Beam Position Monitors

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BPM Resolution Requirements

• Resolution requirements for averaged beam vertical position CW vs. CCW:
  • $\pm 10\mu m$ ($10^6$ Hz) per BPM.
  • $\pm 10$nm (1Hz) per BPM.
  • $\pm 10$pm ($10^{-6}$ Hz) per BPM.
  • With 64 BPMs for $10^7$s, $\pm 1$pm.
  • The above is for magnetic focusing.
  • For electric focusing, we need $10\times$ better.
Strip-line BPM Cartoon for Relativistic Bunch for Non-experts
Strip-line BPM Cartoon for Relativistic Bunch
Strip-line BPM resolution from Peter Cameron’s June C-AD Review Talk

• The average power available in the signals from each of the four lines is about -25dBm at the feedthrus. Conservatively estimating losses of 28dB, the signal power available after digitization will be approximately -53dBm.

• The resulting signal-to-noise ratio, given the thermal noise floor of -173dBm/Hz, will be ~120dB in a 1 Hz bandwidth. With the 10mm half aperture, the resolution in the 1 Hz bandwidth will be 10nm.

• BPM electronics that will provide this measurement resolution are commercially available.
Issues

• Strip-line BPMs have the resolution, but
• Beam impedance Re(Z_L) ≈ 25Ω.
• 64×25Ω = 2.4KΩ.
• This is a lot compared to other stuff, like the E plates, etc., and is a spin systematic.
• Requirement for the whole ring is <10KΩ.
• Also, strip-line systematic errors are challenging at the 1pm level: x = V_R - V_L
Resonant Cavity BPMs

FIG. 1. (Color) First two eigenmodes, $\text{TM}_{010}$ (monopole mode) and $\text{TM}_{110}$ (dipole mode), of a cylindrical cavity.
Dipole TM\textsubscript{110} Mode

- First order: \((l_y)_\text{CW} - (l_y)_\text{CCW}\)
- Monopole mode TM\textsubscript{010} measures \((l_{\text{CW}} - l_{\text{CCW}})\). Need several of these.
- If \(y_{\text{CW}} = y_{\text{CCW}} = y\), then
- Second order: \((l_{\text{CW}} - l_{\text{CCW}}) y\).
- With only one beam measure \(y\), and zero with feedback, i.e. center beam in cavity.
- S/N is better than stripline BPM because cavity has \(Q \approx 5 \times 10^3\), i.e. signal is at one f with narrow \(\delta f\).
Cavity Beam Impedance

- Re($Z_L$) is zero to first order in monopole mode,
  - i.e., zero if $(I_{CW} - I_{CCW}) = 0$.
- Zero to second order in dipole mode,
  - i.e., zero if $(I_{CW} - I_{CCW})y = 0$.
  - Re($Z_L$) $<< 10K\Omega$. 
Dipole Mode Cavity Design

- Working with Mike Blaskiewicz et al.
- Preliminary:
  - 2.5GHz TM\(_{110}\) mode.
  - R/Q = 18\(\Omega\) for 1cm offset.
  - Q \approx 5000.
  - 12cm(V)\(\times\)12.8cm(H)\(\times\)5cm(L).
- RF is 0.1GHz with 2.5GHz modulation.
Two Cells using dipole mode

\[ f = 2.5 \text{ GHz} \]
\[ R/Q = 18\Omega \text{ for } y=1\text{cm} \]
\[ Q = 15,000 \text{ for Cu} \]
Take \( Q=5000 \)

\[ D(t) = I_{cw}(t)y_{cw}(t) - I_{ccw}(t)y_{ccw}(t) \]

Drive at exact multiple of freq
Are We the Only People Trying for Nanometer Precision?

- ILC R&D at KEK ATF.
- Achieved $\pm 9\text{nm}$ precision over a dynamic range of $5\mu\text{m}$ with 6GHZ Dipole Resonant Cavity for each $7 \times 10^9$ electron bunch. This is best resolution achieved yet. Their goal is 1nm.
- Our requirement: $\pm 10\text{nm}$ for $\delta y$ for $10^6$ turns of $2 \times 10^{10}$ $\beta=0.6$ protons.
- Light Source 2 also needs nm precision.
- We benefit from their efforts, even though we can’t just use their designs.
Sensitivity/Systematics

- Add $B_R \sin(\omega_{BR} t)$ and $E_v \sin(\omega_{EV} t)$
- $\approx 1$ Hz frequency.
- This moves the CW/CCW beams in the same or opposite directions.
- Set to $\approx 10$ nm during setup, for example.
- Set to $\approx 10$ pm during physics running, for example.
- See effect in both the BPM and spin signals.
Peter’s Level of Effort Estimate

- 0.5FTE during detailed design,
- 1 FTE during construction and commissioning.
- Total $0.45M.
- Peter didn’t give us plan, milestones, etc., before he had heart attack last month.
- Low technical risk for magnetic focusing,
- Higher technical risk for electric focusing.