LANSCE-LINAC BEAM-CENTROID JITTER IN TRANSVERSE PHASE SPACE*

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Abstract

In order to characterize the beam-centroid jitter in transverse phase space, sets of position data of the 100-MeV H^+ beam and 800-MeV H^- beam were taken in the transport lines of the Los Alamos Neutron Science Center (LANSCE) accelerator complex. Subsequent data evaluation produced initially puzzling inconsistencies in the phase-space plots from different pairs of beam-position monitors (BPMs). It is shown that very small random measurement errors will produce systematic differences between plots that should nominally be identical. The actual beam-centroid jitter and rms BPM measurement errors can be deduced from the data, and simulations can validate the deductions. The phase-space plots can also reveal the presence of problem beamline components. Examples will be shown.

OVERVIEW

The proposed Materials Test Facility (MTS) at LANSCE can only tolerate minimal beam-position jitter of the 800-MeV H^+ beam at the split target surrounding the samples.

In order to assess the beam-centroid jitter to be expected, position data were taken of the H^+ beam at 100 MeV (H^+ beam is not currently accelerated to 800 MeV) and the H^- beam at 800 MeV. Simultaneous data from three consecutive BPMs allow computation of beam-centroid coordinates in transverse phase space. For the H^+ beam, the first two BPMs were separated by a 1.58-m drift, the third was 1.90 m from the second, with a 22.331° dipole between them. For the H^- beam, all three BPMs were in the same drift, with 2.46 m between the first two, and 6.97 m between the first and last.

Data were taken during the 2005 and 2006 run cycles [1]. The jitter during a macropulse (less than 1 ms) is small compared to the macropulse-to-macropulse jitter. Only the latter is addressed here. The 2005 data consisted of 1-μs samples of horizontal and vertical beam positions at a particular time into a train of macropulses, and simultaneously acquired at all three BPMs. Except for transient behavior during the first ~50 μs, no fundamental differences in the results were observed with data from the beginning, middle and end of the macropulse. Data were typically taken at a low repetition rate, for a number of minutes. Data taken after a number of hours reproduced earlier results. The 2006 data included repeats of the 2005 data, but also data that were averaged over tens of adjacent 1-μs samples in a train of macropulses.

Beam-centroid jitter results from fluctuations in a beamline component that cause beam steering, such as poor power-supply regulation of a dipole, or time-dependent position of a quadrupole (e.g., when the drift tubes of the LANSCE DTL, housing the quadrupoles, execute pendulum-like motions).

For a single such beamline component, beam centroids at downstream locations lie on a line in phase space. With a large number of locations where small time-dependent deflections occur, the beam centroids at downstream locations will occupy ellipses in phase space that are similar to the beam ellipses. This assertion was verified by a simulation of beam jitter due to time-dependent random misalignments of the DTL quadrupoles. Conveniently, then, the beam-position jitter should be proportional to the beam size at the location of interest, and thus small, but with corresponding large jitter in beam angle, at locations with a small beam size (such as the MTS target).

INITIAL DATA ANALYSIS

With simultaneously measured horizontal beam-position values x_1, x_2 and x_3, and known transfer matrix R between the first two BPMs and S between the first and last BPM, the beam-centroid angle at the first BPM can be computed as $x'_{12}=(x_2-R_{11}x_1)/R_{12}$ and $x'_{13}=(x_3-S_{11}x_1)/S_{12}$, thus allowing production of (nominally identical) $x_1x'_{12}$ and $x_1x'_{13}$ scatter plots from the sets of data. The analysis of the vertical data is analogous.

2005 DATA OF 100-MEV H^+ BEAM

A typical data set taken in the H^+ line in 2005 yielded the vertical phase-space plots of Fig. 1, and comparable horizontal phase-space plots.

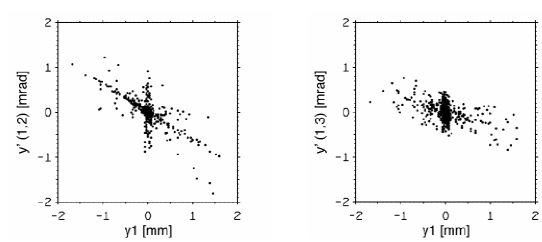

Figure 1: Vertical beam-centroid coordinates at first BPM of 100-MeV H^+ line, computed from data of first two BPMs (left) and from data of first and last BPM (right).

