EFFECTS OF DYNAMIC MISALIGNMENTS AND FEEDBACK PERFORMANCE ON LUMINOSITY STABILITY IN LINEAR COLLIDERS

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Abstract

The performance of high energy linear colliders depends critically on the stability with which they can maintain the collisions of nanometer-size beams. Ground motion and vibration, among other effects, will produce dynamic misalignments which can offset the beams at the collision point. A system of train-to-train and intra-train beam-beam feedbacks, possibly combined with additional beam-independent active systems, is planned to compensate for these effects. Extensive simulation studies of ground motion and luminosity stabilization have been performed as part of the work of the International Linear Collider Technical Review Committee [1]. This paper presents a comparison of the expected performance for TESLA, JLC/NLC and CLIC under various assumptions about feedbacks and the level of ground motion.

INTRODUCTION

Small emittances and nanometer-size beams at the interaction point of a linear collider lead to tight stability tolerances on the collider components. Ground motion and vibration can disturb alignment and degrade the luminosity via separation of the beams at the IP or beam emittance growth. A train-to-train beam-beam deflection feedback (or intra-train, as planned for TESLA) is necessary to keep the beams colliding. Below, we will investigate performance of such beam-beam feedback, in the presence of ground motion. Alignment tolerances for beam offset at the IP are much tighter than those for emittance growth, and therefore beam separation can occurs on a faster time scale than beam emittance growth. We therefore can ignore other orbit feedbacks (in the linac or beam delivery) which act on much slower time scales and the concentrate discussion only on the IP feedback and its performance.

ASSUMPTIONS AND METHODS

Ground motion amplitudes and correlation properties vary significantly from site to site and depend on many factors. To span the possible range of site conditions, three models of ground motion were considered: (**A** – "Low", **B** – "Intermediate", and **C** – "High" noise). These models are based on measurements on the tunnel floor of LEP and at California representative sites for **A**, at the SLAC tunnel and the Aurora mine near FNAL for **B**, and on the tunnel floor of HERA for **C**. The models are represented by a parameterized 2-D power spectrum $P(\omega, k)$, to properly describe both the spatial and temporal correlations of ground motion. The models include a contribution from diffusive ATL motion that dominates at low frequencies and vanishes for high frequencies, contribution from isotropically-distributed plane waves propagating in the ground representing fast motion including cultural noise, and systematic motion (occurring in month-year time scale). Each model is described by a couple dozens of parameters. The traditional spectra can be obtained from the 2-D spectrum, see an example in Fig.1. Details of the models and relevant parameters can be found in [2]. The models have been implemented in the codes Matlab-LIAR [3] and PLACET [4].

In addition to "on the tunnel floor" ground motion, it is important to consider any noises generated on the girders, inside and near of a cryostat, or amplification by imperfect girders (see more discussion in [1] and [5]). The specific case of vibration of an experimental detector that affects the stability of the final doublet (FD, which has the tightest jitter tolerances) is considered separately. The detector noise model is based on measurements made at SLD in 1995 [6] shown in Fig.2. These measurements would indicate about 30 nanometers of final doublets relative motion due to detector vibration. This should be considered a pessimistic upper limit as vibration control was not a design criteria for the SLD and the measurements were made under less than optimal conditions (e.g. the cooling water was on, but the magnetic field was off, which would otherwise stiffen the detector). Therefore, it is important to stress that the assumed model for detector vibration is pessimistic.

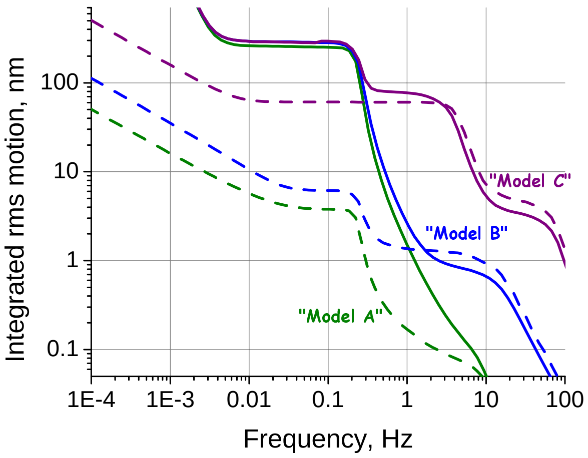

Figure 1: Example of ground motion modeling spectra. The integrated absolute spectra (solid lines) and the integrated relative (for dL=50m) spectra (dashed lines).

