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FEEDBACK STUDIES

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Abstract

Dynamic imperfections in future linear colliders can lead to a significant luminosity loss. We discuss different orbit feedback strategies in the main linac that can mitigate the emittance dilution and compare their efficiency. We also address the impact of ground motion in the beam delivery system and the potential cures.

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Dynamic imperfections in future linear colliders can lead to a significant luminosity loss. We discuss different orbit feedback strategies in the main linac that can mitigate the emittance dilution and compare their efficiency. We also address the impact of ground motion on the beam delivery system and the potential cures.

INTRODUCTION

Future linear colliders, such as ILC or CLIC, require final beam spot sizes of the order of few nanometers. This characteristic imposes very rigorous stability requirements on the design. The limiting factor for stability along the beamline is ground motion. If uncorrected, ground motion causes a total loss of luminosity within seconds, through beam misalignment and emittance growth. To cure this, a program of passive and active support systems, to stabilize the beamline elements, together with different levels of beam-based feedback systems, is being pursued[1][2].

Three levels of beam-based feedback system are being developed: a slow feedback correcting the beam orbit to compensate for low frequency ground motion, an inter-pulse feedback acting in a few locations to correct accumulated errors that occur in between the action of the slow system and to provide the possibility of straightening the beam; finally, a fast intra-train feedback system acting at the IP to keep the beams in collision, correcting for the high frequency ground motion that moves the final quadrupole doublet.

In this paper we study some aspects of the orbit feedback in the ILC main linac and the impact of the ground motion in the CLIC beam delivery system. We outline the phenomenology of these phenomena and the potential cures. All simulations have been performed using PLACET[3] and GUINEA-PIG[4].

ILC MAIN LINAC

One of the important challenges in future linear colliders is the emittance preservation in the main linac. The emittance is affected by static and dynamic imperfections. Static imperfections will be mitigated using beam-based alignment (a procedure establishing a golden orbit that minimizes the emittance growth). Dynamic imperfections, such as ground motion, cause the beam emittance to grow with time and the beam to deviate more and more from the golden orbit. The slow orbit feedback must counteract this emittance growth.

One-to-One Orbit Correction and MICADO

In the following, two main methods are investigated to minimize the emittance growth due to ground motion: permanent one-to-one steering with a low gain and the MICADO method. In order to isolate the contribution of the instrumentation noise, we applied the orbit feedback correction to a perfectly aligned machine, showing the direct impact of the BPM noise on the emittance growth.

Result of the simulations, as shown in Fig. 1 and Fig. 2, is that the permanent one-to-one correction (actually implemented as a "few-to-few" correction, where all BPMs and all correctors are used), seems acceptable for long time scales, but has the disadvantage that requires small step sizes to converge. A good convergence for larger step sizes would be preferable because correctors are likely to be more effective for larger variations than for smaller ones.

The MICADO algorithm[5] solves the least squares problem and calculates the correction picking out the correctors that best correct the orbit/dispersion. In fact, compared to the one-to-one correction, it shows better performances: it reduces the emittance growth to smaller values, it seems to be more stable over longer lapses of time and it finally shows a good convergence also for larger step sizes.

The difference between these results lies in the set of correctors and beam position monitors that are used by the two algorithms. The MICADO method makes use of *optimal set* of correctors and BPMs, extracted from the system response matrix via an eigenvalue analysis, that best corrects the orbit/dispersion; whereas the One-to-One (Few-to-Few) algorithm makes use of *all* correctors and *all* BPMs, magnifying the negative impact of the BPM noise.

CLIC BEAM DELIVERY SYSTEM

A very significant difference exists between ILC and CLIC: in ILC the long pulse duration allows the use of intra-pulse orbit feedback; in CLIC the short pulse duration does not allow to use an intra-pulse feedback system, with the exception at the interaction point, where a fast beam-beam feedback keeps the beams in collision correcting the offset. In CLIC, the relevant beam emittance is the multi-pulse emittance, i.e. the phase space taken by the beam during a sequence of pulses. Hence the beam orbit jitter is a part of this emittance and it consequently needs to be limited.

