TEVATRON LATTICE FUNCTION MEASUREMENT USING TBT DATA

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Abstract

The Fermilab Tevatron operates in two modes. The 900 GeV collider mode requires low beta lattice function at the BØ and DØ interaction point to enhance luminosity. The Fixed-Target mode uses the 39th harmonic quadrupoles to control the horizontal plane half integer stop band for slow extraction of 800 GeV protons. The lattice function measurements using TBT BPM data were conducted at the end of collider run 1b and during the Fixed-Target run that followed. The results of analysis and their comparison with calculation are reported in this write-up.

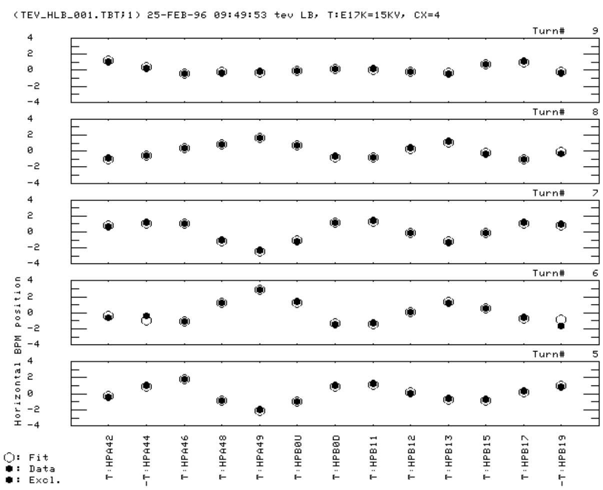

Figure 1. The horizontal BPM positions around the BØ collision point.

1. INTRODUCTION

With Turn-By-Turn (TBT) BPM data it is possible to simultaneously extract beta and alpha lattice function. This technique had been reported elsewhere [1] with data taken from the Fermilab Main Ring. The process of fitting for beam position and angle provides useful diagnostics information as well as insights to the phase space dynamics and will be covered briefly.

Two sections in the Fermilab Tevatron are equipped with TBT hardware. One is around the collision point BØ of CDF experiment. Data from this section is used mainly for analysis of collider lattice function. The other section is at E1 and E2 where the effect of low beta squeeze is expected to be zero. This section is also useful for Fixed-Target lattice function analysis because of the absence of 39th harmonic quadrupoles which is ramped during the resonance extraction.

It is the intention of this write-up to show that this technique produces results that is in good agreement with calculation. The ability of this technique to measure effects of changes made elsewhere on the machine is clearly demonstrated in the case of Fixed-Target data.

2. DATA

The Collider mode data was taken with protons only. The machine was brought to the low beta collision lattice after reaching 900 GeV energy. The pinger was fired to excite betatron oscillation. The proton beam was aborted promptly after the completion of TBT data sampling. The horizontal and vertical plane data were taken in separate beam cycle. Data from other study of 900 GeV proton beam at normal lattice will be shown as comparison.

For the Fixed-Target operation horizontal plane half-integer resonance is the means to slow-extract protons from Tevatron. At 800 GeV flat top energy the horizontal tune was moved to 19.458 to prepare for the extraction. Instead of ramping the 39th harmonic quadrupole current, as was done during normal operation, a fixed setting was used to produce a +10 unit in sine driving term in one case and -10 units in cosine driving term in another.

3. ANALYSIS

Two steps are needed in the analysis of TBT BPM data. The first is to fit for the beam position and angle at a given reference location. For the Collider data BØ interaction point is a logical choice. Each turn of BPM data yields a phase space point. The next step is to fit the elliptical trajectory traced out by the successive phase space points in order to extract the lattice function.

