Storage Ring Kicker Update

D. Rubin and A. Mikhailichenko
Cornell University
January 11, 2012
• Status of E821 kicker prototype
  • Concept
  • Components
  • Configuration
  • Hardware
• Injection dynamics
  • Trajectories
  • Energy and angular acceptance
  • Time dependence
• Kick amplitude and width
  • Pulse forming network
  • Implementations
• Muon beam
  • Bunch length
  • Energy and angular spread
Kickers are $90^\circ$ in betatron phase from the inflector exit

Injected muons are crossing the central trajectory inside the kickers

Kick directs muons onto central orbit
End of inflector is displaced 7.7 cm radially outward from the central orbit

Radius of central orbit = 7.112 m

Kick ~ 10 mrad on first pass and 0 on next turn
E821 – Pulser schematic
E-821 Pulser
Pulser electronics
Kicker chamber

Power

Downstream end of kicker
Kicker plates

Kicker chamber
Pulser feed
Pulser housing
High voltage feedthrough
Plan for E-821 prototype kicker /pulser test

Reassemble

Test at low voltage (no oil) and measure field with single turn coil
Test at 100kV with high voltage components in oil
Injected Beam dynamics

Weak focusing – with vertical focusing from electrostatic quadrupoles approximately uniformly distributed around ring

Field index \( n \approx 0.139 \)

\[
\beta_x = \frac{R}{\sqrt{1 - n}} = 7.67 \text{ m}
\]

\[
Q_x = \frac{R}{\beta_x} = 0.927
\]

\[
\eta = \frac{R}{1 - n} = 8.26 \text{ m}
\]

\[
x_{\text{inf}} = 7.7 \text{ cm}
\]

\[
x(s) = x_{\text{inf}} \cos \phi_x + \beta x'_{\text{inf}} \sin \phi_x
\]

\[
x'(s) = -\frac{x_{\text{inf}}}{\beta} \sin \phi_x + x'_{\text{inf}} \cos \phi_x
\]
At $\phi_x = \pi/2$, $x(s) = 0$, and $x'(s) = -x_{\text{inf}}/\beta$

Kicker changes angle by $\theta = x_{\text{inf}}/\beta \approx 10$ mrad to put injected muons on central orbit

Now suppose the injected muon has fractional energy error $\Delta E/E = \delta$

$$x_{\text{inf}} = x_\beta + \eta\delta$$

$$\rightarrow x_\beta = x_{\text{inf}} - \eta\delta$$

$$x(s) = (x_{\text{inf}} - \eta\delta) \cos \phi + \eta\delta$$

$$\rightarrow x\left(\frac{\pi}{2}\right) = \eta\delta$$

The ideal kick for off energy muons is $\theta = (x_{\text{inf}} - x)/\beta$

$$\rightarrow x'\left(\frac{\pi}{2}\right) = -\frac{x_{\text{inf}} - \eta\delta}{\beta}$$
If the kicker field depends on displacement from central orbit according to
kick [mrad] $\approx 10(1-x/x_{\text{inj}})$ then all energies kicked onto corresponding closed orbit
Dependence on angular distribution of injected muons

\[ x(s) = x_{\text{inf}} \cos \phi_x + \beta x'_{\text{inf}} \sin \phi_x \]

\[ x'(s) = -\frac{x_{\text{inf}}}{\beta} \sin \phi_x + x'_{\text{inf}} \cos \phi_x \]

Then at \( \Phi = \pi/2 \)

\[ x\left(\frac{\pi}{2}\right) = \beta x'_{\text{inf}} \]

\[ x'\left(\frac{\pi}{2}\right) = -\frac{x_{\text{inf}}}{\beta} \]

There is no kick that puts the muon onto the central orbit.
The best we can do is to minimize the invariant amplitude.
Invariant amplitude

\[ a = \frac{x^2}{\beta} + \beta x'^2 \]

The best we can do with the kicker is to set angle to zero.

Then

\[ a_{min} = \frac{x^2}{\beta} = \beta x_{inj}'^2 \]

If the kick is not uniform but has radial dependence to match energy offset then

\[ a = 2\beta x_{inj}'^2 = 2a_{min} \]

We find that the kick that minimizes the betatron amplitude of off energy muons will increase the amplitude for on energy particles with finite injection angle.

Optimal kicker field profile depends on energy and angular distribution of muons exiting the inflector.
Time Dependence

Kicker Pulse width

Matched line ($Z_0 = Z_L$)

$$\tau = \frac{2L}{c} \sqrt{\mu_r \varepsilon_r}$$
L=10m => τ = 115 ms

Rigid coaxial delay line
L = 10m $\Rightarrow \tau = 115$ ms

Rigid coaxial delay line

Flexible coax delay line in transformer oil tank
Matched line PFN issues

1. Current $I = V/Z$ and the impedance of the kicker magnet is relatively high ($Z > 100\Omega$), implying a high charging voltage. (Require $I \approx 4kA$)
2. If muon bunch is long, then so is the coax
3. Mismatch of impedance of line and load gives reflections. Quantify?
4. Voltage on kicker is half the charging voltage implying an even higher charging voltage (Blumlein?)

We will test sensitivity to impedance match at low voltage
   1. With flexible coax delay line
   2. Rigid line
Conclusion

- Reconstruction and test of E-821 prototype kicker and pulser is underway
- Low voltage tests of delay line pulse forming network
- Explore alternative kicker plate geometry for
  - lower impedance
  - optimal field profile
- Investigate in simulation sensitivity to muon energy and angular distribution and bunch length

Bunch length – shorter is easier to deal with
We can achieve good acceptance for energy spread or angular spread but not both
Additional kickers

central orbit

injected muons

Inflector

E-821 kickers
Two turn kickers

central orbit
first turn
second turn

Inflector