In order to analyze the evolution in time of the luminosity, under the effects of the ground motion and the instrumentation noise, we have examined two cases, separately:

- impact of the orbit correction on the intra-pulse beam-beam feedback in absence of ground motion (where

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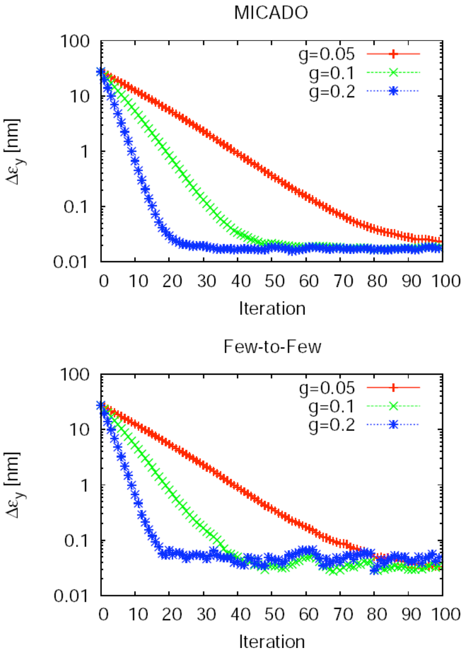

Figure 1: Emittance growth in the ILC main linac as a function of orbit correction iterations. For MICADO and permanent One-to-One (Few-to-Few) orbit correction. (ILC)

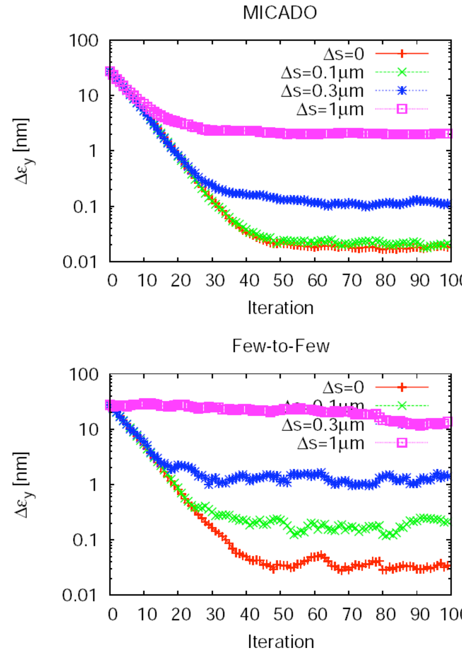

Figure 2: Emittance growth in the ILC Main Linac as a function of orbit correction iterations. MICADO shows a good convergence also for large step sizes, whereas One-to-One correction shows instability and requires small step sizes to converge. (ILC)

we expect the finite resolution of the BPMs to cause luminosity loss via the feedback)

- study of the luminosity evolution when both pulse-to-pulse orbit feedback and fast beam-beam feedback are fully operative, for very long time scales and with perfect resolution, in order to evaluate when accumulated errors will require the application of further beam straightening procedures (such as waist optimization via tuning knobs)

Pulse-to-Pulse Orbit Correction

To highlight and isolate the impact of the orbit correction on the beam-beam intra-pulse feedback, and evaluate the consequent luminosity fluctuation, we simulate two consecutive pulses passing through a perfectly aligned CLIC Beam Delivery System. Firstly, a low gain orbit feedback is applied to the BDS until the beam emittance growth converges toward an equilibrium. In this phase, in fact, the beam emittance is stretched by two opposite phenomena: on the one hand, it is shrunk by the orbit correction itself -as desired-, whereas on the other hand it grows because of the BPM noise that simultaneously interferes with the correction. Once this equilibrium is reached, we enable the intra-pulse beam-beam feedback until the luminosity is recovered. At this point, when the machine has reached its optimum luminosity for the first pulse, we apply one step of orbit correction to simulate the passing of the second pulse. Fig. 3 shows the luminosity when the fast intra-pulse beam-beam feedback has converged also for the second pulse.

We applied this schema to several cases, in order to study the impact of the various parameters involved. Figures 3, and 4 show the luminosity as a function of (1) the BPM resolution, (2) the weight of some peculiar BPMs, and (3) different gains for the orbit correction. Each point is the average of 25 different machines (seeds).

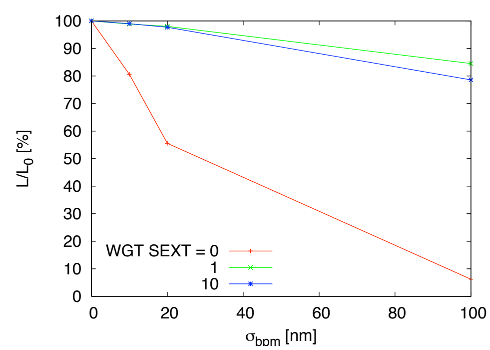

Figure 3: Luminosity as a function of the BPM resolution, for different weights of the BPM in the sextupoles, after slow orbit correction feedback (gains 0.01 and 0.1 in x and y respectively) and intra-pulse beam-beam feedback. (CLIC)

