BEAM-BEAM SCANS WITHIN A LINEAR COLLIDER BUNCH-TRAIN CROSSING*

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Abstract

Beam-beam deflection scans provide important beam diagnostics at the interaction point of a linear collider. Beam properties such as spot sizes, alignment, and waists are measured by sweeping one beam across the other. Proposed linear colliders use trains of bunches; if beam-beam scans can be done within the time of a bunch-train crossing rather than integrating over the bunch train, the acquisition rate of diagnostic information can be increased and the sensitivity of the scan to pulse-to-pulse jitter and slow drifts reduced. The existence of intra-train deflection feedback provides most of the hardware needed to implement intra-train beam-beam scans for diagnostic purposes. A conceptual design is presented for such beam-beam scans at the Next Linear Collider (NLC).

1 INTRODUCTION

The beam-beam deflection feedback[1] consists of a fast position monitor, kicker, and feedback regulator that 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: NLC Interaction Point Beam Parameters

Parameter	Value	Comments
CM Energy	490 GeV	Stage 1
Bunch Charge	0.75×10^{10}	$e^{+/-}$ / bunch
Bunches / train	190	
Bunch Spacing	1.4 ns	
Repetition rate	120 Hz	
σ_y / σ_x	2.7 nm / 245 nm	At IP
σ_z	110 μm	
Deflection slope	20 x 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 modeled 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	Baseband
Baseband filter	3-pole lowpass	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 bandwidth around the 714 MHz BPM center frequency. The processor consists of an RF hybrid, bandpass filter, and mixer driven by 714 MHz from the timing system, followed by a lowpass filter. See Figure 2. This produces an amplitude proportional to the product of beam position and beam current. A variable

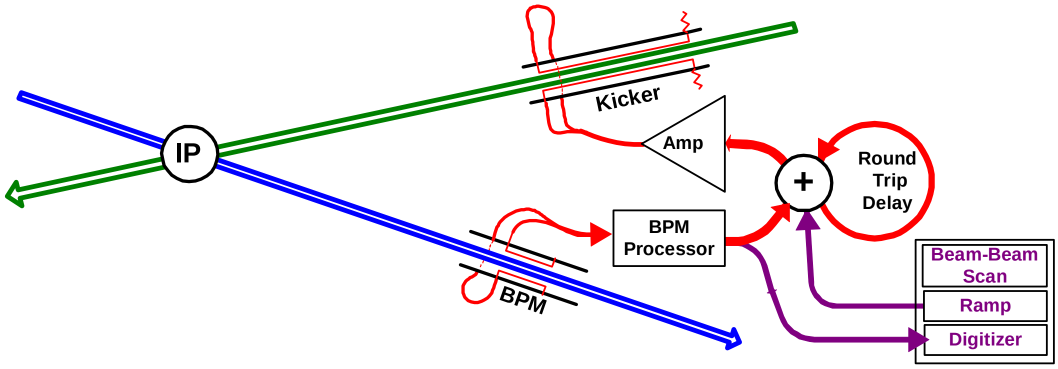

Figure 1. Intrapulse Feedback Block Diagram.

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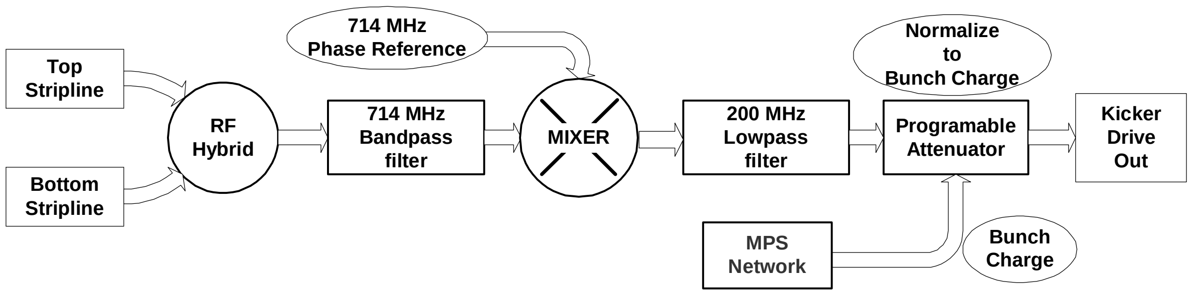

Figure 2. Position Processor Block Diagram.

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.

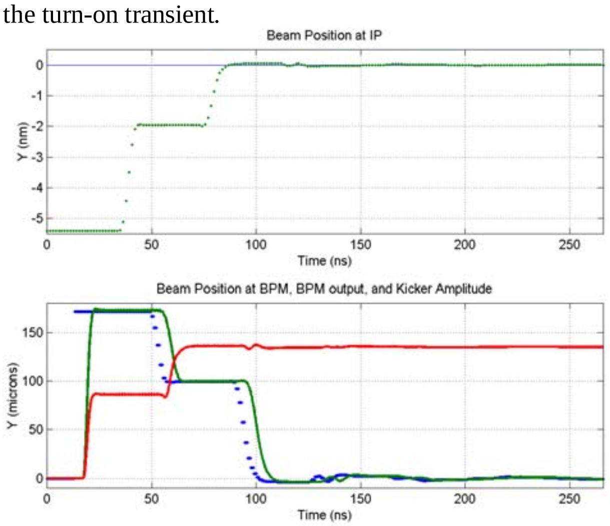

Figure 3: Capture transient for 2s initial offset

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 striplines is another potential source of position noise. This design is sensitive at the level of about 3 pm per secondary electron knocked off the striplines, 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 cutoff frequency well above the processing frequency so external RF fields are excluded.

