ION INSTABILITY IN THE ILC DAMPING RING

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Abstract

We investigate the ion instability in the ILC electron damping ring with high beam intensity and low-emittance. It is shown that the ion instability can cause beam oscillations that grow exponentially and give a significant limitation in the damping ring. We have performed a weak-strong simulation to show characteristic phenomena of the instability in the damping ring. In particular, we investigated the effects of the various different bunch filling patterns, vacuum pressures and a feedback system on the fast-ion instability. It is also shown that the fast-ion instability can be cured by a bunch-bunch feedback per about 50 turns.

INTRODUCTION

When electron beams circulate in the ring, ions are generated by the ionization of residual gas in the ring. The ions may be trapped by the electron beams and oscillate in a certain frequency ω_i in the electric potential of the electron beam. A coherent motion between the beam and the ions may cause the beam instability[1] and then the frequency of the ion oscillation is given by

$$\omega_{i,x(y)}^2 = \frac{2\lambda_e r_p c^2}{A}\frac{1}{\sigma_{x(y)}(\sigma_x+\sigma_y)}, \quad (1)$$

where r_p, A, c and $\sigma_{x(y)}$ are the proton classical radius, the atomic number of the ion, velocity of the light and the horizontal (vertical) beam size, respectively.

The fast-ion instability can cause an exponential growth of the vertical amplitude in the beam. Then the oscillation frequency of the ions is related to beam sizes as shown in Eq. (1). The beam size at a longitudinal location is varied depending on the beta and dispersion functions in the ring. Thus, the frequency is changed from position to position and the frequency spread may act as the Landau damping in the coherent ion oscillation.

In the ILC damping ring, a bunch includes the population of about $1 \sim 2\times 10^{10}$ to optimize or relax the beam-beam effect at the interaction point. Thus, to keep a high luminosity for a low bunch population, the bunch spacing is required to be narrower. Because the ion instability strongly depends on the bunch filling patterns in the ring, we in detail investigate the ion instabilities in the various filling patterns in ILC damping ring that has a very low-emittance of ε_x=5×10^{-10} m. In this paper, we also show the growth time and characteristics of the fast-ion instability in the ILC damping by using a simulation method. Table 1 shows the basic parameters of the OCS6 damping ring[2].

Table 1: Basic parameters in the OCS6 damping ring.

Variable	Symbol	Value
Circumference	L	6695 m
Beam energy	E	5 GeV
Betatron tune	ν_x/ν_y	52.397/49.305
Momen. compaction factor	α	4.2×10^{-4}
Transverse damping time	τ_x	25.6 ms
Energy spread	ϵ_E	1.28×10^{-3}
Normalized emittance	ϵ_x	5 μm
RF frequency	f_{rf}	650 MHz
Bunch population	N_e	$1 \sim 2\times 10^{10}$
Harmonic number	h	14516
Bunch spacing	L_{sp}	$2 \sim 4$
Bunch length	σ_z	6 mm

A SIMULATION MODEL FOR THE ION INSTABILITY

We consider CO^+ ion for the instability source, because the major components of the residual gas are CO and H_2, and the ionization cross-section of CO is 5 times higher than that of H_2. We assume that the partial pressure of CO gas is $P = 3\times 10^{-8}$ Pa. The number of ions that are generated by an electron beam with the population of N_e is given by

$$n_i[\mathrm{m}^{-1}] = 0.046 N_e P[\mathrm{Pa}]. \quad (2)$$

In our parameter, n_i is 27 m^{-1} for $N_e = 2\times 10^{10}$ and $P = 3\times 10^{-8}$ Pa.

In our simulation method, the ions are represented by macro-particles and each bunch is represented by a rigid Gaussian macro-particle. The beam sizes of the bunches are fixed and only their dipole motions are investigated. The dipole moment of each bunch is computed every turn[3]. Ions are generated at positions that all magnetic components and drift spaces locate. New macro-particles for the generated ions are produced at the transverse position (x, x', y, y') of the beam where the ionization occurs. The beam motion and the ion motion are tracked at the positions of all magnets and drift spaces. Ionization in a long drift space is examined by every 2 m. All electron beams are initially set to zero displacement.

Incoherent behaviors of the ions are obtained by our simulations, but that of the beams, such as emittance growth, can not be computed. We compute the time evolution of the growths of the dipole amplitudes of the beam, where the vertical amplitude is half of the Courant-Snyder invariant $J_y = \gamma_y y^2 + 2\alpha_y yy' + \beta_y y'^2/2$, where γ_y, α_y and β_y

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Table 2: Bunch filling patterns in the damping ring.

