Pulse-to-Pulse Simulation of Orbit Feedback for JLC Final Focus System

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Abstract

A realistic, pulse-to-pulse, simulation is done to evaluate performance of an orbit feedback system in final focus system for future linear colliders. Accumulation of errors and long time stability of the system including time evolution of ground movement are estimated by this simulation. The result of simulation confirms that the orbit feedback system can maintain nano meter beam size at a colliding point and can keep beams in head-on collision

I. Introduction

In future linear colliders, 1 μm r.m.s. vertical random displacement of focusing elements in final focus system can cause 10 times larger beam spot at interaction point (IP) than designed nano meter beam size. After the beam based alignment technique [1] recovers the proper alignment of the elements, we still need a feedback against the ground motion.

The authors of reference [2] suggested the use of a simple orbit correction method. With this method, 3 μm r.m.s. random ground motion does not harm 3 nm beam size at IP, if the error is a static one. To manage the time evolution of the errors, a pulse-to-pulse feedback is necessary.

In this paper, we propose a feedback method and check its effectiveness by a more realistic simulation. This feedback method not only corrects the global orbits in both beam lines but also keeps the head-on collision. We also include incoming beam position jitter, BPM jitter, and orbit correctors setting errors in the simulation.

II. Simulation of Orbit Feedback

a. Beam Optics

The optics used in the simulation is the optics for the final focus system of JLC[3] designed by K.Oide[4]. Figure 1 shows the optical functions of this optics. The beta functions at the interaction point are 10 mm in horizontal and 100 μm in vertical direction.

Assuming the invariant emittances of $\epsilon_x = 3.6 \times 10^{-6}\mathrm{m\cdot rad}$ and $\epsilon_y = 5 \times 10^{-8}\mathrm{m\cdot rad}$ at the entrance, the designed beam cross section at the interaction point is 280 nm × 3.5 nm including 15 % increase of emittance due to aberration. Non linearity of sextupole magnets for chromaticity correction is canceled out each other by $-\pi$ transformer between a pair of sextupoles.

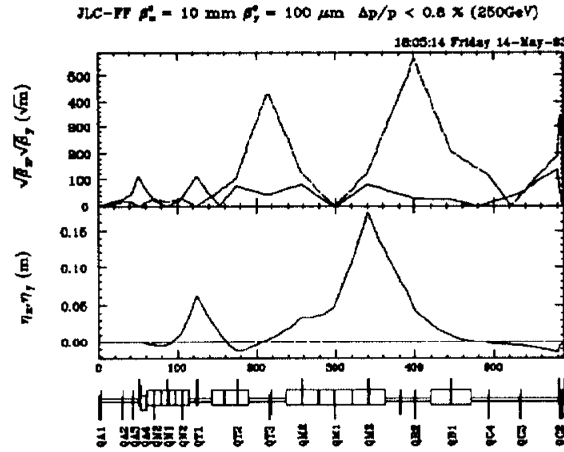

Figure 1: Optical functions of the JLC final focus system. The upper: horizontal and vertical beta functions. The lower: dispersion functions.

b. Feedback System

We consider the feedback system which consists of two kinds of orbit correction methods. Result from each method is summed and applied for the next pulse of the beam.

The first feedback cures the global orbit distortions caused by the transverse displacement of quadrupole and sextupole magnets, such as the ground motion. The orbit correction method discussed in [2] is used as a correction algorithm. The algorithm 1) centers the orbit at each BPM (so-called one to one correction) and 2) keep the beam position at IP unchanged. It follows that any linear dispersion is not produced at IP in the ideal case.

The second feedback keeps beams in collision. The relative distance between colliding beams, Δ_x and Δ_y, will be measured by the beam-beam deflection monitor in future linear colliders. The feedback controls the beam positions at IP by making dispersion-free bump orbits near the IP. Figure 2 shows an example of such a bump orbit.

c. Feedback Loop Parameter

Because of randomness in the error sources, it is necessary to average input data for the feedback loops. The global orbit correction feedback does not directly correct the orbit distortion, $z(s)$, but a filtered quantity $f_i(s) = \alpha z(s) + (1-\alpha)f_{i-1}(s)$, as a target of i-th pulse. The head-on collision feedback has a similar damping constant β. Search for luminosity-optimum for these parameters by simulations results in $\alpha = 0.25$ and $\beta = 0.5$ as shown in Figure 3. These values are used in the rest of simulation.

