SPOTSIZE STABILIZATION STUDIES FOR THE TESLA BEAM DELIVERY SYSTEM

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Abstract

Studies of the ground motion induced spotsize growth in the interaction region of the TESLA linear collider and some tools to recover are presented here. Analytical results are given and compared with simulations by particle tracking. Performance of different procedures, such as orbit correction, adaptive alignment and knob scan, studied by tracking simulations, is reported.

1 INTRODUCTION

The main parts of the TESLA Beam Delivery System[1] are the Collimation Section, Tuning and Diagnostic Section and the Final Focus Sytem (Fig. 1). It is the BDS where the most important tolerances on transverse misalignments of focusing elements are located.

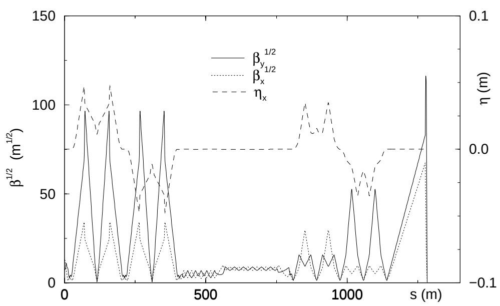

Figure 1: Optics of the TESLA Beam Delivery System[1].

Ground motion is one of the main sources that will produce, after certain time, an intolerable value of misalignments resulting in reduction of luminosity via the beam offset and distortion at the Interaction Point. The fast orbit feedback, which is possible for TESLA due to uniquely long bunch separation, will cure the beam-beam offset. We will concentrate therefore only on the spotsize stabilization.

When the beamline is affected by ground motion only (no correction applied yet), the free evolution of the beam spotsize can be evaluated analytically using the ground motion spectrum $P(\omega, k)$ and the corresponding spectral response functions, determined in linear approximation[2]. This analytical treatment is incorporated into the "FFADA" program[3]. The analytical results provide quite helpful information on the critical time scales, however the question "whether the linear approximation is sufficient?" should not be forgotten.

Semi-analytical methods, appeared recently, are able in some cases to evaluate efficiency of a correction in linear collider. The generalized spectral approach[4] can give clear analytical expression for several correction method applied to a regular linac. The method proposed in[5] is more general and may be of great help if fully developed. However, when a correction is applied to a BDS to stabilize the spotsize, simulations must be used to determine the procedure performance since such procedures may be quite complex and the focusing structure is very irregular.

2 FREE EVOLUTION OF THE BEAM

Since the critical time scales are quite large for the beam size growth, it is sufficient to consider only the diffusive "ATL" ground motion[6]. The motion assumed to have the same coefficient A in both horizontal and vertical planes. Neighboring elements (such as quadrupole – sextupole pairs or the final doublet) were assumed to be placed on the same support. The beam parameters used in simulations were: 250 GeV/beam, $\varepsilon_x = 2.8 \cdot 10^{-11}$ m, $\varepsilon_y = 5 \cdot 10^{-13}$ m, $\beta_x^* = 25$ mm, $\beta_y^* = 0.7$ mm, $\sigma_E = 10^{-3}$. After the beam tracked through the misaligned beamline, the offset was removed and the average beam matrix elements, for example $\sigma_{xy} = \overline{xy}$, were computed. Tracking was performed then with different seeds that gave the rms beam matrix $\langle\sigma_{xy}^2\rangle^{1/2}$. It was convenient to normalized it to the nominal values in the point of observation: $\langle\sigma_{xy}^2\rangle_n^{1/2} = \langle\sigma_{xy}^2\rangle^{1/2}/\sqrt{\sigma_{xx0}\,\sigma_{yy0}}$.

Let us first consider only the the FFS part of the BDS. The analytically found dispersion, waist shift and coupling (which the spot size growth is determined by) versus the $A \cdot T$ coefficient are presented on Fig. 2 in comparison with the tracking results. One can see that the linear approximation and tracking are in perfect agreement for the FFS part of BDS. If one assumes $A = 10^{-5}$ μm^{2}s^{-1}m^{-1} then the critical time scale for 2% luminosity loss is about 200 s for the FFS part of the TESLA BDS.

However, when the complete TESLA BDS was studied by tracking, much faster spotsize degradation has been found (Fig. 3). The terms like yy', yx' and yx of the normalized beam matrix, which were proportional to $A \cdot T$ that indicates on nonlinear effects, have shortened the resulting

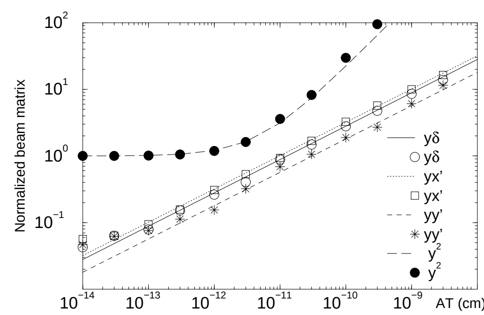

Figure 2: Elements of the normalized rms beam matrix σ_n for the FFS part of the TESLA BDS versus AT. Linear model prediction (lines) and tracking results (symbols).

