STABILIZATION OF BEAM INTERACTION IN THE TESLA LINEAR COLLIDER

I. Reyzl *, DESY, Notkestr. 85, 22 603 Hamburg, Germany

Abstract

Vertical beam offsets at the interaction point will degrade the luminosity ($3.4 \cdot 10^{34}$ cm^{-2}s^{-1}) in the TESLA linear collider. In order to limit the luminosity loss to 10% per bunch crossing the electron (e^-) and positron (e^+) beams must interact with an offset and angle of less than $1/10$ of the beam size and the angular divergence respectively. The required stabilization of the beam interaction will be provided on a bunch to bunch basis by two feedback systems. One system, located upstream of the vertical chromatic correction system, controls the beam angle. The second system placed at the interaction region steers the two beams into collision using the beam-beam deflection method. This paper describes the feedback designs and presents simulation results. Design modifications necessary for the $\mathrm{e^-e^-}$ mode are briefly discussed.

1 FAST CORRECTION CONCEPT

Vertical beam separation Δy and crossing angle $\Delta\alpha$ are considered as one of the most harmful sources for luminosity degradation in TESLA. The nominal luminosity is $3.4 \cdot 10^{34}$ cm^{-2}s^{-1} and $4.5 \cdot 10^{33}$ cm^{-2}s^{-1} for the $\mathrm{e^+e^-}$ and $\mathrm{e^-e^-}$ operation mode respectively (Table 1). The luminosity is produced in head-on collisions. Each bunch train consists of 2820 bunches separated by 337ns. At the interaction point (IP) a beam spot size of 553nm horizontally and 5nm vertically is required. Due to the large disruption D_y of 25 a value well beyond the on-set of the kink instability the luminosity is very sensitive to vertical beam separations or crossing angles. For the collision of

Table 1: Main parameter list of TESLA 500 [1].

TESLA 500 parameter list		
Center of mass energy	E_{cm}	500 GeV
Bunch charge	N	$2{\cdot}10^{10}\,1/e$
Bunches per pulse	n_b	2820
Bunch spacing	t_{b}	337 ns
Pulse length	t_{p}	950 μs
Repetition rate	f_{rep}	5 Hz
Bunch length	σ_z	0.3 mm
Vertical spot size at IP	σ_y	5 nm
Vertical divergence at IP	$\sigma_{y'}$	12.3 μrad
Vertical Disruption	D_y	25
$\mathrm{e^+e^-}$ Luminosity	$\mathcal{L}$	$3.4 \cdot 10^{34}$cm^{-2}s^{-1}
$\mathrm{e^-e^-}$ Luminosity	$\mathcal{L}^-$	$4.5 \cdot 10^{33}$ cm^{-2}s^{-1}

- $\mathrm{e^+e^-}$: The luminosity loss per bunch crossing is limited by 10% if two bunches interact within $\Delta y < 10\%\sigma_y$ and $\Delta\alpha < 10\%\sigma_{y'}$.
- $\mathrm{e^-e^-}$: The luminosity loss is less than 20% if $\Delta y < 10\%\sigma_y$; An offset in crossing angle does not degrade the luminosity.

Luminosity calculations are performed with GUINEA PIG [2].

Vibration of the final doublets is expected to be the main source of beam separations. From final doublet displacement measurements in HERA a train-to-train separation jitter of $20\sigma_y$ is estimated for TESLA [3]. Further contributions come from the other quadrupoles in the linac and in the beam delivery system (BDS). The expected size of train-to-train orbit variations are listed in Table 2. In addition, HOM effects cause orbit offsets of the first 200 bunches of a train in the high frequency range. Microphonics and insufficient compensation of Lorentz force detuning cause energy errors leading to bunch-to-bunch orbit variations.

Table 2: Expected train-to-train orbit variations corresponding to 70 nm rms quadrupole vibration in TESLA [4].

Train-to-Train Jitter (5Hz) in TESLA		
At end of linac	$0.5\sigma_y$	$0.5\sigma_{y'}$
At IP	$\Delta y < 35\sigma_y$	$\Delta\alpha < 5\sigma_{y'}$

The size and the time scale of arising disturbances emphasizes the need of correction of the beam separation and crossing angle on a bunch-to-bunch basis. Three intra-bunch train feedback system are envisioned: 1) one at the end of the linac correcting position and angle of each bunch [5]. 2) one in the chromatic correction section (CCS) removing angle offsets at the IP. After the angle is corrected, downstream quadrupole vibration will mainly affect the beam position at the IP (quadrupoles separated by $(n + 1/2)\pi$ to the IP have a large beta functions). 3) the third intra-train feedback system located at the IP finally steers the beam into collisions.

It follows a description of the intra-train feedbacks correcting angle and beam separation. Simulation results are presented. Design modifications necessary for $\mathrm{e^-e^-}$ operation are briefly discussed.

