BEAM DIAGNOSTIC FOR THE NEXT LINEAR COLLIDER

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Abstract

The Next Linear Collider (NLC) is proposed to study e+ e- collisions in the TeV energy region. The small beam spot size at the interaction point of the NLC makes its luminosity sensitive to beam jitter. A mechanism for aligning the beams to each other which acts during the bunch-train crossing time has been proposed to maintain luminosity in the presence of pulse-pulse beam jitter[1]. We describe a beam-beam deflection feedback system which responds quickly enough to correct beam misalignments within the 265 ns long crossing time. The components of this system allow for a novel beam diagnostic, beam-beam deflection scans acquired in a single machine pulse.

1. INTRODUCTION

The beam-beam deflection feedback consists of a fast position monitor, kicker, and feedback regulator which properly compensates for the round-trip time-of-flight to the interaction point (Figure 1). A system consisting of conventional components may be effective at reducing the loss of NLC luminosity in the presence of vertical beam jitter many times larger than the vertical beam size.

Table 1: Beam Parameters at the IP

Parameter	Value	Comments
CM Energy	490 GeV	Stage 1
Bunch Charge	0.75×10^{10}	$e^{+/-}$ / bunch
Bunches / train	95 / 190	
Bunch Spacing	2.8 / 1.4 ns	
Repetition rate	120 Hz	
σ_y / σ_x	2.7 nm / 245 nm	At IP
σ_z	110 µm	
D_y	14	Disruption
Deflection slope	20×10^{-6} /nm	Head-on

2. POSITION MONITOR

2.1. Transducer

We propose a stripline-type position monitor pickup, located about 4 meters from the IP. The strips are 50 Ohm lines and are assumed to be 10 cm long, peaking the response at the 714 MHz bunch spacing frequency. A 20 mm diameter BPM diameter is modelled here. Care must be taken to minimize radiation hitting the BPM, and to keep RF from propagating into the BPM duct.

Table 2: Beam Position Monitor Parameters

Parameter	Value	Comments
Distance to IP	4 m	
Duct diameter	2 cm	
Stripline length	10 cm	
Impedance	50 Ohms	
Frequency	714 MHz	Center
Bandwidth	360 MHz	
Input filter	4-pole bandpass	Bessel
Bandwidth	200 MHz	Base band
Base band filter	3-pole low pass	Bessel
Rise time	3 ns	0-60%

2.2. Processor

The position processor produces an analog output proportional to beam position. This signal must be fast to be useful in intra-pulse feedback. We propose to demodulate a 360 MHz band width around the 714 MHz BPM center frequency. The processor consists of an RF hybrid, band pass filter, and mixer driven by 714 MHz from the timing system, followed by a low pass filter. See Figure 2. This produces an amplitude proportional to the product of beam position and beam current.