	Case	A	B	C	D	E
Number of bunches	N_b	5782	5658	4346	3646	2767
Bunch population	$N_e(\times 10^{10})$	0.97	0.99	1.29	1.54	2.02
Number of the train	N_{tr}	118	123	177	203	236
Bunch spacing in a train	L_{sp}	2	2	2	3	4
Number of bunches in each train	N_e	49	46	53	25	22
Gap between trains	L_{gap}	25	26	71	25	28
Growth time by analytic formula	$\tau(/turn)$	45.4	47.4	31.6	56.0	48.5
Minimum gap	$Lgap, min$	8.5	8.4	6.4	5.4	4.1

are the Twiss parameters. ILC damping ring has a circumference of 6.6 km and the number of trains of 61 to 123, depending on the filling patterns, in the ring. For the fast simulations, one train bunch and 1/6 section of the whole lattice are considered by our simulations. Figure 1 shows Twiss parameters of 1/6 section in the damping ring that is considered by our simulation.

Beam-ion interaction is expressed by Basetti-Erskine formula for the beam with Gaussian distribution in the transverse direction[4]. The equations of motion for the beams and ions are expressed by

$$\frac{d^2\boldsymbol{x}_{b,a}}{ds^2} + K(s)\boldsymbol{x}_{b,a} = \frac{2r_e}{\gamma}\sum_{j=1}^{N_i}\boldsymbol{F}(\boldsymbol{x}_{b,a}-\boldsymbol{x}_{i,j}), \quad (3)$$

$$\frac{d^2\boldsymbol{x}_{i,j}}{dt^2} = \frac{2r_ec^2}{M_i/m_e}\sum_{a=1}^{N_b}\boldsymbol{F}(\boldsymbol{x}_{i,j}-\boldsymbol{x}_{e,a}), \quad (4)$$

where suffices b and i denote the beam and the ion, respectively. M_i and m_e are masses of the ion and the electron, respectively, and N_i and N_b are the number of the ions and bunches, respectively. γ and r_e are Lorentz factor of the beam and classical electron radius, respectively. $\boldsymbol{F}(\boldsymbol{x})$ is the Coulomb force expressed by Basetti-Erskine formula.

Various bunch trains and lattice of the ring are applied by our simulation. Bunch-by-bunch feedback is also involved in the simulation. The feedback system has a damping time of 50 turns and fluctuation of $0.02\sigma_y$. The gain is rather conservative with the present technology.

SIMULATION RESULTS ON THE VARIOUS FILLING PATTERNS

Table 2 shows the various bunch filling patterns for the ILC damping ring. Growth rates by the analytic theory are written by the table. Case A and Case B show similar parameters, but Case A is slightly severe than the Case B, because the shorter gap and more bunches exist in one train. Case C shows the fastest growth time among five patterns. Simulations are performed to show the aspects on the fast-ion instability for the five filling patterns. The simulation provides the positions of all bunches in turn-by-turn. The horizontal and vertical maximum amplitudes in

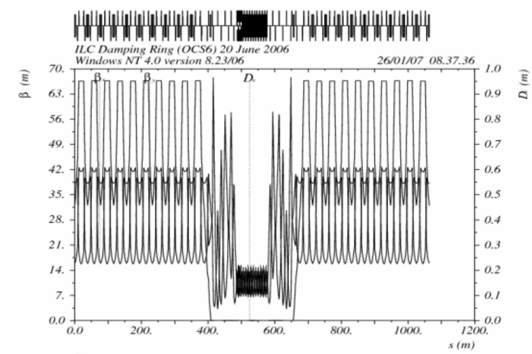

Figure 1: Twiss parameters of 1/6 section in the OCS6 damping ring that is used in the simulations.

the all bunches, $\sqrt{J_{x,y}}$, are obtained by turn-by-turn in the simulation.

Figure 2 shows the evolutions of the vertical maximum values $\sqrt{J_y}$ for the five filling patterns in Table 2 in a vacuum pressure of 0.23 nT without (top) and with (bottom) the bunch-by-bunch feedback per 50 turns, respectively. It is shown that the maximum amplitudes are saturated for all the filling patterns when the feedback is off. It is shown that the Case C (green line) gives the fastest exponential growth time, as shown in analytical estimation. It is also shown that vertical maximum amplitudes can be well suppressed by the feedback per 50 turns for all the filling patterns.