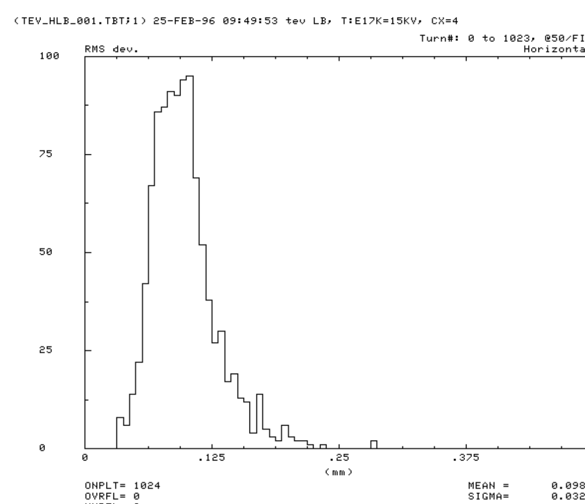

Figure 2. Histogram of horizontal BPM RMS deviation from the fitted positions.

3.1 Fitting BPM data

Figure 1 shows examples of the horizontal data at each BPM locations for 5 consecutive turns. The expected BPM positions, calculated from the fitted beam position and angle at the reference location, are shown in open circles. In Figure 2 is the histogram of RMS deviations between data and fitted positions, evaluated at each turn. A mean of 0.098 mm and width of 0.033 mm from the histogram is shown at the lower right corner. This is considered acceptable given the Tevatron BPM digitizer resolution of 0.15 mm and the noise contribution.

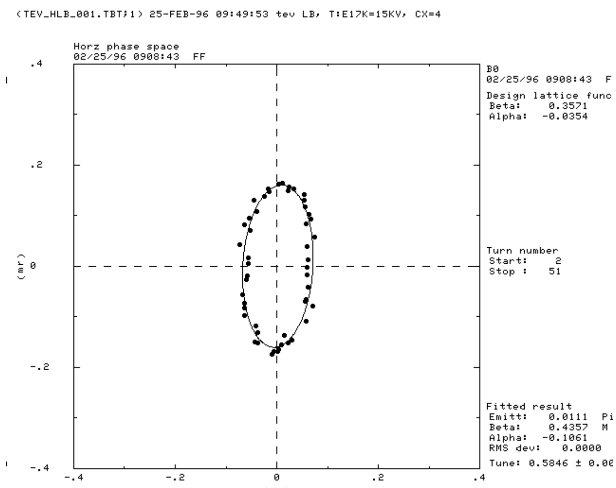

Figure 3. Fitted phase space coordinates in horizontal plane.

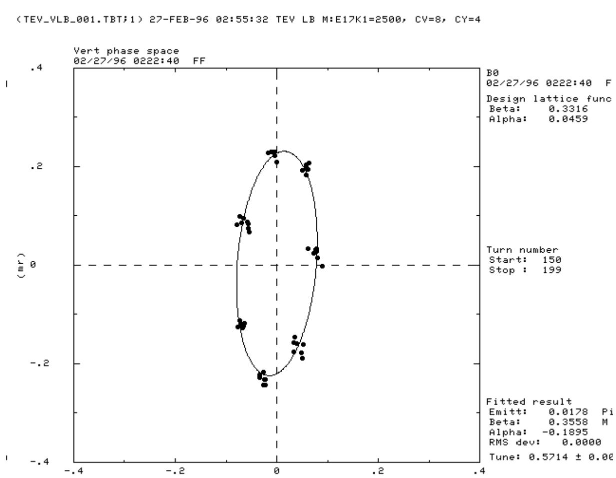

Figure 4. Fitted phase space coordinates in vertical plane.

3.2 Fitting Phase space ellipse

Figure 3 shows a phase space plot of fitted x-x' coordinate at BØ for a fixed number of turns with the fitted ellipse. The design lattice function is listed at the upper right hand corner. The lattice function inferred from the fitted ellipse is shown at the lower right corner. The area enclosed by the ellipse is shown as emittance. Also shown is the tune calculated from the normalized TBT phase angles, not from the FFT algorithm. About 20 successive turns are enough to fit for the lattice function and get a tune resolution of 0.002, statistically speaking. The corresponding plot for vertical plane is in Figure 4.

