LINEARIZING INTRA-TRAIN BEAM-BEAM DEFLECTION FEEDBACK*

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Abstract

Beam-beam deflection feedback acting within the crossing time of a single bunch train may be needed to keep linear collider beams colliding at high luminosity. In a short-pulse machine such as the Next Linear Collider (NLC) this feedback must converge quickly to be useful. The non-linear nature of beam-beam deflection vs. beam-beam offset in these machines precludes obtaining both rapid convergence and a stable steady-state lock to beam offsets with a linear feedback algorithm. We show that a simply realizable programmable non-linear amplifier in the feedback loop can linearize the feedback loop, approximately compensating the beam-beam deflection non-linearity. Performance of a prototype non-linear amplifier is shown. Improvement of convergence and stability of the beam-beam feedback loop is simulated.

1 INTRODUCTION

The NLC beam-beam deflection feedback[1,2] consists of a fast position monitor, kicker, and a feedback regulator that properly compensates for the round-trip time-of-flight to the interaction point (Figure 1). NLC bunch trains are short, only 250 ns in duration, so such a feedback must be very fast if it is to bring trains into collision in the presence of pulse-to-pulse jitter and drift. Propagation delay and convergence rate must be minimized to make the system useful. Propagation delay is minimized by placing the position monitor and kicker close to the interaction point and making the electronics as fast as possible. The convergence rate is limited by the non-linear response of beam-beam deflection.

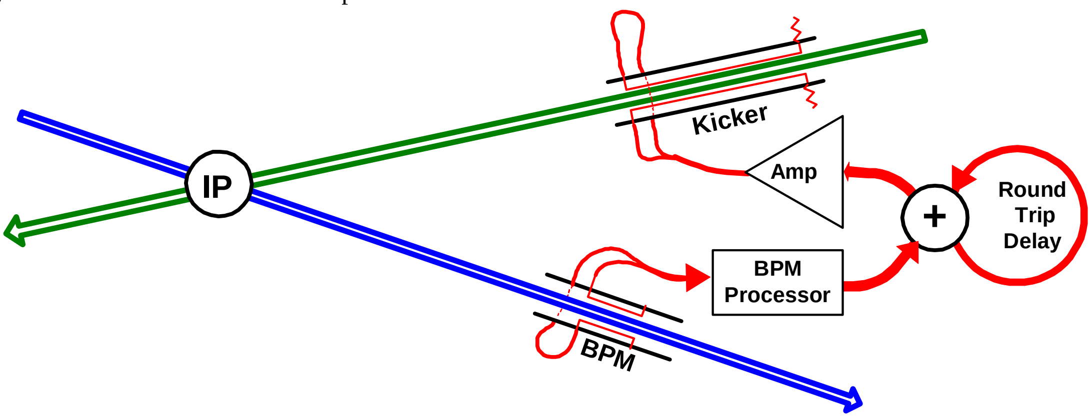

Figure 1. Intrapulse Feedback Block Diagram.

2 BEAM-BEAM DEFLECTION

The deflection of one beam by the other is linear in beam offset only for small vertical displacements; the slope flattens when the beam offset is greater than a few σ of the vertical beam size[3]. Figure 2 shows a simulation of beam-beam deflection for the NLC interaction point parameters[4]. This means a linear feedback regulator cannot provide optimum response for both small and large beam offsets. If the loop gain is set for good convergence and stability at small offsets, then convergence is too slow to restore luminosity for large (~10 σ) initial offsets. Conversely convergence speed from far out is improved by increasing loop gain, at the cost oscillation at small offsets. The optimal loop gain then depends on average jitter conditions. For large initial offsets, convergence is too slow to recover luminosity before the end of the train[5]. Figure 3 shows response of a linear regulator optimized for various initial beam offsets.

Figure 2. Beam-Beam deflection vs. beam offset for nominal NLC interaction point parameters[4].

* Work supported by Department of Energy contract DE-AC03-76SF00515.

