Steering in CEBAF since January 1, 2000

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Introduction

As of noon August 16, 2006, there had been 4574 “all-saves” taken since January 1, 2000. These allsaves contain magnet, BPM and beam mode information. At my request Anthony Bavuso (coder) and Chris Slominski (QC) created a program, steering_analysis, http://devweb.acc.jlab.org/controls_web/certified/steering_analysis/, to make several checks on data validity, exclude injector-only allsaves, and provide statistical information for each allsave. Horizontal offsets in arcs used for pathlength adjustment (GOF) are included in the X values analyzed. Of the 4574 allsaves, 3826 were taken with tune or CW beam beyond the injector. 345 of these had mean values of X and Y orbits outside [-0.5, 0.5] and/or fewer than 50 BPMs after 1L02 and were excluded from further analysis. The 3481 remaining allsaves will be examined in this tech note. RMS values for X and Y planes are 1.25 and 1.15 mm respectively. There is no significant difference between rms values for tune and CW allsaves. Maximum and minimum values are concentrated in spreaders and recombiners. These were truncated at +­15mm in this analysis but extend to +­22mm in the beam pipe offset dominated BPMs [123]S00 and [123]R11 which were placed after/before the two common dipoles in the first three passes a few years ago. The large excluded values are found in the error logs also output by steering_analysis. These BPMs were salvaged from the FEL when it switched from 2” to 3” beam pipe, are mounted on 2” beam pipe, and are valid to +­23mm. No further analysis of values outside the range [-15,15] has been made.

Distributions

This tech note consists mostly of figures generated with JMP, a data exploration program from SAS. Histograms, box-outlier plots and normal quantile plots are provided. Normal distributions are fitted to the histograms. Normal distributions are straight lines on the normal quantile plot, making it easier to see if one has two normal distributions with different widths, one normal distribution with non-normal tails, or something altogether strange.

The first nine figures deal with the entire post-injector machine. The final ten deal only with the region beginning with 6S01 and ending at AT05, excluding 6R11. [1-6]S00 and [1-6]R11 BPMs are associated with the common dipoles in the spreaders and recombiners and are some of the outliers in the first six plots.
Figure 1. mean and standard deviation for X plane for all saves, CW and tune. Means limited to +0.5 by allsave selection. Operations does a very good job steering the machine to mean orbit zero. More than 80% of the means are under 200 microns (quantile table).
Figure 2. RMS and number of post-injector BPMs in the data sets, X plane. 10% of the RMS values are above 1.5 mm. RMS is calculated about zero while standard deviation is calculated about the mean, so RMS is more appropriate physically.
Figure 3. Minimum and maximum values of X for each allsave, truncated at ±15mm. Most of these are in the spreaders, recombiners or nA01. About 40% of the BPMs appear at least once in the lists, however.
Figure 4. Mean and standard deviation for Y plane.
Figure 5. RMS and number of post-injector BPMs, Y plane, 3841 allsaves
Figure 6. Min and max Y plane values, truncated at +-15 mm. Most of these are in the spreaders, recombiners or nA01. About 40% of the BPMs appear at least once in the lists, however.
Figure 7. RMS for X and Y planes for tune allsaves
Figure 8. RMS for X and Y planes for CW all saves. Means for both planes differ with tune beam values (figure 7) only in second decimal place.