We also studied the impact of the orbit feedback on the luminosity, in that delicate lapse of time between two consecutive pulses. Precisely, we studied how the fast beam-beam corrector can be used to further correct the orbit at the IP, to limit the luminosity loss between two pulses. In one case, we applied the orbit correction without consid-

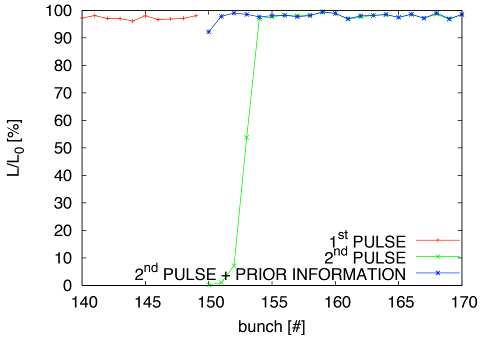

Figure 4: Luminosity fluctuation between two consecutive pulses, under the effects of the BPM noise. The green curve shows the luminosity loss occurring when the orbit feedback is applied without modifying the fast beam-beam corrector. One should note that this fluctuation is only due to BPM noise. The blue line shows the luminosity fluctuation when the fast beam-beam corrector is simultaneously changed to compensate for the orbit change at the IP. This plot shows the average of 25 machines, with orbit correction gains x and y are equal to 0.1 and 0.5 respectively, and a BPM resolution of 10 nm. (CLIC)

ering the beam-beam corrector (that will be used by the fast intra-pulse feedback); in the other case, we simultaneously varied the beam-beam corrector, using a prior estimation of the orbit change at the IP due to the pulse-to-pulse feedback. Fig. 4 highlights the relevance of this study: the green line shows how large the luminosity loss can be when the fast beam-beam corrector is left unchanged between two pulses; the blue line shows how the luminosity can be rapidly recovered, within few bunches, making use of this prior information.

Luminosity evolution for large time scales

To estimate the lifetime of the luminosity, in the case of CLIC, under the effects of the ground motion and the counteracting feedback loops described in this paper, we calculate the luminosity at different times: 1, 10, 100, 1000, 10000, 100000 seconds. At time $t = 0$ the CLIC BDS is perfectly aligned, then the ground motion is applied and the feedback loops activated. The orbit correction, in this study, made use of all correctors and BPMs via a basic one-to-one algorithm. This choice shows a lower limit for the performances of the correction, because other algorithms can be used to achieve better results. For instance, the MICADO method as well as the use of a Kalman Filter are under study. The luminosity optimization of the beam-beam feedback has been simulated via offset and angle scans at the IP, in order to maximize the luminosity. Fig. 5 shows that after about 30 minutes, the luminosity is decreased by 5%. To correct for this loss, the application of further optimization procedures will be required.

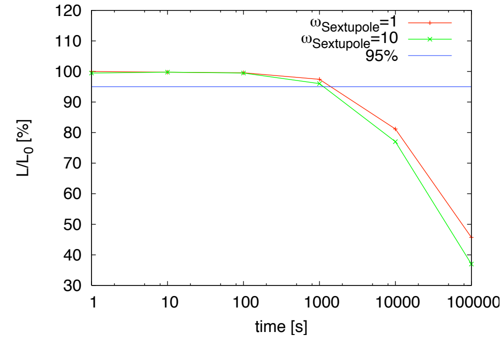

Figure 5: Luminosity evolution for very long time scales. Here both pulse-to-pulse and intra-pulse orbit feedbacks are used. After about 30 minutes, the luminosity is decreased by 5%. To correct for this loss, the application of further optimization proedures (tuning knobs) is required. (CLIC)

CONCLUSIONS

In this paper, the performances of the MICADO and of the One-to-One correction algorithms in the ILC main linac have been studied and compared. The impact of the BPM noise both on the emittance preservation and on the luminosity, in the ILC main linac and in CLIC, have also been studied, showing that the performances of the feedback system depend very much on which beam position monitors and correctors are used in the correction. Finally, the luminosity lifetime for very long periods, in the case of the CLIC BDS, has also been shown.

A detailed study of the pulse-to-pulse and of the intra-pulse feedback, in the beam delivery system of CLIC, showed that, to preserve the luminosity, a BPM resolution of 100 nm requires a careful selection of the BPMs used in the correction; whereas BPM resolutions of 10 nm, or 20 nm, are less sensitive to the BPM selection (see Fig. 3). Nevertheless, the results obtained giving different weights to particular BPMs and the experience gained from applying the MICADO method in the main linac of ILC (where its optimal set of correctors and BPMs significantly mitigated the impact of the noise), allow us to expect relevant improvements from the application of a MICADO-like algorithm to the CLIC BDS. Further studies are in progress.

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