Contributed to 26th Advanced ICFA Beam Dynamics Workshop on Nanometer Size Colliding Beams (Nanobeam 2002),

09/02/2002--9/6/2002, Lausanne, Switzerland

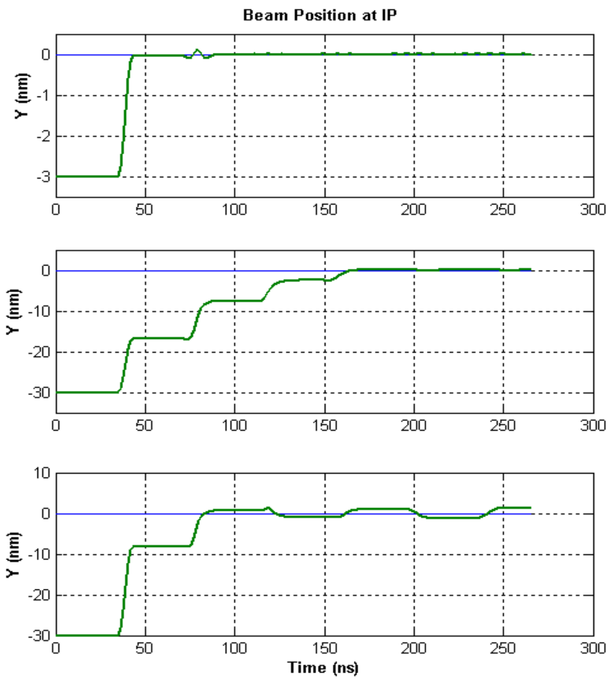

Figure 3. Feedback capture transients: small offset with optimized gain (top); same gain, but large initial offset (middle); and gain re-optimized for rapid convergence from far out (bottom), where loop oscillates when beams collide.

3 LINEARIZER

We can linearize this loop by compensating (approximately) the deflection non-linearity in the feedback regulator. Diodes in the feedback of a simple op-amp stage create the required non-linearity. The desired response is one with low gain for small beam offsets, sharply rising as the beam-beam deflection flattens. Since the deflection at which the knee occurs depends on beam parameters, we provide adjustable diode bias to program the gain breakpoint. A sketch of the circuit is shown in Figure 4. We built a prototype non-linear gain stage to verify the modeled circuit. The measured transfer function is shown in Figure 5 and the differential gain versus input voltage in figure 6.

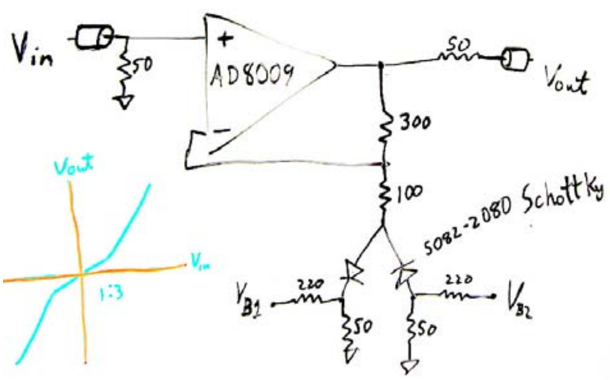

Figure 4. Non-linear op-amp stage.

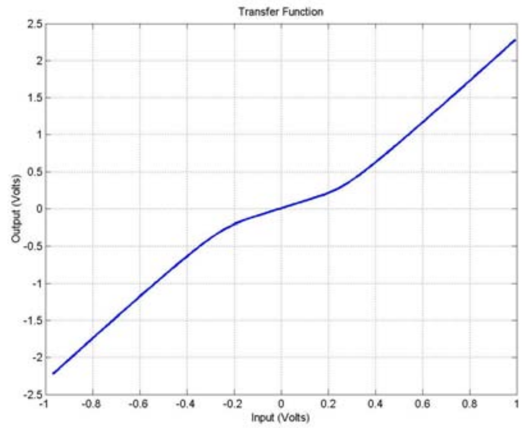

Figure 5. Transfer function: output voltage vs. input

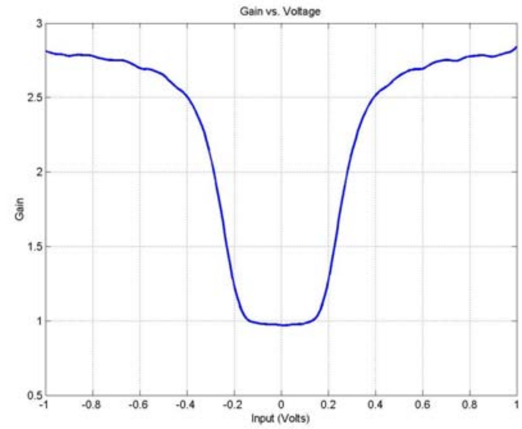

Figure 6. Differential gain versus input voltage.

