is no pretzel orbit.

Figure 3 gives vertical orbit and vertical dispersion function along the ring. It can be seen from Figure 3 that the vertical orbit and vertical dispersion function are negligible.

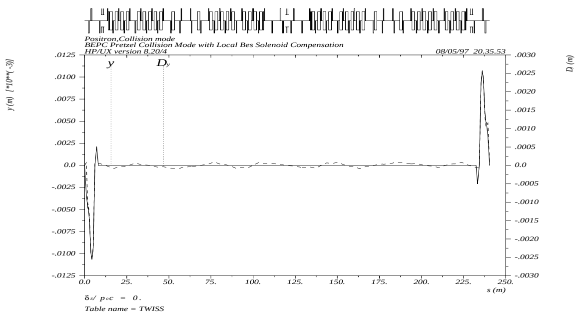

Figure 3: vertical orbit and dispersion function

3 CHROMATICITY CORRECTION

Pretzel orbits pass off-center horizontally in sextupoles, and then an effective normal quadrupole of opposite sign for two beams is generated:

$$(k_1)_{eff} = k_2 x_c^{\pm} \tag{2}$$

where $x_c^{\pm}$ are the horizontal orbits of two beams. The equivalent quadrupoles will disturb the betatron motion, the betatron function, betatron tune and other parameters get different for two beams. As there is only one interaction point with head-on collision in the pretzel scheme, this leads to the conditions for a symmetric pretzel scheme (see figure 1 and 2) in which the effects of sextupole perturbation do not cancel. All sextupoles are adjusted to make betatron tune, chromaticity and betatron function at south IP independent of pretzel amplitude (and therefore the same for electron and positron). Eighteen independent sextupoles are needed in the pretzel scheme. Code PCCC(pretzel chromaticity correction code)[2] will be used to compensate the chromaticity. PCCC code also gives the analysis of the resonance excited by sextupoles. Figure 4 shows the particle tracking spectrum given by PCCC. Figure 5 and 6 show the dynamic aperture of positron and electron beams respectively.

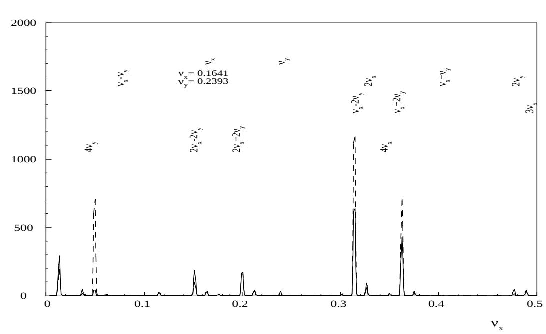

Figure 4: tracking FFT spectrum

4 PHYSICAL APERTURE

The beam stay clear region in pretzel scheme is defined as:

BSC$_x$=x$_c$$\pm 10\sigma_x \pm$10mm BSC$_y$=$\pm 10\sigma_y \pm$5mm

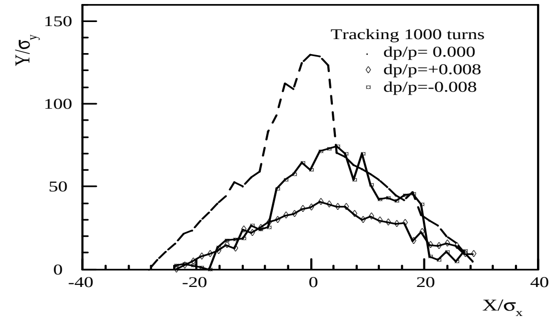

Figure 5: Dynamic aperture of positron

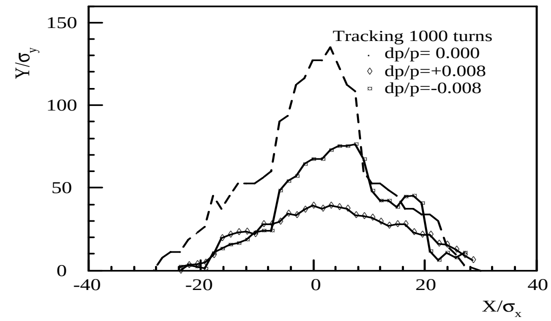

Figure 6: Dynamic aperture of electron

here, x_c is the horizontal pretzel orbit. The investigation shows that there are enough vertical physical aperture for both electron and positron beams. Figure 7 and Figure 8 display the horizontal physical aperture of positron and electron beams respectively. It can be seen from these figures that the positron beam has enough horizontal physical aperture, but it is not satisfied for electron beam in the injection region, which needs to be improved.

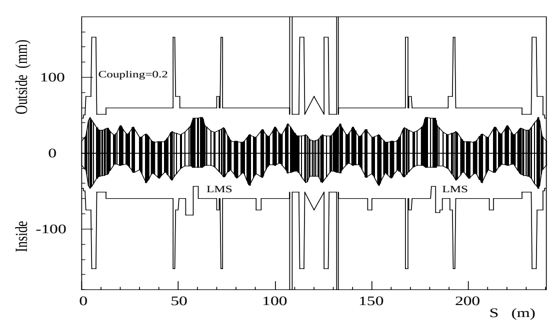

Figure 7: Horizontal physical aperture of positron beam

5 LONG RANGE BEAM-BEAM INTERACTION

The strength of the parasitic beam-beam effects are characterized by the equivalent linear tune shift

$$\xi_x = \frac{N\beta_x r_e}{2\pi\gamma}\int_0^{\infty} dt(1 - \frac{2X^2}{2\sigma_x^2 + t})$$
$$\frac{exp(-X^2/(2\sigma_x^2+t) - Y^2/(2\sigma_y^2+t))}{(2\sigma_x^2+t)^{3/2}(2\sigma_y^2+t)^{1/2}}, \tag{3}$$

