MERLIN-BASED START-TO-END SIMULATIONS OF LUMINOSITY STABILITY FOR THE ILC *

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Abstract

In this paper, we report the progress and status of a full-featured so-called start-to-end simulation based on the MERLIN library. The current model comprises acceleration in the superconducting main linac, beam delivery system and finally collision at the IP. Realistic modelling of the beam-beam interaction is included by using the code GUINEAPIG. Results on ground motion modelling and trajectory control are presented.

INTRODUCTION

The International Linear Collider (ILC) requires the preservation of an ultra-small vertical emittance from the damping ring to the interaction point (IP) where the nanometre-sized beams are made to collide. It is well-known that ground motion and component vibration will need to be compensated by fast intra-train feedback systems and slower semi-continuous trajectory corrections. This complex system can in general only be modelled using simulation. The ILC is still an evolving system. Technical specification and details of the overall design will change. The software of a start-to-end simulation must easily allow for modifications and should provide a framework to study design alternatives.

GENERAL LAYOUT OF THE SIMULATION CODE

A model from the main linac to the beam delivery system and the interaction point has been set up as a first step towards a full ILC simulation. The model contains wake fields within the accelerating cavities and will allow for realistic alignment and field errors. The electron main linac includes the bypass for the undulator which is part of the positron source.

For the study of correlated ground motion it is necessary to model both, the electron and the positron side, of the ILC. Both halves are defined by independent lattice files which have to be integrated into a common model. Here, the MERLIN library provides the concept of *support structures* which represents an independent layer of geometrical relations on top of the lattice file geometry. Beyond that, a special kind of *support structures (girders)* can be used to define rigid structures, as for example cryomodules or a common support for the magnets of the final focus system.

Our code includes an interface for several ground motion models: a random walk approach (ATL [4]) and the models for correlated ground motion from A. Sery[5] [1].

Another interface is implemented to accommodate different beam steering algorithms. This is currently used to realise a one-to-one steering for the horizontal and vertical planes. Fast feedback systems between the main linac and the beam delivery system and for the colliding beams at the IP are part of the simulation although still in a simplified way. The same holds for the tuning of beam parameters at the IP (see below).

MERLIN provides two different bunch types: The *ParticleBunch* class is a collection of 6D phase space coordinates, whereas in the *SMPbunch* (sliced macro-particle) class the transverse coordinates are replaced by 1st and 2nd order moments. SMP tracking is faster but not sufficient for higher-order magnetic fields, or in cases where the detailed bunch distribution is of interest (collimation, beam halo etc.). In our model SMP tracking is favourable for the first and second half of the electron main linac (before and after the undulator insert) and for the whole positron main linac. When SMP tracking is used in these areas the total (ML and BDS) simulation time is reduced typically by a factor of 5.

Finally, GUINEAPIG [3] is utilised to calculate the total cross-section and luminosity for the colliding bunches including beam-beam effects.

SOFTWARE DESIGN FOR FLEXIBILITY

MAD8 [7] is used to define the ILC lattice. Standard accelerator components are defined by MAD keywords, and so-called markers are used to label begin and end of subsystems, or structures as cryo-modules, non-standard components (e.g. undulator) and so forth. In addition names, i.e. character strings, are use to identify individual elements as magnets, monitors etc. The simulation code has to cope with the fact that naming conventions may change and new elements appear or disappear. Therefore it is crucial for the long-term usability that already the basic program design takes into account potential changes. Wherever possible, string identifier should only be used in isolated places so that the program can be adapted quickly. For special studies or cross-checks the simulation code should be able to track only parts of the ILC lattice, and it should support an easy change change between the two different bunch models. Furthermore, a modular accelerator construction should allow a stepwise development of the full simulation

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[1] We would like to thank Daniel Schulte (CERN) for providing us with the necessary program code and data files.

