NanoBPM tests in the ATF extraction line

Calibrate movers (tilters) and BPM’s
Understand and test dynamic range and resolution

June 2003
What are the uses of nanometer-resolution BPMs?

- 200 nm resolution is needed for linac operation (similar for DR and other collider regions)
  - *for LC, this is not it*...
- 3GLS evaluation of sub-micron stability
  - *Interesting, but still not it*

- **nanoBPMs:**
  - Measure beam position with accuracy better than support stability
  - Use the beam as a *mechanical ‘device’* to prove active stabilization
  - Measure beam parameters other than position
  - Many applications in beam manipulation - *correlations*
Why are RF BPMs ideal?

- $kTB$ energy corresponds to $<$1nm at 1MHz, room temp.
- Narrow bandwidth
  - Allows easy oversampling and direct downconversion
- Accurate, stable construction
- High central frequency
  - This is what allows *correlation* measurement
    - (ATF 6400 MHz, 28mm $\lambda/2$, 20mm FWHM)
    - (NLC/JLC 11424 MHz, 12mm $\lambda/2$, .25mm FWHM)
More On Using Magnetic Coupling

T. Shintake, C-band structure design.

Vladimir Vogel, BINP, for ATF (from a paper by Marc Ross)

Z. Li

NLC DDS structure.
Using slots to damp dipole wakefields.
Signal used for SBPM.
Micron resolution.
Cavity BPM With TM$_{11}$-mode Selective Coupler

- Dipole frequency: 11.424 GHz
- Dipole mode: TM$_{11}$
- Coupling to waveguide: magnetic
- Beam $x$-offset couple to $y$ port

- Sensitivity: 1.6$mV/nC/\mu$m
  $(1.6\times10^9V/C/mm)$

- Couple to dipole (TM$_{11}$) only
- Does not couple to TM$_{01}$
  - Low Q with narrow cavity gap
  - May need to damp TM$_{01}$
  - OR, use stainless steel to lower $Q$

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TM_{11} Selective-coupling Scheme

- Beam pipe
- Port to coax
- "M" coupling
- NO coupling
- Slot modes
$R$ or $Z$ Waveguide Orientation

$R$-orientation

$Z$-orientation

$R$ or $Z$ waveguide orientation to fit into different space.
Waveguide Signal With Beam Excitation

- Beam off in $x$ plane
- $y$-port only picks up dipole signal
- Total rejection of $TM_{01}$ mode achieved by the selective coupling scheme

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cavity height</td>
<td>3mm</td>
</tr>
<tr>
<td>Guide height</td>
<td>3mm</td>
</tr>
<tr>
<td>Guide R pos</td>
<td>8mm</td>
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<tr>
<td>Pipe radius</td>
<td>6mm</td>
</tr>
<tr>
<td>$Q_{dipole}$</td>
<td>1050</td>
</tr>
<tr>
<td>$W_2$ amplitude</td>
<td>1.3E12</td>
</tr>
</tbody>
</table>

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Intrinsic Resolution

- Resolution of BPM limited by signal/noise ratio
- Signal voltage determined by energy loss by the beam and the external coupling

\[ V(q, x) = \sqrt{q^2 Z_0 \frac{\beta}{1 + \beta} \frac{\omega_0 k_{\text{loss}} x^2}{Q_L}} \]

- Thermal noise determined by temperature and bandwidth

\[ V = \sqrt{Z_0 kT \Delta F} \]

- Signal/noise ratio independent of bandwidth
- Resolution limit 0.1-nm at room temperature for 1-nC charge beam
Tolerance

- Frequency: $-0.7 \text{MHz/µm}$ in cell radius. Can be made tunable, but need to keep cavity symmetry.
- We consider the impact of machining errors in coupling slots: $\Delta x$, $\Delta \theta$ and $\Delta r$.

- Both $\Delta x$, $\Delta \theta$ errors result in non-zero projection of the azimuthal magnetic field of the TM$_{01}$ mode along side the slot opening, causing coupling of the TM$_{01}$ mode to the waveguide and $x$-$y$ coupling.
- $\Delta r$ error may shift electric center of modes, results in potential TM$_{01}$ leakage and $x$-$y$ coupling.
Tolerance On Slots

$\Delta x/\Delta \theta$ misalignment

$\Delta x=0.5\text{mm}$

$\Delta r=-0.5\text{mm}$

$\text{TM}_{01}/\text{TM}_{11}$ signal ratio is about 25 for $\Delta x=100\mu \text{m}$, 1$\text{nm}$ beam offset

- For a misalignment in $\Delta x$ of 100$\mu \text{m}$, one can achieve resolution near thermal noise limit of about 0.1$\text{nm}$ with modern electronics.
- Tolerance on $\Delta r$ Significant looser than on $\Delta x/\Delta \theta$. 

$\text{TM}_{01}/\text{TM}_{11}$ signal ratio is about 25 for $\Delta x=100\mu \text{m}$, 1$\text{nm}$ beam offset
With C-band cavity, 357MHz, Best "conventional" electronics:

~5nm resolution, 1um maximum train offset

With 30GHz cavities, resolution ~1nm, but maximum train offset ~200nm
Raw signals
Signal fits using root

Mark Cooke - UCB

uncut

uncut residual

residual prior

residual after
Typical Calibration – MM5X_y

Readings from BPM1 as its mover is adjusted: 32 ATF pulses x ~10 mover settings superimposed. 320 ATF pulses in total.

Position mover calibration
(units are current-normalized ADC counts)

Tilt mover calibration

I (real)

I (real)

Marc Ross/SLAC

19.06.03

Collaboration meeting

X – Collaboration meeting

Marc Ross/SLAC

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**Typical Calibration – MM5X y (2)**

Average I/Q BPM1 data as its mover is adjusted vs mover setting: 32 ATF pulses x ~13 mover settings superimposed. 320 ATF pulses in total.

**Position mover calibration**

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Typical Calibration – MM5X y’ (3)

Average I/Q BPM1 data as its mover is adjusted vs mover setting: 32 ATF pulses x ~13 mover settings superimposed. 320 ATF pulses in total.

Mover - urad

Tilt mover calibration

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ATF Beam instabilities

- Initial tiltmeter tests were in a more favorable location (lower beta 3x)
- Slow – few minute period, 5um (y) amplitude
  - annoyingly similar to time for calibration
- Fast – pulse to pulse 1 um
- Fliers

- With:
  - Better resolution on existing 13 extraction line BPM’s
  - Readout integration with cavity BPMs
  - Connection to other diagnostic signals (temp)

- Should be able to pinpoint instability sources AND THEN FIX THEM
High Bandwidth Cavity BPMs for Multibunch

- Can imagine building a low Q cavity.
  - Strong coupling difficult
  - Fundamental mode overlap problem increases.
- Can look at signals from standard cavity BPM with higher bandwidth electronics.
- Integration time of 3ns vs ~300ns causes a loss of X10 in resolution.
- Since bunches add coherently, train offsets or tilts can generate very large signals.
Simulated Multibunch Signals

1um bunch noise
100nm train offset

1um bunch noise
1um train offset

1um bunch noise
1um train tilt

ISG X – Collaboration mee
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New Injection/Extraction scheme 2

Pulse Length of EXT kicker: 60ns -> 300ns
(PFL cable Length: 13m -> 37m)