2 INTRA-TRAIN ANGLE FEEDBACK

The intra-train angle feedback is located at the entrance of the vertical chromatic correction section (distance to the

* email address: ingrid.reyzl@desy.de

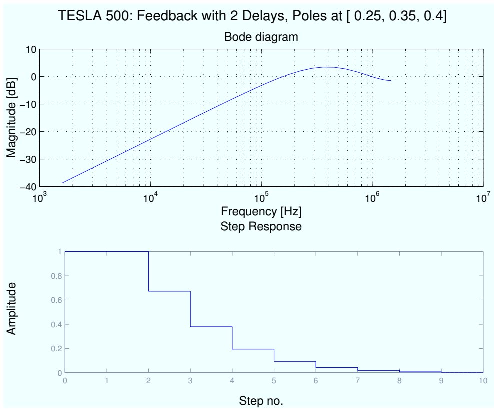

Figure 1: Frequency and step response of intra-train feedback system in TESLA.

IP: 450m). Angle offsets at the IP are removed by correcting the bunch position at the first high beta point. The non-chromatic correction is applied by fast kickers, separated by 3π to the IP, with a field rise time of 30ns [6]. A beam position monitor (BPM) measures $\pi/2$ downstream wrt. the kicker the bunch position with a single bunch resolution of 1μm. Due to the distance of 45m between kickers and BPM a correction from bunch to second bunch becomes feasible. The correction is calculated by a digital proportional-integral (PI) controller. It provides a fast response (P-part) and removes a residual offset in case of incoming DC-disturbances (I-part). The feedback shows a good DC-bias and disturbance rejection (Fig. 1). Disturbances up to 170kHz are damped with 15dB per decade. A step is reduced by a factor 100 after 8 samples. The step response shows no overshoots.

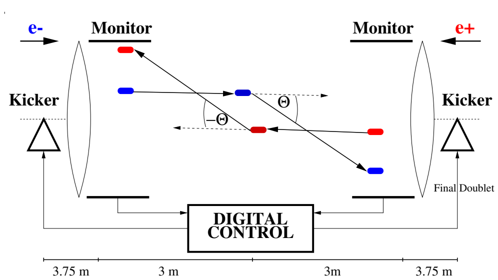

Figure 2: Scheme of intra-bunch train feedback at the IP maintaining the collision of the two beams.

3 INTRA-TRAIN SEPARATION FEEDBACK

Vertical separations between the e^- and the e^+ beams are corrected within the bunch train by measuring the beam-beam deflection and steering subsequent bunches back to zero deflection. The schematic layout of the Δy feedback is shown in Fig. 2. The strong angular kick (maximum deflection is 325μrad for $\Delta y = 40\sigma_y$) allows to observe separations even below the nanometer range (Fig. 3). In order

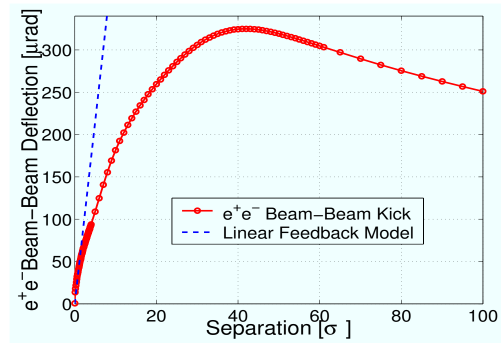

Figure 3: Beam-beam deflection vs. beam separation. The dash dotted graph shows the linear control model.

to measure the beam-beam deflection and thus the actual beam separation, the position of the incoming e^-e^+ and outgoing e^+e^- bunches are measured 3m away from the IP. A single bunch BPM resolution of 5μm and a time resolution of 20ns is required. A digital PI-controller (response shown in Fig. 1) determines the necessary correction by means of a linear model of the beam-beam deflection curve. The model slope defines the correction accuracy in case of small Δy, and by how much large separations are underestimated retarding the feedback response. The correction is provided with a latency of two bunches by two kickers placed in front of the final doublets. The feedback control range is $\pm 100\sigma_y$.

4 INTERACTION STABILIZATION

In the simulation the following noise sources are included: residual bunch-to-bunch orbit variations due to HOM effects in the linac; BPM resolution and quantization of 1μm and 5μm of the $\Delta\alpha$ and Δy feedback systems, respectively; kicker field imperfections of 0.1%. In addition, the beam-beam deflection, defined as a function of Δy and of $\Delta\alpha$ [1], randomly varies for each interaction by 10% in order to include beam size variation or charge fluctuation effects.

