

STUDIES OF ORTHOGONAL BUMPS FOR ILC MAIN LINAC*

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Abstract

To preserve small vertical emittance of the beam in ILC main linac a few beam-based alignment techniques were proposed and studied in recent years. Dispersion and wake field bumps are one of the effective tools for final tuning of the machine. New design of bumps, so called orthogonal (or SVD) bumps, was recently proposed for CLIC [2]. In this paper we present study of orthogonal bumps performances for final alignment of the ILC main linac.

INTRODUCTION

High luminosity in ILC is relied on small emittance of the colliding beams. Small emittance obtained in the DR (normalized vertical and horizontal emittances are 20 nm and 8 μm correspondently) has to be conserved during the transportation of the beam in the Ring-to-Main Linac (RTML) system and then in the main linac (ML). The emittance growth in the linac is mainly caused by dispersion due to misaligned quadrupoles, by wake fields in misaligned accelerating structures, and horizontal-vertical coupling due to rotation errors of quads. The nominal misalignments provided by survey service are shown in Table.1 [1].

Table 1: Nominal initial alignment errors in ILC

Element	RMS error
Quadrupole offset	300 μm
Quadrupole rotation error	300 μm
Accelerating structure offset	300 μm
Accelerating structure pitch	300 μrad
BPM offset	300 μm
BPM resolution	1 μm
Girder offset	200 μm
Girder angle	20 μrad

Those pre-alignment precision leads to unacceptable emittance growth, and beam-based alignment (BBA) methods are required to obtain acceptable emittance growth. In this paper we are using two BBA methods: one-to-one correction and dispersion-free steering (DFS) algorithms before applying orthogonal bumps. ILC main linac accelerates electrons from 15 to 250 GeV in superconducting accelerating cavities at gradient of 31.5 MV/m. In simulations a simple laser straight linac with FODO lattice have been used with 75°/60° phase advance per cell in horizontal and vertical plane correspondingly. Quads are separated by 32 cavities.

As was shown in previous studies the emittance growth is still too large in case only one-to-one correction is used. By using DFS in addition, the performance is significantly improved, the mean value of emittance growth is reduced to ~ 4-5 nm, which is acceptable, but

the spread in emittance is large and some number of seeds (each seed represents the machine with particular misalignments) have emittance higher than the budget goal. To reach the emittance goal for all seeds, emittance tuning bumps have to be used, which allows to reduce emittance growth significantly in ILC [1-5]. Combination of a few local dispersion and wakefield bumps with the optimized location in linac works well in many cases, but simulation indicates that errors in measurements limit the performance of bumps. Another disadvantage of local bumps is the fact that several iterations may be needed to reach an optimum, if emittance is measured only at the end of the linac.

More robust performances can be obtained by using orthogonal emittance bumps. This approach was developed in recent papers [2-4]. In this paper we are presenting the result of studying orthogonal bumps for ILC main linac.

DESIGN OF ORTHOGONAL BUMPS

In simulation a beam is represented by a number of macroparticles described by position, angle, energy and weight. Let's define the final state of the beam at the end of the each linac (seed j) after DFS alignment by the vector of state:

$$s_j = (y_{1,j}, \dots, y_{p,j}^n, \beta y'_{1,j}, \dots, \beta y'_{p,j})^T$$

where y_i and y'_i - position and angle of macroparticle i , β - beta function at the end of linac. Similarly, each knob k_j may be described by changes in final state caused by a unit change of the knob (we assume that effect of knob is linear):

$$k_j = (\Delta y_{1,j}, \dots, \Delta y_{p,j}, \beta \Delta y'_{1,j}, \dots, \beta \Delta y'_{p,j})^T, \quad j = 1 \dots n_{knob}$$

The matrices **S** and **K** will be used to denote the collection of seeds and knobs, respectively, i.e.

$$S = (s_1, s_2, \dots, s_{nseed}); \quad K = (k_1, k_2, \dots, k_{nknob})$$

For each seed **s**, knob settings **x**_{*j*} exist such that

$$s_j + K \cdot x_j = 0$$

These settings will minimize (zeroing) the emittance growth in the linac.

