SIMULATION STUDIES OF CORRELATED MISALIGNMENTS IN THE ILC MAIN LINAC AND THE INFLUENCE OF GROUND MOTION *

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Abstract

Component misalignments are an important source of emittance dilution in the main linac of the International Linear Collider (ILC). The impact of static uncorrelated alignment errors has been widely studied with various simulation codes and several beam based alignment algorithms. For a realistic scenario one has to take into account that the survey and alignment process will introduce correlations between the component errors. In the present paper we study the performance of the Dispersion Matched Steering (DMS) technique for the case of such correlated misalignments. Different models for the correlations are investigated including a model characteristic of the alignment and survey technique envisaged for the ILC [1] which has been implemented into the Merlin C++ library [2] based package ILCDFS [3]. In addition to the initial static errors, dynamic errors due to ground motion will produce an emittance growth with time. For this case we have also investigated the stability of DMS tuning over time.

INTRODUCTION

At the ILC, the luminosity will depend on preserving the ultra-small emittance beams delivered to the collision point. The emittance growth in the Main Linac (ML) – particularly in the vertical plane – arises primarily from misalignment and rotation errors of the various elements such as Beam Position Monitor (BPM), quadrupole, and RF cavities. This increase can be mitigated within the ML using Beam Based Alignment (BBA) techniques such as Dispersion Matched Steering (DMS).

In the following report, we evaluate the impact of a static correlated misalignment model as well as a dynamic model of the ground motion for the ILC main linac when DMS is applied in both cases.

IMPACT OF CORRELATED ALIGNMENT

The correlated alignment model of the components used in the following section is based on a simplified version of a proposed alignment strategy. This alignment is parameterised such that relevant parameters can be studied and later used to specify the requirements on real world alignment procedures. The models presented here are the result of discussions between the ILC metrology groups and beam dynamics communities.

The Survey Line

The present model assumes a set of primary reference points which are located along the machine where there is a convenient access to the surface; currently these are assumed to be at the major shaft locations separated by approximately 2.5 km. The primary points are established (for example) using GPS techniques, and are the main anchor locations for the survey network in the tunnel. Between the primary points, normal reference points are defined every L_{step} meters, the distance being dependent on the technique used to perform the alignment. All errors of the normal reference points are modelled by a pseudo-random walk including systematic errors from one primary reference point to the next. The exact deviation of the normal reference points is essentially constrained by the location of the bounding primary points.

Model Implementation

The complete survey-line was generated using a model implemented in scilab [4]. The resulting alignment errors were then included into the MERLIN beam dynamics model. The primary points are interspaced by 2.5 km corresponding approximately to the possible location of shafts. The location errors of the primary points with respect to absolute straight line of reference are assumed to be uncorrelated and to have a Gaussian distributed with a RMS error of σ_{yp},

Simulation of the correlated errors of the normal reference points is performed in two steps: first a pseudo-random walk is generated starting at one primary point; second, the resulting offsets are ‘corrected’ to constrain both the position and angle at the end primary point.

The random walk of the normal reference points is parameterised by the following equations:

$$\theta_{j,n+1} = \theta_{j,n} + a_\theta + \Delta\theta_{syst}$$

$$y_{0,j,n+1} = y_{0,j,n} + a_y + l_{step}\theta_{j,n} + \Delta y_{syst}$$

$$y_{0,j,0} = y_{p,j}$$

$$0 \le n \le N_{rfpt}$$

where a_θ, a_y are random Gaussian errors and $\Delta\theta_{syst}$ and Δy_{syst} are the systematic errors for the angle and offset respectively [5]. $y_{0,j,n}$ is the offset of the survey line (before correction) at the normal reference point n for the primary section j and $y_{p,j}$ is the coordinate of the primary point and N_{rfpt} is the number of normal reference points. In order to adjust the y_0 offsets as explained earlier, a correction scheme based on a parabolic fitting using an error weighted average is applied. Fig. 1 shows an

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example with one set of random numbers, five primary points, the offsets y_0 and the adjusted (corrected) coordinates y_c.

