Transient Electromagnetic Analysis of MEBT Kickers for PXIE

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Outline

- Introduction: MEBT Chopper
- Proposed Kicker Structures
- Electromagnetic Tool
- Dispersion Wide Pulse
- Field on Axis Wide Pulse
- Dispersion of Actual Pulse
- Kick Efficiency
- Paraxial PIC Simulation
MEBT Chopper Requirements

- Chopper consists of sections of 2 travelling-wave kicker assemblies working in sync (each is 500 mm in length, electrode to electrode distance ≥ 16 mm)
- Any bunch of the 162.5 MHz (β=0.0668) CW train can either pass or be removed
- Kick is in the vertical direction
- A 3.7 mrad deflection angle is required per each kicker assembly (bipolar scheme)
- Voltage on plate with respect to ground (bipolar drive scheme) 250 ±25 V, -250 ±25 V
- A minimum length of time of ±0.65 ns with respect to the bunch center
- 5% uniformity of the kicker electric field within 6σ=±8 mm
- Any reduction in integral kick is compensated by increasing the applied voltage
- Any difference between kicker and beam velocities is corrected by widening the flattop
- 2·10⁻⁷ Torr vacuum level

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Table 1. Typical beam parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ion type</td>
<td>H⁻</td>
</tr>
<tr>
<td>Beam energy</td>
<td>2.1 (+/-1%) MeV</td>
</tr>
<tr>
<td>Velocity (beta)</td>
<td>0.0668</td>
</tr>
<tr>
<td>Frequency of bunches (CW)</td>
<td>162.5 MHz</td>
</tr>
<tr>
<td>Beam current, nominal/range</td>
<td>5/(1 – 10) mA</td>
</tr>
<tr>
<td>Nominal charge per bunch</td>
<td>30 pC</td>
</tr>
<tr>
<td>Relative residual charge of removed bunches</td>
<td>&lt; 10⁻⁴</td>
</tr>
<tr>
<td>Beam loss of pass through bunches</td>
<td>&lt; 5%</td>
</tr>
<tr>
<td>Bunch size, 6-sigma X/Y (horizontal/vertical)</td>
<td>16/12 mm</td>
</tr>
<tr>
<td>Bunch length, 6-sigma</td>
<td>1.3 ns</td>
</tr>
</tbody>
</table>
Proposed Kicker Structures: 200Ω Kicker

Front View

Electrodes

Ground Tube

Dielectric Support

Electrodes
Proposed Kicker Structures: 50Ω Kicker

Geometry provided by Margaret J Jones

Electrodes
Tools

- Time domain solver of CST is used
- Excite the geometry with a pulse and examine the transient time response
- Investigate the following
  - Transmitted signal to the output port
  - Delay and the group velocity
  - Transverse electric field on beam axis
  - Characteristic impedance
  - Dispersion
- Three kind of pulse excitations are used
  - Gaussian pulse: useful to find the frequency response
  - Wide rectangular pulse: useful to see the pulse dispersion on flattop
  - Actual pulse to be used in kicker
Kicker Frequency Response (using Gaussian Pulse)

**200Ω Kicker**

**50Ω Kicker**
Kicker: Dispersion (Wide Pulse)

Characteristic impedance was calculated by changing the port impedance to minimize reflections.
Field on Axis (Wide Pulse)

![Diagram showing field on axis with dimensions 20 mm, 5.3 mm, 2.84 mm, 10.46 mm.](image)

![Graphs showing norm transverse electric field vs. Z in for 200 Ohm Kicker: 20ns and 50 Ohm Kicker: 20ns.](image)

![Another graph showing norm transverse electric field vs. Z in for 200 Ohm Kicker: 30ns and 50 Ohm Kicker: 30ns.](image)
200Ω Kicker: Actual Pulse

Transmitted Pulse

200Ω Kicker

$\beta_g = 0.0671$
50Ω Kicker: Actual Pulse

- Dispersion is noticeable on the transmitted pulse
- Shape of electric field is different than shape of transmitted pulse

Transmitted Pulse

50Ω Kicker

$\beta_g = 0.0662$

Field on Beam Axis
Kick Efficiency: Definition

- In order to estimate the kick efficiency, it was necessary to have a reference case of parallel plate structure simulated under the same conditions and excitation.

