



Study of Fast Beam-Ion Instability in ILC Damping Ring

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Abstract

By using the update damping ring parameters, the growth time of fast beam-ion instability (FBII) is analytically estimated according to the linear theory. The two different fill patterns are taken into account and the results show that the growth time is larger than the response time of current feedback system, especially when the ion frequency spreads exist along the damping ring lattice.

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1 Introduction

Fast beam-ion instability was first studied by T. Raubenheimer and F. Zimmermann in 1995. After that, some experiments were carried out to verify the theory of FBII. The ions generated by the head of the bunch train oscillate in the transverse direction and resonantly interact with the betatron oscillation of the subsequent bunches, resulting in the growth of the initial perturbation of the beam. This phenomenon is called fast beam-ion instability. In the damping ring of International Linear Collider (ILC), the beam emittance is smaller and the bunch train is longer compared with some existing storage rings, the number of ions ionized by a single bunch train is large (not trapping from turn to turn), therefore FBII is severe. In this note, we estimate the growth time of FBII by using the update electron damping ring parameters of ILC.

2 Linear Theory of Fast Beam-Ion Instability

According to the linear theory, the characteristic rise time of FBII can be described as [1, 2]

$$\frac{1}{\tau_c} = \frac{4d_{gas} \sigma_{ion} \beta_y N_b^{3/2} n_b^2 r_e r_p^{1/2} L_{sep}^{1/2} c}{3\sqrt{3}\gamma \sigma_y^{3/2} (\sigma_x + \sigma_y)^{3/2} A^{1/2}} \quad (1)$$

where $d_{gas} = p/k_b T$ is the density of residual gas, p is the gas pressure in vacuum chamber, k_b and T are Boltzmann Constant and gas temperature respectively. σ_{ion} is the ionization cross section, β_y is the average vertical beta function, N_b is the particle number per bunch, r_e and r_p are the classical radius of electron and proton respectively, L_{sep} is the bunch spacing, γ is the relativistic factor, σ_x and σ_y are the horizontal and vertical beam sizes respectively, A is the ion mass in unit of proton mass and c is the speed of light.

The ion coherent angular frequency ω_i is given by

$$\omega_i = \left(\frac{4N_b r_p c^2}{3AL_{sep} \sigma_y (\sigma_x + \sigma_y)} \right)^{1/2} \quad (2)$$

Actually, there are some sources which can cause the ion frequency ω_i spreads along the damping ring lattice structure. One of them is due to the horizontal beam density profile in a flat beam which causes the local ion frequency to depend on the horizontal position. Other sources of spread in ion frequency are due to the nonlinearity of the ion oscillations inside the beam and the presence of multiple ion species, etc.

Taking into account of the ion coherent frequency spread, the linear theory gives the coupled bunch motion in the bunch train like $y \sim \exp(t/\tau_e)$; the growth time is given

$$\frac{1}{\tau_e} = \frac{1}{\tau_c} \frac{c}{2\sqrt{2}l_{train} (\Delta\omega_i)_{rms}} \quad (3)$$

where $(\Delta\omega_i)_{rms}$ is the rms spread of ion coherent angular frequency, l_{train} is the length of bunch train and $l_{train} = n_b L_{sep}$.

According to Eq.(1)~(3), assuming 10%, 20% and 30% relative coherent frequency spread along the baseline and alternative damping rings, for 0.1nTorr, 1.0nTorr CO gas pressure, the growth times τ_c , τ_e versus bunch index are plotted in Fig.1-8. It can be seen that the growth time becomes less with respect to the bunch index, while considering the ion coherent frequency spread, the growth rates become much slower.

3 The Growth Time Estimation of FBII

According to the latest configuration of electron damping ring, the fill pattern is changeable in order to alleviate the ion effect. The baseline and alternative damping rings parameters are listed in Table 1 and Table 2 respectively [3]. In order to calculate the growth time of FBII, we use the beam sizes parameters in Frank Zimmermann's report [4]. Here, only two fill patterns are considered, one is at the left side of Table 1 and Table 2, namely the bunch charge is 2.0×10^{10} and the number of bunch trains is 60 for baseline damping ring, while for 17km alternative ring, the bunch spacing is 13.85ns and there is 6 bunches per train, the bunch charge is 2.25×10^{10} . The other fill patterns we care about are the data from the right side of these two Tables, namely, the bunch charge is 1.0×10^{10} and the number of bunch trains is 120 for baseline damping ring, while for 17km alternative ring, the bunch spacing is 4.62ns and there is 18 bunches per train, the bunch charge is 0.75×10^{10} . We named them mode 1 and mode 2 respectively. The two different vacuum gas pressures 0.1nTorr and 1nTorr are assumed in our calculation.