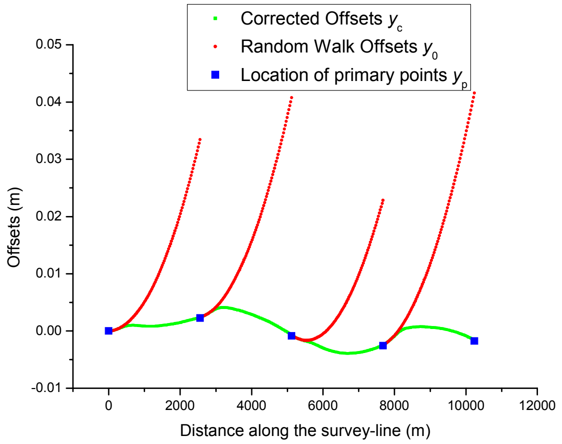

Figure 1: Example of one seed of offsets y0 of the random walk, coordinates yp of primary points and offsets yc of the parabolic correction of the survey line. Note that in this example, the systematic error dominates the 'random' walk.

The location of the very first normal reference point is assumed equal to the location of the first primary point. The angle of the survey line at the latter primary points is constrained to be $\theta_{0,j} = (y_{0,j-1,N_{rfpt}} - y_{0,j-1,N_{rfpt-1}})/l_{step}$ to avoid discontinuities at the boundary (i.e. primary) points.

Simulation Model of Main Linac

The adjusted offsets created with scilab are used by the Merlin based ILCDFS package to perform the particle tracking through the entire main linac and to study the achievable performance of Dispersion Matched Steering[†] (DMS). The initial energy of the test beam and a constant gradient adjustment of -20% are used. This strategy was shown to be the most effective in reducing the emittance growth along the linac [6]. Throughout the study, a simplified lattice with a split phase advance 75/60 degrees was used. The initial beam energy was 15 GeV (accelerating up to 250 GeV), with an initial RMS energy spread of 1.07%. In addition, the linac is modelled curved with kinks of 2.72 µrad at each cryomodule.

The machine components are located on 'girders' (cryomodules) which are aligned with a least square fit to the three closest normal reference points of the survey line.

The set of values for the error on the parameters of the random walk used are given in Table 1. These values are thought to be achievable with survey techniques such as LICAS [9].

Table 1: Initial parameters for the alignment model.

a_y	a_θ	$\Delta\theta_{syst}$	Δy_{syst}	σ_{yp}	l_{step}
5 µm	55.4 nrad	260 nrad	5.3 µm	2 mm	25 m

Results from Simulation

Fig. 2 shows the mean (over 100 seeds) vertical emittance, after the linear energy correlation has been removed numerically, as a function of each parameter. The alignment parameters have been modified individually from their initial values given in Table 1 by the specified percentage.

The performance of the DMS algorithm is dependent on the relative weights of the trajectory difference between the on and off energy beams, and the absolute trajectory (on-energy beam). Here the weights are fixed to give an optimal result when the de facto standard uncorrelated errors are applied [5]. Using these weights the mean emittance growth for the survey-line errors using the parameters in Table 1 (and no other errors) is 0.8 nm which is negligible compared to the typical values observed with the uncorrelated component errors (~2.4 nm). The study also indicates that the emittance is mostly sensitive to the errors σ_{yp} on the location of the primary points, and to the systematic angular errors $\Delta\theta$. The emittance growth increases to a value of 1.4 nm when σ_{yp} is increased by 150% (= 5 mm): However, this emittance growth is still lower than the emittance growth due to uncorrelated errors. When both uncorrelated and correlated (survey-line) errors are included in the simulation, the emittance growth can be made approximately the same as for the uncorrelated errors alone case by adjusting the weights in the DMS fit, even if σ_{yp} is increased to 150%.