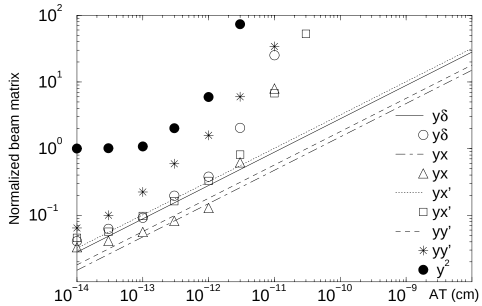

Figure 3: Elements of the normalized beam matrix σ_n for the complete TESLA BDS versus AT. Linear model prediction (lines) and tracking results (symbols).

critical time scale by about one order of magnitude. This time is still quite large with respect to the repetition rate, nevertheless, allowing safe operation of the collider.

The reason for this nonlinearity has been found to be the vertical misalignment of quadrupoles located in maxima of betatron function in the IP-phase part of the collimation section. Since these quadrupoles are in phase with the IP one could expect that they have little effect on the IP beam size. However, misalignments of these quadrupoles produce a vertical beam offset in sextupoles of the Chromatic Correction Section (CCSY). If the matrix between paired sextupoles in CCSY is not perfectly $M = -1$, then the beam distortion at IP will appear.

Assuming that the vertical misalignment of the quadrupole in IP-phase collimator is y_c the following expression for the element of the normalized beam matrix in the IP can be finally deduced:

$$(\overline{yy'})_n = 6K_2^2\, K_1^2\, R_{12}\, \beta_c\, \beta_s^2\, y_c^2$$

where β_c is the maximum of the vertical betatron function in the IP-phase collimation section, β_s is the vertical betatron function in CCSY sextupoles, K_2 is the strength of CCSY sextupoles, K_1 is the strength of quadrupoles in the IP-phase collimation section, R_{12} is the matrix element between paired sextupoles in CCSY. The latter cannot be much smaller than the length of CCSY quadropoles or sextupoles, in our case $R_{12} \approx 1$ m. The 2% luminosity loss criterion gives $y_c \lesssim 0.1\ \mu$m for our parameters, much tighter than the value given by the linear approximation.

3 CONTROLLED EVOLUTION

Different procedures may be used to prevent the beam size growth in the IP of a BDS. We consider here the orbit correction à la "one-to-one", the adaptive alignment[7] and tuning by knob scan[8]. All these procedures have their advantages and disadvantages. So, a proper combination of these or other techniques should be used to provide reliable luminosity stabilization.

Finding the proper combination of algorithms requires to know performance of each individual procedures. In particular, one needs to know influence of Beam Position Monitor resolution (the effect of BPM offset is not considered in the paper) and capability of a procedure to struggle against the increase of misalignments driven by ground motion.

The beam dispersion growth can be found analytically if the first two procedures are applied to a regular FODO linac[4]. The qualitative dependence of the beam dispersion when the "one-to-one" orbit correction is applied

$$\langle\eta^2\rangle \propto (\sigma_{\rm bpm}^2 + A\,T\,L)\,N \;+\; A\,\Delta T\,L\,N^3$$

where N is the number of quadrupoles in the linac, L is the quadrupole spacing, T is the time since the moment of perfect alignment, ΔT is the time interval between successive corrections, $\sigma_{\rm bpm}$ is the BPM resolution. From the other hand, if the adaptive alignment is applied, we have

$$\langle\eta^2\rangle \propto (\sigma_{\rm bpm}^2 \;+\; A\,\Delta T\,L)\,N^3$$

We see the obvious fact that for the "one-to-one" orbit correction the beam dispersion grows with time, since the algorithm does not realign quadrupoles, in contrast to the adaptive alignment where the beam dispersion does not increase with time. From the other hand, the influence of the BPM errors is more severe for the adaptive alignment since a single BPM error produce the trajectory offset in all downstream quadrupoles, while only three quadrupoles will have the trajectory offset for a single error for the "one-to-one" orbit correction.

For a irregular focusing system, such as the BDS is, the dependencies given above are valid too, but the quantitative answer may be obtained only by simulations. The results are shown in Fig. 4 and Fig. 5.

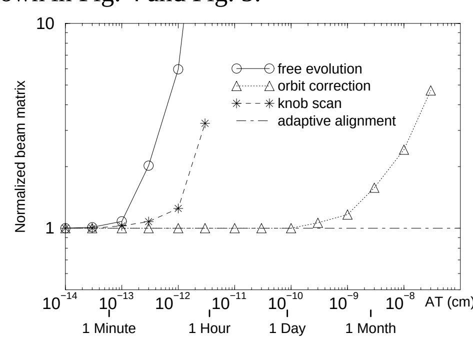

Figure 4: Normalized vertical beam size $(\sigma_{yy})_n$ for the TESLA BDS versus AT for different procedures applied solely. The second axis assumes $A = 10^{-5}\ \mu\text{m}^2\text{s}^{-1}\text{m}^{-1}$.