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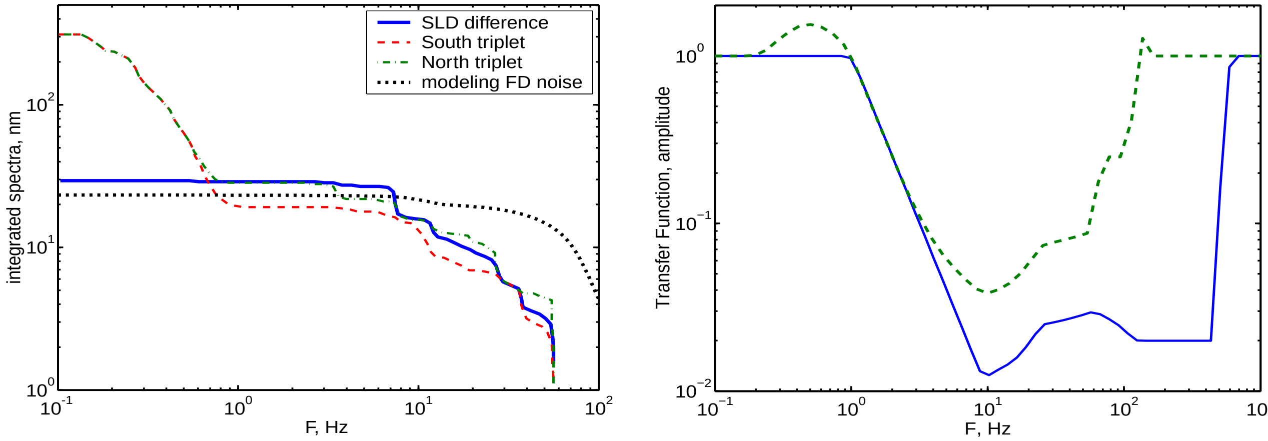

Figure 2: Results of 1995 vibration measurements on the SLC detector [6] (left plot). The integrated spectra shows that the difference of the motion (blue solid line) of the South triplet (red dashed curve) and the North triplet (green dash-dot curve) is about 30 nm, as measured by two STS-2 seismometers installed on the triplets. Black dotted line shows an approximation for the FD noise used in the integrated simulations. The right plot shows the modeling transfer functions used in simulations to represent FD stabilization.

In such conditions the final doublet in warm machines would require active stabilization. Both JLC/NLC and CLIC propose to use a combination of laser interferometers and/or inertial sensors to drive piezoelectric or electrostatic mechanical actuators or dipole correctors to adjust the position of the FD magnetic center, and such methods are being developed. The doublet stabilization was modeled by the idealized transfer function shown in Fig.2 (solid) or, for some cases, with a less idealized curve (dashed).

The train-by-train IP beam-beam feedback based on the NLC design [7] was reoptimized for each vibration assumption. The intra-train feedback was simulated in a “simple” way where the average position and angle offset was simply zeroed, and latency was ignored. For TESLA, a “full optimization” version was also studied which varied the offsets during the train to find maximum luminosity [8].