Table 1 Fill patterns of baseline damping ring

Ring circumference [m]	6642.4784									
Harmonic number	14402									
Ring RF frequency [MHz]	650									
Linac RF frequency [GHz]	1.3									
Linac pulse length [ms]	1.00									
Linac bunch spacing [linac RF wavelengths]	480	450	400	384	360	320	300	288	240	
Linac bunch spacing [ring RF wavelengths]	240	225	200	192	180	160	150	144	120	
Linac bunch spacing [ns]	369.23	346.15	307.69	295.38	276.92	246.15	230.77	221.54	184.62	
Ring bunch spacing [linac RF wavelengths]	5.2									
Ring bunch spacing [ring RF wavelengths]	2									
Ring bunch spacing [ns]	3.08									
Bunches per train	45									
Number of bunch trains	60	64	72	75	80	90	96	100	120	
Gaps per train	75	67.5	55	51	45	35	30	27	15	
Gap length [ns]	233.85	210.77	172.31	160.00	141.54	110.77	95.38	86.15	49.23	
Total number of bunches	2700	2880	3240	3375	3600	4050	4320	4500	5400	
Bunch charge [$\times 10^{10}$]	2.00	1.87	1.67	1.60	1.50	1.33	1.25	1.20	1.00	

Table 2 Fill patterns of alternative damping ring

Ring circumference [m]	17227.9195		
Harmonic number	37353		
Ring RF frequency [MHz]	650		
Linac RF frequency [GHz]	1.3		
Linac pulse length [ms]	1.03		
Linac bunch spacing [linac RF wavelengths]	540	360	180
Linac bunch spacing [ring RF wavelengths]	270	180	90
Linac bunch spacing [ns]	415.38	276.92	138.46
Ring bunch spacing [linac RF wavelengths]	18	12	6
Ring bunch spacing [ring RF wavelengths]	9	6	3
Ring bunch spacing [ns]	13.85	9.23	4.62
Bunches per train	6	9	18
Number of bunch trains	415		
Gaps per train	12		
Gap length [ns]	60.00		
Total number of bunches	2490	3735	7470
Bunch charge [$\times 10^{10}$]	2.25	1.50	0.75

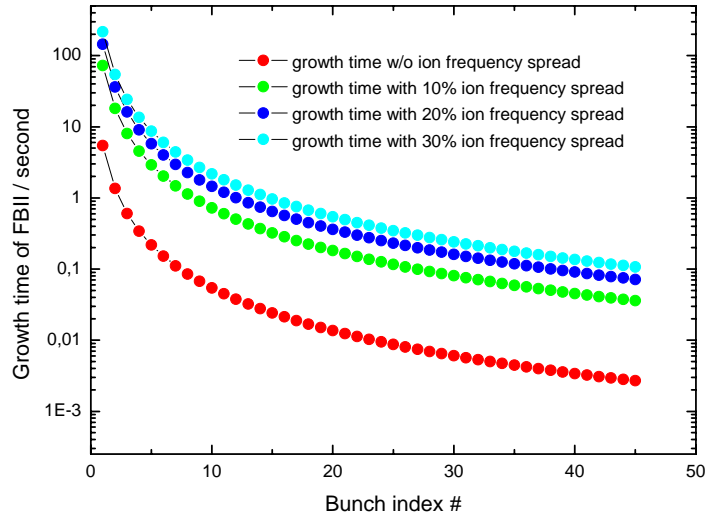


Fig. 1. Growth time of FBII versus bunch index in 0.1nTorr for baseline damping ring (Mode 1)

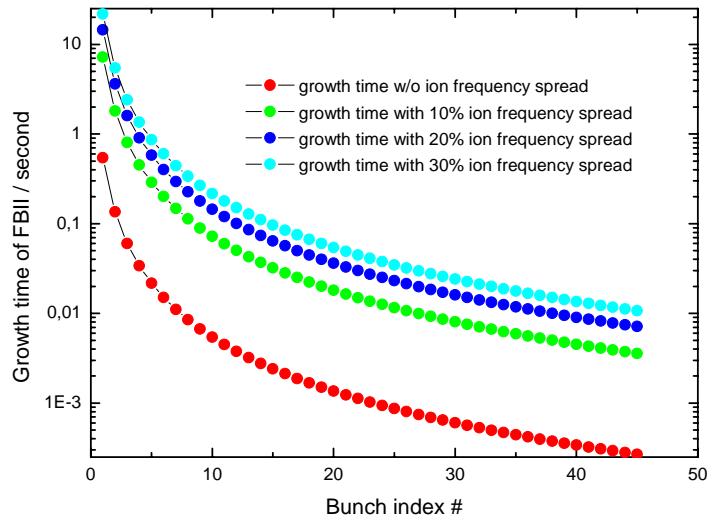


Fig. 2. Growth time of FBII versus bunch index in 1nTorr for baseline damping ring (Mode 1)