Fig. 1 shows several distinct lines, indicating three to four strong sources of beam deflections in the upstream beamline. The resulting beam jitter amounts to in excess of 1.0 rms of the beam size at the first BPM. Sparking in the 750-kV electrostatic accelerating column was identified as the likely culprit. The phase-space plots thus revealed themselves as a good diagnostic for detecting the presence of problem components.

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More puzzling, though, the two plots of Fig. 1 were expected to look the same but do not actually do so.

2005 DATA OF 800-MEV H^- BEAM

A typical data set taken in 2005 in the H^- line yielded the vertical phase-space plots of Fig. 2, and similar horizontal phase-space plots. The 0.5-rms beam ellipse at the first BPM at the time of data taking is also shown.

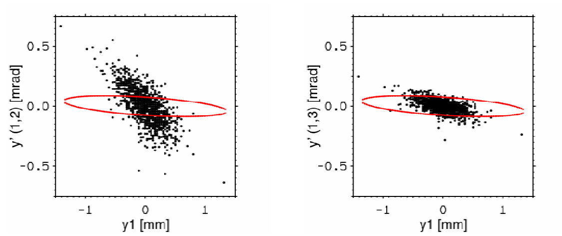

Figure 2: Vertical beam-centroid coordinates at first BPM of 800-MeV H^- line, computed from data of first two BPMs (left) and from data of first and last BPM (right). The 0.5-rms beam ellipse is shown in red.

Fig. 2 exhibits the same puzzling inconsistencies between its two plots as Fig. 1. Also, the ellipses occupied by the beam centroids are not similar to the beam ellipses.

DATA ANALYSIS WITH BPM ERRORS

Here the actual beam position at a BPM is X, the measured position is x, and $x=X+\delta$. Likewise, the actual angle is X', the computed angle is x' and $x'=X'+\delta'$. Thus, with X'_1 being the actual angle at the first BPM $x'_{12}=X'_1+(\delta_2-R_{11}\delta_1)/R_{12}$ and $x'_{13}=X'_1+(\delta_3-S_{11}\delta_1)/S_{12}$. Since x'_{12} and x'_{13} are plotted against x_1, not X_1, δ_1 is a fixed value for each data point, while δ_2 and δ_3 are random values. With a plotted data point shifted horizontally from its actual position by δ_1, the angle is shifted by $-(R_{11}/R_{12})\delta_1$ in the $x_1x'_{12}$ plot and by $-(S_{11}/S_{12})\delta_1$ in the $x_1x'_{13}$ plot. There are additional random shifts proportional to δ_2 and δ_3, respectively. With a transfer matrix T between the second and third BPM the beam-centroid angle at the second BPM can be computed as $x'_{23}=(x_3-T_{11}x_2)/T_{12}=X'_2+(\delta_3-T_{11}\delta_2)/T_{12}$. Since $X'_2=X'_1$, the $x_1x'_{23}$ plot also represents the jitter at the first BPM but without systematic errors. The analysis of the vertical data is analogous.

Assuming that the rms errors are g times larger for individual 1-µs samples than for averaged samples, and that $x^2_{rms}=X^2_{rms}+\delta^2_{rms}$ and $x'^2_{rms}=X'^2_{rms}+\delta'^2_{rms}$ for the averaged samples, and consequently $x^2_{rms}=X^2_{rms}+g^2\delta^2_{rms}$ and $x'^2_{rms}=X'^2_{rms}+g^2\delta'^2_{rms}$ for the 1-µs samples, it is possible to extract the actual jitter and measurement errors from the rms values of the phase-space distributions.

2006 DATA OF 100-MEV H^+ BEAM

By 2006, the accelerating-column electrodes had been cleaned, and the lines had disappeared from the phase-space plots.

