Storage Ring Kicker Update

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• Kicker function
• Kicker magnet
• Pulser
• Pulser test status
Kickers are 90° 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.
Kicker has 3 identical sections of 1.76 m-long each

Each section fed by individual HV pulser

Magnetic field lines (or electric potential)

These circled regions influence mostly to the field strength

Field distribution in transient moments
Kicker chamber

Downstream end of kicker

Power
E-821 prototype kicker plates

End jumpers in the model

Macor© insulators
Modeling E-821 pulser with SPICE

\[ V \quad (100 \text{ kV}) \]

\[ R \quad C \quad L \]

E-821 pulse (200ns/big division)
Kicker Magnet

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

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

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

But the ideal kick for on energy muons with finite divergence angle $\phi$ emerging from inflector is $\theta = \frac{x_{\text{inf}}}{\beta}$, independent of $\phi$.

Optimum radial field profile depends on energy and angular distribution of injected beam.

Proceed with design that gives uniform field.
Some profiles of the kicker electrodes and guidelines


Make an impedance of the stripline kicker as low as possible;

Take care on the field distribution

Choice of materials

Stray fields in surroundings are another subject for research.

Profile of electrodes will be chosen with appropriate 3D modeling

g-2 Collaboration meeting 6/28/12 D. Rubin, A. Mikhailichenko, J. Bennett
3D field calculation is in progress with FlexPDE
Plans to do this with HFSS and CTS studio (License granted)

Field distribution in a transverse plane
Potential distribution. Longitudinal cut, top view
NMR cartridge

New plate profile

Macor rails

Old plate profile

Vacuum chamber
Thin (0.4mm) Al profiled electrodes; will consider Ti also. Perforation might be useful.
The NMR cartridge profile

End jumper

NMR cable duct wheels
Electrodes at the end will have the chamfer (similar to the magnetic pole chamfer) for better 3D field distribution. (The same could be recommended for the electrostatic Quadrupole)
Potential for another 20% increase of kick

Jumper

Macor© rails

Vacuum chamber
Pulser

Kicker Pulse width

RLC pulser

Matched line \((Z_0 = Z_L)\)

\[ \tau = \frac{2L}{c} \sqrt{\mu_r \epsilon_r} \]
Computed pulse shape
Meanwhile the current shape from previous figures, if embedded in Fig. 51 from [1] (and all other publications), become as the following:

The Fig. 51 from [1] with superimposed pulse shape obtained from Mathematica©.

The source of this discrepancy is under investigation.
For modeling with PSPICE (Cadence)

a) Original Blumlein scheme;

b) In a second coaxial the conductors are switched, so the potential of inner left coaxial is the same as the potential of outer right coaxial;

c) Right coaxial inserted into the left one. For this purposes its radiuses increased accordingly.

d) Final scheme.
Scheme under development

While using a bi-polar thyratron, one can control the HV out-polarity. Voltage at the input exists only for the time while the pulse front travels to the end jumper and back. The tubing of the same outer diameter will be used for prototyping; in a future the outer diameter can be reduced ~2 times. We will add~4 m to the length.

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L=10m => τ = 115 ms

Rigid coaxial delay line
Thyratron end station with transformer tank and HV pulser

For prototyping we are planning to use existing thyratron housing and tubing system
Generator for 120ns pulse line in scale with g-2 ring

Matching resistor
Blumlein application at BNL with similar to parameters to g-2

Pulsed Power Supplies for RHIC
E. Forsyth, M. Meth, W. Zhang
October 1991
Fig. 12a. THE OUTPUT PULSE WAVEFORM WITH $C_2 = 27$ pF, $C_3 = 38$ pF, $R_3 = 33 \Omega$.

Fig. 12b. THE OUTPUT PULSE WAVEFORM WITH $C_2 = 32$ pF, $C_3 = 38$ pF, $R_3 = 33 \Omega$.

5ns/div

RHIC kicker pulse

RHIC kicker

Kicker pulse with blumlein PFN

Matching components
Few triaxial Blumlein generators at RHIC inflector
Pulser Modeling

Blumlein equivalent circuit

preliminary
Lumped line blumlein equivalent

Preliminary
Modeling plan

- Continue to develop facility with SPICE

- J. Bennett is learning CST Micro-wave studio to model
  - blumlein coax
  - magnet stripline
  - eddy currents in vacuum chamber
  - time dependence of kick field
Status of prototype test

Restoring the E-821 prototype pulser and kicker

Repaired and replaced electronic components
- Thyratron electronics
  - Reservoir
  - Heater
  - Trigger pulser (second grid)
    (Meanwhile, primary grid supply has failed)
- HV power supply tested
- HV transformer tested
Thyratron grid pulser; this pulse goes to the second grid

For triggering CX1699 the amplitude on grid 2 required: 500-2kV, 0.5 μS
Thyratron/capacitor

HV transformer tank
For the Blumlein generator prototyping this 1.5 m-long section will be extended by 4 meters

This will allow having 50ns flat top pulse

*Fits in the room*
We recommend to purchase the thyratron feeding unit

New HV regulation block

This block replaces the thyratron triggering pulser, the PS for the heater, reservoir, prime, bias.

The cost is $5500/one
$15000/set of three

For the reference: the cost of this HV PS is 12.5k$
Inductance $\sim 1\mu\text{H}$

Without oil this device can operate at $\sim 30\text{KV}$
High voltage operation > 30kV (target is 100kV) requires that HV transformer, resistor, thyatron be bathed in oil – requires flanges to seal.

We had hoped to test without oil, but thyatron does not fire at 30kV

Thyratron problem

or 30kV insufficient to initiate breakdown in tube

Next step is to fill with oil and test with dummy load
Meanwhile we are building a prototype blumlein

Three sections of the Blumlein generator in a machine shop.
Summary

1. Design for kicker plates with uniform field
2. Design for PFN (bumlein) for 50 ns pulse
3. Developing models of pulser, kicker, including interconnects and vacuum chamber for simulation of time dependence of B-field, eddy currents etc. using SPICE and MicroWave Studio
4. Very nearly testing E-821 pulser with load
5. Fabricating prototype blumlein
6. Plan to test blumlein, and tune, guided by simulation
Scheme (and hardware) received from Chris Jensen

This scheme is restored finally and is ready to use.

Generates ~860 V unloaded, ~800ns duration
With matched resistor the distance between HV pulser and the kicker could be arbitrary

**Blumlein pulser:**
- Provides higher current;
- Flat top pulse without tails;
- Optimized electrodes will provide higher Field/current ratio

**THEORETICALLY JUST A SINGLE KICKER CAN PROVIDE ENTIRE KICK**
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.

Vacuum chamber aperture \( \pm 45\text{mm} \)
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.
E821 – Pulser schematic
Thyratron feeding section is running
SCOPE OF WORK

At a period of 2012, Cornell plans to provide:

- Analyses of injection efficiency;
- Optimization of injection;
- Analyses of existing kicker system performance with 3D codes;
- Reinstallation the E-821 hardware at Cornell and test; (accommodation in HV lab)
  - Fast field measurement equipment in existing model;
- Suggest the primary modification of the pulse generator and the kicker;
- Analyses of a new generator;
  - **Complete drawings** of the new generator and kicker;
  - Assembling a full scale prototype of a new pulser (Blumline) and the kicker;
  - Test the prototype and the kicker together;
  - Design drawings of a Blumlein pulsed system able generation of bi-polar pulses without mechanical switching;
Inflector

central orbit
injected muons

Additional kickers

E-821 kickers
Two turn kickers

Inflector

central orbit
first turn
second turn