DEVELOPMENT OF A 10 MW SHEET BEAM KLYSTRON FOR THE ILC*

D. Sprehn, E. Jongewaard, A. Haase, A. Jensen, D. Martin, SLAC National Accelerator Laboratory, Menlo Park, CA 94020, U.S.A.
A. Burke, SAIC, San Jose, CA 95110, U.S.A.

Work supported by the Department of Energy under contract No. DE-AC02-76SD00515
ILC Sheet Beam Klystron

• Plug compatible alternative for ILC source
  – “Better” → Could be a talk unto itself

• If possible, use permanent magnets

• Challenges - Everything is 3D!
  – 3D PIC takes a LONG time
  – Discover how to use 2D effectively
  – Concern of 3D gun → perform BSD first
  – Adjustable gun during prototype experiment
In brief – PCM to focus SBK (115kV, 130A, 5Hz, 1.6ms, 1.3GHz)

XP3 HV seal and PEP collector parts

Horizontal operation
Electron Gun

• Features
  – 2A/cm²
  – Gradients ~BFK
  – Linear convergence

• For experiments
  – Adjustable A-K gap during operation
  – Adjustable upper/lower bias voltages ~0 to -1kV
  – Easily removable FE for possible upgrade
  – Split anode to measure interception of top or bottom of beam

• Downside – definitely for prototype
  – Oil cooling required to accommodate the “For Experiments”
F.E. bias allows for some recovery from mechanical misalignments.
Tank and gun showing K-A gap adjustment mechanism
Electron Gun construction and F.E. mounting
Electron Gun – measure hot mechanical movements
Anode

• For experiments
  – Isolated to measure interception from top and bottom planes separately
  – Easily removable for possible upgrade

• Downside – definitely for prototype
  – Complex: cooling, isolated, removable
  – Requires precise alignment to F.E.
Beam Sampling Device (BSD) Requirements

- 8mil diameter, 1kV biased, carbon cup
- 3 axis scanning of beam (z-axis is limited)
- Removable: Experiments go between it and gun
- Operates microsecond pulse lengths
Static BSD test
Magnetic PCM with BSD test on tank
BSD Probe detail
Ceramic seal

- Maintain old BFK gradients → Original smaller diameter BFK seal run at 83.5 kV
- Use the XP3 seal
- Change inner corona ring to Whale tail to reduce gradients to old BFK levels

- Result – Gradients at old BFK levels
Spent beam power using a PEP collector

Cylindrical collector used since we have one available.

80 kW/cm² on the edge of the side zones

X-Compression: By field is introduced from step in last polepiece to allow the beam to spread in y-direction before impact → 30 kW/cm²
Cavities

Loss coupler for setting the Q

Cold test and simulation agree on the modes
Cu Output Cavity

Q = 40, R/Q = 20, M = 0.89  
(R/Q & M averaged over beam)

Hybrid use between output window and load to optimize the output cavity match for best performance
Windows and waveguide

Gradients <= other designs

Multipactor and trapped modes were analyzed and deemed not an issue.
Magnet Structure Requirements

- Common magnets and pole pieces
- Shielded to external fields
- Tunable to taper field and zero the axis
- Can be measured ~exactly as it is used
- Fast replacement—don’t have to pull tube
Translation between codes looks very reasonable
Beam entrance to PCM stack, edge focusing, and earth’s field
Edge Focusing Selection

- Too little
- Too much
- Just right
Entrance tilt Selection

MICHELLE Beam @ z=84cm

MICHELLE Beam @ z=84cm with Px(z=0) = 0

PAC May 4-8, 2009 Vancouver BC
Slide 23
Earth field cancellation

No cancellation

With cancellation (coil on @ 20 A Turns)
Sensitivity simulation #3 – thermal beam
Gun stem (cathode + FE) twist w.r.t. anode

A-K gap = 46 mm (nominal)

**Twist = 0.1° (Cathode and FE w.r.t. anode)**

Bias = -500 V (nominal)

Perveance = 129.49 A (-0.4%)

Peak emission current density = 2.2 A/cm²

**Zero intercepted current** through z = 18 cm (end of model)

MICHELLE model: Full geometry

Mesh elements = 2,146,000; Mesh nodes = 2,192,290

Electrostatic DOF = 2,115,731; Magnetostatic DOF = 6,346,175

Particles = 189,164 before decimation; 63,088 after 3x decimation (memory limitation); (4 emission sites/mesh; 6 thermal rays/emission site)

Iteration cycles = 58 (Runtime = 5 days 18 hours)

Data file: 071029_SensSimNo3_thermal.RLB
Start by getting agreement with 1D, 2D and 3D simulations using a sheet beam geometry with a solenoid→ done.
Field profile and 2D MAGIC runs of PCM SBK using 2D MAGNET and a symmetry plane at the $y=0$ axis.
Field ramp and beam of 3D MAGIC runs using 3D MAGNET and a symmetry plane at the y=0 axis.
Removing the symmetry plane and beam symmetry is broken. This caused a slight detour of the original design (alter B and drift tube size).

Some Theoretical analysis has been done for 2-cavity system at lower current, see

Friday 8:30-1230 poster session (FR5RFP082) K.L.F Bane et al
The frequency of the trapped mode is a function of cavity spacing and only lightly couples to the cavities. The Q has to be < ~30 for no oscillations to form.
Practical Mitigation of the TE Mode

- Increase confinement field
  - Solenoid works at low fields
  - PCM more difficult, has transport bands

- Increase drift tube
  - PCM more difficult
  - Spoils the rf coupling at some point

- **Add** loss or chokes
  - Tail chase (may not eliminate all modes)

Combine
Make sure the rf design is still valid!

Nominal Cavity Geometry

Output Cavity Geometry

<table>
<thead>
<tr>
<th>Nominal Cavity</th>
<th>Drift Height</th>
<th>Gap Width (mm)</th>
<th>M</th>
<th>R/Q (Normalized)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>18.5</td>
<td>0.958</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>18.2</td>
<td>0.908</td>
<td>1.113166432</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>21</td>
<td>0.63</td>
<td>1.332216677</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Output Cavity</th>
<th>Gap Width (mm)</th>
<th>M</th>
<th>R/Q (Normalized)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>30.5</td>
<td>0.690</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>35.5</td>
<td>0.619</td>
</tr>
</tbody>
</table>

To maintain $M^2 \cdot R/Q$ …
Backup plan – use a solenoid. Will a 400G Solenoid Beam Transport down to the output cavity plane at 85cm without doing anything different? Yes, with a slight tilt.
Long 2D 2x drift tube runs for the klystron (B=390G Solenoid) shows stable operation at 10MW
Long 2D 2x drift tube runs for the klystron (B=390G RMS PCM) shows stable operation

Without RF

With RF, Just shy of 10MW, in process of fine tuning
BSD Testing – Alteration of original plan to validate latest TE mode interception data for a 2-cavity system

Point – much easier to build now than solenoid, many parts in house, keeps plan on track
BSD test to begin Monday, May 11
Summary

• Challenges - **Everything is 3D!**
  – Good 1, 2 & 3D code agreement
  – BSD testing this Monday
  – 2-Cavity PCM transport BSD test coming next

• Plug compatible alternative for ILC source
  – PCM preference, solenoid backup
  – TE mode: increase drift tube and field
  – Design meets spec, now need to build it