4. LATTICE FUNCTION

The set of transformation matrices used for fitting BPM data can also be used to propagate fitted lattice function elsewhere. By doing so it is possible to compare the result with design calculation at other locations.

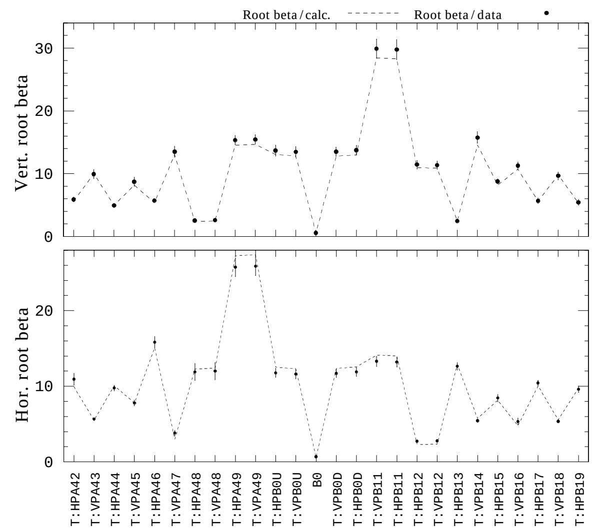

Figure 5. The root beta plot of data and calculation. Error bars represent the 3-sigma variation in measured values.

4.1 Collider low beta lattice data

Figure 5 shows the horizontal and vertical square-root beta function around the BØ location. The connected dash line represents the design values and the solid dots are the measured. The variation of the measured data is shown as vertical line at a 3-sigma level for clarity. Both horizontal and vertical data are in good agreements with the calculation except at high beta locations.

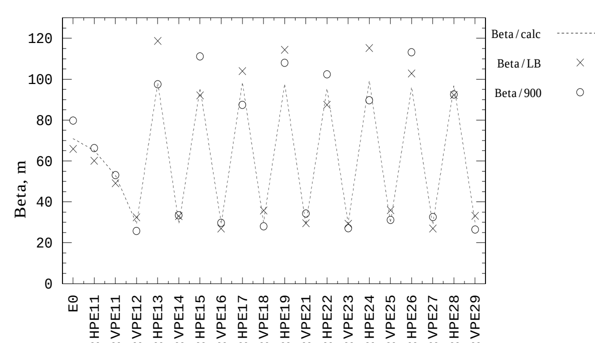

Figure 6. Section E1 & E2 horizontal beta plot of the low beta data, the 900 GeV data, and the design values.

The horizontal plane beta measurement results for section E1 and E2 are shown in Figure 6. The ×'s are results from low beta lattice data. The circles are from flat 900 GeV lattice data included for comparison. The connected dash line represent the design calculation. The visible differences between the two measurement results would imply non-local low beta squeeze at the interaction regions. The vertical plane results do not differ as much and will not be shown.

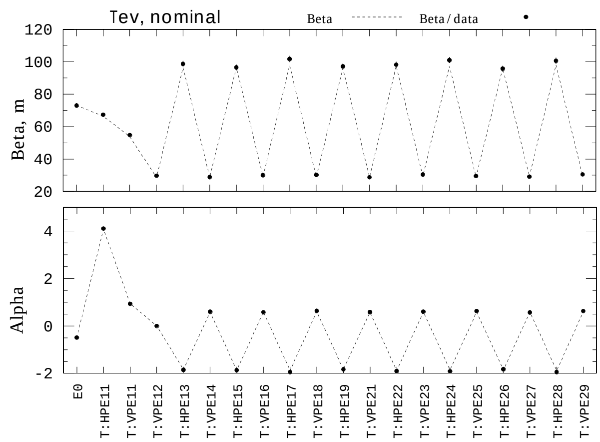

Figure 7. Fixed-Target lattice plot of data and calculation.