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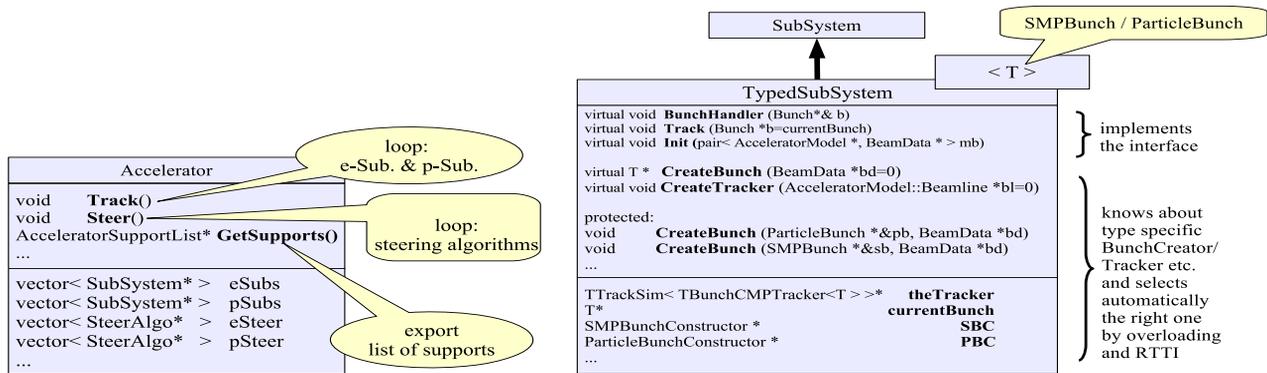
Figure 1: Outline of the *Accelerator* and the *TypedSubSysytem* classes.

Parser, Accelerator and SubSystem

The model construction starts with parsing the lattice file and the main tasks in this process can be separated into individual classes: reading the file (syntax), understanding the meaning of keywords (semantic) and constructing the corresponding classes (pragmatic). A translation table defines an arbitrary vocabulary of keywords and markers. In Addition, several methods are implemented to modify the parsing behaviour at run time.

The accelerator itself is represented by the *Accelerator* class. The class mainly performs loops over a list of *SubSystems* (see below) and a separate list of steering algorithms. In addition it exports a list of *support structures* to the ground motion model.

The core functionality is provided by the *TypedSubSystem* template class. Depending on the template type (*SMPBunch* or *ParticleBunch*) the class automatically implements the appropriate bunch constructor and tracker class and provides a bunch handler. In general the bunch handler gets the bunch from the previous sub-system, checks if it belongs to the right bunch type and calls, if necessary, the appropriate converter. For the initial sub-system the bunch handler calls a bunch constructor instead. The bunch is then passed to the tracker that propagates the particles through the sub-system. Within this concept the full model is just a line-up of sub-systems and many of technical details on how to implement a simulation model using the MERLIN library are solved in a general way (Fig. 1).

RESULTS

Emittance growth in the Electron Linac

The framework presented in the previous section has been used to build a first model (Fig. 2). A detailed lattice file for the positron side had not been available until recently. Therefore, we only present preliminary results for a symmetric model based on a ILC electron side lattice file. Ground motion is model by an ATL approach

$(A = 4 \cdot 10^{-18}$ m/s$)$. Our model starts with the first half of the electron main linac (ELIN1) followed by the undulator insert (EUND). The undulator itself is not yet simulated. The model considers only the bypass (bends and dispersion correcting sections). There are no beam monitors or corrector magnets included in the current lattice description of the undulator bypass. For our model we assume that each quadrupole is equipped with corrector dipoles for the x- and y-plane and beam position monitors. In total we use 433 corrector and monitor pairs for the y-plane of the main linac (ELIN1-EUND-ELIN2). A one-to-one steering algorithm keeps all beam monitor readings at zero. No other alignment or measurement errors are applied besides the displacements due to the ground motion model.

Fig. 3 shows the projected vertical emittance along the main linac for three different time steps. The emittance at start of the main linac is set to $\gamma \epsilon_y = 20$ nm. At least for the perfect machine considered here the main linac is robust enough to keep the vertical emittance near the nominal value for about 1 month. The clear step at the beginning of the undulator insert shows that in the present design the bypass adds significantly to the sensitivity for ground motion and vibration.

Luminosity Stability

Although the present design of the beam delivery system includes several corrector and diagnostic elements, for the ground motion studies presented here we again add to each quadrupole a pair of corrector dipole and beam monitor (altogether 86 pairs in the BDS). Several beam delivery
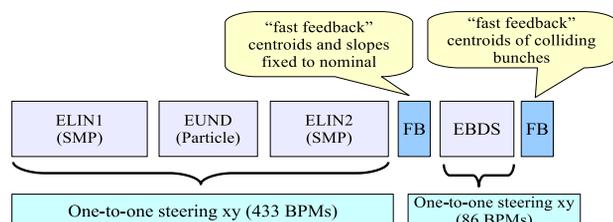