Figure 3 shows the effects of the vacuum pressures on the fast-ion instabilities. Top and bottom in Figure 3 show evolutions of the maximum values of $\sqrt{J_y}$ and exponential growth times for the different vacuum pressures when the feedback is off in Case A, respectively. Top in Figure 4 shows evolutions of the maximum values of $\sqrt{J_y}$ in all bunches for the different turns of feedback in Case A. It is shown that the feedback per 50 turns provides a sufficient damping. Bottom in Figure 4 shows evolutions of the maximum values of $\sqrt{J_y}$ in all bunches for the different bunch intensities in case A with the feedback per 50 turns. It is shown that vertical amplitude in the bunch intensity larger than

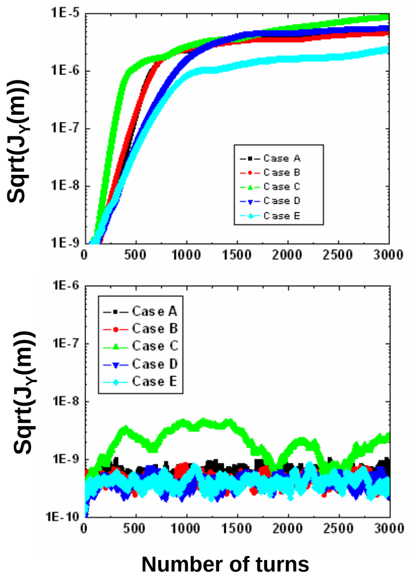

Figure 2: Vertical amplitudes for the five filling patterns without the feedback (top) and with the feedback per 50 turns (bottom). Case A, B, C, D and E show the exponential growth times of 84, 96, 67, 143 and 213 turns, respectively.

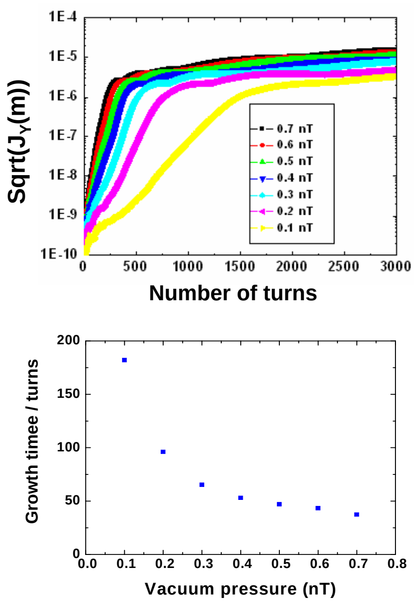

Figure 3: (Top) Vertical amplitudes for the different vacuum pressures in Case A. (Bottom) shows the exponential growth times in the different vacuum pressures.

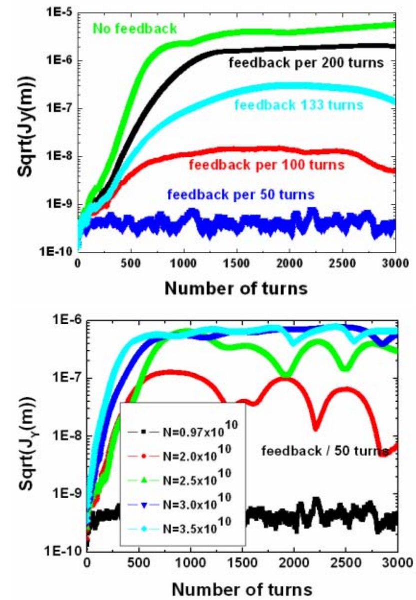

Figure 4: (Top) Vertical amplitudes for the different number of the feedbacks in the case A. (Bottom) Vertical amplitudes for the different bunch intensities with the feedback per 50 turns in Case A.

CONCLUSION

We have investigated the simulation studies on the fast-ion instability in the ILC damping ring. By using a weak-strong simulation method, we showed aspects of fast-ion instabilities on the various bunch filling patterns in the ring. The simulation results also showed that the bunch-by-bunch feedback of about 50 turns is required to cure the fast-ion instabilities in the damping ring.

REFERENCES

[1] T.O. Raubenheimer and F. Zimmermann, Phys. Rev. E 52 p. 5487 (1995).

[2] Reference Design Report for ILC, ILC 2007-01 (2007).

[3] K. Ohmi, Phys. Rev. E 55, p. 7550 (1997).

[4] M. Bassetti and G. Erskine, CERN Report No. ISR TH/80-06 (1980).