# Turnplot — A Graphical Tool for Analyzing Tracking Data *

V. Paxson† and L. Schachinger†
Cornell Electron Storage Ring
Cornell University
Ithaca, NY 14853

## Abstract

We have developed an interactive graphical interface for exploring turn-by-turn data. A variety of plots are available, not only the traditional phase space plots and Fourier Transforms, but also plots of tune as a function of amplitude and of tunes on a resonance diagram so that resonance-crossing is easily diagnosed. Multiple particles and groups of particles can be plotted together or separately, and synchrotron sidebands can be identified in data that includes synchrotron oscillations. The program is written in C++ and designed to make it relatively easy to accommodate different tracking data formats. We have found turnplot to be a useful tool in dynamic aperture studies, since it gives insight into the reasons for particle loss.

## Introduction

Often tracking and dynamic aperture studies are done "blind"—particles are tracked with varying amplitudes until one is lost before the specified number of turns, and the largest-amplitude particle which survives defines the dynamic aperture. This method is applied without any insight into the reasons for particle loss — Is a resonance being crossed? What is the tune shift with amplitude? What Fourier components are prominent in a frequency analysis of the motion? At times the effect of a resonance is missed because the step in particle amplitude is too large. Our intent in developing Turnplot was to shed some light on these issues.

Turnplot is written using InterViews [1], a freely available X11 graphics toolkit written in C++. The input file is simply an ascii file of particle coordinates for each turn, with a short header at the front which contains the Twiss parameters at the tracking point, the number of particles and turns, and a title for the plots.

To demonstrate the capabilities of turnplot, we will show several plots from a tracking run using a CESR lattice.

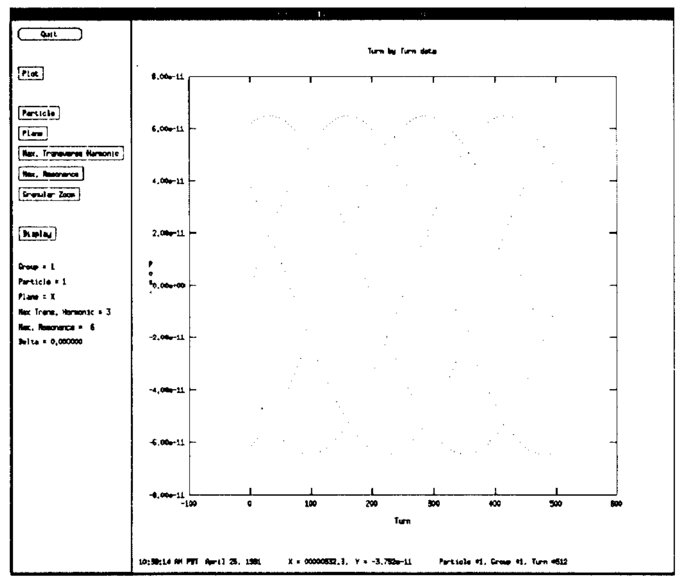

Figure 1: A plot of amplitude *vs.* turn number

## Overview of User Interface

The pull-down "Plot" menu near the upper left corner in Figure 1 allows the user to choose from the available plots: Turn-by-Turn, Phase Space, Normalized Phase Space, Smear, FFT, Tune *vs.* Amplitude, and Resonances. For a given plot, one uses the pull-down Particle menu to choose which particle to view, or whether to view all particles superimposed on the same plot. All plots allow zooming with the mouse. Pointing at the objects in the plot causes them to identify themselves below the plot — for instance, a point might tell you which particle and turn number it is associated with, or a resonance line which linear combination of tunes it represents.

## Example Plots

Figure 2 shows a plot of normalized phase space with all particles selected, which results in the points for all tracked particles being displayed on the same plot. It is easy to tell which particle produced which contour by pointing at that contour with the mouse. One can also plot any one particle using the Particle menu. The appearance of a

*Work supported by the National Science Foundation.
†Now at Lawrence Berkeley Lab, Berkeley, CA 94720

0-7803-0135-8/91$01.00 ©IEEE

structure with 5-fold symmetry indicates that one of the particles is near a fifth-order resonance.