RMS values did not change significantly from year to year either.
Figure 9. Minimum and maximum X values as a function of number of valid BPMs in the allsave. The vertical bands correspond roughly to number of passes with beam in the allsave. The group at the far right represents five pass machines with beam in the halls. This suggests, together with the Quantile tables in figures 3 and 6, that an absolute max of 4 mm is achievable with present hardware, improved software and improved procedures. 188/3481 allsaves meet this criterion, but only 30 of these are five pass machine saves, under 1% of allsaves in the set.
Figure 10. Mean and standard deviation for X plane from 6S01 through AT05. Width of X mean distribution is in part due to horizontal beam offset for pathlength adjustment.
Figure 11. Number of BPMs and rms for X plane 6S01-AT05. Tune beam data sets have BPM values for four linacs (7-10) while CW beam data sets have only two linacs, the “long pulse averages” for NL and SL.
Figure 12. Minimum and maximum values for X plane, 6S01-AT05.
Figure 13. Mean and standard deviation for Y plane, 6S01-AT05
Figure 14. Number of BPMs in data set and rms value for Y orbit, 6S01-AT09
Figure 15. Minimum and maximun Y plane values for 6S01-AT05. 340 of these data sets have all BPM values between [-3,3]mm, about 10%. These are displayed in the next four figures. ~3/4 of them are CW data sets.
Figure 16. Mean and rms values for X plane when data sets are constrained to have all BPM values within +3mm for 6S01-AT05. Standard deviation and Nx will not be plotted, unlike earlier sets of plots.
Figure 17. Minimum and maximum X values, 6S01-AT05, for data sets selected to have entire orbit in this region within ±3mm. About 10% of the data sets considered meet this criterion. Most of these minima/maxima are located in the linacs, spreaders and nA01.
Figure 18. Mean and rms values for Y plane when data sets are constrained to have all BPM values within $\pm$3mm for 6S01-AT05.
Figure 19. Minimum and maximum Y values, 6S01-AT05, for data sets selected to have entire orbit in this region within $\pm 3$mm. About 10% of the data sets considered meet this criterion. Most of these minima/maxima are located in the linacs, spreaders and nA01.
Summary and recommendations

Analysis of 6.5 years of allsaves provides information on how well CEBAF may be steered given present hardware (BPMs and correctors) and software complement. Orbit was kept within $\pm 4$ mm through the entire five pass machine in only 1% of allsaves examined here. Orbit was kept within $\pm 5$ mm in 3% of these allsaves. For the region of the machine between 6S01 and AT05, 10% of the orbits remained within $\pm 3$ mm. The regions with largest excursions, the spreaders and recombiners, are under-instrumented and the values measured may not be the largest in the accelerator. Additional BPMs cannot be installed in the S/R common dipoles and before/after YR pairs due to vacuum vessels which cannot be changed without magnet disassembly.

Automated steering of multiple S/R pairs in concert with steering one linac with five beams of differing energies will likely require the assistance of those who specialize in optimization, for example faculty in the Operations Research department at William & Mary. Algorithms developed in the accelerator community for circular machines and single pass linacs do not meet the needs of the unique CEBAF and FEL machines. Since recirculating linacs are being proposed and/or built in several locations worldwide, this is an important topic for research. The work might be staged: multipass linac steering only; multipass linac steering with fourth and fifth pass S/R; simultaneous steering of all five S/R and the associated linac.

Debugging the software to “quad center” BPMs is necessary for improvement of the real orbit in the machine. Once debugged, it should be applied to all BPMs associated with quads. Resurvey of BPMs associated only with dipoles may also be desirable: S00, T00*, R11, etc.

The program used to generate the data examined here has a configuration file which allows the exclusion of individual BPMs or machine regions via regular expressions. If there is interest in looking at regions other than those shown here this may be accomplished with a couple of days turnaround including statistical analysis.

A request has been made to the controls group to provide computed EPICS signals (PVs) of rmsX and rmsY once per minute per art++ machine segment, 18 segments. Values for the entire post-injector machine will also be computed. These will be archived and made available to Ops for guidance during machine setups. The R11/S00 BPMs in the first three passes might be excluded from the PVs as the values in these are always large yet CASA and Ops do not want to attempt to find another solution compatible with all five passes for the common dipoles they monitor. Goals for Ops and CASA for end 2007 might then be no rms values above 1.5 mm and mean rms value 1mm. The latter is now about the 20% percentile. Keeping min/max values under 7mm outside the R11/S00 BPMs is another worthwhile goal for end-2007.