THE INFLUENCE OF FABRICATION ERRORS ON THE WAKEFIELD AND EMITTANCE GROWTH FOR THE NEXT LINEAR COLLIDER

R.M. Jones, T. Higo; KEK, Tsukuba, Japan,
R.H. Miller, T.O. Raubenheimer,
G.V. Stupakov, and J.W. Wang;
SLAC, Stanford, CA, USA

Abstract

The heart of the NLC (Next Linear Collider) will consist of several thousand X-band accelerator structures which damp the transverse wakefield via detuning the modal frequencies such that the amplitudes of the modes destructively interfere and by four damping manifolds per structure. Errors in the fabrication of the individual cells, which constitute each structure, will result in a poor cancellation of the modes and here we explore the effects of random errors within a particular structure and errors which are systematically repeated within a given accelerator and are distributed randomly over the whole collider. The beneficial effects of an effective interleaving of cells due to these fabrication errors is discussed together with results of tracking a multi-bunch beam through 11km of accelerator structures.

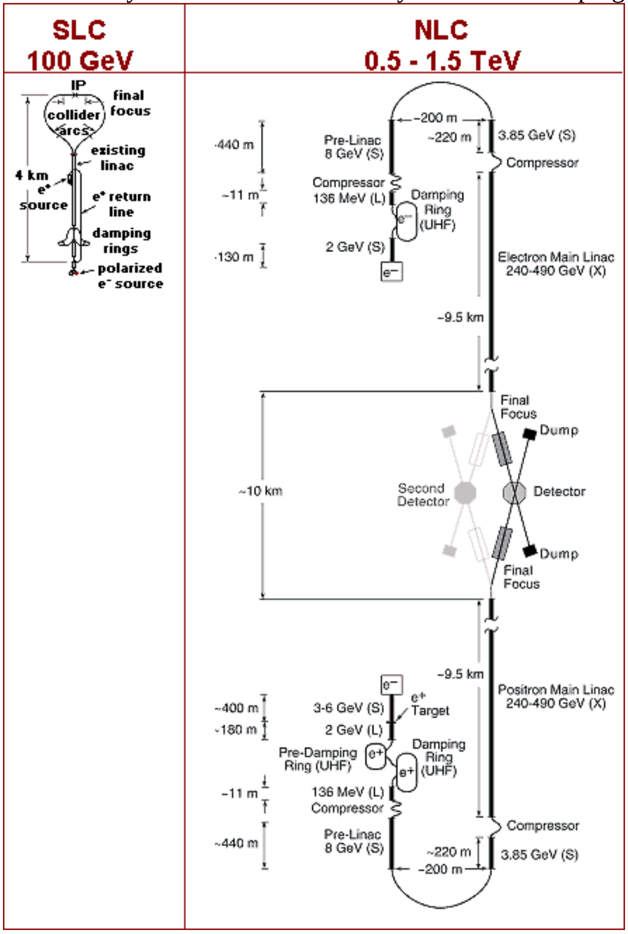

Figure 1: NLC Schematic Compared to the Present SLC

Figure 2: RDDS1 Cells as Fabricated

1 INTRODUCTION

In order to answer fundamental questions posed by particle physics (the structure of quarks and leptons and whether or not Higgs particles exist being two major unanswered questions) a high energy e^+-e^- is being designed at SLAC and KEK with an intial center of mass energy of 500 GeV with the possibility of a later upgrade to 1.0 TeV or even 1.5 TeV. A schematic of the NLC is shown in Fig 1 and it is to be compared with the present SLC (Stanford Linear Collider). The main components are indicated and it is evident that the heart of the collider consists of 10,000 or so X-band accelerating structures. The linacs accelerate a particle beam from 10GeV to 250GeV. Each accelerating structure consists of 206 cells (two of which are shown in Fig. 2) bonded together. Small misalignments in the beam or cells gives rise to a deflecting force, or wakefield, which may resonantly drive the beam off the axis and dilute the beam emittance. Forcing the modes (which constitute the beam) destructively interfere and damping provided by four manifolds per structure reduces the deflecting force to manageable proportions. However, errors in fabricating and aligning the cells significantly increases the deflecting force and it is important to carefully analyse each error component and this is the purpose of this paper

2 MACHINING ERRORS AND EMITTANCE DILUTION

In fabricating a linear accelerator operating at an X-band frequency, there are a number of different error types introduced into the structure. Small dimensional errors in the geometry of the iris' and cavities gives rise to an error in the synchronous frequency [1]. Also, once the individual cells are bonded together small angular misalignments (or "bookshelving") and slippage of cells relative one another gives rise to an enhanced wakefield. In this paper we consider the effect of cell fabrication errors (and leave the case of bookshelving and cell slippage errors to another publication). There are two types of errors associated with cell errors, namely, the errors that arise due to cell-to-cell geometrical errors and those that occur from structure-to-structure. The nomenclature we adopt is that an error type that is repeatable from cell-to-cell and random from structure-to-structure is referred to as: a **systematic-random** error. Whereas, an error that is repeatable from structure-to-structure, but not is fixed from cell-to-cell we refer to as a **random-systematic** error. We also consider **random-random** and **systematic-systematic** error (potentially the most damaging error) types making a total of 4 error types. The random errors we consider here have an RMS deviation of 5MHz and 2 MHz about the mean dipole frequency of the cells. In fabricating RDDS1 the RMS error in the synchronous frequency prior to bonding the cells was 0.5MHz [2] and thus simulation of larger errors is pursued with a view to understanding how much the cell to cell fabrication tolerances can be relaxed.