In simulations, first, the machines were misaligned and then a simple one-to-one trajectory correction applied to mimic a ‘tuned’ collider. In addition to quad and structure offsets, structure tilts were included. The rms magnitudes of the misalignments were chosen to produce nominal luminosity on average and to reproduce approximately the expected amount of yz and $y'z$ correlation along the bunch to realistically account for the banana effect. The beam-beam collisions were realistically simulated using the GUINEAPIG program [9]. In all cases, the luminosity was calculated for 256 pulses at the collider repetition rate, corresponding to an elapsed time of 51 seconds for TESLA, 2.1 seconds for NLC/JLC and 1.3 seconds for CLIC. For TESLA, this time is long enough to see a slow degradation in luminosity from orbit errors in the BDS, and consequently requires the inclusion of an upstream orbit feedback, not needed on a 1-2 second time scale. Simulations were made with Mat-LIAR and PLACET and represent in total over half a year of CPU time. For the cases cross-checked, good agreement between the codes was found. For these studies, only one bunch was tracked, and bunch-to-bunch effects were ignored.

SIMULATION RESULTS

Figure 3 is an example of results with only the train-to-train IP feedback, showing luminosity as a function of train number for each project (beam-beam parameters and train repetition rate affect strongly this performance, see more in [7]). All the simulation results are summarized in Figure 4 showing the percentage of luminosity obtained for each linear collider under GM models **A** through **C**, with and without additional final doublet vibration induced by the detector, and with different combinations of IP feedbacks and FD stabilization. Each point represents nine different seeds of Mat-LIAR run – three for the machine and three for the ground motion (PLACET simulations typically involved 25 seeds). The results are averaged over 256 trains (50 for TESLA, to ignore absence of BDS orbit feedback).

From these studies, one can see that for ground motion models **A** and **B** with no additional detector noise, all designs maintained nominal luminosity with the specified beam-based IP feedback alone (intra-train for TESLA, inter-train for the others).

For pessimistic estimate of detector noise the luminosity drops significantly (to ∼35% for NLC/JLC and to ∼12% for CLIC) independent of ground motion model. For models **A** & **B** the FD stabilization recovers full luminosity. For more pessimistic assumptions on FD stabilization, less FD vibration can be accommodated without degrading the luminosity – e.g. for NLC with model **B** the recovered luminosity is about 75%. For TESLA, the intra-train feedback is expected to compensate for detector noise.

For ground motion **C**, there was a significant deterioration of the luminosity. Even without detector noise, the luminosity dropped to below 30% for CLIC and below 60% for NLC/JLC. Doublet stabilization only improved this to 50-70%, independent of whether detector noise was included. For TESLA, the luminosity was 85% assuming a perfect intra-train angle and offset feedback. This could be raised to 95% with perfect luminosity maximization.

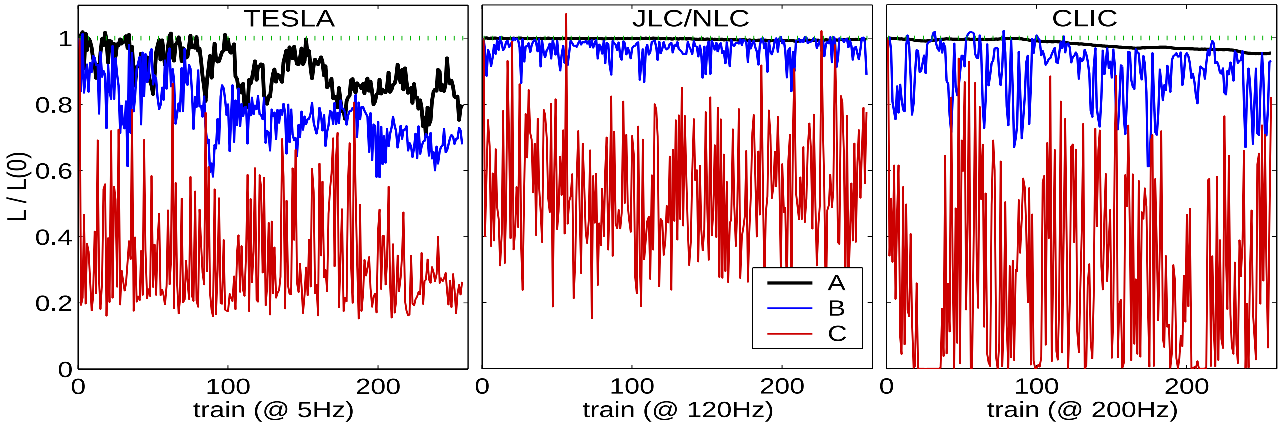

Figure 3: Simulations of LCs with three models of ground motion and only the train-to-train IP feedback. The FD follows the ground. The slow decline of luminosity in TESLA is due to the absence in simulations of the orbit correction in BDS.

