IP FEEDBACK GROUND MOTION SIMULATION STUDIES FOR THE ILC

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Abstract

The International Linear Collider (ILC), as described in its Technical Design Report (TDR), must maintain strict control of its electron and positron beams in order to achieve the desired luminosity at each of its proposed center-of-mass energies. Controlling the beam parameters requires a dynamic system, capable of adjusting to a myriad of perturbations and errors. One of the components used to control the beam is the Interaction Point (IP) feedback system, which is used to dynamically steer the beams back into collision within nanoseconds. This work will show the simulation of the IP feedback system's compensation for ground motion model K at the ILC.

INTRODUCTION

Particle colliders require the maintenance of strict control over the beams to ensure they collide in such a way that maximizes the luminosity, thus providing the maximum number of collisions. This presents a unique challenge in linear colliders, which do not maintain the same periodic conditions present in circular colliders. Rather, the beams in linear machines only pass through once, effectively providing a single shot from each arm.

The International Linear Collider (ILC) (see Fig. 1), as described in its technical design report (TDR) [1], will collide electrons with positrons at center-of-mass energies up to 500 GeV. In the TDR, a beam delivery system (BDS) is presented which allows for effective tuning and contains feedback (FB) systems to control the beams as they approach the interaction point (IP). This work will describe simulations of the IP feedback system, which has been designed and thoroughly tested by the Feedback On Nanosecond Timescales (FONT) group at the University of Oxford (see Fig. 2) [2].

The FONT IP feedback system uses a beam position monitor (BPM) to measure the deflection angle of the beam after it interacts with its counterpart. The system then computes the beam offset which would correspond to the measured deflection angle and provides a signal to an upstream dipole kicker. The kicker is then used to steer the beam centroid back toward the nominal trajectory in an effort to achieve a head-on collision of the two beams.

In a similar manner to previous treatments of the IP feedback system for the Compact Linear Collider (CLIC) [3-6], these simulations start by applying various ground motion models to the 500 GeV ILC BDS, which is described in the TDR. Once ground motion is applied, the IP feedback system performs as described above. This whole process is performed in nanoseconds. In the ILC, the FONT FB system is capable of both recovering luminosity loss and providing a stable luminosity for the entirety of the bunch train, which is of order 725,000 ns.

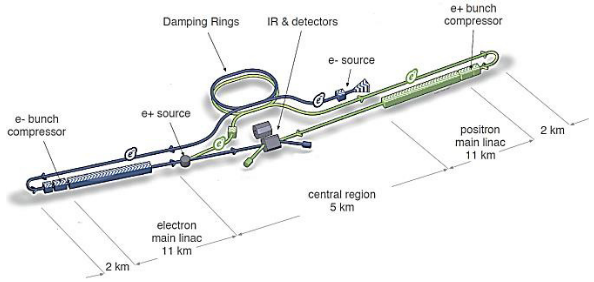

Figure 1: The ILC [1].

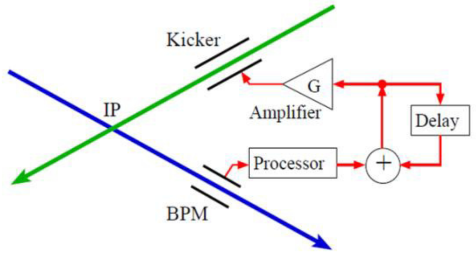

Figure 2: General FONT IP feedback system [2].

BACKGROUND

This work will focus on the 500 GeV center-of-mass collision energy ILC design. Some of the beam parameters for this design can be found in Table 1.

The focus of this work is on ground motion model K, which is the model based upon measurements at KEK in Tsukuba, Japan [7, 8]. Since the proposed site of the ILC is in northern Japan, this model is one of the most relevant. Several ground motion models are under investigation, but due to the site-specific relevance of this model, it will remain the focus of this work.

For the IP feedback simulations, the LinSim [9, 10] framework of the programs PLACET [11] and GUINEA-PIG [12] is used. Within this framework, 100 random seeds of ground motion model K are applied along the BDS (excluding the main linac and other parts of the accelerator), misaligning the beamline elements and altering the trajectory of the beams. The intratrain IP feedback system is then simulated for the length of the bunch train. Previous simulation studies from the CLIC system and real-beam tests at the Accelerator Test Facility (ATF2) at KEK and the CLIC Test Facility (CTF3) at CERN have demonstrated the ability of the FONT IP feedback system to recover luminosity in nanoseconds. At the ILC, with its significantly longer bunch train length and bunch separation than that of CLIC, the FONT FB system is more than capable of recovering luminosity, as well as maintaining a stable luminosity for the entirety of the bunch train.

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Table 1: ILC 500 GeV Beam Parameters

Parameter	Value	Units
Collision Rate	5	Hz
Number of bunches	1312	
Bunch Population	2	10^{10}
Bunch separation	554	ns
Luminosity	1.8	10^{34} cm^{-2}s^{-1}
IP Horizontal Beam Size	474	nm (RMS)
IP Vertical Beam Size	5.9	nm (RMS)

PREVIOUS INVESTIGATIONS

Previous studies [13] have found that ground motion model K may create offsets that are too large for the IP feedback system to recover more than 70% of the luminosity when combined with other feedback systems and under ideal circumstances. Without inter-train feedback systems and beamline tuning, the dipole kick used by the IP feedback system is incapable of correcting for nonlinear and high-order aberrations which degrade the overall luminosity. However, the IP feedback system is capable of re-steering the beam back to the nominal trajectory and preserving it. If higher-order aberrations are present, they can only be corrected by other beamline elements. But the dipole kick will allow for the most head-on beam-beam collisions possible given the beam distributions.

