LONGITUDINAL PHASE-SPACE TOMOGRAPHY IN RHIC*

C. Montag, N. D'Imperio, R. Lee, J. Kewisch, and T. Satogata, BNL, Upton, NY 11973, USA

Abstract

In recent years, longitudinal phase-space tomography has become a useful diagnostic tool in the domain of particle accelerators. A computer code has been developed to visualize and quantify dynamic effects in longitudinal phase space, like transition crossing and rebucketing. This code is capable of reconstructing the longitudinal phase space distribution during turn-by-turn parameter changes such as RF phase and voltage jumps. This paper describes the reconstruction code as well as recent applications at the Relativistic Heavy Ion Collider (RHIC).

1 INTRODUCTION

To reconstruct the full n-dimensional picture of an object, tomography uses a set of (n-1) dimensional projections of this object, taken from different angles spanning at least 180 degrees. In the case of a particle bunch in an accelerator, this rotation is naturally provided by the phase space dynamics. However, particularly in the longitudinal phase space the dynamics is intrinsically nonlinear with the rotation frequency (synchrotron frequency) being a function of the phase space amplitude; it therefore does not simply resemble a rigid, rotating object. To overcome this difficulty, the exact equations of motion have to be taken into account [1]; this is realized by tracking test particles that are equally distributed in phase-space. These test particles are sorted into the $N_{\rm bins}$ bins that correspond to the binning of the measured profiles each time a profile i was obtained by the wall current monitor. Each particle k is therefore assigned a bin number $N_i^{\rm bin}(k)$. The number of test particles in the jth bin at the time the ith profile was taken, $N_{i,j}^{\rm population}$, is determined. Since situations such as transition crossing or rebucketing involve turn-by-turn RF parameter changes, parameter changes have also been implemented in the tomography code.

During the tomographic reconstruction process following the tracking, an "intensity" I is assigned to each test particle according to the measured longitudinal bunch profiles, using an iterative back-projection algorithm [2]. This is done such that the "intensity" of all test particles that could potentially have contributed to a certain profile bin j at a specific time when the ith profile was taken is increased by the same amount. This increment $\Delta I_{i,j}$ is determined as

$$\Delta I_{i,j} = \frac{h_{i,j}^{\rm meas}}{N_{\rm profiles} N_{i,j}^{\rm population}}, \qquad (1)$$

where $h_{i,j}^{\rm meas}$ is the measured profile height of the jth bin in the ith profile, and $N_{\rm profiles}$ is the total number of profiles used for the reconstruction.

After this has been done for all profiles, projections of the resulting distribution are calculated that correspond to the profiles measured by the wall current monitor. The difference of measured and reconstructed profiles is then iteratively back-projected.

The evolution of this discrepancy between measured and reconstructed profiles during the iterative process may then be used as a quantitative measure of the quality of the reconstruction, thus allowing for parameter fitting [1].

2 TRANSITION CROSSING

During acceleration of gold beams from injection ($\gamma = 10.5$) to flat-top ($\gamma = 107$), the transition energy of $\gamma_t \approx 23$ has to be crossed. This is done by flipping the sign of a set of specially-designed quadrupoles, resulting in a γ_t jump of $\Delta\gamma_t \approx 0.6$ within $35\,\rm msec$ [3]. During the RHIC 2001 run, these quadrupoles were kept at a constant field around transition energy, which resulted in some optics changes as the beam energy increased, making tomographic reconstruction more difficult. The RF phase was shifted by 180 degrees at the same time as the γ_t quadrupoles changed sign.

During this process, a slight RF bucket mismatch occurs, resulting in a longitudinal quadrupole oscillation after transition crossing, as shown in Figure 1. About $0.45\,\rm sec$ after transition, a fast instability leads to partial beam loss if the bunch intensity exceeds a certain limit. Later in the RHIC 2001 run, this instability was successfully cured by increased Landau damping using octupoles [4].

