

# NEW FEATURES OF THE PARALLEL TRACY FOR NONLINEAR BEAM DYNAMICS

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## Abstract

The TRACY\_TPS code is used to analyze and simulate the nonlinear beam dynamics of the designed lattice. To speed up the lattice design flow, we parallelized the TRACY by MPI and developed a GUI by GTK+ to integrate the functions of TRACY and added a function of nonlinear optimization adapted from OPA, which is used to optimize the nonlinear driving terms by Powell algorithm. The GUI is used for parameter input and data visualization. The procedures of nonlinear optimization and beam dynamics analysis are integrated and streamlined. Users do not need to write and compile the code any more. The results will be demonstrated in this report.

## INTRODUCTION

Usually, lattice design for electron storage ring can be divided into two stages: the first stage is linear lattice design; the second stage is optimization of dynamic aperture by varying the sextupoles' strengths. To achieve an optimized lattice, iterative searching processes between linear and nonlinear lattice routinely proceed with existing tools MAD [1], OPA [2], TRACY [3], and Elegant [4] *et al.* It is very inconvenient and time consuming. To streamline these processes, we try to develop a tool to integrate these processes. This tool should include Twiss parameters matching, tune diagram plotting, optimization of nonlinear driving terms to enlarge dynamic aperture, orbit correction, optics correction, dynamic aperture tracking, phase space tracking, tune shift with amplitude and energy, frequency map analysis (FMA), Touschek lifetime calculation and so on.

It is known that MAD is used frequently to design linear lattice, and OPA is used to optimize the dynamic aperture by varying the sextupoles' strengths. Even though these two tools can calculate most of the items mentioned above, they have no function to calculate the frequency map. OPA has some limitations: It cannot deal with the betatron coupling, and take care only 4D tracking in phase space [2]. TRACY can track particle in 6D phase space and also can calculate the frequency map. However, it is distributed as library. Users need to write a program with C language to call the functions of TRACY libraries to perform their wished tasks for beam dynamics simulation. After calculations, post-processing tools e.g. gnuplot are needed to plot the output.

Based on these facts, we start with TRACY-3 library as a tracking code and develop a GUI with free package GTK+ [5] for parameter input and data visualization. The code integrates the functions of TRACY-3 library and

incorporates the idea of OPA to optimize the dynamic aperture with Powell algorithm (It is the same as OPA used) and add a function for Twiss parameters matching to imitate the matching module in MAD.

To speed up the calculations of frequency map and local momentum acceptance around the whole ring (Local momentum acceptance are needed for Touschek lifetime calculation with Bruck's formula), the functions of TRACY-3 library for these two items are modified and added MPI [6] functions inside. These two routines "fmap" and "MomentumAcceptance" of TRACY-3 become parallel. This code is still under development. Its main panel is shown in Fig. 1.

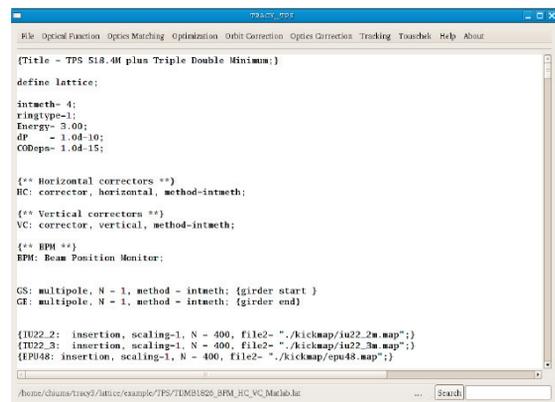


Figure 1: Main panel of TRACY\_TPS.

The main panel contains a menu bar on the top of the window and a text editor. There are many functions on the menu bar, including File, Optical function, Optics matching, Optimization, Orbit correction, Optics correction, Tracking and Touschek. The submenu of Tracking contains phase space tracking, dynamic aperture tracking, and frequency map analysis. In the following sections, we shall describe how to use TRACY\_TPS, and do not intend to go into detail about the physics behind TRACY-3, because that can be found in the manual of TRACY-3. As to the input parameters for TRACY\_TPS, it is nearly the same as that of TRACY-3 for convenience. Thus, those who are familiar with TRACY can learn how to use TRACY\_TPS quickly.

## LATTICE FILE

Users can edit the lattice file or open an existing lattice file in the text editor. Since the code is to call TRACY-3 functions to perform beam dynamics simulation, the format of the lattice file in the code is the same as TRACY-3 used.

