Beam-Based Alignment at the KEK-ATF Damping Ring

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Outline

- A Brief Description of ATF
- Beam-Based Alignment (BBA)
  Data Acquisition and Analysis
- BBA Results
- Conclusions and Future Prospects
Circumference: 140 m
Energy: 1.3 GeV
Arc Cells: 36 × FOBO
Physical Emittance\(^\dagger\) (x/y): 1.1 nm / < 5 pm
Normalized Emittance (x/y): 2.8×10\(^{-6}\) m / < 1.3×10\(^{-8}\) m
Coupling (emittance ratio): < 0.5 %

\(^\dagger\)Note: low intensity, single-bunch operation; at 10\(^{10}\) e-/bunch the vertical emittance increases by 50% due to IBS

The Accelerator Test Facility at KEK

The World’s Largest Linear Collider Test Facility
Some early challenges ...

- 20 µm single-shot BPM resolution
- No multi-turn BPM data (one readout per injection/extraction cycle; each measured orbit is a new beam)
- Systematic dependence of BPM readings on bunch intensity

... and recent improvements

- Upgraded BPM electronics (now < 5 µm resolution)
- “Scrubbing mode” operation
- Frequent BPM calibration (suggested by MIA)
2D “grid” scan: closed local bump and quadrupole strength
BBA Data Analysis† (1)

Change in closed orbit ($\Delta x_{co}, \Delta y_{co}$) due to a change in strength ($K \rightarrow K^{(1)}$) of a misaligned quadrupole ($x_{bq}, y_{bq}$):

$$\begin{pmatrix} \Delta x_{co} \\ \Delta y_{co} \end{pmatrix}_{S} = \left[ K^{(1)} \overline{C}^{(1)}(s; s_0) - K \overline{C}(s; s_0) \right] \left[ I + K \overline{C}(s_0; s_0) \right]^{-1} \begin{pmatrix} x_{bq} \\ y_{bq} \end{pmatrix}$$

$$C(s; s_0) = R(s; s_0) \left[ I - R(s_0; s_0) \right]^{-1}$$

$$\overline{C}(s; s_0) = \begin{bmatrix} -C_{12} & C_{14} \\ -C_{32} & C_{34} \end{bmatrix}, \text{ normal quadrupole}$$

$$\overline{C}(s; s_0) = \begin{bmatrix} -C_{14} & -C_{12} \\ -C_{34} & -C_{32} \end{bmatrix}, \text{ skew quadrupole}$$

✓ includes closed orbit effects of $\Delta K$ (both kick and position shift)
✓ includes optics effects of $\Delta K$ (change in closed orbit response matrix)
✓ fits both planes simultaneously, including coupling

BBA Data Analysis (2)

Difference orbit fits
(blue = measured; red = fit)

Fitted vertical beam-to-quadrupole offsets (Ybq) averaged at each bump setting

QF2R.12: Y-bump = +100.0 μm, ltrim = +6.0 amp
Xbq = +117.4 ± 7.0 μm, Ybq = +580.2 ± 10.1 μm

Y-bump setting #1
Ybq = +265.3 ± 6.7

Y-bump setting #2
Ybq = +426.7 ± 8.1

Y-bump setting #3
Ybq = +499.4 ± 7.0

Y-bump setting #4
Ybq = +578.2 ± 8.4
BBA Results (1)

- Measured offsets are large (» 100 µm) compared to survey alignment (< 100 µm)
- Average error on measured offsets is small (< 10 µm) ... offsets are stable
- Separate tests have shown that offsets come from the BPM electronics
BBA Results (2)

Residual Vertical Dispersion After Emittance Tuning

- **old BPMs; no BBA (Nov-2002)**
  - $\eta_y^{rms} = 5.8$ mm
  - $\epsilon_y > 10.5$ pm

- **new BPMs; no BBA (Mar-2003)**
  - $\eta_y^{rms} = 4.2$ mm
  - $\epsilon_y = 6 - 10$ pm

- **new BPMs, BBA (May-2003)**
  - $\eta_y^{rms} = 1.7$ mm
  - $\epsilon_y = 3.5 - 5$ pm
Conclusions and Future Prospects

- BBA has been successfully used at the KEK-ATF Damping Ring to determine BPM offsets.

- Use of these BPM offsets has contributed to the achievement of < 5 pm vertical emittance, which is better than needed for the present GLC/NLC Damping Ring design.

- This BBA analysis allows us to use the quadrupoles themselves as BPMs, determining the actual beam offsets w.r.t. the magnetic center of each quadrupole; in the proposed GLC/NLC Damping Rings, magnet movers will be used to center the quadrupoles on the closed orbit.

- The analysis developed at the ATF has also been used successfully at PEP-II and will continue to be used.

- We hope next to demonstrate high resolution BBA of the ATF sextupoles, with the aim of further reducing the vertical emittance.
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