4.2 *Fixed Target mode data*

For the fixed-target mode only the data from the horizontal plane is available and only the data from section E1 & E2 will be shown. Figure 7 shows the result from data taken before the 39th harmonic quadrupoles were changed. The upper plot is for beta function and lower plot for alpha function. Open circles are the measured values and connected dash line represents the calculation. In much the same format, the results from data taken with the harmonic quadrupoles giving +10 units in sine driving term are shown in Figure 8 and results from data taken with -10 units in cosine driving term are shown in Figure 9. In all plots excellent agreements between measurement and calculation are clearly demonstrated.

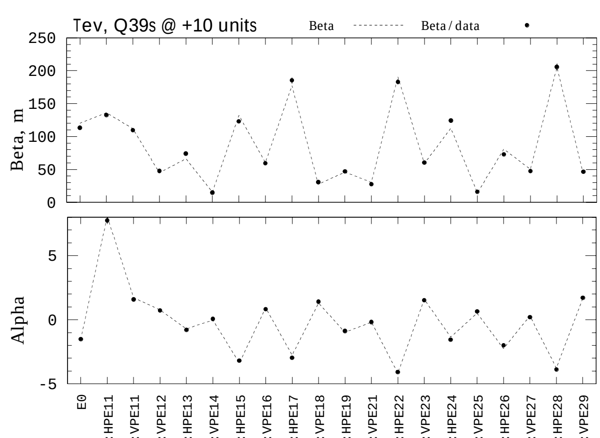

Figure 8. Lattice plot of data and calculation with harmonic quadrupoles giving a +10 unit sine driving term.

It is important to point out that all three sets of data were analyzed using a single set of transformation matrices, derived from the lattice function shown in Figure 7. This is not a problem as long as neither section E1 nor E2 includes any of the harmonic quadrupoles. Without knowing the changes made to the harmonic quadrupoles the analysis nevertheless reported the correct lattice function. This is the power of TBT analysis and is what set it apart from other analysis method.

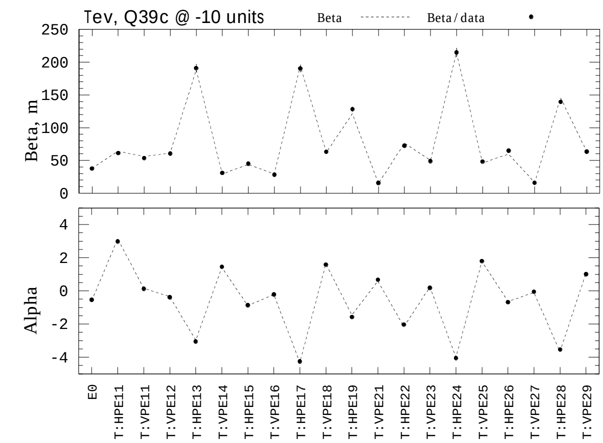

Figure 9. Lattice plot of data and calculation with harmonic quadrupoles giving a -10 unit cosine driving term.

5. CONCLUSION

The result of TBT BPM data analysis for either the collider mode or Fixed-Target mode exhibit excellent agreement with calculation which takes all necessary factors into account. The tune of the machine is a by-product of analysis not a necessary information.

The data shown represent the first time ever TBT data for Tevatron was taken at low beta lattice. The possibility of quenching by pinging the beam is an extra burden during study. On the other hand, the TBT technique offers a very unique measurement result and is well worth the effort to prepare the study and carry it out carefully.

It is important to keep in mind that no technique is perfect and that using inaccurate transformation matrices will result in serious systematic error. The RMS deviation from fitting BPM data contains a wealth of information and should be given full attention.

6. ACKNOWLEDGMENTS

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REFERENCE

[1] M.-J. Yang, "Lattice Function Measurement with TBT BPM Data", in Proc. PAC 1995, pp. 2500.