FAST ION INSTABILITY AT UNDULATOR INSERT OF ILC

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ABSTRACT

In the linac of International Linear Collider (ILC), there is no conventional ion-trapping due to the long bunch spacing of 176ns. However, the vacuum at the undulator section of ILC is order of 100 *nTorr*, the fast ion instability may occur due to the poor vacuum there. A strong-weak simulation program is applied to study the fast ion instability at this section.

LINEAR MODEL OF GROWTH TIME OF FAST ION INSTABILITY

The exponential growth rate of fast ion instability due to a bunch train with a spread of ion frequency $\Delta\tilde{\omega}_i^{rms}$ is given by [1]:

$$\frac{1}{\tau_e} \approx \frac{1}{\tau_c} \frac{c}{2\sqrt{2} l_{train} \left(\Delta\tilde{\omega}_i\right)_{rms}} \tag{1}$$

Where

$$\frac{1}{\tau_c} = \frac{4 c r_e r_p^{1/2} \lambda_i \beta_y N^{1/2} n_b S_B^{1/2}}{3\sqrt{3} \gamma \sigma_y^{3/2} \left(\sigma_x + \sigma_y\right)^{3/2} A^{1/2}} \tag{2}$$

Here, β_y is average beta-function, γ is gamma factor, r_e is the classical electron, A is mass number of ion, n_b is number of bunches, N is number of electrons per bunch, l_{train} is length of a bunch train and λ_i is the ion line density

$$\lambda_i = \sigma_i \frac{P}{kT} N n_b \tag{3}$$

Here P is the pressure, σ_i is the ionization cross-section, *2 Mbarn* for CO^+ ion is assumed.

Without gaps in the beam fill pattern, the ions with a relative molecular mass greater than A_{xy} will be trapped horizontally (vertically), where

$$A_{xy} = \frac{N r_p S_b}{2(\sigma_x + \sigma_y)\sigma_{x,y}} \tag{4}$$

Where r_p is the classical radius of proton, N is the number of electrons per bunch, S_b is the bunch spacing in length and σ_{xy} is beam size.

The ions at the undulator section are not trapped due to the long bunch spacing (176 ns). Also there are no gaps at the beam fill pattern. Therefore, the ion density (Eq. 3) doesn't apply in this case.

SIMULATION MODEL AND RESULTS

A numerical method is used to study the fast ion instability here. Ions are represented by macro-particles. The ions are initially distributed along the whole section in order to include the damping effect of the ion frequency-spread. In order to clearly see the instability and reduce the CPU time, some assumptions are applied:

- Beam Energy 5 GeV. The growth time is proportional to beam energy (Eq. 2). After we get the growth time at 5GeV, we scale it back to 150GeV.
- Periodically extends the insert section to long enough for instability

The helical fields are [2]

$$B_r = 2B_0\big(I_0(kr) - (j/kr)I_1(kr)\big)\sin(\theta - kz) \tag{5}$$

$$B_\theta = (2B_0/kr)I_1(kr)\cos(\theta - kz) \tag{6}$$

$$B_z = -2B_0 I_1(kr)\cos(\theta - kz) \tag{7}$$

The fields near the beam are:

$$B_x = B_0\sin(2\pi z/\lambda) \tag{8}$$

$$B_y = B_0\cos(2\pi z/\lambda) \tag{9}$$

$$B_z = 0 \tag{10}$$

Here, λ=1 *cm* and B_0=1*T*. The diameter of wiggler is 6mm and the nominal beam energy is 150 *GeV*. Bunch spacing is 176 *ns* and bunch intensity is 2×10^{10}. A vacuum pressure of 100 *nTorr* is assumed.

Figure 2 shows the vertical oscillation of a beam at 5 *GeV* with 176 *ns* bunch spacing. The growth time is 38 μs, which corresponds to 1.14 *ms* at 150 *GeV*. Figure 3 shows the distributions of ions at different time. The size of ion increases but the density decreases with time due to the beam's oscillation. Therefore the instability slows down as shown on Figures 3 and 4.

