

SIMULATIONS OF THE TESLA LINEAR COLLIDER WITH A FAST FEEDBACK SYSTEM

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Abstract

The tolerances on the beams as they collide at the interaction point of the TESLA linear collider are very tight due to the nano-metre scale final vertical bunch spot sizes. Ground motion causes the beam to increase in emittance and drift out of collision leading to dramatic degradation of luminosity performance. To combat this, both slow orbit and fast intra-train feedback systems will be used. The design of these feedback systems depends critically on how component misalignment affects the beam throughout the whole accelerator. A simulation has been set up to study in detail the accelerator performance under such conditions by merging the codes of PLACET, MERLIN and GUINEA-PIG, together with Simulink code to model feedback systems, all under a Matlab environment.

INTRODUCTION

All of the proposals for the future Linear Collider (LC) require similarly challenging final beam spot sizes: TESLA [1] 5nm, NLC/JLC [2] 2.7nm and CLIC [3] 1nm, are the proposed vertical bunch spot sizes at the IP. This places very rigorous stability requirements on all three designs. The most severe tolerance is for the final focusing quadrupole magnets. To keep the luminosity loss to within a few percent at TESLA, the beams need to be kept in collision to within about 10% of the vertical beam spot size. This implies a tolerance on the final quadrupoles of 0.1nm. The limiting factor for stability along the beamline of TESLA is that of ground motion. There has been a considerable effort undertaken into the study of the magnitudes and effects of ground motion at different possible sites for the LC which are covered in detail elsewhere[4]. If uncorrected, ground motion causes a total loss of luminosity within seconds through beam misalignment and emittance growth[4]. To combat this, a program of passive and active support systems to stabilise the beamline elements, together with different levels of beam-based feedback systems, is being pursued.

Three levels of beam-based feedback system are being developed. A slow orbit correction feedback will adjust the beam trajectory periodically to compensate for low frequency ground motion. An inter-pulse feedback acts in a few locations to correct accumulated errors that occur in between the action of the slow system, and also to provide the possibility of straightening the beam. Finally, a fast intra-train feedback system acting at the IP keeps the beam in alignment, correcting for high frequency cultural ground motion moving the final quadrupoles. For TESLA, a second intra-train system will be used further upstream to additionally remove any incoming angle jitter which also

leads to a loss in luminosity. Fig. 1a shows the results of a GUINEA-PIG [6] simulation of the expected luminosity loss for gaussian bunches as a function of vertical beam offset at the IP.

BEAM SIMULATIONS INCORPORATING FAST-FEEDBACK SYSTEMS

The fast feedback systems are designed to remove beam jitter that occurs at frequencies comparable with the repetition rate of the machine by measuring the first few bunches in the train and correcting the following bunches within that train. The bunch structure thus dictates the operating requirements for the system. For NLC/CLIC designs there are 192/154 bunches per train separated by 1.4/0.7 ns. TESLA will have 2820 bunches separated by 337 ns. The NLC/CLIC case requires a much more aggressive design requiring, at present, a purely analogue electronic approach. The TESLA scheme allows for a more complex digital based algorithm to be employed. Simulations of the fast feedback systems are written in the Matlab/Simulink environment. The feedback system for TESLA is implemented as per the TESLA TDR [5]. This consists of an IP feedback operating within the TESLA interaction region, consisting of a BPM approximately 3m downstream of the IP and a fast stripline kicker downstream of the final focusing quadrupole doublet. The system relies on the beam-beam kick behaviour shown in fig.1b, where the nm scale offsets give rise to a large angular kick leading to a measurable BPM signal of many $\mu m.s$. TESLA also requires a fast angle feedback system to counter incoming angle jitter at the IP. The system uses fast stripline kickers placed at the IP phase 850m upstream of the IP to cancel the orbit offset in a BPM 450m downstream with a 90° phase advance. Three kickers are used to give a maximum correction of $10\sigma_{y'}$ at the IP to the $0.1\sigma_{y'}$ level assuming a BPM resolution of $2\mu m$.

SIMULATION OF THE TESLA FAST FEEDBACK SYSTEM

For TESLA, a simulation has been put together under Matlab of the TESLA collider from the exit of the damping rings through to the IP, including the beam-beam interaction and the fast feedback systems. This brings together the codes of PLACET [7], MERLIN [8] and GUINEA-PIG together with the purpose written feedback code. This allows the effect of 'banana' bunches caused by short-range wake-field effects in the accelerating structures to be accounted for. This has been found to be an important effect- the vertical emittance growth of just 1-2% naively would give a