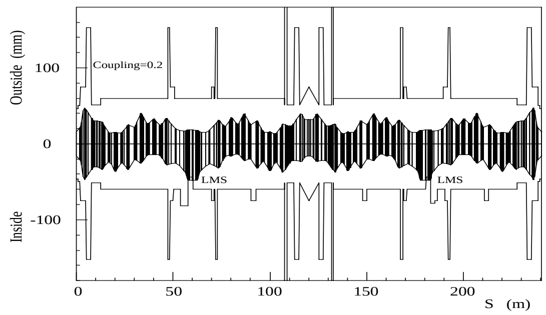

Figure 8: Horizontal physical aperture of electron beam

where X and Y are horizontal and vertical separations respectively. The formula for ξ_y is similar. Figure 9 gives the parasitic beam-beam parameters versus horizontal separation calculated with eq.(3). The Figure 9 indicates that the horizontal parasitic beam-beam parameter is negative when horizontal separation is larger than about σ_x. The parasitic beam-beam parameters of collision mode in the parasitic IPs are given in Table 2.

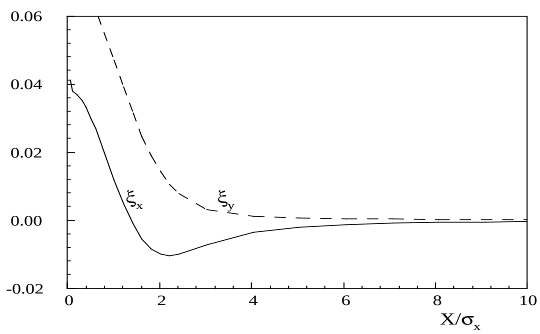

Figure 9: parasitic beam-beam parameters vs. separation

Table 2 : Long range b-b parameter of collision mode

X(mm) min	X/σ_x min	$\lvert\xi_x{}^j\rvert$ max	$\xi_y{}^j$ max	$\sum \xi_x^j$	$\sum \xi_\nu^j$
15.0	10.4	3.92×10^{-4}	8.95×10^{-4}	-0.0018	0.0017

In each parasitic interaction point, the bunches receive a kick. In the case of X¿¿σ_x, the beam-beam kick can be expressed as

$$x' = -\frac{2Nr_e}{\gamma X}, \tag{4}$$

where N is the bunch population, r_e is the classical electron radius and γ is the relativistic energy. The closed orbit distortion at south IP caused by all parasitic beam-beam kicks is calculated as 0.25 mm which is about half of the horizontal beam size. This current dependent horizontal orbit at IP should be adjusted during collision. The long range beam-beam interaction will reduce the stable tune space and cause betatron tune split. In the case of horizontal separation, the injection on the horizontal plane will make a larger tune spread due to long range beam-beam interaction, and therefore vertical injection is preferred.

6 COUPLED BUNCH INSTABILITIES

The transverse growth time due to HOMs[3] is estimated as 2.0 second which is longer than transverse radiation damping time 22 ms, the longitudinal growth time due to HOMs[3] is as 0.20 ms, which is shorter than the its radiation damping time of 11 ms.

As the two beams are stored in the same vacuum chamber in BEPC, the wake field excited by one beam will disturb the motion of another beam. The shunt impedance $\tilde{R}$ seen by the counter-moving bunches becomes complex in the general case. For a symmetric cavity,

$$\tilde{R} = \pm R, \tag{5}$$

where R is the shunt impedance seen by the co-moving bunches, the "+" ("-") sign applies to the symmetric (anti-symmetric) mode. The longitudinal growth time is calculated as 0.11 ms when the counter-moving bunches is considered[2]. Figure 10 gives the transverse growth rate versus transverse tune due to resistive wall effect. Therefore the feedback system is needed for pretzel scheme.

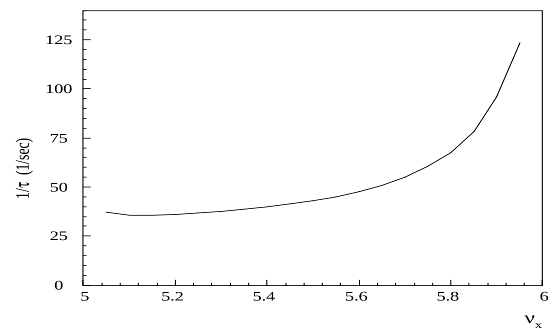

Figure 10: transverse resistive wall growth rate vs. tune

7 SUMMARY

The pretzel scheme is one of the feasible methods for BEPC to increase the luminosity. The solenoid can be locally compensated. The chromaticity can be compensated by adding more independent sextupole power supplies. The long range beam-beam effect is tolerable. However, the longitudinal coupled bunch instability may limit the multi-bunch performance and feedback system is needed.

8 REFERENCES

1. H. Grote and F. .C Iselin, CERN/SL/90-13(AP), 1996.
2. F.L.Wang, Ph.D. thesis, 1997.
3. J.Qin, Private communication.