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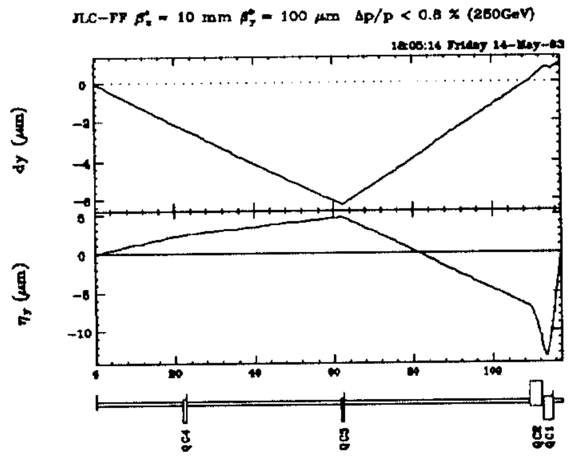
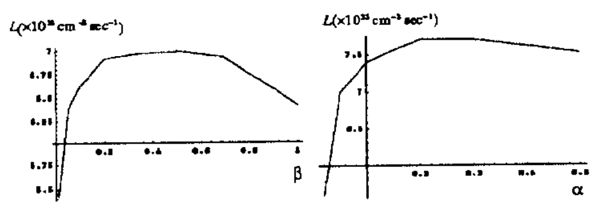


Figure 2: Dispersion-free bump orbit for the head-on collision feedback.



(a) Optimum search of β for α=0.05 (b) Optimum search of α for β=0.5

Figure 3: Optimum values of feedback parameters.

d. *Luminosity Enhancement by Beam-Beam Interaction*

Disruption parameter, $D_{x/y}$, of the colliding beam for the future linear colliders is in the range from 3 to 10. For such an intense beam, luminosity enhancement by beam-beam interaction is important. Luminosity enhancement factor was calculated by simulation in [5]. We used the approximate formula,

$$H_D = (1 + D_y)^{\frac{1}{3}} \frac{15e^{-\frac{1}{4}\frac{\Delta_y{}^2}{(1+D_y)^{\frac{4}{3}}}} + D_y e^{\frac{-|\Delta_y|}{1+D_y}}}{15 + D_y}$$

for vertical offsets. This formula agrees well with the result in [5] for flat Gaussian beam with $D_y \leq 10$. For horizontal offset, we used a simple Gaussian overlap formula for the luminosity.

e. *Ground Motion*

Random transverse displacement of the magnet is generated by using the ATL rule [6]. Although meaning of the ATL rule and its validity are not understood completely yet, we use the ATL rule as a guideline for the estimation of long-term ground motion.

The ATL rule implies squared average of the relative displacement, σ, between two points at distance L after time interval T follows the relation $\sigma^2 = A \times T \times L$. A is a constant parameter depends on the site. In the reference [6], 10^{-16}msec^{-1} is reported as a value of A. We use this value in the most of simulations. Using the repetition rate 150Hz, we get $AT = 6.67 \times 10^{-19}$ m.

f. *Other Error Sources*

We used the following numbers for the other error sources.

Error sources	Horizontal	vertical
Beam jitter	0	$1 \times \sigma_y$
correctors error.	0.1%	0.1%
correctors rotation error	1 mrad	1 mrad

g. *Simulation Method*

Particle tracking simulation in this study was performed by using computer code SAD developed at KEK. SAD tracks particles in full 6 dimension phase space in a symplectic way.

Two computer processes corresponding electron and positron lines are activated simultaneously. Both processes exchange data of beam position at IP for each pulse, and use them for the head-on collision feedback. In this simulation, we do not include the deflection curve with beam-beam effect. We assumed that the offset of two beams can be directly measured. The global orbit correction uses the BPM data supplied by multiparticle simulation with 100 particles/pulse/beam. Synchrotron radiation was turned off due to the limit of computer power.

III. Results of Simulation

Figure 4 summarizes the results of simulation for 10^5 pulses. From the top to the bottom, 1 and 2) are horizontal and vertical relative beam offset at IP as a function of pulse number; 3 and 4) Horizontal and vertical beam sizes at IP for electron beam; 5 and 6) Luminosities without and with the pinch effect. Factor 2 enhancement due to the pinch effect is clearly seen. We have assumed that the beam energy is 250 GeV and the number of particles/bunch 1.11×10^{10}, the number of bunches/rf pulse 72, and the repetition rate 150 H_z. The achieved average luminosity is 7.2×10^{33}cm^{-2} for above parameters.

Figure 5 shows the performance of this orbit feedback. Beam positions and beam sizes at IP are tracked for first 5000 pulses without the orbit feedback. Both beam sizes and beam positions drift away from their nominal values in this period. Feedback loops start at the 5001st pulse. Beam positions and beam sizes recover their nominal values after a few hundred pulses. To visualize an effect of long term ground motion, we used large value of $AT = 10^{-16}$ m in this case, which corresponds to 1 Hz repetition rate. One thousand pulses corresponds to 17 minutes assuming $A = 10^{-16}$m/sec.