The growth rate of instability can be reduced by increasing the bunch spacing. Figure 4 shows the beam's vertical amplitude with a double bunch spacing 352 *ns*. The growth time for a 5 *GeV* beam is 75 μs, which corresponds to 2.25 *ms* at 150 *GeV*. Comparing with Figure 3, the growth time increases by a factor 2 with a double bunch spacing. It is not an efficient way to mitigate instability by increasing bunch spacing in this case.

The effects of Hydrogen are small comparing with CO ion. Figure 5 shows the vertical oscillation amplitude of different bunches with a bunch spacing of 176 *ns*. Again, a pressure of 100nTorr is assumed. The growth time is 234μs at 5*GeV*, which corresponds to 7 *ms* at 150 *GeV*.

SUMMARY

The fast ion instability growth time due to CO ion is 1.14 *ms* for a 150 *GeV* beam with a bunch-spacing of 176 *ns* and a pressure of 100 *nTorr*. The beam vertical amplitude increases 0.25% during passage of this section. The growth time is 2.25 *ms* with a bunch-spacing of 352 *ns*, which can cause 0.13% increase in the beam's vertical amplitude. The growth time with 100*nTorr* of Hydrogen is 7 *ms*, which causes only 0.04% rise of the beam's amplitude. The ions effect at this section is negligible due to the long bunch spacing and short length of this section.

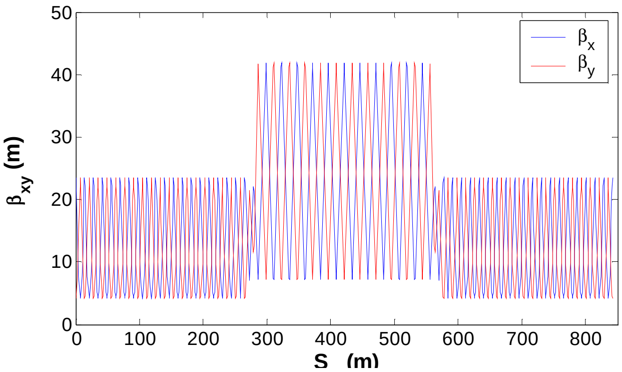

Figure 1 Betatron functions at the undulator insert

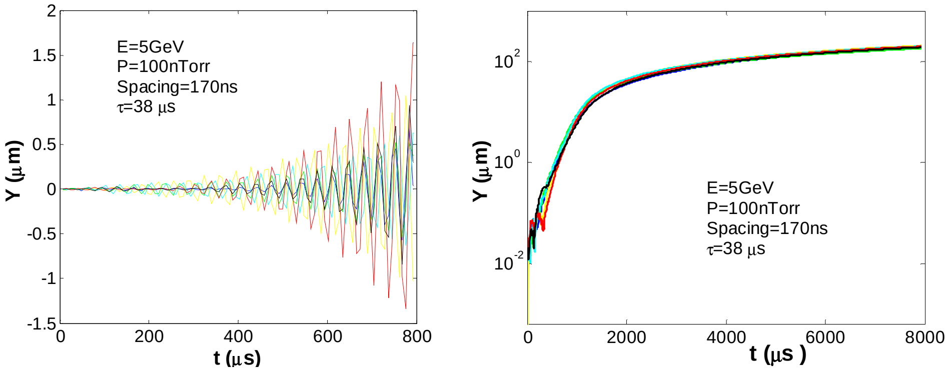

Figure 2 Vertical oscillation (left) and amplitude (right) of different bunches with a bunch spacing of 176 *ns*.