While these effects are already somewhat visible using mountain range plots of subsequent longitudinal bunch profiles, as shown in Figure 2, they are best illustrated using tomographic phase-space reconstruction, as depicted in Figure 3. $0.5\,\rm sec$ before transition the beam appears well matched, while the longitudinal mismatch is clearly visible $0.3\,\rm sec$ after γ_t. After the fast instability has occured, the core of the bunch is destroyed, leading to a double-peak structure. Though the double peak appears clearly in the corresponding mountain range plot, Figure 2, the depth of the "hole" in the center can only be detected by tomographic phase-space reconstruction.

Since the detailed dynamics of the instability is still unknown, the phase-space plots presented in Figure 3 are reconstructed from a small number of profiles each, spanning some 270 degrees of phase-space rotation for each plot, rather than using the full turn-by-turn parameter change capability of the code. The latter is foreseen for the upcoming

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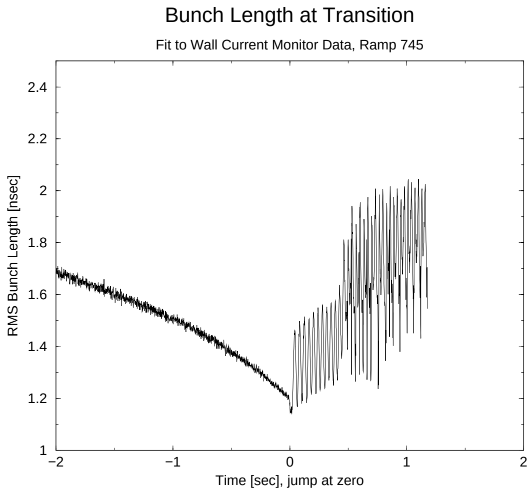

Figure 1: RMS bunch length during $3.2\,\mathrm{sec}$ around transition in the RHIC Yellow ring, as obtained from a gaussian fit to longitudinal bunch profiles measured by the wall current monitor. After transition crossing, a slight mismatch occurs. A fast instability sets in about $0.45\,\mathrm{sec}$ after the jump.

RHIC run, when the γ_t quadrupoles will be kept at a constant strength rather than a constant field, resulting in fixed optics around transition.

3 CONCLUSION

Tomographic phase-space reconstruction has been successfully applied to transition crossing in RHIC. However, the full turn-by-turn parameter change capability of the code has not been used yet. For the upcoming RHIC run, a slightly different γ_t jump scheme will keep the machine optics constant before and after the jump, so only a sign change of the γ_t quadrupoles will occur near the transition energy. We plan to to apply the code to a larger set of profiles, spanning the entire transition jump. This should give detailed insight into the transition crossing process itself, helping to significantly improve RF bucket matching and longitudinal emittance preservation.

We also plan to develop the code into an online control room application, thus giving the RHIC operators a tool to judge the efficiency of the γ_t jump.

4 ACKNOWLEDGEMENTS

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5 REFERENCES

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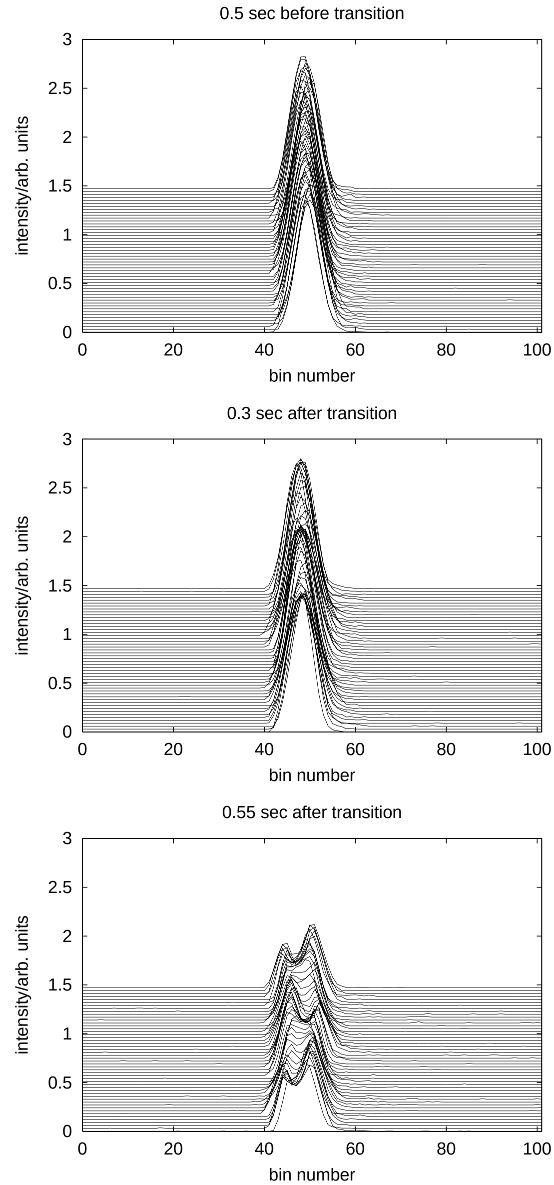