The 2006 data with H^+ beam consisted of individual samples and data that were averaged over 100 samples. Thus assuming g=10, horizontal and vertical rms measurement errors of 0.0566 mm for the individual samples were computed, as were the rms parameters and correlations of the actual jitter shown in Table 1. The correlations were computed from the $x_1x'_{23}$ distribution and $y_1y'_{23}$ distribution of the averaged data.

Table 1: Parameters of ellipses containing 1 rms of actual beam-centroid jitter at first BPM of 100-MeV H^+ line.

Horizontal Parameters	Vertical Parameters
X_{rms} = 0.063 mm	Y_{rms} = 0.024 mm
r_{12} = –0.470	r_{34} = +0.384
X'_{rms} = 0.079 mrad	Y'_{rms} = 0.021 mrad

The computed values are reasonable if a simulation of the measurement procedure yields the same results as the data. This simulation consists of choosing actual beam-centroid coordinates at the first BPM based on the parameters of Table 1, computing the actual beam positions at the second and third BPM, adding random measurement errors to the computed X_1, X_2 and X_3 and then computing x'_{12} and x'_{13} from the resulting values.

Fig. 3 shows horizontal phase-space plots derived from data (left) and from simulations (right) for individual samples (top) and averages over 100 samples (bottom). Because the actual beam jitter is on the order of the measurement errors for the individual samples, there is no great difference between $x_1x'_{12}$ plots and $x_1x'_{13}$ plots, and only the former are shown.

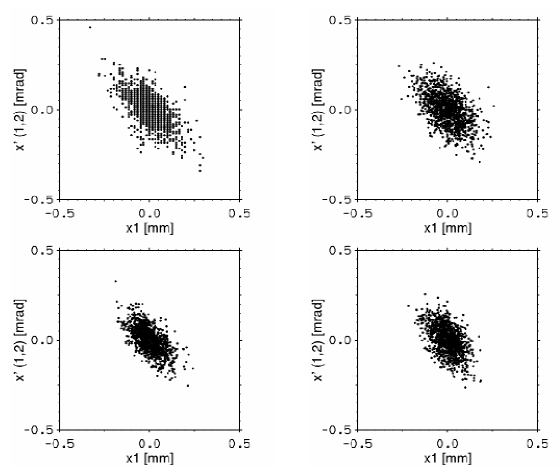

Figure 3: Horizontal beam-centroid coordinates computed from data (left) and from simulation (right), for individual samples (top) and averaged data (bottom) from first and second BPM.

Fig. 4 shows vertical phase-space plots derived from data (left) and from simulations (right). For the individual samples, the measurement errors dominate over the actual jitter, so that the $y_1y'_{12}$ plots (top) and the $y_1y'_{13}$ plots (middle) do not look the same. For the averaged samples, there is no noticeable difference between $y_1y'_{12}$ plots and $y_1y'_{13}$ plots, and only the former are shown (bottom).

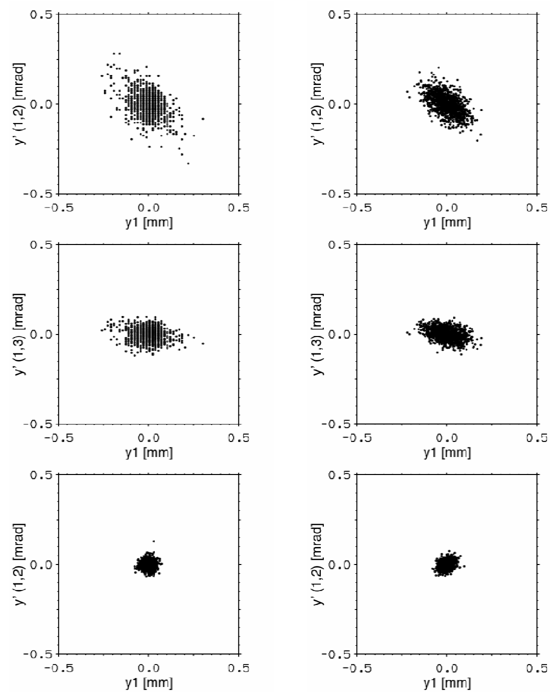

Figure 4: Vertical beam-centroid coordinates computed from data (left) and from simulation (right), for individual samples from first two BPMs (top), individual samples from first and last BPM (middle), and averaged data from first two BPMs (bottom).