Cell-to-cell errors within an individual structure allows the modes (which constitute the wakefield) to partially add constructively. An indicator as to whether or not the particle beam travelling down the accelerator will be resonantly kicked off axis is provided by the wakefield at a particular bunch which is formed by summing all wakefields left behind by earlier bunches and this we denote as the "sum wakefield".

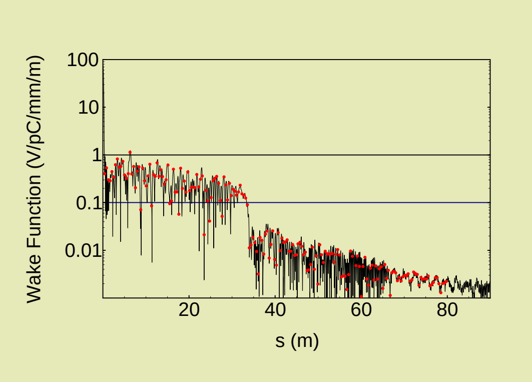

Figure 3: Envelope of Wakefield (2MHz RMS error)

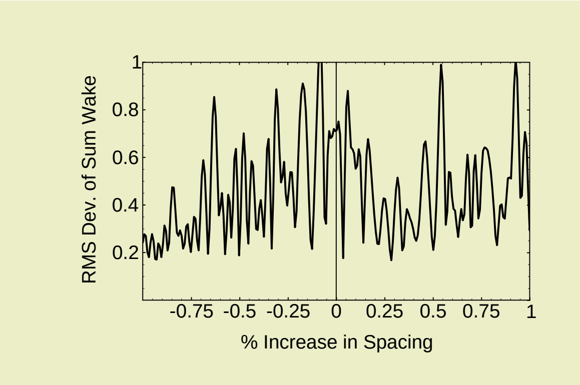

Figure 4: Sum Wakefield (2MHz RMS Error)

We calculate the RMS of the deviation of the sum wakefield from the mean as a function of a small change in the bunch spacing (changing the bunch spacing is a convenient method to represent a systematic error in the synchronous frequency of all the cells: **a systematic-systematic** error). Peak values in the sum wake correspond to the particle beam being resonantly driven off axis and can lead to a BBU (Beam Break Up) instability or at the very least can lead to significant degradation in the beam emittance. For the case of a 2 MHz RMS error in the synchronous the wakefield (see Fig. 3) is larger by a factor of 2 or more compared to the perfect structure. However, tracking the particle beam through 5,000 structures reveals that a very small growth in the emittance occurs (approx 3% or so, refer to Fig. 5) and the particles are well contained within normalised phase space (Fig. 6).

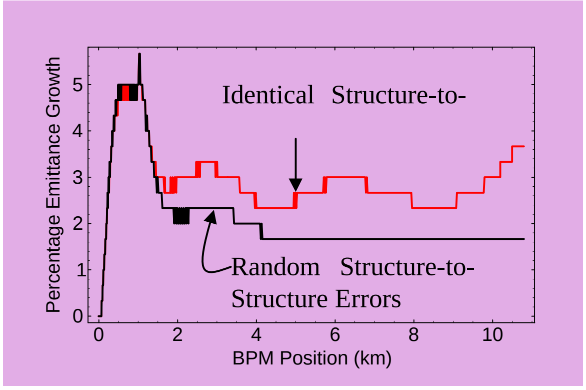

Figure 5: Emittance Growth (2MHz RMS Error)

This particle tracking simulation has been performed with the code LIAR [3] and it was assumed that all structures have identical random errors (this is the case of random-systematic errors). In practice each structure will have a different random error (this is the random-random case). Tracking the multi-bunch electron beam through 11km of structures under the influence of random-random errors reveals that the emittance dilution is reduced even further (see Fig 5)

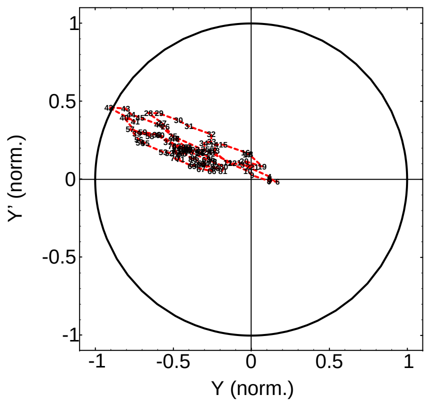

Figure 6: Phase Space (2MHz RMS Error)

compared to the random-systematic case. Another important case, is the case of an identical systematic error in the synchronous frequencies of the cells and this is investigated by varying the spacing of the bunches in the train of particles. The case of a **systematic-systematic** error (corresponding to an error in the cell frequency that is repeated over all linacs) at a particular bunch spacing that results in a peak in the sum wakefield leads to a resonant growth in the beam emittance. However, imposing a small random error (2MHz was utilized) from structure-to-structure prevents a resonant growth occurring in the beam.