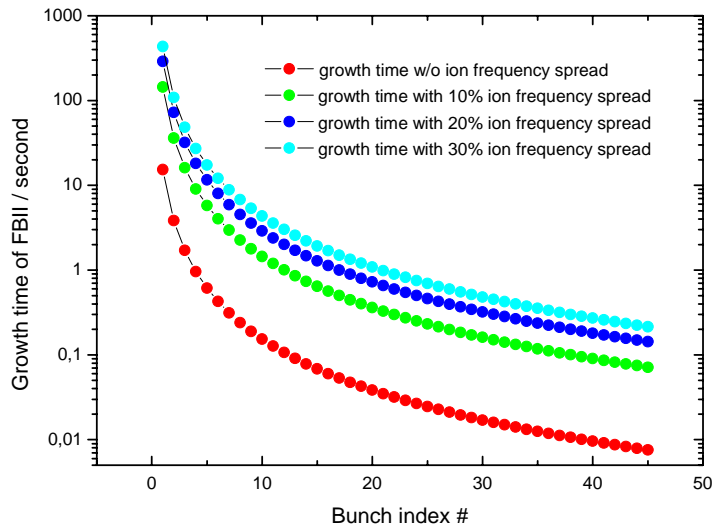


Fig. 3. Growth time of FBII versus bunch index in 0.1nTorr for baseline damping ring (Mode 2)

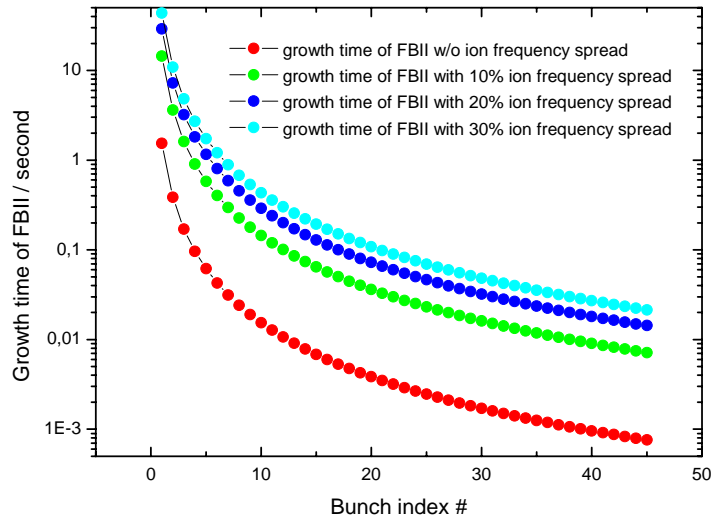


Fig.4. Growth time of FBII versus bunch index in 1nTorr for baseline damping ring (Mode 2)

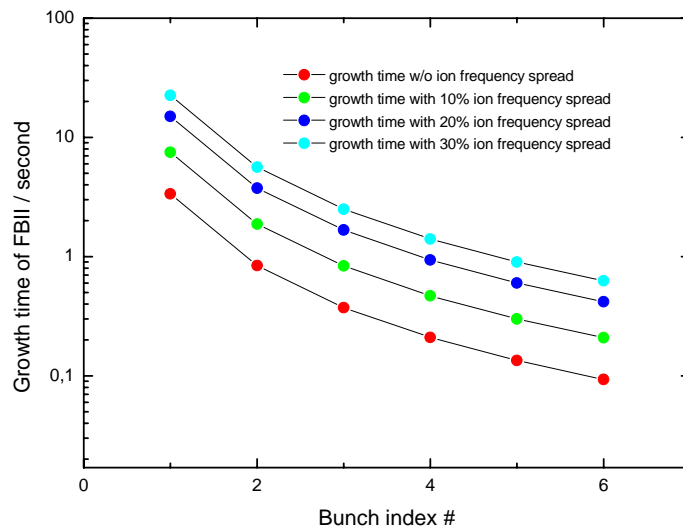


Fig.5. Growth time of FBII versus bunch index in 0.1nTorr for alternative damping ring (Mode 1)

