Fourier Series Pulse Compression
Damping Ring Kicker:
a Progress Report

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and
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The specs

Dog bone (TESLA TDR) kicker specs:
• impulse: 100 G-m (3 MeV/c) ± 0.07 G-m (2 keV/c)
• residual (off) impulse: 0 ± 0.07 G-m (2 keV/c)
• rise/fall time: < 20 ns

Perhaps larger (but less precise) impulse at injection, smaller (but more precise) impulse at extraction will be desirable.

Small ring kicker rise, fall times can be asymmetric:
• leading edge < 6 ns, trailing edge < 60 ns
Fourier series pulse compression kicker

Instead of a pulsed kicker, construct a kicking pulse from a sum of its Fourier components.

Combine this with a pulse compression system to drive a small number of low-$Q$ cavities.

Illinois, Fermilab, Cornell are involved.
### Participants

This project is part of the US university-based Linear Collider R&D effort (LCRD/UCLC)

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<tr>
<th>Cornell</th>
<th>Fermilab</th>
<th>Univ. Illinois</th>
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<tbody>
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<td>Gerry Dugan</td>
<td>Tug Arkan</td>
<td>Guy Bresler</td>
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<td>Joe Rogers</td>
<td>Evgene Borissov</td>
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<td>Harry Carter</td>
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<td>Chris Jensen</td>
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<td>Timergali Khabibouline</td>
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Fermilab/Illinois activities

Initial studies: use Fermilab A0 photoinjector beam (16 MeV $e^-$) for studies:

1. concept and design studies of FSPC kicker
2. build a fast, simple strip line kicker
3. use the stripline kicker to study the timing/stability properties of the A0 beam
4. build a single-module pulse compression kicker
5. study its behavior at A0
6. perform more detailed studies in a higher energy, low emittance beam (ATF??)
Right now: simulations and RF engineering discussions…
...and writing it up so it is clearly described...
…and building a stripline kicker.

Start with a simple kicker whose properties are calculable and can be measured independently of its effects on the A0 electron beam.

Most important: how well can we measure a device’s amplitude and timing stability with the A0 beam?

Fermilab is currently building this. Probably ready by February 2005.
Test it in the FNAL A0 photoinjector beam

16 MeV electron beam, good spot size, emittance.

EOI submitted to A0 group last spring.

Space in beamline will be available ~January 2005
Performance modeling studies

Functional units in the system, downstream to upstream:

- RF cavity, $Q = 25$
- Waveguide
- RF amplifier
- Arbitrary function generator

Modeling strategy is to study the consequences of:

- drifts in parameter values (e.g. $Q$ of RF cavity)
- noise in RF power amplifier output signal
- nonlinearities: harmonic and intermodulation distortion
### Parameters in our studies

<table>
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<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Value</th>
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<tbody>
<tr>
<td>Main linac bunch frequency</td>
<td>$f_L$</td>
<td>$\omega_L \equiv 2\pi f_L$</td>
</tr>
<tr>
<td>Damping ring bunch frequency</td>
<td>$f_{DR}$</td>
<td>$\omega_{DR} \equiv 2\pi f_{DR}$</td>
</tr>
<tr>
<td>RF structure center frequency</td>
<td>$f_{RF}$</td>
<td>$\omega_{RF} \equiv 2\pi f_{RF}$</td>
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<td>RF structure $Q$</td>
<td>$Q$</td>
<td>25</td>
</tr>
<tr>
<td>Waveguide cutoff frequency</td>
<td>$f_{cutoff}$</td>
<td>1300 MHz</td>
</tr>
<tr>
<td>Desired on field integral</td>
<td>$A(0)$</td>
<td>(100 ± .07) Gauss-meters</td>
</tr>
<tr>
<td>Desired off field integral</td>
<td>$A(t)$</td>
<td>(0 ± .07) Gauss-meters</td>
</tr>
<tr>
<td>$f_{DR}/f_L$</td>
<td>$N$</td>
<td>60</td>
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<tr>
<td>$f_{RF}/f_{DR}$</td>
<td>$\Gamma$</td>
<td>10.25</td>
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<tr>
<td>$f_{RF}/f_L$</td>
<td>$\Gamma N$</td>
<td>615</td>
</tr>
<tr>
<td>Bunch length</td>
<td>$\delta_B \text{ or } \tau_B$</td>
<td>±6 mm ~ ±20 ps</td>
</tr>
<tr>
<td>Karma</td>
<td>☺</td>
<td>Impeccable</td>
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Nothing has been optimized yet!
RF cavity