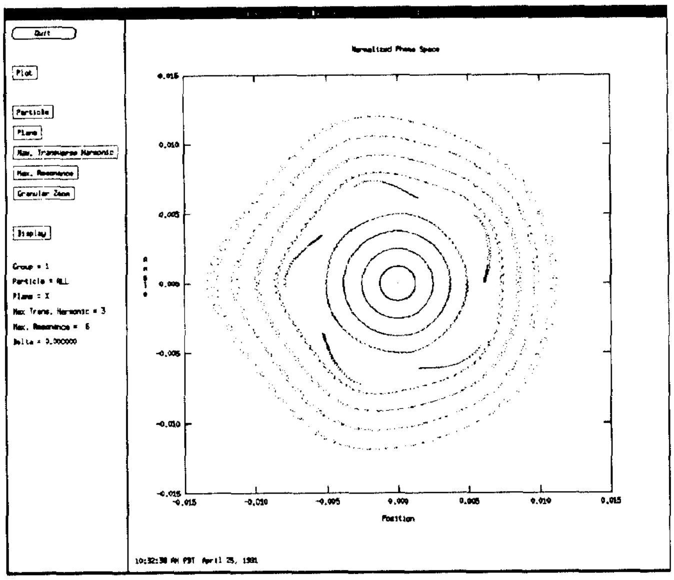

Figure 2: A normalized phase space plot, with all particles selected.

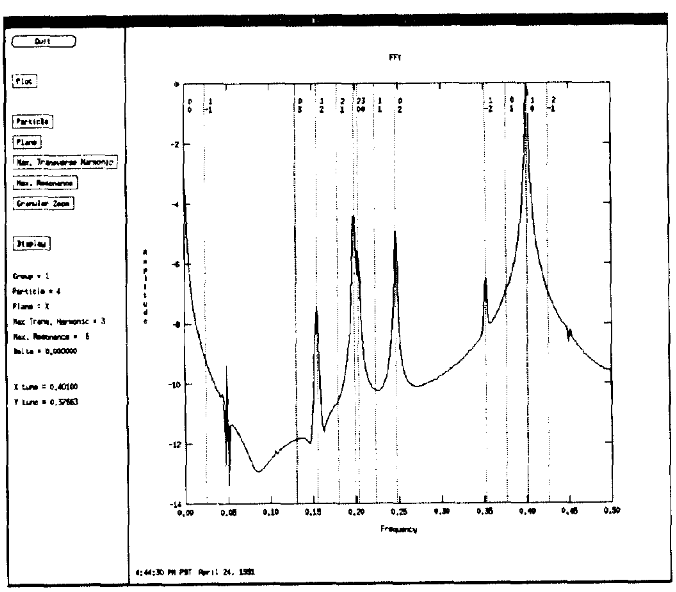

Figure 3: The Fourier Transform of the motion.

Figure 3 shows a plot of the Fourier Transform of the tracking data. A sine window has been applied to the data before the transform is done, and peaks are found as prescribed in [3]. The tunes are identified as the peaks in X and Y, and linear combinations of these tunes are indicated on the plot by vertical lines. If the data contains synchrotron oscillations, the synchrotron tune is found in the same way, and the linear combinations will automatically include that tune, as well, as seen in Figure 4. The maximum sum of the coefficients of the two transverse tunes and of the synchrotron tune can be selected using pull-down menus.