Figs. 3 and 4 show that both individual samples and averaged data can be approximately reproduced with simulations using the computed actual jitter and measurement errors, thus validating these numbers.

The beam parameters were not measured in 2006, but two sets of 2005 values are available (which are however considerably different from each other). Based on these 2005 values, the rms of the actual jitter will likely amount to less than 0.2 rms of the horizontal beam size, and less than 0.1 rms of the vertical beam size.

2006 DATA OF 800-MEV H^- BEAM

The 2006 data with H^- beam consisted of individual samples and data that were averaged over 60 samples. A large (1.0 mm rms horizontally, 0.5 mm rms vertically) measurement error manifested itself in about 15% of individual samples, generally at just one of the three BPMs at a time. These data points were excluded when computing the rms values of the plots from individual samples, and (using $g=\sqrt{60}$) rms measurement errors of around 0.1 mm for individual samples and the actual-jitter rms parameters and correlations of Table 2. Both types of measurement errors were included in the simulations.

As an example, Fig. 5 shows horizontal phase-space plots derived from data (left) and from simulations (right) for individual samples. Agreement between data and simulations is not perfect but certainly supports the claim that the presence of measurement errors largely explains the discrepancies between plots obtained with different combinations of BPM data.

Table 2: Parameters of ellipses containing 1 rms of actual beam-centroid jitter at first BPM of 800-MeV H^- line.

Horizontal Parameters	Vertical Parameters
X_{rms} = 0.146 mm	Y_{rms} = 0.0916 mm
r_{12} = –0.345	r_{34} = –0.202
X'_{rms} = 0.0124 mrad	Y'_{rms} = 0.00967 mrad

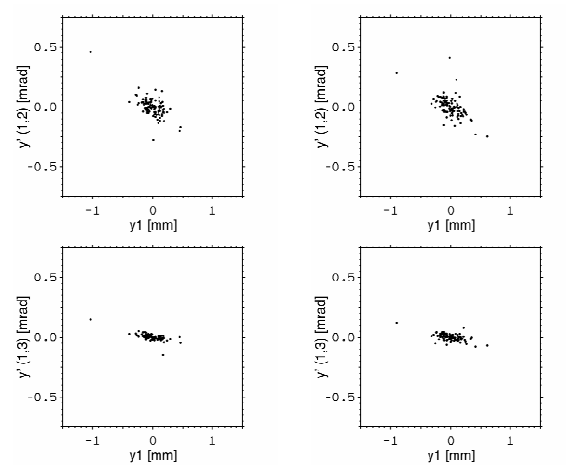

Figure 5: Vertical beam-centroid coordinates computed from data (left) and from simulation (right), for individual samples from first two BPMs (top) and from first and last BPM (bottom).

The beam parameters at the first BPM were not measured in 2006, but available 2005 data indicate that the rms jitter is less than 0.1 rms of the horizontal beam size, and less than 0.07 rms of the vertical beam size.

SUMMARY

By producing phase-space plots of beam-centroid coordinates one has available a diagnostic to determine the presence of problem components in the beamline that cause large time-dependent deflections of the beam.

The discrepancies between nominally identical plots have been resolved and can be attributed to measurement errors. When producing phase-space plots of beam-centroid coordinates from BPM data, averaged data should be used to reduce the measurement errors. One does not obtain the actual beam jitter unless the measurement errors are smaller than the actual jitter. When plots from different combinations of simultaneous BPM data look the same, these plots represent the actual jitter. Otherwise, computations are necessary to determine the actual jitter and the measurement errors.

For the beam at the MTS target, the rms of the jitter will likely be less than 0.2 rms of the horizontal beam size, and less than 0.1 rms of the vertical beam size.

REFERENCES

[1] J. D. Gilpatrick et al, "H^+- and H^--Beam Position and Current Jitter at LANSCE," these proceedings.