3 KICKER

We model the kicker as a curved stripline pair at 12 mm diameter with 75 cm length. Each stripline subtends 120º 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 baseband, 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 that 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[2]. 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[3]. Hence the overall gain of the feedback loop drops like $1/\delta$ 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.

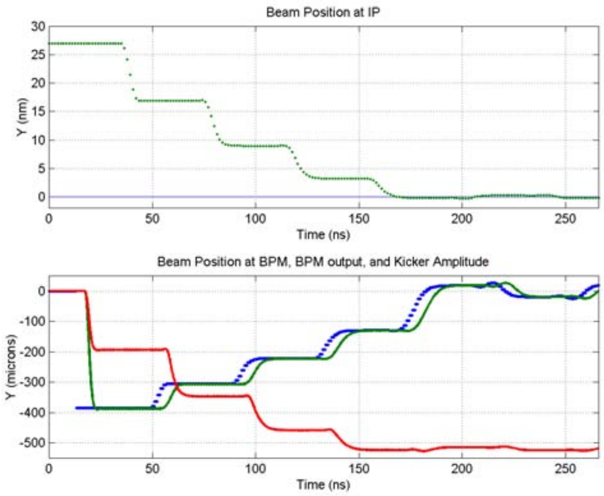

Figure 4. Capture transient from 10σ initial offset

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. Convergence speed from far off is improved by increasing loop gain, at the cost of slowing convergence from small initial offsets[4]. 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.

Another approach to the gain setting problem is to compensate for the beam-beam deflection non-linearity by inserting a programmable non-linear amplifier in the signal path, which approximately linearizes the overall feedback transfer function[5].

4.2 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

Beam-beam deflection scans provide important diagnostics at the interaction point of a linear collider. Beam properties such as spot sizes, alignment, and waists are measured by sweeping one beam across the other. If data are taken one measurement per bunch train, a beam scan takes many machine pulses, involving a substantial time. The measurement is then sensitive to pulse-to-pulse jitter, drifts in machine parameters over the length of the scan, and to low frequency noise.

5.1 Intra-Train Beam Scans

If beam-beam scans can be done within the time of a bunch-train crossing rather than integrating over the bunch train, the acquisition rate of diagnostic information can be dramatically increased and the sensitivity of the scan to pulse-to-pulse jitter and slow drifts dramatically reduced. The existence of intra-train deflection feedback provides most of the hardware needed to implement intra-train beam-beam scans for diagnostic purposes. One can program the kicker with a ramp, open the feedback, and digitize the output of the fast BPM analog output to monitor the 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. See Figure 5 for a simulated intra-train beam-beam scan. This can potentially increase the

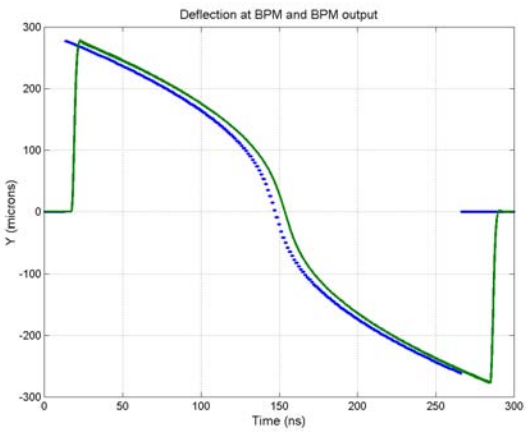

Figure 5. Beam-beam scan simulation.

beam scan acquisition rate by a factor of up to 180, the number of bunches in the train, although if only the 100-200 MHz bandwidth requirements of the intrapulse feedback system are met, the speed-up is only a factor of 50 to 100. This improved beam scan acquisition rate means more parameters can be optimized more often.

5.2 Non-invasive Scans

The reduction of pulse-pulse jitter and low-frequency noise and drift may make possible the use of lower-amplitude excitation for diagnostics. For small-enough excitation, *i.e.* less than the vertical spot size, the diagnostic is non-invasive. Beam scans can then run continuously during luminosity running. Non-invasive beam-beam scans could even function with the intra-train IP feedback loop operational if the feedback transfer function is known sufficiently well.

6 CONCLUSIONS

We've presented a conceptual design of an intra-pulse beam-beam feedback for the Next Linear Collider interaction point. Extension of this hardware to the acquisition of beam-beam diagnostic scans within the crossing time of a single bunch-train is discussed. The rate at which beam scans can be performed is then dramatically increased, making possible the optimization of more parameters more frequently. The acquisition of a beam scan in a single train crossing also dramatically reduces the effects of pulse-pulse jitter, drifts, and low-frequency noise contamination in the measurement.

7 REFERENCES

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