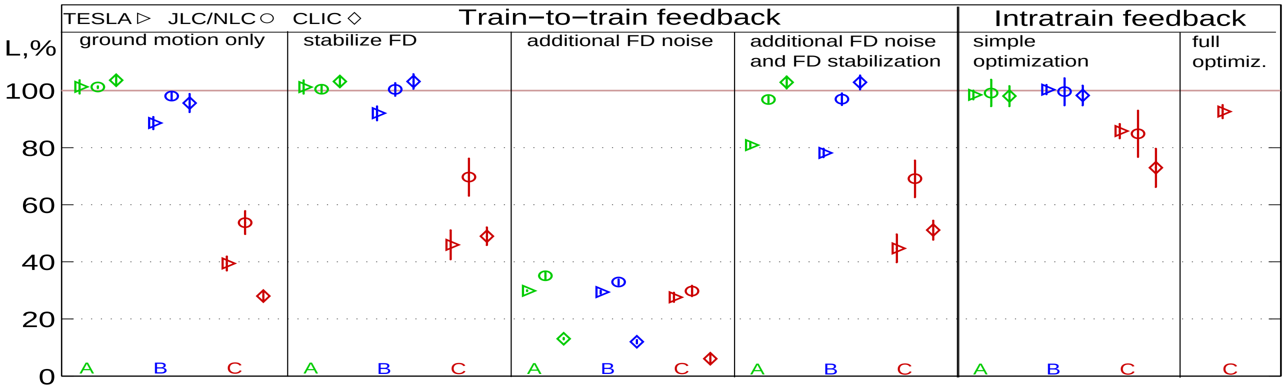

Figure 4: Percentage of luminosity obtained for each LC with ground motion models **A** ,**B**, **C**, with and without additional vibration of FD, and with different combinations of IP feedbacks and FD stabilization.

DISCUSSION AND SUMMARY

Many important effects were either not included or too idealized: multibunch effects; realistic effects of the intra-train position and angle kickers; intra-train IP feedback latency; jitter amplification due either to wakefields in the post-linac collimation system or due to multibunch parasitic beam-beam effects; interplay of different feedback systems with different time scales; hardware imperfections, e.g. beam losses affecting position monitors or finite resolution of the fast luminosity monitors; non-vibrational sources of beam jitter (train-to-train and intra-train), such as damping ring extraction kickers.

One of the challenges is not the luminosity loss itself, but its jitter. The results presented are based on the assumption of a machine tuned to the nominal luminosity at time zero – convergence of such tuning may be hampered by jitter of luminosity and orbits. High repetition rate of warm machines with possibility of averaging for more accurate measurements of luminosity, and possibility of luminosity maximization within the train for the cold machine, are the corresponding hopes of each design. The importance of jitter for tuning convergence is currently being studied.

Choice of a site for a linear collider which is sufficiently quiet now, will remain quiet in the future, would be also compatible with multi-TeV upgrade (which would further tighten the tolerances), is a challenge, especially because the choice cannot be made only on technical reasons. The TRC report [1] discuss the types of sites and expected noise level, and states that a shallow tunnel in unfavorable geology and/or in an urbanized area represents the greatest uncertainty and risk in estimating noise levels, and requires extremely careful study.

Technology-generated in-tunnel, on-girder and in-cryostat noise, for example currently being studied cooling water induced noises, vibration of quadrupoles inside cryostats, vibrations coming from klystron modulators [10], vibration transfer along and between the parallel tunnels, is another challenge which requires vigilant study and careful counter-engineering.

The authors appreciate productive collaboration with all the ILC-TRC group during these studies.

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