In Figures 4 and 5, there is no clear evidence of long term instability. Such an instability is observed for a quite large value of $AT = 9 \times 10^{-16}$: σ_y^*: decays slowly even with the

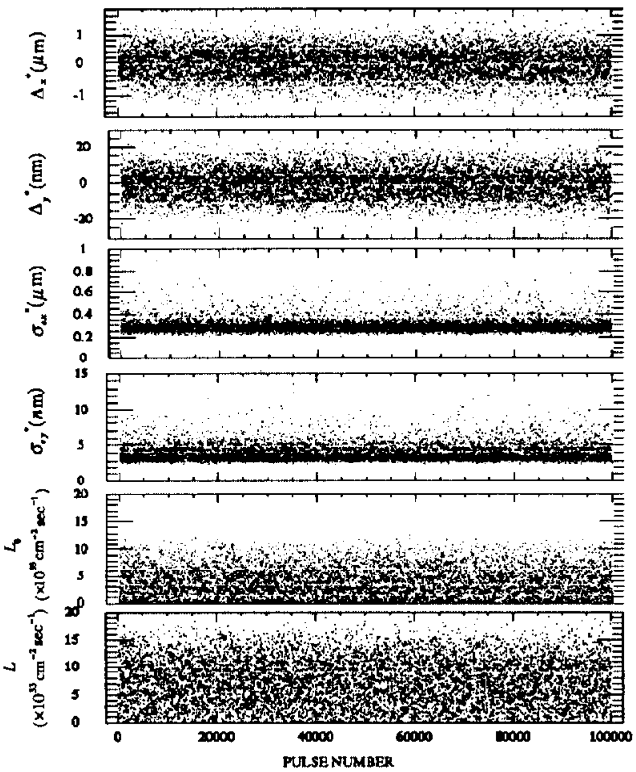


Figure 4: Long term behavior of relative beam displacement, beam size at IP and Luminosity(without/with pinch effect enhancement). Horizontal full scale, 10^5 pulses, corresponds $\sim$ 11 minutes.

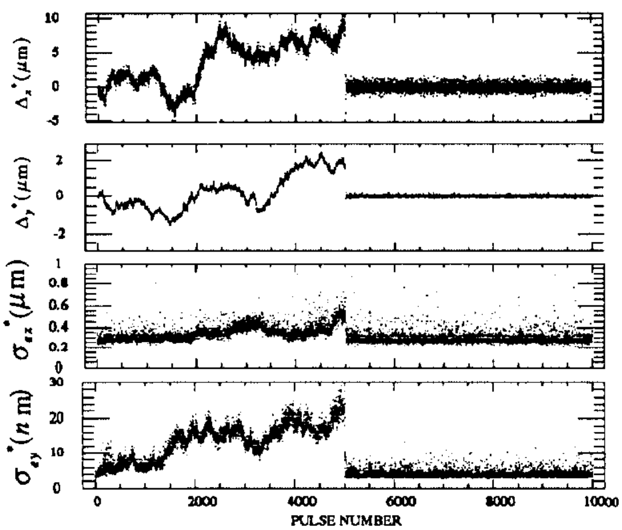


Figure 5: Simulation runs 5000 pulses without feedback. Feedback loops are turned on after 5000 pulses.

feedback. One thousand pulses in this case corresponds 25 hours assuming $A = 10^{-16}$ m/sec.

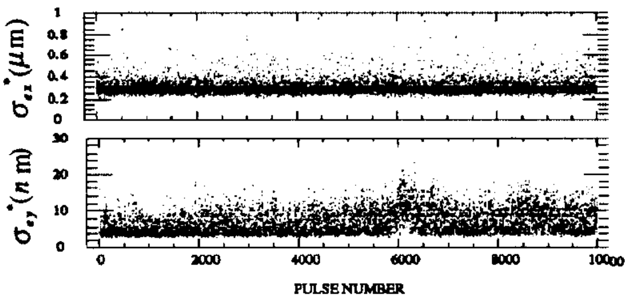


Figure 6: Long term stability of the system. With $AT = 9 \times 10^{-16}$, σ_y^* decays slowly even with the feedback. Horizontal Full scale:25 hours.

IV. Summary and Discussion

Realistic pulse to pulse simulation of orbit feedback for final focus system of future linear colliders has been performed. The simulation includes several important error sources which may degrade performance of the system. The result of simulation indicates that the final focus system keeps good luminosity with this feedback method for more than 3 hours without any other tuning procedure.

There still remain error sources not included, such as the dynamic range and the nonlinearity of the beam-beam deflection monitoring, drift of strength of components, non-ATL vibrational ground motion, synchrotron radiation in magnets, BPM nonlinearlity, and so on. Simulation including these effects is in progress.

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