Intra-Pulse FeedBack
at the
NLC Interaction Point

Steve Smith
NLC Beam Delivery Group Meeting
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Intra-pulse Feedback

- Fix IP jitter within the crossing time of a bunch train (266 ns)
- BPM measures beam-beam deflection on outgoing beam
  - Fast (few ns rise time)
  - Precise (micron resolution)
  - Close (~4 meters from IP?)
- Kicker steers incoming beam
  - Close to IP (~4 meters)
  - Close to BPM (minimal cable delay)
  - Fast rise-time amplifier
- Feedback algorithm is complicated by round-trip propagation delay to IP in the feedback loop.
What I’d like to Add to the Discussion

- **Conceptual design of a BPM processor**
  - Fast: < 3 ns response time
  - Conventional RF design
  - Commercial RF components

- **Higher-order Feedback Regulator design**
  - Faster convergence than first-order
  - Flexible
  - Easier to implement

- **Example of a kicker**

- **System simulation in Simulink**
Beam-Beam Deflection

Hence a 1 mm measurement at 1 meter lever arm is in the ballpark.

If \( N = 0.65 \times 10^{10} \) and \( R = 100 \) mm then \( \Delta \Theta = 0.7 \) radians at 250 GeV.

\[ \Delta \theta = 2 \pi \sqrt{r} \]

(Betatron Initial collisions)

\( r \gg 0 \) \( \Rightarrow \) \( \Delta \theta \)
<table>
<thead>
<tr>
<th>Parameters</th>
<th>Stage 1</th>
<th>Stage 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMS Energy (GeV)</td>
<td>490</td>
<td>888</td>
</tr>
<tr>
<td><strong>Luminosity</strong> $(10^{33})$</td>
<td>22</td>
<td>34</td>
</tr>
<tr>
<td>Repetition Rate (Hz)</td>
<td>120</td>
<td>120</td>
</tr>
<tr>
<td><strong>Bunch Charge</strong> $(10^{10})$</td>
<td>0.75</td>
<td>0.75</td>
</tr>
<tr>
<td>Bunches/RF Pulse</td>
<td>190</td>
<td>190</td>
</tr>
<tr>
<td>Bunch Separation (ns)</td>
<td>1.4</td>
<td>1.4</td>
</tr>
<tr>
<td><strong>Eff. Gradient</strong> (MV/m)</td>
<td>50.2</td>
<td>50.2</td>
</tr>
<tr>
<td>Injected $\gamma\varepsilon_x / \gamma\varepsilon_y$ $(10^{-8})$</td>
<td>300 / 2</td>
<td>300 / 2</td>
</tr>
<tr>
<td>$\gamma\varepsilon_x$ at IP $(10^{-8}$ m-rad)</td>
<td>360</td>
<td>360</td>
</tr>
<tr>
<td>$\gamma\varepsilon_y$ at IP $(10^{-8}$ m-rad)</td>
<td>3.5</td>
<td>3.5</td>
</tr>
<tr>
<td>$\beta_x / \beta_y$ at IP (mm)</td>
<td>8 / 0.10</td>
<td>10 / 0.12</td>
</tr>
<tr>
<td>$\sigma_x / \sigma_y$ at IP (nm)</td>
<td>245 / 2.7</td>
<td>200 / 2.2</td>
</tr>
<tr>
<td>$\sigma_z$ at IP (um)</td>
<td>110</td>
<td>110</td>
</tr>
<tr>
<td>$\gamma_{ave}$</td>
<td>0.11</td>
<td>0.26</td>
</tr>
<tr>
<td>Pinch Enhancement</td>
<td>1.43</td>
<td>1.49</td>
</tr>
<tr>
<td>Beamstrahlung $\delta B$ (%)</td>
<td>4.6</td>
<td>8.8</td>
</tr>
<tr>
<td>Photons per e+/e-</td>
<td>1.17</td>
<td>1.33</td>
</tr>
<tr>
<td>Two Linac Length (km)</td>
<td>5.4</td>
<td>9.9</td>
</tr>
</tbody>
</table>
## Beam-Beam Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D_y$</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>Deflection slope</td>
<td>10 $\mu$rad/nm</td>
<td>At origin</td>
</tr>
<tr>
<td>Displacement slope</td>
<td>40 $\mu$m/nm</td>
<td>At BPM</td>
</tr>
</tbody>
</table>
Limits to Beam-Beam Feedback

- Must close loop fast
  - Propagation delays are painful
- Beam-Beam deflection goes flat beyond \( \sim 12 \sigma \)
- Then feedback gain drops like \( 1/\delta \)
- So feedback converges too slowly beyond \( \sim 30 \sigma \) to make a difference in luminosity
- May be able to fix misalignments of 100 nm with moderate kicker amplifiers
- Amplifier power
  - Goes like square of misalignment
  - Inverse square of kicker length, distance to IP
Simulations of an Intrapulse Interaction Point Feedback for the NLC