\[ A(t) = \frac{1}{N^2} \sin^3 \left( \frac{N \omega_x t}{2} \right) \cos \left( TN \omega_x t \right) \]

- \( Q = 25 \)
- center frequency 1845 MHz
RF cavity $Q$ error

Kick error caused by deviations in $Q$ for the center, head, and tail of the kicked and first two unkicked bunches. Full vertical scale corresponds to 0.07 Gauss-meters (2.1 keV/c).
RF cavity center-frequency error

Kick error as a function of cavity center frequency error for kicked, first unkicked, and second unkicked bunches.
Waveguide: 80 meters long for the time being

- 80 meters long
- 1300 MHz cutoff

relative phase lag (degrees) between adjacent Fourier components per meter of waveguide

$\mu = \frac{\text{relative phase lag (degrees)}}{3 \text{ MHz}}$

$\mu = \frac{\text{degrees per meter}}{3 \text{ MHz}}$

$\mu = \frac{1}{3} \times \frac{1}{\text{MHz}}$

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Waveguide compresses pulse

Pulse compression!

Maximum amplitudes:
- entering ~0.016
- exiting ~0.1
Waveguide length error

Two contributions to problems:
1. change in flight time down the waveguide
2. relative phases of Fourier components are misaligned

#1 dominates.

Differences between delivered kicks and an ideal impulse for waveguides that are 5 mm, 10 mm, 15 mm, 20 mm, and 25 mm too long. The peaks in the kicks have been shifted in time to align with the peak in the ideal impulse that is centered at $t = 0$. In addition, the delivered kicks have been rescaled to have the same magnitude as the ideal impulse.
Waveguide cutoff frequency error

Effects of cutoff frequency errors. The curves represent the difference between delivered and ideal impulses as functions of time after aligning the time of the peaks and rescaling the peak amplitudes. Full scale in the plot is ±100 ps. Nominal $f_{\text{cutoff}}$ is 1.3 GHz. Errors in cutoff frequency for individual curves are indicated on the plot.
For now, look at a linearly increasing error as a function of frequency…

Effects of an amplifier gain error that grows linearly with frequency. The curves represent the difference between delivered and ideal impulses as functions of time. The time region in the plot is centered on the arrival time of the kicked bunch.
Amplifier phase error

Use a linearly increasing error as a function of frequency here too.

Effects of an amplifier phase error that grows linearly with frequency. The curves represent the difference between delivered and ideal impulses as functions of time. The time region in the plot is centered on the arrival time of the kicked bunch. Full (horizontal) scale is ±100 ps. The impulse functions have been shifted in time to align the kicking peaks at $t = 0$ and rescaled to agree in amplitude with the nominal kick.
Amplifier noise…

Model as flat in frequency, from 300 MHz to 6 GHz for now. Cavity is insensitive to frequencies far from center frequency… $10^{-4} \text{ GHz}^{-1/2}$
...amplifier noise

Generate in 300 kHz frequency bins, random phases. More work is needed...

noise voltage added to kicking impulse for 50,000 randomly generated noise "histories"
Next on the list:

Continue with noise study, then begin on harmonic and intermodulation distortion.
UIUC/FNAL, longer term plans

Design, then build one module using existing components.

Fermilab RF group is involved

UIUC HEP electronics design group’s chief is too.

So we’re making progress.

Goals:
• install strip line kicker in A0 by February, 2005
• understand A0 by spring, 2005
• investigate small pulse compression system by summer, 2005