### OPTICAL FUNCTION

When users click the show button at the bottom left corner of the window, the code will call the TRACY-3 functions “Read\_Lattice” and “GetEmittance” to calculate the lattice parameters, such as betatron tunes, energy spread, circumference, Twiss parameters, chromaticity and emittance *et al.* After calculations, the code will open the output file of TRACY-3 “linlat.out” to display the lattice functions: betatron function, dispersion and H function for visualization. The lattice parameters are displayed on the left panel. The magnet symbols are displayed between dispersion and betatron function. Dipole, quadrupole, and sextupole are shown as rectangles colored with blue, red and green, respectively. BPM and corrector are displayed with vertical lines colored with pink and black. See Fig. 2.



Figure 2: Optical function.

### OPTIMIZATION

In this function, we adopt the idea of OPA to minimize a penalty function defined as the summation of weighting factor times the square of nonlinear driving term. Powell algorithm is used to minimize the penalty function. Users need to guess weighting factors for each driving term, and then click the start button to launch the searching process, or manually vary the sextupoles’ strengths with the slider bar to vary the driving terms. Before starting process, users need to choose a pair of sextupoles to fix the chromaticity.

The nonlinear driving terms are calculated with J. Bengtsson’s formula [7]. According to his formula, we need to calculate the optical functions, e.g. betatron function, dispersion, and phase advanced at sextupoles. Hence, the optical function on the menu bar should be executed firstly before starting nonlinear optimization, Fig. 3.

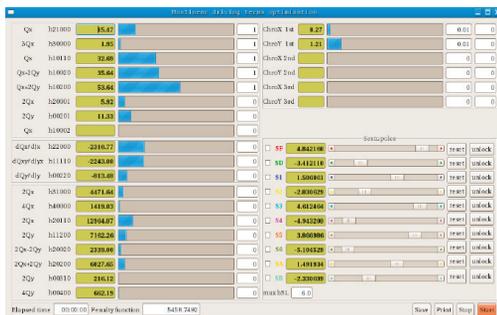


Figure 3: Nonlinear optimization

### CLOSED ORBIT CORRECTION

In this function, two methods SVD and MICADO will be implemented to correct the closed orbit distortion. MICAD is still under development. SVD has been done. Figure 4 and 5 shows the closed orbit distortion before and after correction, respectively. Figure 6 shows the corrector strength. Figure 7 shows the singular values of response matrix.

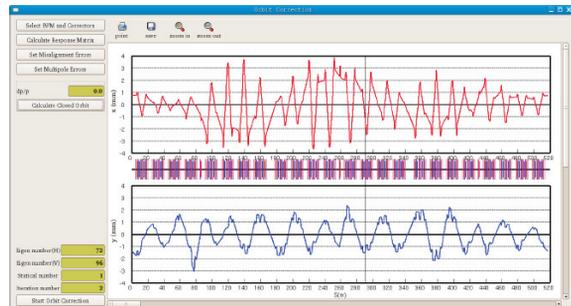


Figure 4: Closed orbit distortion before correction.

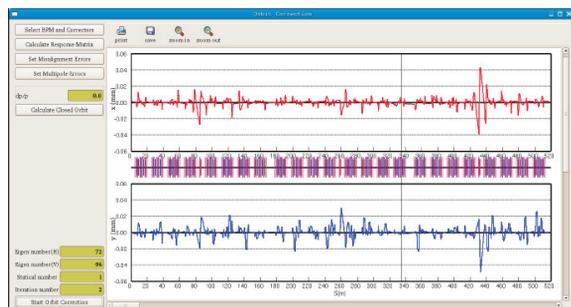


Figure 5: Closed orbit distortion after correction.

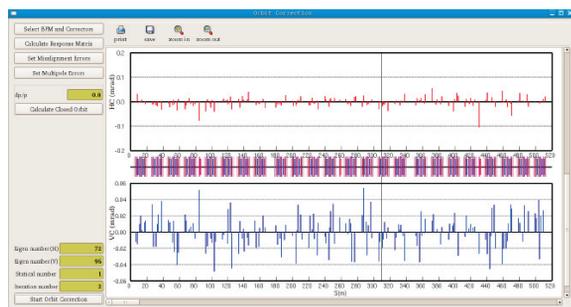


Figure 6: Corrector strength.

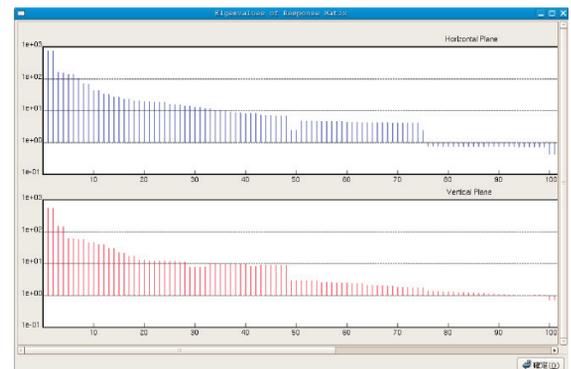


Figure 7: Singular values of the response matrix.