Figure 2: Mountain range plots of logitudinal bunch profiles, obtained by the wall current monitor $0.5\,\mathrm{sec}$ before (top), and $0.3\,\mathrm{sec}$ (middle) resp. $0.55\,\mathrm{sec}$ (bottom) after transition crossing. The time between profiles corresponds to 125 revolutions in RHIC ($16\,\mathrm{msec}$).

[3] J. Kewisch, C. Montag, to be published

[4] C. Montag, J. Kewisch, D. Trbojevic, F. Schmidt, to be published

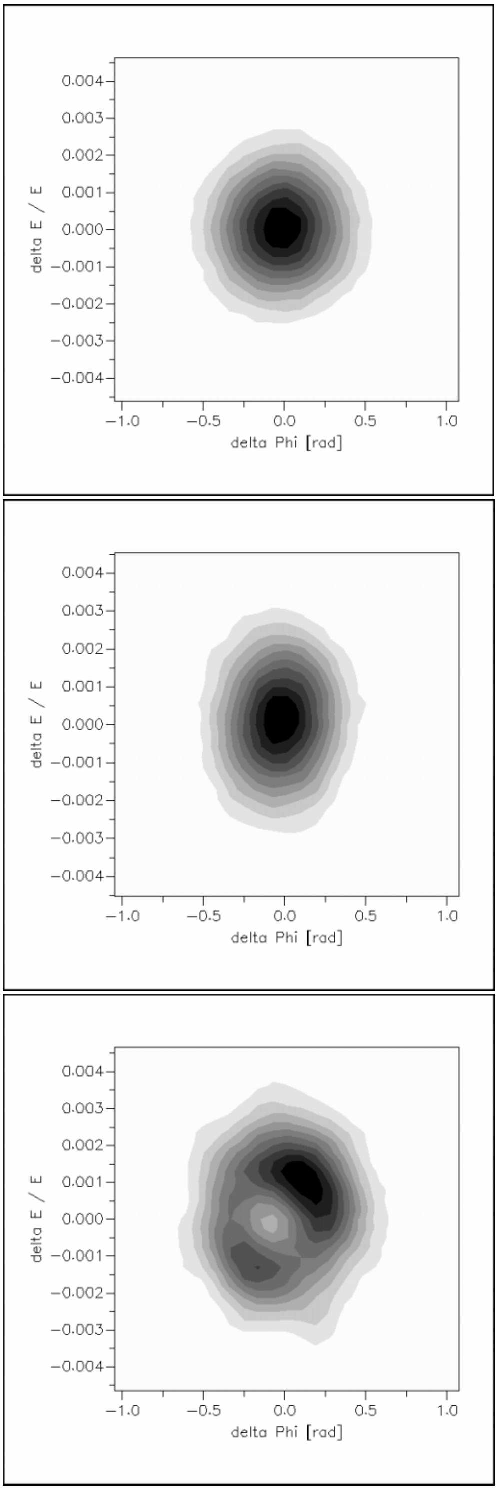

Figure 3: Reconstructed longitudinal phase-space densities around transition energy. Before the γ_t jump, the bunch is perfectly matched (top), while after the jump a slight mismatch occurs, resulting in an elliptical distribution (middle). The bottom plot depicts the distorted phase-space distribution $0.55\,\mathrm{sec}$ after transition, which is about $0.1\,\mathrm{sec}$ after a fast instability destroyed the core of the bunch.