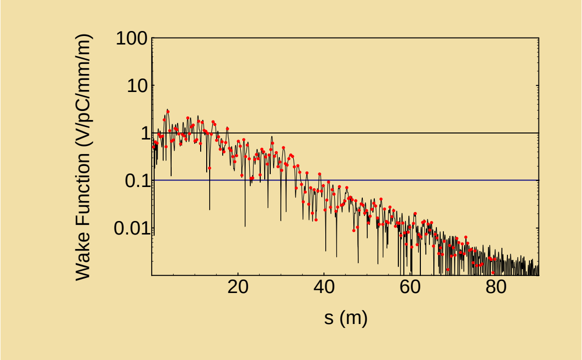

Figure 7: Envelope of the Wakefield (5MHz RMS Error)

In order to understand the effect of relaxing the tolerance requirement on the cells, cells with an RMS error of 5MHz were investigated. A typical wakefield that results from this error is shown in Fig. 7 and it is striking that the wakefield increases by more than an order of magnitude compared to the error-less case. Provided this resonance is not repeated from structure-to-structure then little ill effects result from the enhanced wakefield.

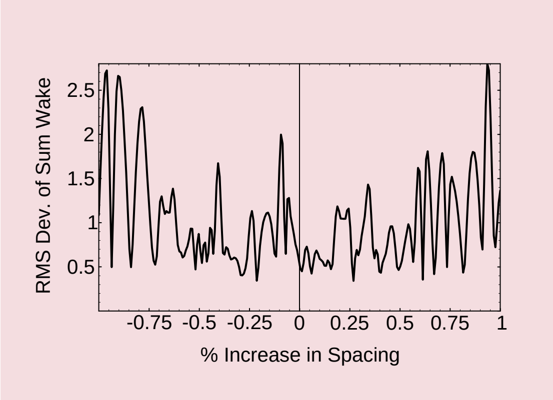

Figure 8: Sum Wakefield (5MHz RMS Error)

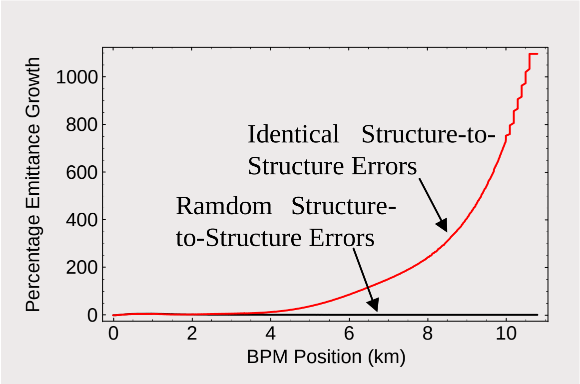

Figure 9: Emittance Growth (5MHz RMS Error)

However, for a cell-to-cell error repeated over all 5,000 or so structures, 1000% growth in the beam emittance occurs (see Fig. 9 and Fig. 10)

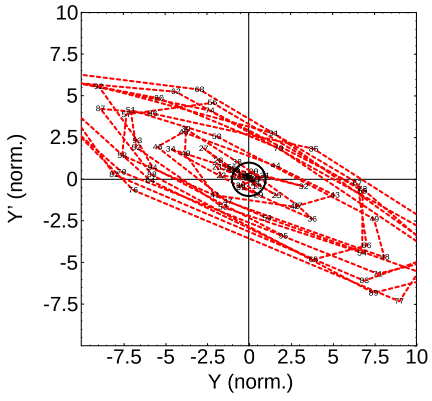

Figure 10: Phase Space (5MHz RMS Error)

3 CONCLUSIONS

If the accelerating structures have an error which is repeatable from structure-to-structure then for large cell-to-cell errors (this is the random-systematic case) substantial emittance dilution will be incurred. In practise it is expected that fabrication errors will occur randomly from cell-to-cell and from structure-to-structure and hence substantial emittance dilution is unlikely to occur.

REFERENCES

[1] R.M. Jones et al, "Equivalent Circuit Analysis of the SLAC Damped Detuned Structure" EPAC'96, Sitges, June 1999
[2] J.W. Wang, et al, "Design, Fabrication and Measurement of the First RDDS", LINAC2000, Monterey, Aug. 2000
[3] R. Assman et al,"LIAR", SLAC-PUB AP-103, 1997