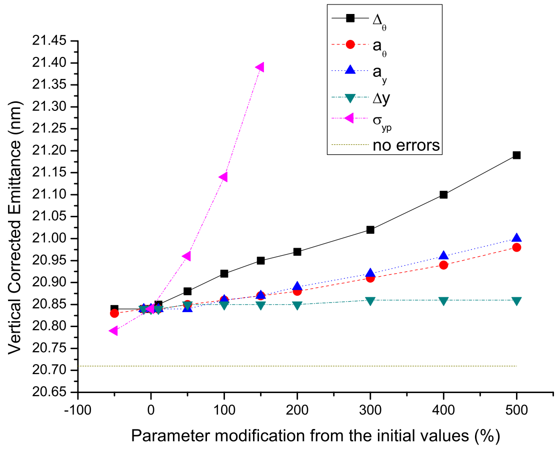

Figure 2: Mean vertical emittance as a function of the survey-line model parameters, modified independently from the initial values by the specified percentages.

[†] Due to non-zero design dispersion which must be matched, the more general algorithm applied here is the DMS rather than the Dispersion Free Steering.

IMPACT OF GROUND MOTION

Correlated displacement between components also occurs due to natural ground motion. In the following section a simulation is reported which includes a diffusive ground motion model (*ATL*) [7]. The ground motion produces vertical displacements of the cryomodules as a function of simulated time. The parameter *A* was chosen to be 4×10^{-18} m.s^{-1}. A DMS correction was applied to the model after a time *t*. The BPM resolution is assumed to be 5 μm.

Uncorrelated standard static alignment errors on each component are included prior to the application of the ATL law. The results for the mean projected emittance and corrected (i.e. linear energy correlation removed) emittance are shown as a function of time for the main linac in Fig. 3. In addition, the 90% limits of the resulting emittance distributions are also plotted. The mean corrected emittance is found to be stable at 22.4 nm and the 90% limit projected emittance at 30 nm.

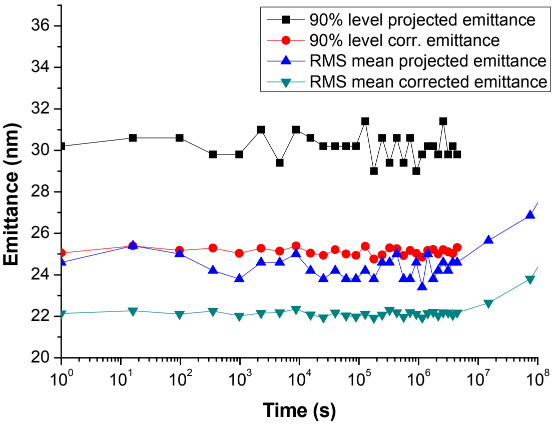

Figure 3: Average over 100 seeds of the vertical emittance (nm) versus time (s) after ATL law and DMS has been applied.

The mean corrected (energy correlation removed) vertical emittance growth reaches 10% of increase with respect to its nominal value at a time $t=8\times10^7$ sec. For a noisier site, with $A=4\times10^{-17}$ m.s^{-1}, this time would be reduced to 2.5×10^7 sec i.e. less than 10 months.

CONCLUSION

Two different studies have been performed in this report. A first study with a correlated alignment characteristic of a survey-line and alignment procedure is described. It indicates a minimal contribution to the emittance growth of the survey-line model with respect to the emittance growth when standard uncorrelated errors are applied. Further studies are required including a full simulation if the value of each parameter is very different that used here. This study is part of an on-going discussion between the ILC metrology group and the beam dynamics group, developing a sufficiently realistic model which is usable by both groups in the future.

A second study focused on the impact of the ground motion when the machine is not perfectly aligned to begin with. The Dispersion Matched Steering correction was found to be suitable for re-establishing the emittance at its nominal level for several months of diffusive ground motion.

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