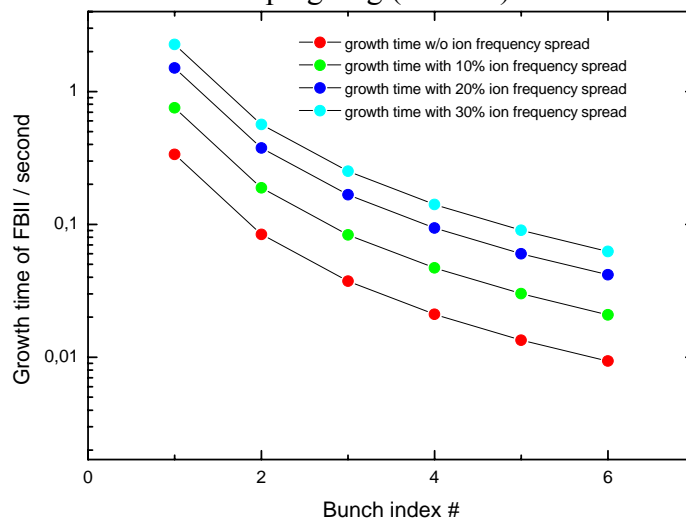


Fig.6. Growth time of FBII versus bunch index in 1nTorr for alternative damping ring (Mode 1)

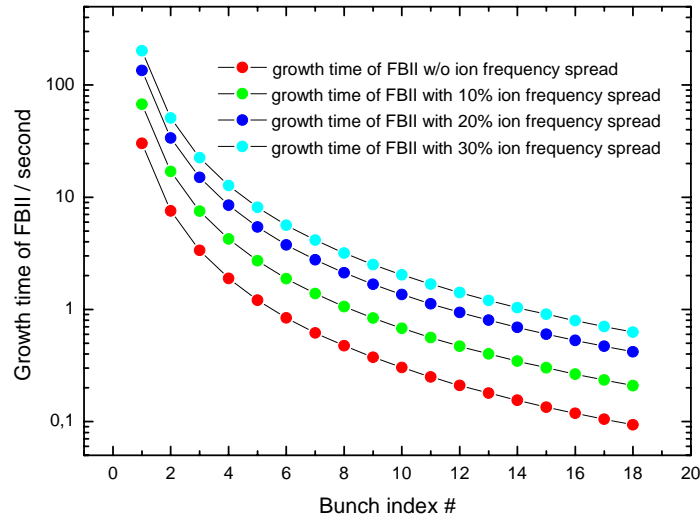


Fig. 7. Growth time of FBII versus bunch index in 0.1nTorr for alternative damping ring (Mode 2)

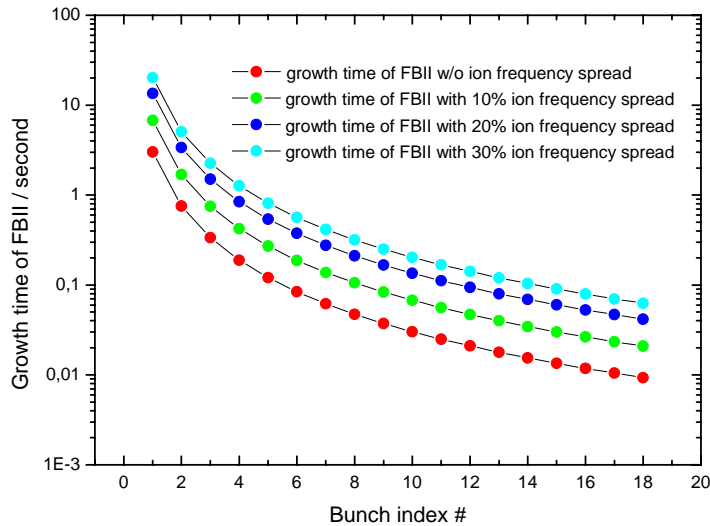


Fig. 8. Growth time of FBII versus bunch index in 1nTorr for alternative damping ring (Mode 2)

4 Conclusion

From the analytical results one can see that the growth time at the bunch train end for baseline and alternative damping rings in both 0.1nTorr and 1nTorr is larger than the revolution period of rings (The revolution period for 6km and 17km rings are 22 μ s and 57 μ s respectively. When there is no ion frequency spread, the growth time of FBII is a few hundred microseconds, so it is within the bunch-by-bunch feedback system). Therefore it is possible to cure the fast beam-ion instability by using the fast feedback system in ILC electron damping ring.

Acknowledgement

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References

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