APPENDIX

Chapter A: Implementing quad-as-BPM position measurement

The process for collecting quadrupole reponse data and converting to quadrupole position data has been automated and stream-lined into the UMER control system. The procedure is conceptually straightforward. For a specified quadrupole, the algorithm:

1. Grabs a list of functioning BPM's, chooses downstream BPM for measurement of quad response (excluding pairs listed in Table **??**).

2. Varies quadrupole over a preset range of ± 0.09 A around nominal set-point, using 5 data points total to calculate response.

3. Calculates response slopes $\frac{\Delta X_{BPM}}{\Delta I_{quad}}$ and $\frac{\Delta Y_{BPM}}{\Delta I_{quad}}$ by applying linear least squares fit to response data.

4. Runs VRUMER simulation 9 times to calculate simulated response slope for given quad-BPM pair. Divide x_q, y_q by response slope to determine slope-to-position calibration factor.

5. Applies VRUMER calibration factor to measured response slope to return measured position in quad.

6. Calculates error to response slope, including 95% confidence interval to slope, as well as quad-BPM separation relation to phase advance, according to Eq. ??.

Arguably, the slope-to-position calibration factor could be generated using a matrix-based tracking technique (as outlined in [?]) and saved as a look-up table. For a given quad-BPM separation (for 72 quadrupoles there are only 8 possible separations), this number is not expected to change much and this approach would require fewer computations. However, this comes with an added loss of flexibility. The look-up table would have to be recalculated for UMER operating points with different quad focusing strengths or non-FODO orientations. For example, Chapter ?? uses an alternative lattice configuration with half the quads turned off. The time savings for using a look-up table are small. Running VRUMER takes ~ 0.06 seconds, so even for the an entire quad scan (9 points) VRUMER costs ~ 0.5 second per quad. This is negligible compared to the time required to measure BPM response for multiple quad settings.

There is a slight discrepancy with the phase-advance contribution to error bar calculation. The error $\sigma_\sigma \equiv |\sigma_{exp} - \sigma_{sim}|$. Simulated phase advance σ_{sim} is estimated from VRUMER results using NAFF algorithm [1], [2]. Experimental phase advance σ_{exp} is hard-coded to be $\nu_x = 6.636$, $\nu_y = 6.752$ for standard 1.826 A operating point. This will result in erroneaously large error bars for different operating points and should be modified in the future to be more general.

Bibliography

[1] J. Laskar. Frequency map analysis and particle accelerators. *Particle Accelerator Conference, Portland*, 1(2), 2003.

[2] Kevin Pedro. Frequency Mapping Analysis for Nonlinear Dynamics in Particle Accelerators. pages 1–12, 2012.