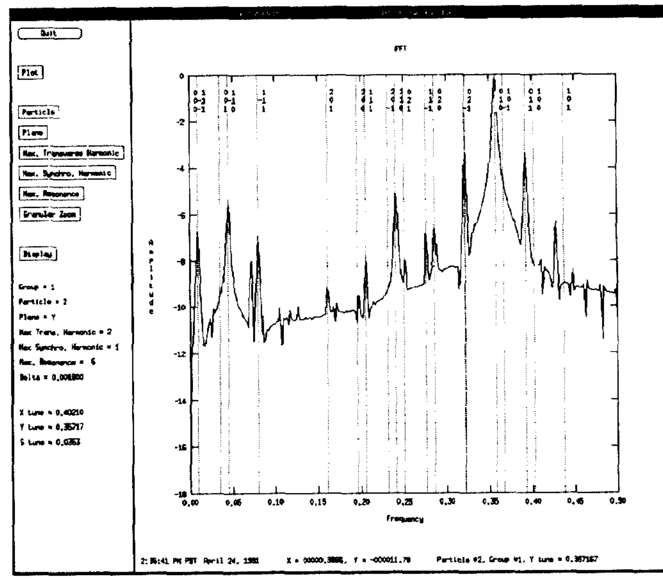

Figure 4: An FFT plot for a particle with synchrotron oscillations.

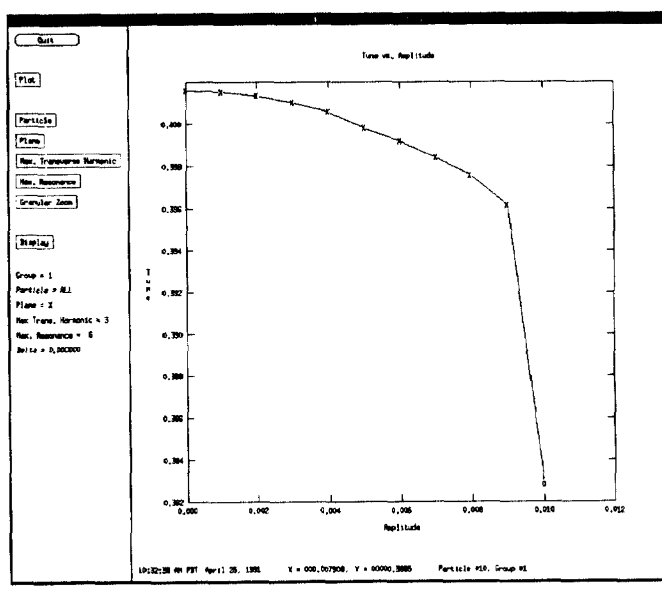

Figure 5: Horizontal tune of each particle as a function of amplitude.

Figure 5 is a plot of the tune of each particle *vs.* amplitude. The amplitude is the Courant-Snyder invariant[2] multiplied by $\beta$. If a particle survived for all tracked turns, it is plotted with an X or a Y. If it was lost prematurely, it is plotted with an O. The data for this plot is the same as that in Figure 2, and we see that, indeed, the tune passes through 0.400, or 2/5. The tracked particles are not lost in passing through the 2/5 resonance, but are lost when the vertical tune gets near 1/3, as seen in Figure 6. In this case, we might be interested in doing more tracking in the region around the 2/5 to explore the structure there. Or if we wanted to improve the dynamic aperture we might decide to try to find a sextupole distribution with a smaller amplitude-dependent tune shift, or choose a new working point.

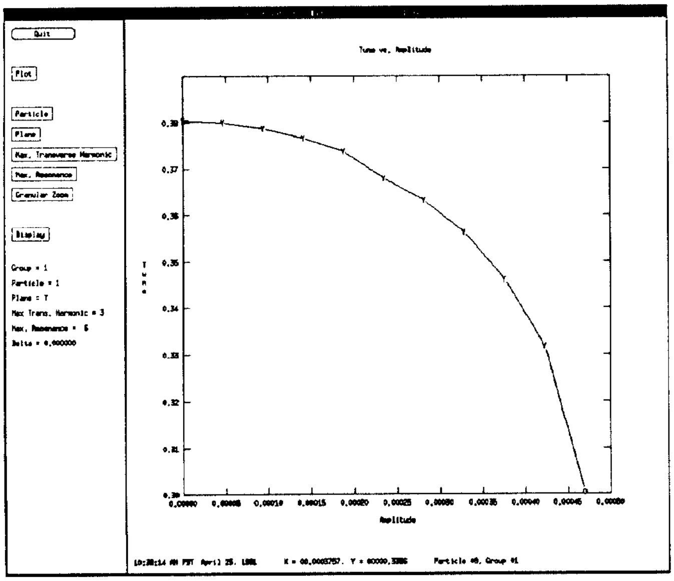

Figure 6: Vertical tune of each particle as a function of amplitude.