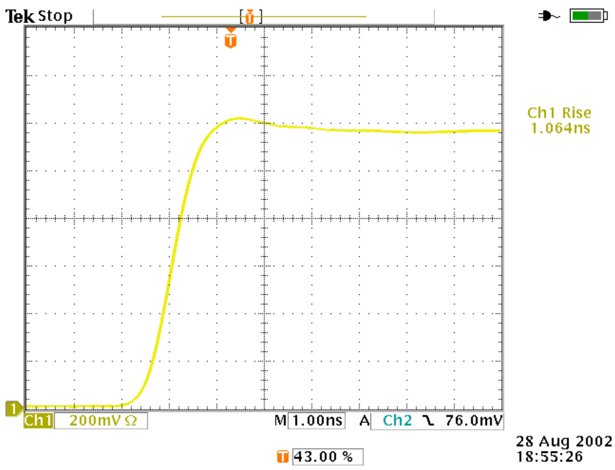

Figure 7. Large signal step response.

The transfer function and gain curves show a crisp increase in gain as expected at the Schottky diode threshold. Propagation delay is about 1 ns, quite suitable for this application. Bandwidth is about 200 MHz, and varies slightly with amplitude, but always remains higher than that of the kicker, the slowest component in the system. The step response is clean; there should be no stability issues including this in closed loop feedback.

Figure 8 shows how a compensating non-linear stage could be incorporated into the feedback system.

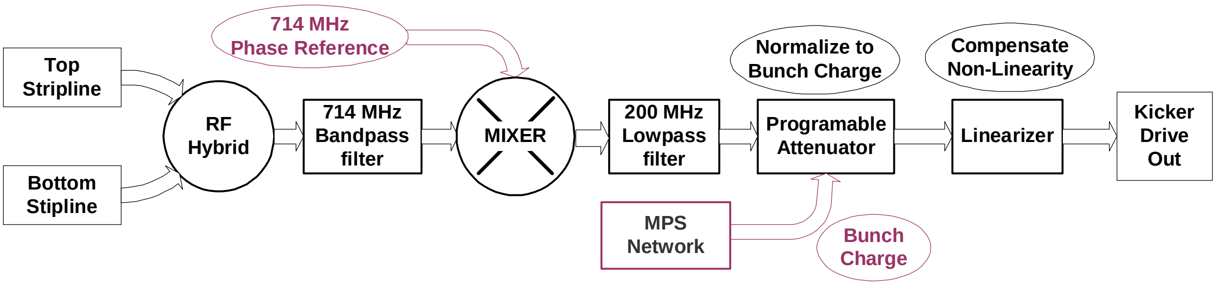

Figure 8. Position Processor Block Diagram.

4 SIMULATION

Performance of the linearized feedback was modeled in Simulink. The transfer function measured on the prototype non-linear amplifier is implemented as a look-up table in the simulation. We find this compensation is sufficient to achieve single round-trip convergence to better than 1σ from a 10σ initial offset. Convergence to less than 0.1σ from 10σ initial offset takes fewer than two cycles. The capture range of the prototype amplifier is limited by dynamic range of present op-amp, not by accuracy of compensation. This range can be improved by substitution of a different op-amp or by tuning the diode bias for lower knee voltage.

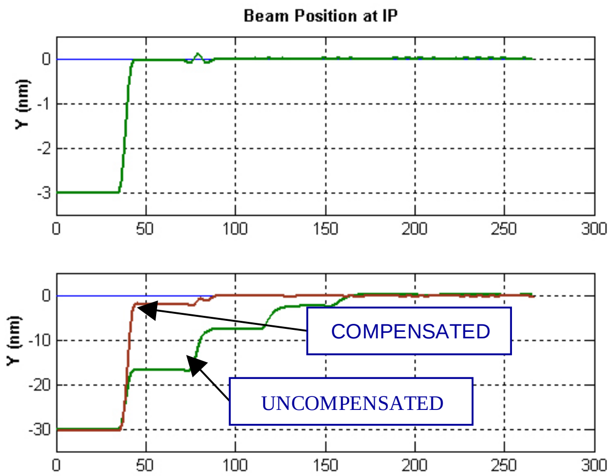

Figure 9. Capture transient with and without non-linearity compensation.

5 CONCLUSIONS

A simple op-amp based non-linear amp is sufficient to linearize the beam-beam deflection feedback. A hand-wired prototype was built and evaluated; it works pretty well for a first try! Presumably we can do better with a little more effort. Simulations show that this can improve stability, convergence speed, and (timely) capture range in the intra-pulse interaction point beam-beam feedback system. We conclude the hardware doesn't limit the intra-train feedback, but the beam physics must be well understood.

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