CURRENT INVESTIGATION

For these simulations, only the vertical plane is under investigation, as the beam size in that plane is orders of magnitude smaller than in the horizontal plane and requires tighter controls to achieve an ideal collision. In these initial stages, ground motion is only applied in the vertical plane. Correspondingly, corrections made by the IP feedback kicker are only applied in the vertical plane.

In a manner similar to that described in [4, 5], a series of gain settings (of arbitrary units) is scanned in order to find that which corresponds to the best luminosity recovery for the BDS under the influence of ground motion model K. Once this is determined, the ratio of $\mathcal{L}$ to $\mathcal{L}_{\text{FBoff}}$ is plotted against bunch number to show not only the recovery, but the ability of the FB system to maintain the luminosity at a steady level throughout the bunch train. Here, $\mathcal{L}$ is the luminosity measured with the IP feedback system turned on, and $\mathcal{L}_{\text{FBoff}}$ is the luminosity measured before the IP feedback system starts. For these simulations, all other feedback systems were excluded, and no beam tuning was performed. The results are only due to the FONT IP feedback system, and thus the luminosity recovery is limited by the capabilities of the feedback dipole kick.

It can be seen in Fig. 3 that the luminosity is recovered within a few bunches (recalling that the bunch spacing is 554 ns). After this recovery, the IP feedback system then maintains the luminosity at a stable level for the remainder of the bunch train (see Fig. 4).

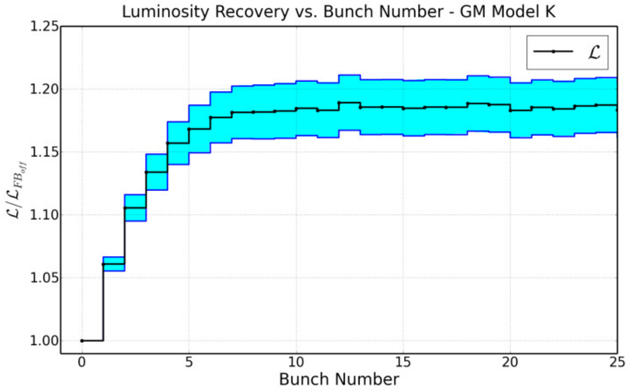

Figure 3: Luminosity recovery through 25 bunches. Shaded region is the standard error.

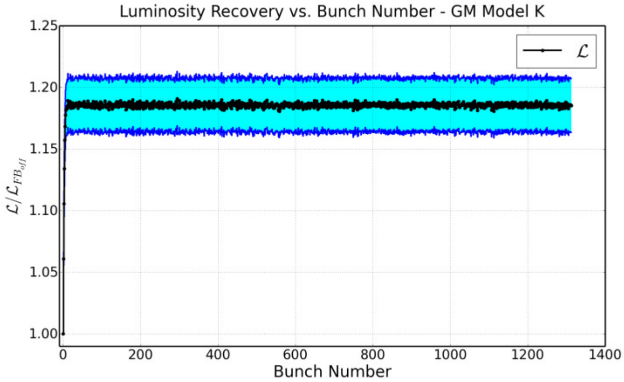

Figure 4: Recovered luminosity maintained through bunch train. Shaded region is the standard error.

FUTURE WORK

Other factors should be included to make the simulations more realistic. Firstly, inter-train feedback is not active, and no tuning has occurred. Furthermore, only the vertical plane is being investigated, and the beam distribution is being ignored. Finally, only a single instance of ground motion is applied, and other external factors are not considered.

In order to increase the realism of these simulations, more of these factors must be considered in a step-by-step process. Each time the simulations are run, further variables and complexities should be added.

By adding layers of complexity into the simulations in a stepwise fashion, the influence of each addition can better be understood.

One factor that will be investigated more thoroughly is the beam distribution at the IP. This is often overlooked, but gives clues as to the nature of the aberrations which cause the luminosity to drop. While dipole kicks may not be able to correct higher-order aberrations, knowledge of these aberrations may lead to insights on how better to apply the IP feedback system.

Finally, the other ground motion models must also be investigated. While model K is the most site-relevant model to the ILC, each of the different models can provide a different insight into the complexities of correction with the IP feedback system.

CONCLUSION

This initial study of the IP feedback system's ability to recover and maintain the luminosity for the bunch train length has confirmed the difficulties that previous studies have discussed when addressing ground motion model K. Under strict and limited conditions, and without any other feedback or tuning systems functioning, the IP feedback system was able to recover luminosity and maintain a stable luminosity. It could not recover the luminosity loss due to nonlinear aberrations created by the higher-order elements in the beamline, but this is an expected result. Further studies will expand upon the limited conditions of this simulation, and will also include other ground motion models.

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