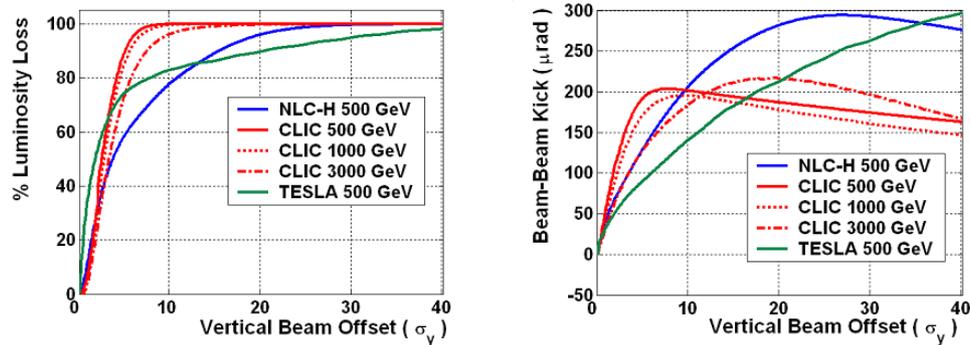


Figure 1: (a) Luminosity loss as a function of vertical beam offset with gaussian beams for TESLA, NLC and CLIC. (b) The beam-beam kick angle as a function of beam offset.

luminosity loss of just a few percent. However, due to the strong beam-beam effect, simulations with GUINEA-PIG have shown that the banana bunch effect can lead to a much larger degradation in luminosity, factors of 2-3 down on the nominal luminosity have been simulated [9]. In addition to a large drop in luminosity, the beam-beam dynamics are also altered with the banana shaped bunches. Fig. 2 shows the expected luminosity of colliding 2 ‘banana’ bunches with offsets in y and y' in the $[-2 : 2]\sigma_{y,y'}$ range. With gaussian beams, the optimal collision parameter is with a zero y, y' offset. With the banana bunches this changes, so that a non-zero offset is now optimal. The blue region shaded in fig. 2 shows where the feedback system will settle by default. The angle system still settles at zero, but the IP feedback system will settle with a small non-zero y offset which, desirably, is always slightly in the direction of optimal luminosity. To optimise the luminosity, it is required that the feedback system now have an additional luminosity feedback element which locates the optimal collision parameters in y and y' . Previous studies [5] have indicated that by using the first layer of the TESLA LCAL system to count the coherent e^+e^- pairs created in the beam-beam interaction, a signal proportional to luminosity could be made available to the feedback system on a bunch by bunch basis.

There is huge parameter space to be explored with such simulations, and it is desirable to compare different parameter sets with as much statistics as possible. Each run of the full simulation takes tens of hours on a single modern CPU. In order to make maximum possible use of each simulation run, all data is stored each time. Summary data is stored of the run, e.g. luminosity, dE/dL , beam parameters at the IP as a function of bunch number and so on. Also, the entire incoming and outgoing beam particles at the IP are kept along with 4-vectors of background particle species formed in the beam-beam collision. Namely, the e^+e^- coherent pairs, photons, hadronic background and mini-jets. An on-going project is to deploy the simulation on a dedicated multi-cpu cluster at QMUL which exists as part of the UK Particle Physics GRID project.

A SAMPLE SIMULATION RUN

Described here is a single seed from an example run of 500 bunches, showing the operation of the feedback system in the presence of banana bunches. The parameters of this run are:

PLACET: This code simulates the passage of the beam through the TESLA Linac. It is set up to give, on average, the design TESLA luminosity after beam-based alignment has been performed. 500 bunch seeds are then generated with an injection error of RMS $0.2\sigma_{y,y'}$ in the vertical axis. To simulate fast ground motion that occurred between trains, the quadrupoles are also randomly offset in the vertical plane with an RMS of 70nm representing a worse-case high frequency ground motion component from measured data at the DESY site[4].

MERLIN: This is responsible for transporting the representation of the beam through the TESLA Beam Delivery System. Vertical Random jitter on quads of 70nm RMS are added. A 0.14% RMS energy jitter was added to the electron bunches to simulate their passage through the positron source undulator. There were 80,000 macro particles per bunch tracked through MERLIN and passed on to GUINEA-PIG which calculates the beam kicks and backgrounds as well as the luminosity data.

Feedback: BPM resolutions of $2\mu\text{m}$ for the angle feedback and $5\mu\text{m}$ for the IP feedback system were assumed, and kicker errors of 0.1% RMS bunch-bunch were also assumed. An algorithm simulating the PI control system was tuned on 2 test bunches to provide stable rejection of noise at the $0.1\sigma_{y,y'}$ level. The PI controller is modelled as the discrete transfer function: $\frac{a0.z+a1}{z-1}$ where the controller coefficients for the IP feedback are 0.135 and -0.001664 for $a0$ and $a1$ respectively. This is obtained from the PI algorithm,

$$u_{PI}(k) = K_P e(k) + K_I \sum_{j=0}^{k-1} e(j),$$

where e is the incoming error (beam kick) signal to be nulled, K_I is a constant which defines the steady-state response, and K_P provides the fast initial response to the error signal. These are tuned to provide the fastest possible error correction whilst keeping the fast jitter to below the

0.1 σ level. The angle feedback controller coefficients are set to 0.168 and -0.1256 guided by similar constraints as the IP feedback system. This system has a naturally slower response due to the 10 bunch latency arising from the large kicker-BPM separation.