- By comparing the transverse field perpendicular to the electrodes, we can estimate the kick efficiency defined as

\[ E_{\text{eff}}^{\text{Kick}} = \frac{V_{\text{Kick}}^K}{V_{\text{Kick}}^P} \frac{V_E^P}{V_E^K} \]

Where

**Kick Voltage**

\[ V_{\text{kick}} = \int_{0}^{L} E_y \bigg|_{\text{beam}}^{} dz \]

**Voltage difference between electrodes**

\[ V_E = \int_{0}^{d} E_y \bigg|_{Z=Z_m}^{} dy \]
200Ω Kicker: Efficiency

Efficiency is 98%
50Ω Kicker: Efficiency

Efficiency is 93%

Plate structure has lower characteristic impedance compared to the meanderline. That is why its field is lower.
200Ω Kicker: Simulation vs Measurements

- Earlier prototype
- Structure simulated open to air
- Actual pulse with 1ns rise/fall time was used as excitation

- Simulated pulse delay for 0.333” pitch is 26.3 ns
- Need to account for 1” input/output coaxial ports 2”/3e8=0.17 ns
- Delay in the helical structure is 26.1 ns (β=0.06)

- About 0.8 ns difference between the simulated and measured transmission pulses (tolerances and dielectric constant variations)
- The structure was optimized to adjust both delay, and impedance. A new prototype is under development

Measurement data provided by Greg Saewert
For comparison it will be great to have the measurements in data format

Measurement data provided by Ding Sun
Particle in Cell Simulation
**Tools**

- PIC simulation to find the kick angle
  - Actual pulse excitation
  - Paraxial Particle of 2.1MeV
  - No kinetic nor angular spreads
  - Eight bunches
  - $6\sigma=1.3\text{ns}$
  - 6ns bunch distance
  - Offset bunch to synch with RF
200Ω Kicker: Paraxial PIC Simulation

@31.6 ns
200Ω Kicker: Paraxial PIC Simulation

\[ \theta_y = 3.37 \text{ mrad} \quad \theta_x = 15.8 \text{ } \mu\text{rad} \]
Per 497.4V plate voltage
50Ω Kicker: Paraxial PIC Simulation

@28 ns
$\theta_y = 3.34$ mrad $\theta_x = 1.4$ $\mu$rad
Per 500.1 V plate voltage
Future Plans

• Need to compare the simulations and measurements of the 50Ω kicker
• Need to compare the simulations and measurements of the final 200Ω kicker prototype
• Further PIC simulations with paraxial beam
• Find precisely the kick angle for both kickers
• More realistic PIC simulations?
Conclusion

- 200Ω kicker has less ripples for the field on axis (smaller distance between electrodes)
- 200Ω kicker has a 98% efficiency vs 93% for the 50Ω one
- Kick angle is 3.37 mrad (plate voltage 497.4V) for the 200Ω kicker while it is 3.34 mrad (plate voltage 500.1V) for the 50Ω kicker
50Ω Kicker Phase Space Monitors (Position)

1D Results\PIC Phase Space Monitor\pic phase space monitor 1

1D Results\PIC Phase Space Monitor\pic phase space monitor 2

- Frame 0000
- Frame 0001
- Frame 0002
- Frame 0003
- Frame 0004
- Frame 0005
- Frame 0006
- Frame 0007
- Frame 0008
- Frame 0009
- Frame 0010

...
50Ω  Kicker Phase Space Monitors (Velocities)

![Graphs of Vx, Vy, and Vz velocities with position [z] in inches for three different phase space monitors.](image-url)

- **Vx**: Graph showing the velocity component along the x-axis (horizontal) for each frame.
- **Vy**: Graph showing the velocity component along the y-axis (vertical) for each frame.
- **Vz**: Graph showing the velocity component along the z-axis (depth) for each frame.
200Ω Kicker Phase Space Monitors (Position)

1D Results\PIC Phase Space Monitor\pic phase space monitor 1

1D Results\PIC Phase Space Monitor\pic phase space monitor 2
200Ω Kicker Phase Space Monitors (Velocities)
CST Transient Signal Excitation

- CST used by default signals normalized for 1W power
Parallel Plate Kick

E = 500/16e^-3 = 31.25 kV/m
For 0.5 mm Kick is 15.625 kV
15.625e3/2*2.1e6 = 3.7e^-3

Field on axis is ~30 kV/m
Ideal Electrostatic Case of Parallel Plate

- Lx = 40 mm
- Vy = 73.208e3
- Vz = 2.00242e7
- θy = 3.656 mrad
Effect of Changing Electrode Size

$w_e = 0.27''$, $g = 0.155''$

$w_e = 0.30''$, $g = 0.125''$

$w_e = 0.32''$, $g = 0.105''$

$w_e = 0.34''$, $g = 0.085''$
Stepped

Tapered

Rp-hs, 1.5t

Helical Kicker: End Effect Compensation