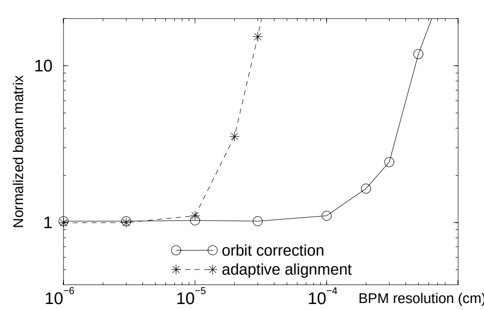

Figure 5: Normalized beam size $(\sigma_{yy})_n$ for the TESLA BDS versus BPM resolution for the orbit correction and for the adaptive alignment.

For the orbit correction simulations we used several monitor-corrector pairs. The monitors are two plane BPM, they are located in all critical places, mainly in maxima of beta functions, at the face of each sextupole, at the face of the final doublet. Correctors are located at the proper place (with respect to the betatron phase) upstream to the corresponding monitor. Simulations assumed that the perfectly aligned line were available at the beginning that gave possibility to store the “gold orbit” to be recovered by the orbit correction after the beam line misaligned.

For the adaptive alignment simulation both the original formula[7] and the one corrected for thick lenses[10], which gave much better but still not quite satisfactory results, were tried. We had to use finally the algorithm which starts from the same conditions as[7] but does not make any simplifying assumptions on the focusing structure. These conditions are the following: a) if three neighboring quadrupoles aligned to the same line but the incoming beam has an offset at the face of the first quadrupole then the displacement applied to the central quadrupole by the algorithm is zero; b) the same but the incoming beam has an angle; c) if the central lens misaligned by Δx the algorithm should move it back by the value $C\Delta x$ where C is the coefficient which control convergence. All the necessary transfer matricis were assumed to be known. The algorithm worked well for the BDS. However, if applied to the beamline with too high misalignments, it diverges because the orbit offset in the CCS sextupoles introduces coupling of x and y planes, which the algorithm assumes independent. Applying the orbit correction before the adaptive alignment will cure the problem.

The knobs used in simulations were the displacements of paired sextupoles of CCSX and CCSY similar as in[9]. The sextupoles can be moved in horizontal or vertical plane, symmetrical or antisymmetrical, in certain relevant range, orthogonally affecting on the IP beam matrix:
in CCSY, horiz., symm., range $2\,\mu$m, affect on $\sigma_{yy'}$
in CCSX, horiz., asymm., range $3\,\mu$m, affect on $\sigma_{x\delta}$
in CCSY, vert., symm., range $2\,\mu$m, affect on $\sigma_{yx'}$
in CCSY, vert., asymm., range $5\,\mu$m, affect on $\sigma_{y\delta}$.
These knobs were scanned with step digitized by range$/N_s$, to maximize the luminosity, which was assumed to be permanently measured. The value $N_s \approx 20$ was found to give good results. The knobs located in the tuning section of the BDS, which control all the linear coupling terms at the FFS entrance, were also used in simulations.

We see that the orbit correction is able to stabilize the luminosity during about one week with quite feasible BPM resolution (about 0.5 μm). The adaptive alignment is able to keep the beam size forever if continiously repeated but the required BPM resolution is 10 times higher (50 nm). One should note here that if the orbit correction will be applied after the adaptive alignment, the BPM resolution of the latter should not be already as high. Formally, for the regular linac $\sigma^2_{\rm bpm} \lesssim AT_{121}L$ is required where T_{121} is the time until the orbit correction is able to recover ground motion influence. The value $\sigma_{\rm bpm}$ will be a few μm in our case and might be limited by other effects not considered here (beamline walking out, etc.). The performance of the knob scan procedure is relatively modest since the linear knobs are not able to help when the distortion produced also by non-linear beam matrix elements. This procedure is an additional remedy, therefore.

Would the choice be limited by these three procedures, the following combination could be used. Normal BDS operation will be done with the orbit correction only. The knob scan procedure will be done a few times per week, in vivo. After about one months the adaptive alignment can be applied to recover the smooth beam line. For this the experiment should stop. Of course, another combination as well as other methods of orbit correction and beam based alignment can be used, it will be studied further.

4 CONCLUSION

The IP spotsize growth induced by the diffusive ground motion has been studied by simulations and analytically in the linear approximation. The linear approximation was found to be in perfect agreement with the tracking results for the FFS part of the BDS, while much faster beam degradation caused by nonlinear effects has been found when the complete BDS was studied. The resulting critical time scale is still quite large with respect to the repetition rate, nevertheless, to ensure safe operation of the collider.

The possible spotsize stabilization strategy for the TESLA BDS is to work only with the simple orbit correction, à la one-to-one, performing knob scan procedure several times per week. With this strategy a beam based realignment of all focusing elements will be required only about each month.

5 ACKNOWLEDGEMENT

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