The resonance structure is seen more clearly in Figure 7, which shows the tunes of all tracked particles plotted on a resonance diagram. The maximum resonance order plotted is controlled via a menu. Zooming on this plot yields Figure 8.


# Acknowledgments

The plotting paradigm for the FFT plot is based on an earlier one by R. Talman. Thanks to Johan Bengtsson for his relentless advocacy of the sine window.


# References


[1] M. Linton *et al.*, "Composing User Interfaces with InterViews," IEEE Computer, **22** 2, Feb. 1989, pp. 8-22.

[2] E. D. Courant and H. S. Snyder, "Theory of the Alternating Gradient Synchrotron," Annals of Physics, **3**, 1-48 (1958).

[3] E. Asseo, "Moyens de Calcul pour la Mesure des Force et Phase des Effets Pertubateurs des Resonances sur le Faisceau," CERN/PS/LEA Note 87-1 (1987).


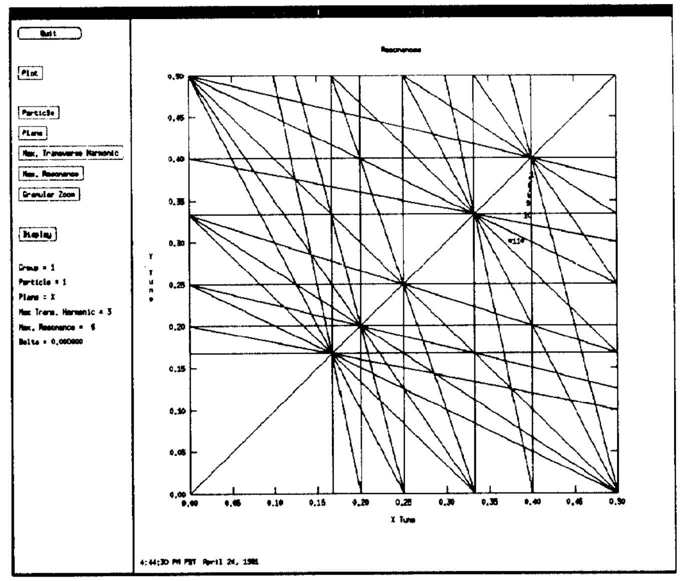

Figure 7: The tunes of each particle are plotted on a resonance diagram. The tunes are computed using a Discrete Fourier Transform.

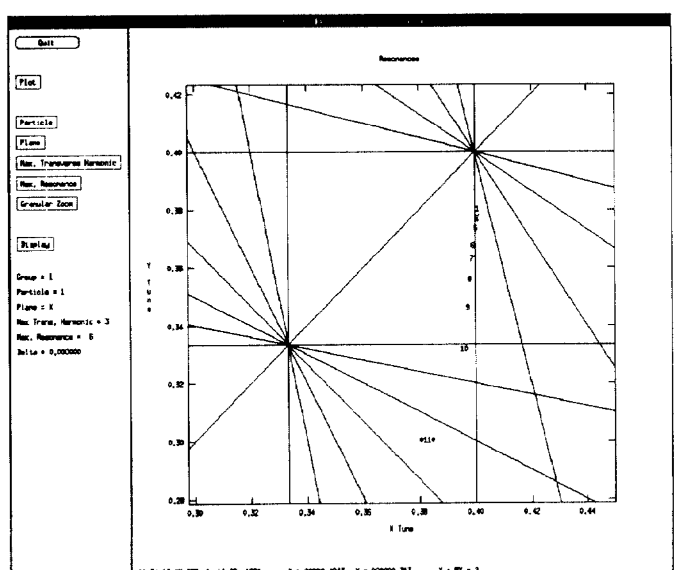

Figure 8: The result of zooming in on a resonance plot.