### PHASE SPACE TRACKING

In this function, users need to input the initial conditions for tracking. Then click start button. Users can use 4D or 6D tracking. Figure 8 shows the panel for phase space tracking.

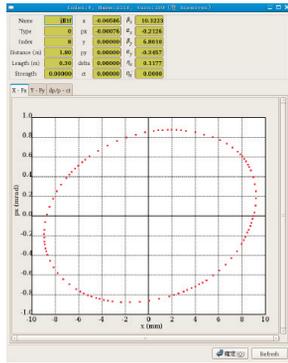


Figure 8: Phase space tracking.

### DYNAMIC APERTURE TRACKING

In this function, users need to input the turn number for tracking: Turns, momentum deviation: dp/p. TRACY-3 use binary search to determine the dynamic aperture. Hence, the radius and the number of steps within 180 degree also need to be given. Then click run button. Figure 9 shows the panel for dynamic aperture tracking.

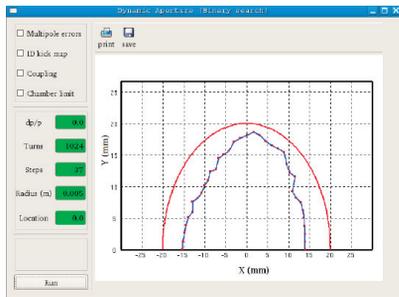


Figure 9: Dynamic aperture.

### FREQUENCY MAP ANALYSIS

In this function, users need to input horizontal and vertical maximum amplitude: Xmax, Ymax; step number: Xstep, Ystep; number of turn for tracking: Turns; particle momentum deviation: dp/p. Then click the run button. The code will call the TRACY-3 function fmap to track particle in 4D phase space. We had modified fmap as parallel. Figure 10 shows the panel for frequency map analysis.

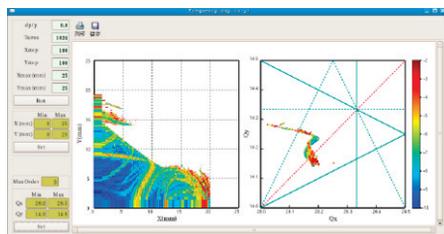


Figure 10: Frequency map analysis.

### TOUSCHEK LIFETIME

Touschek lifetime is calculated with Bruck formula. It is expressed as

$$\frac{1}{\tau} = \frac{r_e^2 c N}{8\pi\gamma^3 \sigma_s L} \int \frac{F(x)}{\sigma_x(s)\sigma_y(s)\sigma_{x'}(s)\varepsilon_{ac}^2(s)} ds$$

$N$  is the number of electron per bunch,  $L$  is the ring circumference,  $c$  is the speed of light,  $\sigma_s$  is the rms bunch length,  $\gamma$  is the Lorentz factor,  $\sigma_x$  and  $\sigma_y$  are the rms bunch size in the transvers direction,  $\sigma_{x'}$  is rms horizontal beam divergence.

$$F(x) = -\frac{3}{2}e^{-x} + \frac{x}{2} \int_x^\infty \frac{\ln u}{u} e^{-u} du + \frac{(3x - x \ln x + 2)}{2} \int_x^\infty \frac{e^{-u}}{u} du$$

$x = (\varepsilon_{ac}(s) / \gamma\sigma_{x'}(s))^2$ ,  $\varepsilon_{ac}(s)$  is momentum acceptance.

According to the above formula, we should calculate the local momentum acceptance around the whole ring. TRACY-3 use 6D tracking to determine the local momentum acceptance. Users need to input the turn number for tracking, the index of starting and ending elements, the minimum and maximum momentum deviation for positive and negative momentum acceptance, the step number for positive and negative momentum acceptance. Figure 11 shows the panel for momentum acceptance tracking and Touschek lifetime calculation.

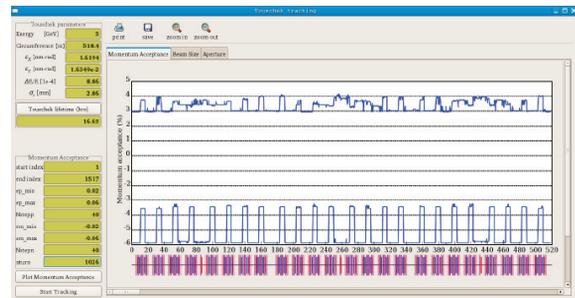


Figure 11: Momentum acceptance.

### SUMMARY & ACKNOWLEDGEMENTS

TRACY\_TPS is still under development. We hope this project can be finished as soon as possible. The authors would like to express gratitude to A. Streun for discussing OPA and driving terms calculation, L. Nadolski & J. Zhang for providing and discussing TRACY-3, and Dr. P.J. Chou for supporting PC cluster.

### REFERENCE

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