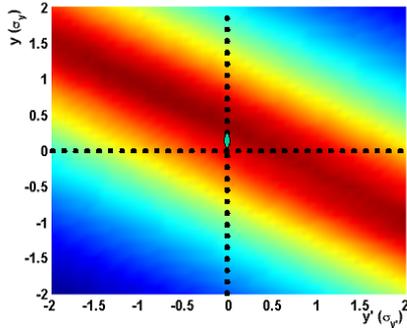


Figure 2: Luminosity as a function of vertical position and angle beam offset at the IP. The blue shaded area depicts the area that the feedback system automatically corrects to.

Fig. 3 shows the feedback systems bringing the beams into angular alignment over the first 150 bunches. The beam fluctuates substantially for about the first 100 bunches until the HOM's are damped in the LINAC. Feedback is performed by steering the positron beam only. This reduces bunch-bunch noise enhancement by the feedback system. In the inset to fig. 3 it can be seen how the feedback system enhances high frequency uncorrelated jitter in the beam. There is a 10 bunch latency of the angle feedback system due to the kicker-BPM separation. The system is assumed to then settle down to its 'zero' position after the 150 bunch mark. The simulation then uses a luminosity monitor signal corresponding to the first LCAL layer to optimise the collision parameters- this is simulated as the number of e^+e^- pairs passing through an annulus, radius of between 1.2 and 6.2cm at a distance of 220cm after being tracked through a 4T solenoid field. It was found to be optimal to integrate the luminosity signal over 10 bunches to avoid statistical luminosity fluctuations. Fig. 4 shows the operation of the luminosity feedback system in conjunction with the IP feedback system. One beam is ramped past the other in $0.1\sigma_y$ steps and the corresponding LCAL signal is found, the BPM input signal corresponding to this maximum signal is then passed to the PI feedback controller as a set-point allowing this optimal collision parameter to be held. The same procedure is applied to the angle system after the y-position is re-established. The luminosity as a function of bunch number is shown in fig. 5.

REFERENCES

[1] R. Brinkmann. Proc. EPAC 1998
 [2] T. Raubenheimer (ed.). SLAC Report 474.
 [3] J. P. Delahaye et al. Act.Phys.Polon.B30(2029-2039).

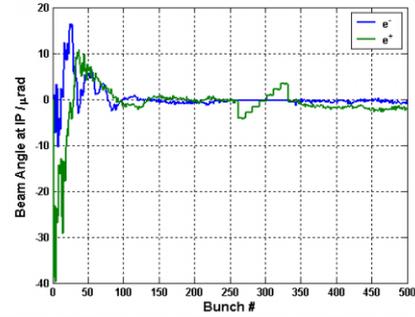


Figure 3: Beam vertical angle at the IP for the first 500 bunches at TESLA with fast feedback.

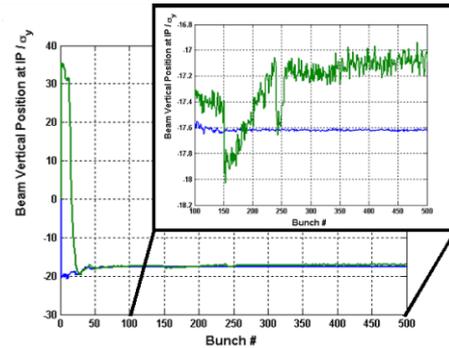


Figure 4: Beam vertical position at the IP for the first 500 bunches at TESLA with fast feedback.

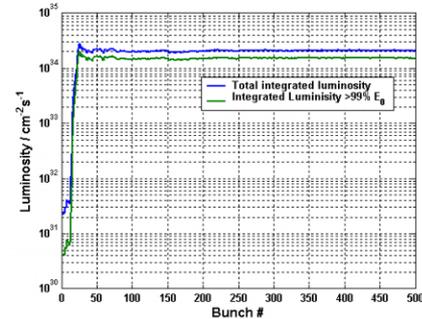


Figure 5: Total integrated luminosity and luminosity within 1% of 500GeV energy peak.

[4] N. Walker, A. Walski, 'Luminosity stability issues for the TESLA Beam Delivery System.' TESLA 2000-22 Oct. 2000.
 [5] http://tesla.desy.de/new_pages/TDR_CD/PartII/accel.html
 [6] D. Schulte, DESY-TESLA-97-08, 1997.
 [7] <http://dschulte.home.cern.ch/dschulte/placet.html>
 [8] <http://www.desy.de/merlin/>
 [9] D. Schulte, Nanobeams Workshop 2002 "Update on banana simulations".