MURI Kick-off Meeting
Testing of low energy gun and cavity designs

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Outline

• Initial testing with a low-energy gun to explore:
  – Bench marking of, MICHELLE, CST and WARP full 3D PIC codes
  – Modulation techniques: using solid-state grid drivers in class-D amplification mode to gate the beam current
  – Prototype resonant cavity structures
  – Multiple beams in a single guide field using a 4 beam-let aperture

• Initial modeling of resonant output cavities in HFSS:
  – Initial approach to using large mechanically tuned resonant cavities
  – Other approaches that minimize leakage flux with the use of ferrites and allow the ability to electronically tune the resonant structure
Initial Testing with a Low Energy Gun

Experimental Plan

• Bench mark codes to a small scale experiment
• Prototype grid electronics and cavity designs
Variable Gap Gridded Electron Gun

Initial Test Gun

Thermionic Dispenser Cathode

Indirectly heated

4.1mm radius

Class-D Operation

Using a Pulse-Forming-Line (PFL) to vary the pulse width (~1ns rise and fall times)

~100ns

~23 cm
Diagnostic Capabilities

• Multiple fast current transformers (CTs)
• Slow phosphor screens (Transverse images)
• Fast phosphor screens (Sliced transverse images through the bunch using a fast gated camera)
• Two energy analyzers (Longitudinal energy profile of the bunch)
Operating Space-Charge Limited vs Temperature Limited

Initial measurements to compare with beam simulations in MICHELLE, CST, WARP

At a fixed grid pulse voltage of -26.3 volts

- V=7.93
- V=7.47
- V=6.94
- V=6.43
- V=6.15

At a fixed accelerating potential of 5 kV

- V=7.93, 7.47
- V=6.94
- V=6.43
- V=6.15

~800 °C

~1100 °C
Child-Langmuir Comparison to Experimental Measurements

Small Signal Calculations

\[ \mu = r_p g_m = \left( \frac{\partial e_p}{\partial e_g} \right)_{I_b} = 27.74 \]

\[ g_m = \left( \frac{\partial i_b}{\partial e_g} \right)_{E_p} = 6.28 \times 10^{-4} \frac{1}{\Omega} \]

\[ r_p = \frac{\mu}{g_m} = 44.172k\Omega \]

\[ A = 0.582cm^2 \]

\[ d = 22.04mm \]

\[ I = A \times 2.33 \times 10^{-6} \frac{V^{3/2}}{d^2} \]
Transverse Images with Magnetic Focusing

**Magnetic Guide Field**

- Peak of 101.4 Gauss at 5.7 A
- FWHM 2.74 mm

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**FWHM**

- 2.92 mm

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**Intensity**

- x (mm)
- y (mm)

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**Bz (Gauss)**

- z (cm)
Initial Modeling of Resonant Output Cavities

- Large cavity designs without the use of ferrites
- Smaller cavity designs with the use of ferrites, still mechanically tunable
- Alternative electronic approach used at the Fermilab booster
Example Cavities

Very similar to HF transmitter tank circuits

Compose of Lumped Elements L’s & C’s

\[ f = \frac{1}{2\pi\sqrt{LC}} \]

50 MHz PSI Cyclotron Cavity
Tuning range of 560 kHz
Large Reentrant Style Cavities

Resonant at 6.6 MHz

\[ L = \frac{\mu_0 a^2}{2(R_o + a)} \]
\[ C = \frac{\varepsilon_0 \pi R_o}{d} \]
\[ f = \frac{1}{2\pi \sqrt{LC}} \]

Without ferrite loading, this cavity would exceed the laboratory ceiling at these frequencies (and most bridges)

a = 0.8 m
R_o = 1 m
d = 1.2 cm

5.2 m
Shrinking the Cavity Through the use of Ferrites

Mechanically tunable by Adjusting the gap

Resonant at 8.26 MHz

Resonant at 6.54 MHz

Gap $d=6\text{cm}$

Ferrite $\mu_r=1500$

$0.3\text{m}$

$1.4\text{m}$

$10\text{cm}$

$0.9\text{meter}$

$d=3\text{cm}$

$10\text{cm}$

$1.4\text{m}$

$0.9\text{meter}$
Alternate Approach to Allow for Electronic Tuning

Fermilab Booster Ring RF Cavity
Frequency varied from 37-53 MHz

Consecutive Ferrite rings

Current biased ferrite tuners

Our Resonant Cavity
Resonant at 7.1 MHz with a relative permeability of 750

Tuning the Resonant Cavity

Ferrite Cores

- http://www.allaboutcircuits.com/
Where we go next

• Breadboard fast grid pulser circuits to operate the low energy gun and understand the grid

• Refine beam models through detailed (experimental<->simulation) comparisons in MICHELLE/CST/WARP

• Refine various HFSS models, weighting losses and other constraints

• Begin prototyping a resonant cavity on the low energy beam line

• Begin testing a high peak power gun (SLAC MKIII)

• The equipment can be seen in the Lab Tour!!