SVD and Principal Directions

Both **S** and **K** matrices can be transformed by using singular value decomposition (SVD) algorithm, which is realized in MatLab, used for LUCRETIA interface. It represents seed and knob matrices in form:

$$S = U \cdot S_{svd} \cdot V^T$$

$$K = U \cdot K_{svd} \cdot V^T = (U_1 \quad \dots \quad U_n) \begin{pmatrix} \alpha_1 & & \\ & \ddots & \\ & & \alpha_n \end{pmatrix} \begin{pmatrix} V_1 \\ \vdots \\ V_n \end{pmatrix}$$

Here \mathbf{U} is a matrix whose orthogonal columns span the range of \mathbf{S} . The diagonal matrix \mathbf{S}_{svd} contains the real singular values of \mathbf{S} in a decreasing order in the diagonal. \mathbf{V} is a square orthogonal matrix. Similar transformation can be written for knob matrix \mathbf{K} . Columns of \mathbf{U}_K gives the weight of each knob in new orthogonal knob and will be referred to as principal knob directions. All principal knob directions have nonzero singular values. Similarly, columns of vector \mathbf{V} gives the changes in final beam state for particular principal knob. The great advantages of using normalized coordinate space become visible when singular values of the diagonal SVD matrix is quickly decreases with the number, as for example shown in Figure 1 for seed matrix built for 50 misaligned ILC linacs after applying 1-to-1 and following DFS alignment algorithms. From plot one can see that only 3 principle directions give the major contribution, all the rest have singular value less than 1% of the maximum.

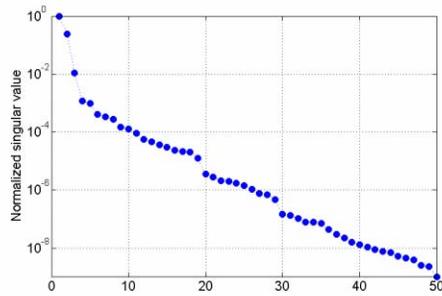


Figure 1: Plot of the singular values (normalized) of the seed vector for 50 seeds.

Singular values of knob matrix presented in Figure 2 shows similar behavior. It means that only few principle orthogonal knobs will give the highest contribution in the emittance control.

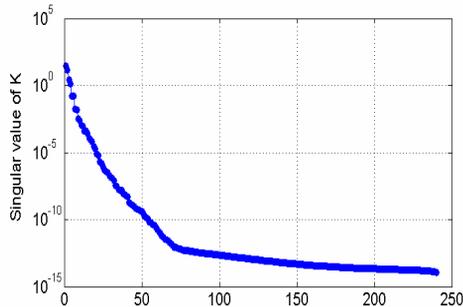


Figure 2: Singular values of the knob vector plotted for all Y-correctors in ILC linac.

RESULTS

For studies of orthogonal bumps the simulation code LUCRETIA was used [6]. For the lattice described above we first steered initially misaligned linacs (usually ~100 seeds were taken in simulation) by using 1-to-1 and DFS technique. Then S and K matrices were calculated and SVD transformation applied. There are three sources of emittance growth in ILC main linac: a) dispersion, caused by misaligned quads, cryomodules and cavity pitch; b) x-

y coupling, caused by quad rotation errors and c) wake field, caused by misaligned cavities and cryomodules. Typically they give approximately equal contribution in emittance growth rate for the set of parameter used [1]. Bumps can effectively minimize dispersion part and will be less effective for wake field and coupling parts. Below results for few cases are presented. In all cases the only vertical emittances are shown.

Case 1: Dispersion Only

In this case only BPMs and quadrupoles were misaligned. Results of applying orthogonal bumps are shown in Fig.3a, where emittance along the linac is plotted. Blue curve show emittance after DFS, each next curve corresponds of using orthogonal bumps starting with highest singular value. All curves represent emittance averaged over 50 seeds.

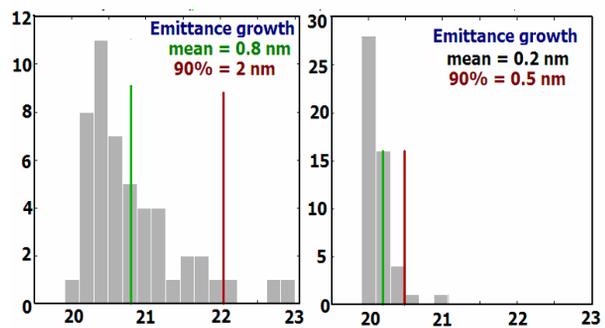
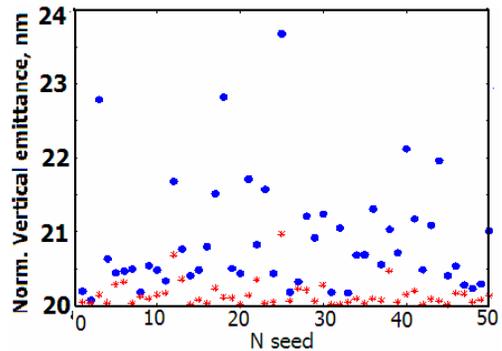
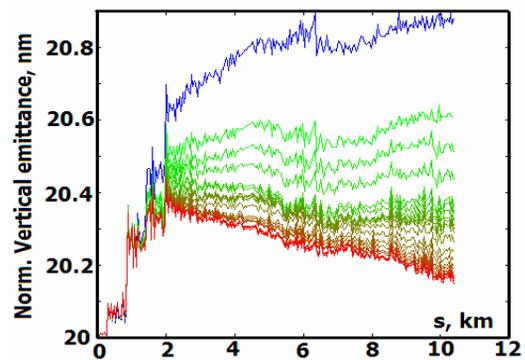