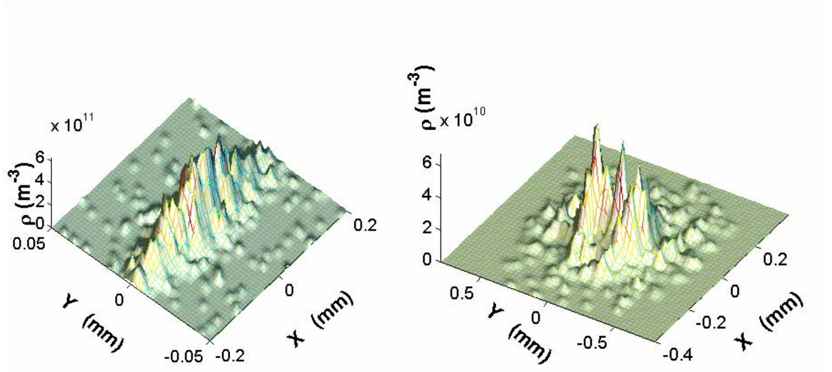

Figure 3 ions distribution at early time (left) and late time (right)

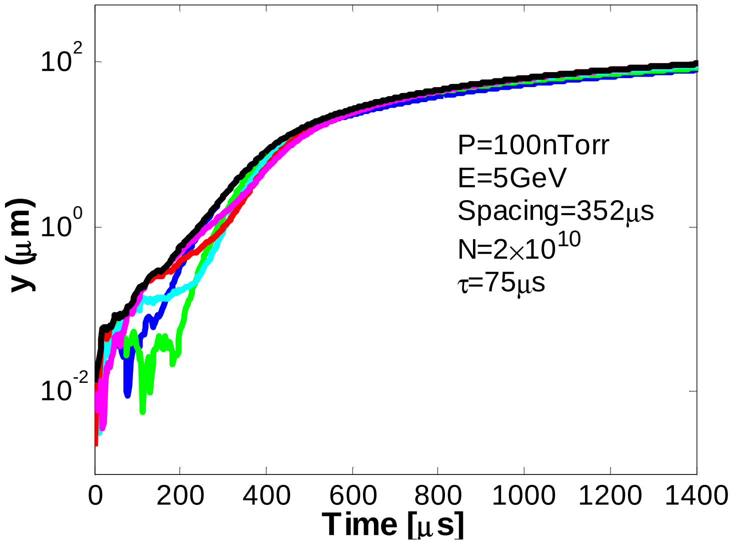

Figure 4 Vertical oscillation amplitude of different bunches with a bunch spacing of 352 *ns*.

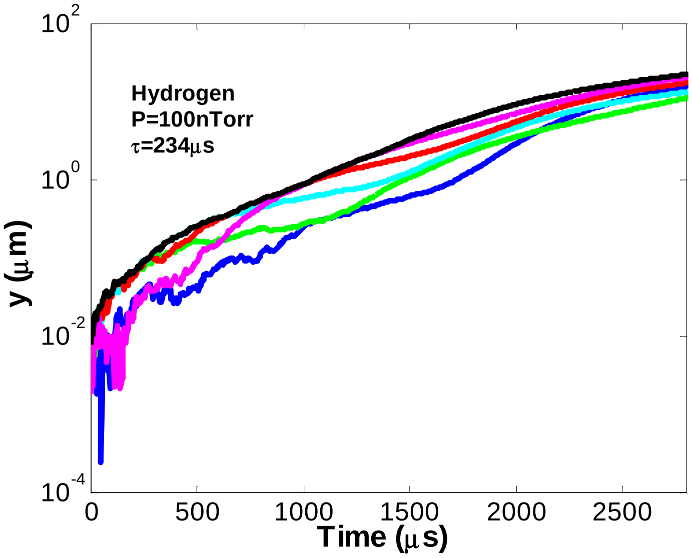

Figure 5 Vertical oscillation amplitude of different bunches with a bunch spacing of 176 *ns*. A pressure of 100nTorr Hydrogen is assumed

REFERENCE

1. G.V. Stupakov, Proc. Int. Workshop on Collective Effects and Impedance for B-Factories KEK Proc. 96-6 (1996) p243.
2. J. Blewett and R. Chasman, Journal of Applied Physics, Vol. 48, No. 7, 2692 (1977)