September 20, 1999

Daniel Schulte
CERN
Geneva, Switzerland

Abstract:
Position and angle jitter of the beams at the interaction point are important sources of luminosity degradation in future linear colliders. In order to reduce their effect, intrapulse feedback can be used. Some simulations are presented to evaluate a position feedback at the interaction point. The influences of angle jitter onto this feedback are investigated and possible fixes are discussed. A feedback is proposed that also allows the effect of angle jitter to be reduced.
4 Correcting Offsets

The effect of the feedback on the relative beam positions is shown in Figure 6. An initial offset $\Delta_y = 2\sigma_y^*$ is corrected with three different gains. Here, the gain $g$ is defined via the correction $\delta_y$ applied in between two bunches

$$\frac{\delta_y}{\sigma_y} = g \frac{\sigma}{\sigma_y}$$

As can be seen, the gain $g = 0.03$ achieves a smooth correction while $g = 0.06$ and $g = 0.09$ produce an overshoot. As is visible in the bottom part of the figure, the value of $g = 0.06$ is best (the total loss of luminosity is proportional to the area below the curves).

Figure 6: The effect of the feedback on the relative offsets of the two beams. Three different gain factors are shown.
Model the System

- **Beam Position Monitor (BPM)**
  - Fast rise time
  - Analog output
- **Feedback Controller**
  - Novel (for us) higher-order integrator
- **Kicker**
  - Simple model, keep driver requirements modest
- **Close the Loop in Simulink**
Beam Position Monitor

• BPM Pickup
  – 50 Ohm striplines
  – 1 cm radius
  – 10 cm long
  – 7% angular coverage
  – 4 m from IP
  – Must be careful of propagating RF from IP region

• BPM Processor
  – Fast, < 3 ns propagation delay (+ cable lengths)
  – Amplitude difference at 714 MHz
    • Downconvert to baseband
    • (need to phase BPM)
    • Wideband: 200 MHz at baseband
  – Low noise
    • Thermal noise resolution limit ~ 50 nm (~ 1 pm beam-beam offset)
  – Suppress interference
    • A secondary electron knocked off stripline makes apparent position shift of ~ 3 pm
    • An imbalance of $3 \times 10^5$ (few $10^{-5}$ of bunch) would cause a 1 micron error
BPM Processor
Propagation Delay

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## BPM Processor Parameters

| First Filter (RF) | Second-order bandpass  
|                  | Center Frequency 714 MHz  
|                  | Bandwidth 360 MHz  
|                  | Second-order lowpass  
|                  | Bandwidth 1 GHz  
| Mixer            | Double balanced  
|                  | GaAs diodes for rad-hardness  
|                  | Max. linear input: 300 mV  
|                  | RF bandwidth: 500 MHz – 900 MHz  
|                  | IF bandwidth: 200 MHz  
| Baseband Filter  | Fourth- order Lowpass  
|                  | 200 MHz Bandwidth  
| Hybrid           | Printed circuit  

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**Stripline Kicker**

- **Baseband Kicker**
  - Parallel plate approximation \( \Theta = 2eVL/pwc \)
  - (half the kick comes from electric field, half from magnetic)
  - 2 strips
  - 75 cm long
  - 50 Ohm / strip
  - 6 mm half-gap
  - 4 m from IP
  - Deflection angle \( \Theta = 1 \text{ nr/volt} \)
  - Displacement at IP \( d = 4 \text{ nm/volt} \)
  - Voltage required to move beam 1 \( \sigma \) (5 nm) 1.25 volts (30 mW)
  - 100 nm correction requires 12.5 Watts drive per strip
  - Drive amp needs bandwidth from 100 kHz to 100 MHz
  - Low end requirement may be relaxed via pre-compensation
Example Kicker for IP Feedback

- Odd mode impedance is ~50 Ohms per strip
- 10% stronger than parallel plate kicker with same half-gap
Next Linear Collider

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BPM Scope

Response at BPM

First 100 ns

Full bunch train
IP Beam Position

Next Linear Collider

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Capture Transient from Way Out

120 nm initial offset
Capture Transient from Way Out

120 nm initial offset
Conclusions

- BPM stripline is conventional
- Processor can be conventional technology
  - Conventional BPM processor technology (PEP-II, most light sources)
  - Conventional RF components
    - *i.e.* use commercial parts spec’d for this kind of application
- Processor can be built from commercially available parts
  - Low cost
  - Hybrid, mixer, amplifier available off-the-shelf
  - Filters readily available
  - custom ordered
  - fill out standard form for center frequency, bandwidth, and characteristic
- Electronic propagation delay can be very small
- An appropriate feedback regulator is proposed
  - looks great in simulation
- Kicker drive requirements are modest