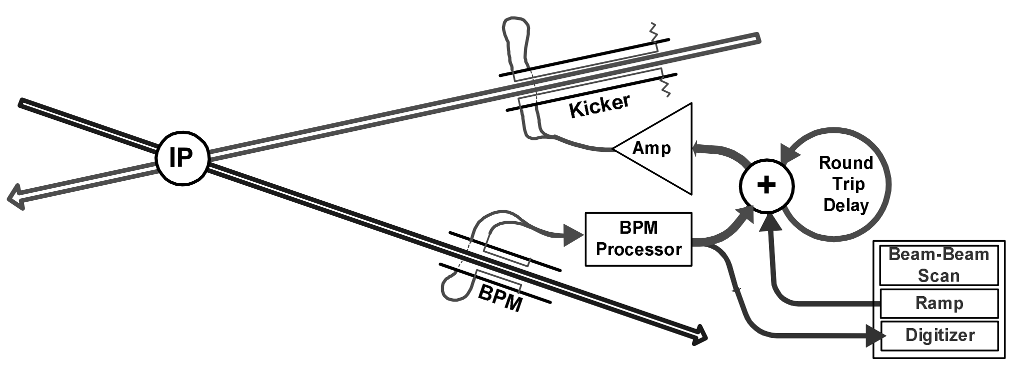

Figure 1: Intrapulse Feedback Block Diagram

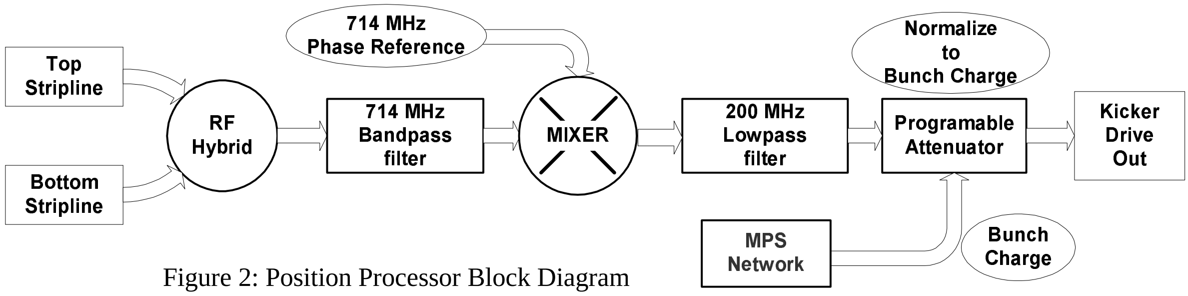

Figure 2: Position Processor Block Diagram

A variable attenuator scales the output inversely proportional to the beam intensity to recover the position signal. This scaling is set up before the pulse, either with charge information from the damping rings, or from slow feedback based on the charge of recent pulses. Using common RF parts we can achieve output rise times less than 3 ns and position resolutions below a micron. Figure 3 shows simulation of the turn-on transient.

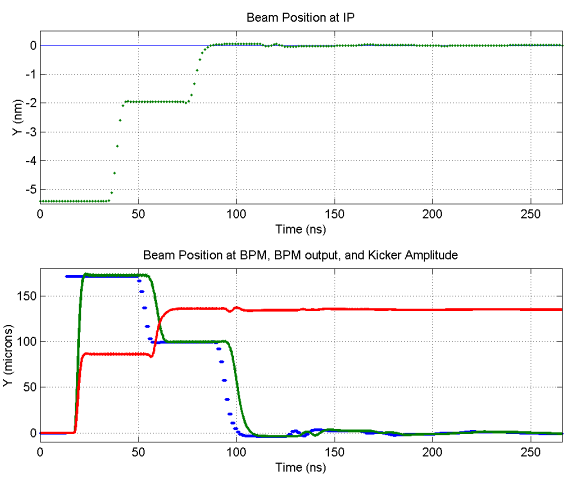

Figure 3: Capture transient for 2σ initial offset.

2.3. Noise

Intrinsic (thermal) resolution of such a BPM is less than 50 nm rms, This corresponds to a beam-beam offset resolution on the picometer scale, absent other error terms. The feedback system requires position resolution of only microns, so this is an excellent start.

Absorption of charged particles and secondary emission from the strip lines is another potential source of position noise. This design is sensitive at the level of about 3 pm per secondary electron knocked off the strip lines, and somewhat less for those knocked off the walls of the walls inside the BPM. Imbalances of intercepted spray of 10^5 particles per bunch would be a problem for this BPM.

The near-IR region is likely to be a rich source of RF power. These fields propagating into the BPM give rise to position errors. The proposed BPM diameter has cut off frequency well above the processing frequency so external RF fields are excluded.

3. KICKER

Our model for the kicker has curved strip lines at 12 mm diameter and a length of 75 cm. Each stripline subtends 120° from the beam. Such a kicker will have an impedance of 50 Ohms if its enclosed in a beam duct of radius about 10 mm. The kicker is to be operated at base band, so that several bunches may be propagating concurrently through it. The impulse response of the kicker is a rectangular pulse of 5 ns width. The step response is a linear ramp with this rise time. In the present system model, this represents the slowest rise-time in the system. Faster response may be obtained by shortening the stripline, with power required for a given deflection increasing quadratically.

4. FEEDBACK REGULATOR

The feedback regulator must converge rapidly to the optimal beam position. There are three major issues here. The lag in loop response due to the roundtrip time-of-flight to the IP must be compensated to get rapid, stable convergence. The beam-beam deflection response has a non-linear character which slows convergence for large initial beam-beam offsets. Finally, angle jitter in the incoming beam contributes to an error in estimation of the beam-beam deflection angle.

4.1. Compensating Loop Delay

The IP round-trip delay, about 30 ns for BPM and kicker 4 meters from the IP is 10% of the entire bunch train length, making a conventional PID regulator work poorly; the gain on the integral term must be kept small to avoid oscillation due to round-trip lag. Low gain leads to slow convergence[1]. A higher-order regulator allows for improved convergence. We assume a comb-filter integration of the response from one full loop delay time earlier. The physical implementation is a cable transmitting the output of the kicker driver back to the summing node. The length of this cable is adjusted to the loop propagation delay, including the round-trip to the IP and electronics delays. This lets the feedback compare the kicker amplitude from the time when it was relevant to the beam deflection now being measured. Critical tuning is not required for convergence or stability. Compensation for the kicker fill time is warranted; a simple RC is adequate. Loop compensation is an electrical model of the response of the system, composed of cable delay, and shaper with the rise time of the kicker.