Figure 3: a) Averaged vertical emittance along main linac. b) emittances after DFS (blue) and after applying 20 orthogonal bumps (red) . c) histogram of emittance distribution before (left) and after bump correction.

In Figure 3 final emittance is shown for each seed before (blue trace) and after applying 20 orthogonal bumps (green and red). Using bumps allow reduce not only averaged emittance but also spread of emittances, which is clear from histograms presented in Figure 3c. Here one can see distribution of the final vertical emittance before (left) and after applying 20 knobs (right).

Case 2: All Misalignments Are Included

When all initial misalignments from Table 1 were included, orthogonal bumps can correct mostly dispersion part of emittance increase, as one can see from Figure 4. In this case the residual emittance growth is due to x-y coupling and wakefields, which can not be fully corrected by orthogonal bumps. Figure 5 shows the effect of individual orthogonal bumps on average emittance in linac. All results were averaged over 50 seeds. More effective are the knobs with the highest weight (singular value).

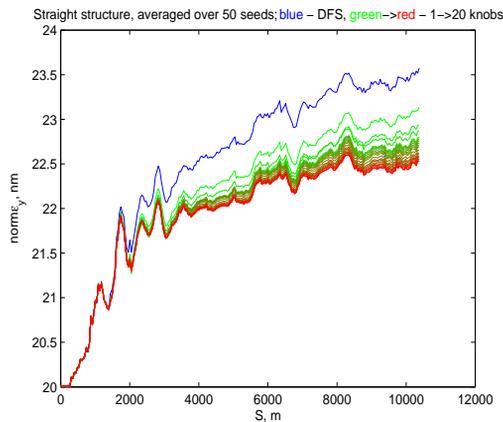


Figure 4: Averaged vertical emittance along main linac. Blue trace shows emittance before applying bump correction. Each following curve shows the result of additional bump included.

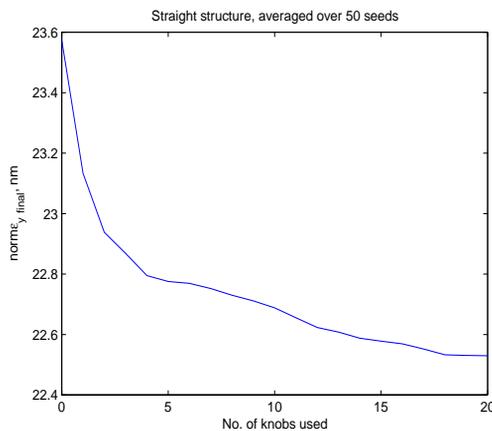


Figure 5: Averaged vertical emittance at the end of linac vs. number of orthogonal bumps applied.

Case 3: Wake Fields Are Turned off

For this case we use same misalignments as in Case 2, but wakefields were switched-off in all ILC cavities. The effect of orthogonal tuning bumps is shown in Figure 6. The residual emittance growth rate of ~ 1.3 nm is due to x-y coupling, which is not compensated by bumps.

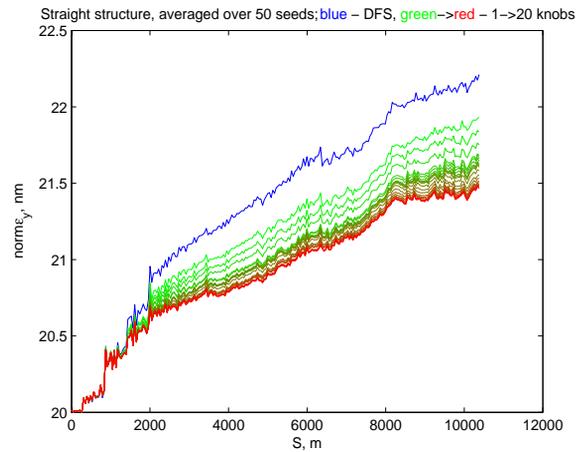


Figure 6: Averaged vertical emittance along the main linac. Blue trace is emittance before bump correction. Each following curve shows results of additional bump included.

ACKNOWLEDGEMENTS

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