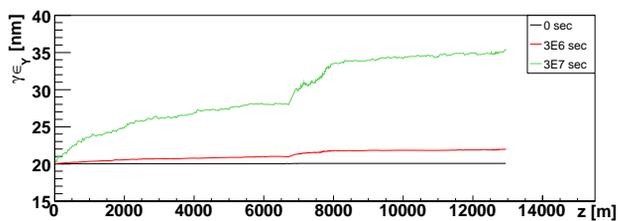Figure 2: A first model. See text for details

Figure 3: Projected vertical emittance along the electron main linac. ATL ground motion ($A = 4 \cdot 10^{-18}$ m/s) with one-to-one steering. Each point shows the average over 100 random configuration i.e. ground motion seeds. The green line is the emittance after about 1 year. The undulator bypass is clearly visible as a step at 6890 m.

magnets are set on magnet movers. In our simulation they are replaced by dipole correctors for simplicity. At the entrance to the BDS the simulation code sets the bunch centroids and the bunch slopes to their nominal values, thereby emulating the effect of a fast feedback system. In a similar way the centroids of the colliding beams are adjusted to zero at the IP.

For the full model (ELIN1-EUND-ELIN2-FFB-BDS-FFB) with ATL ground motion as above the luminosity stability has been studied. The luminosity is calculated with GUINEAPIG and normalised to $L(t = 0)$. At the start of the main linac the emittance is set to $\gamma\epsilon_y = 20$ nm and $\gamma\epsilon_x = 8000$ nm. Since the model does not contain any other alignment errors the resulting luminosity ($L = 2.8 \cdot 10^{34}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$) is large compared to the ILC reference design report [6] and the relative luminosity loss will be overestimated slightly.

Fig. 4 shows the relative luminosity between 1 and 10^8 seconds. A reference line is shown for a luminosity loss of 20%. Without trajectory control (black) this line is already passed after 10 seconds. The one-to-one steering (red) keeps the luminosity for about 1.5 days above the 80% level. In reality luminosity tuning in the final focus system will help to preserve the luminosity even longer. To investigated the potential improvement the following tuning parameters has been chosen: the beam waists w_x and w_y, the dispersions d_x and d_y, and the coupling between x and y'. We do not define any realistic tuning knobs[2] but apply the corresponding similarity transformation directly to the bunch particles. In an iterative procedure first the beam matrix is calculated from the bunch particles and used to estimate the tuning parameters. These parameters are then applied one after the other until there is no significant improvement. With this procedure the luminosity can be kept for about 15 days (blue line in Fig 4). The RMS over different random seeds, i.e. random machine configurations, covers the range from 8 days to 1 month. Considering the idealistic tuning approach and other simplifications in our model, we expect a somewhat worse behaviour of the real

[2]Such tuning knobs have been realistically modelled. See [6] and G. White, ILC accelerator physics meetings.

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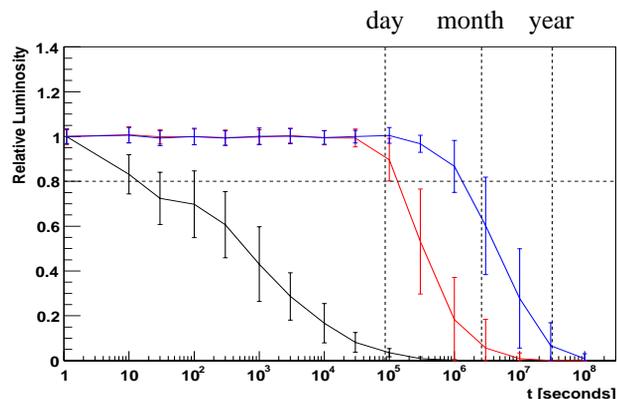
accelerator.

Figure 4: Relative luminosity over time. ATL ground motion ($A = 4 \cdot 10^{-18}$ m/s) with one-to-one steering. Each point shows the average over 80 random configurations i.e. ground motion seeds corresponding to 40 colliding bunch pairs. The error bars show the RMS over these random configurations.

CONCLUSIONS

We have developed a flexible and expandable framework for a start-to-end simulation of the ILC. Special care has been taken that the program code is prepared for future modifications. The present model still contains several simplifications but it can already be used to study the influence of ground motion on the luminosity stability. In our model the luminosity can be kept above 80% of the nominal values for about 15 days. After which the luminosity would need to be re-established by a re-application of beam-based alignment.

Further studies on the luminosity stability with correlated ground motion and realistic component errors will be performed. Multi-bunch modelling and realistic feedback systems will enable us to study luminosity tuning in more detail. The model will be extended by adding the RTML (ring to main linac) and algorithms for beam-based alignment [2].

REFERENCES

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