An initial beam separation of $100\sigma_y$ is reduced by three orders of magnitude after 90 bunches corresponding to 3% of the bunch train. After this, the beams interact well within the required $0.1\sigma_y$ limiting the luminosity loss per bunch crossing by 10%. The angle feedback counteracts incoming disturbances at a much faster rate than the Δy feedback, because its performance is not affected by a modeling error. The crossing angle of the first bunches in a train is not sufficiently corrected, since the HOM effects lie in a frequency range of low damping. After 150 bunches the angle feedback efficiently rejects $\Delta\alpha$ offsets.

Both feedback systems in series, crossing angle and separation, stabilizes successfully the beam interaction. During the correction of an additional DC-bias of $10\sigma_{y'}$ in crossing angle and of $100\sigma_y$ in beam separation, 91.7%

[1] The beam-beam deflection for zero crossing angle is reduced by 50%, if the beams interact with $\Delta\alpha = 1\sigma_{y'}$.

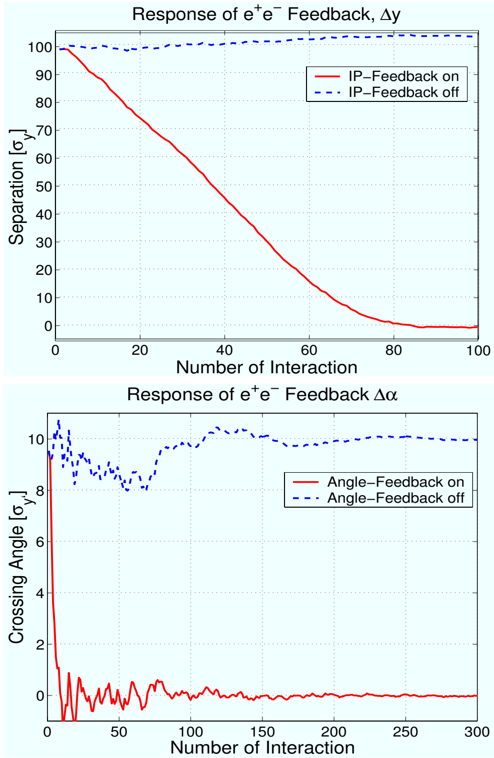

Figure 4: Response of the beam separation and angle feedback to an initial crossing angle of $10\sigma_{y'}$ and beam separation of $100\sigma_y$. Noise sources listed in section 4 are taken into account. The luminosity is kept beyond 90%.

of the nominal e^+e^- luminosity of $3.4 \cdot 10^{34} cm^{-2}s^{-1}$ is achieved. This simulation result allows to relax the train-to-train jitter tolerance of the final doublet to 200nm.

5 FEEDBACK FOR e^-e^- OPERATION

The e^-e^- intra-train feedback system is described in detail in [7]. We focus on the Δy control at the IP, since a crossing angle does not degrade the luminosity. The Δy feedback response is shown in Fig. 5. Two different controller are planned. An aggressive controller design is used to reject a large initial beam separation at a fast rate. After 60 bunches it is substituted by a more moderate design achieving the control accuracy required. The luminosity loss is 6% in the case of a stationary $50\sigma_y$ separation.

6 BANANA EFFECT

Wakefields deform the bunch shape (so-called banana) degrading the luminosity due to an increase of the projected single bunch emittance. Due to the large disruption an additional luminosity loss will be caused, since the luminosity is maximized for banana shaped bunches for non-zero beam separation, crossing angle and beam-beam deflection [8]. A static effect can be tuned away by a re-adjustment of the feedback reference values. Of major concern are randomly varying bunch shapes since they will lead to a

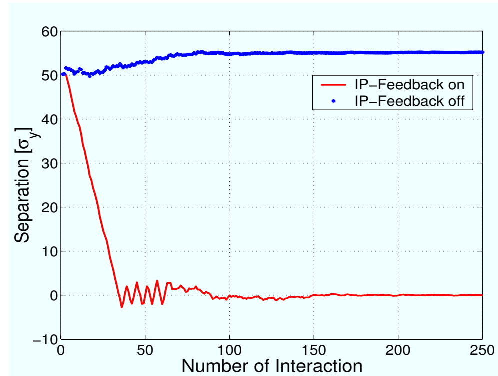

Figure 5: Response of the e^-e^- separation feedback to an additional beam separation of $50\sigma_y$.

luminosity degradation which can be hardly corrected. Future studies focus on the determination of the fraction of correlated emittance growth and its effect on the feedback performance.

7 CONCLUSION

The stabilization of the beam separation and crossing angle within a fraction of the beam spot size is of great importance for the TESLA linear collider . Due to the large bunch spacing of 337ns, the correction can be applied to subsequent bunches with a latency of two bunches. In simulations, the luminosity of both operation modes, e^+e^- and e^-e^- is kept well beyond 90% for conservative assumptions of beam orbit offsets at the IP. Effects of bunch shape deformations on the feedback performance are under study.

8 ACKNOWLEDGMENTS

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