4.2. Deflection Curve Non-Linearity

Deflection is linear in displacement for small vertical displacements, but the slope flattens when the beam-beam offset is greater than a few σ of the vertical beam size[2]. Hence the overall gain of the feedback loop drops like 1/δ for large offsets. A linear regulator will then take many loop propagation delays to reach the linear part of the deflection curve, where it converges rapidly. Figure 4 shows a simulated capture transient from an initial beam-beam offset of 27 nm. This shows restoration of full luminosity in about 130 ns, so a little more than 50% of nominal luminosity is recovered when the beams start out missing each other by 10 σ.

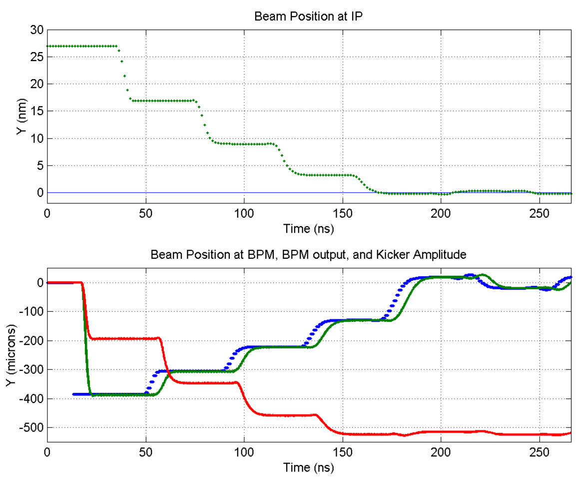

Figure 4. Capture transient from 10σ initial offset

Convergence speed from far off is improved by increasing loop gain, at the cost of slowing convergence from small initial offsets[3]. The optimal loop gain then depends on average jitter conditions. At sufficiently large initial offsets, convergence is too slow to recover luminosity before the end of the train.

4.3. Incoming Angle Compensation

Jitter in the interaction-point angle of the incoming beams has two consequences. The high aspect ratio of the beam spots in the y-z plane means bunches must be aligned precisely to get luminosity. If the incoming angle jitter is of the order of σ_y/σ_z, then incoming angle feedback, not considered here, must be implemented.

Second, the incoming angle of the beam heading to the feedback BPM contributes to the position signal at that BPM. If not compensated, this angle is interpreted as beam-beam deflection signal and is incorporated, in error, in the intra-pulse feedback. This may be compensated within the beam crossing time if another fast BPM is installed on the incoming beam, on the other side of the IP, and its analog output brought through the detector in some timely fashion.

5. DIAGNOSTIC BEAM-BEAM SCANS

The existence of the fast BPM and kicker allows for a novel beam diagnostic. One can program the kicker with a ramp, open the feedback, and record beam-beam deflection throughout a single machine pulse. This provides initial beam-beam alignment and beam spot size information, free of pulse-to-pulse machine jitter.

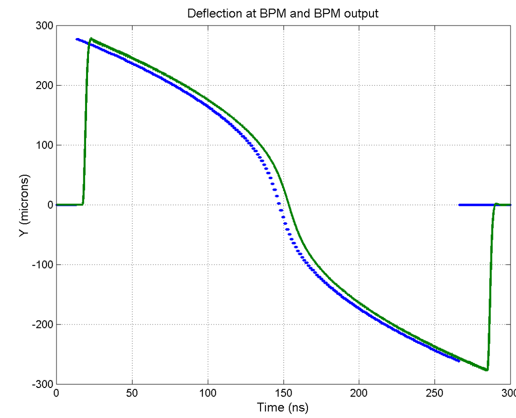

Figure 5. Beam-beam scan simulation.

6. CONCLUSIONS

We've presented a conceptual design of an intra-pulse beam-beam feedback for the Next Linear Collider interaction point. Principle components have been sketched in sufficient detail to model the system, including beam-beam effects, BPM and processor, feedback regulator and kicker. Simulink was used to perform the simulations; its output shows rapid convergence from initial offsets of a few beam σ. With these tools, beam-beam alignment and spot sizes may be measured in a single pulse.

REFERENCES

[1] Daniel Shulte, "Simulations of and Intra-Pulse Interaction Point Feedback for the NLC", Sep. 1999, LCC-Note-0026 on web at http://www-project.slac.stanford.edu/lc/nlc-tech.html.

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[3] O. Napoly, N. Tesch, I. Reyzl, "Interaction Region Layout, Feedback, and Background Issues for TESLA", **Proceedings of the World-Wide Study on Physics and Experiments with Future Linear e+e- Colliders Vol. 2,** April 28 – May 5, 1999, ed. E. Fernandez and A. Pacheco, Sitges, Barcelona, Spain, p. 663.