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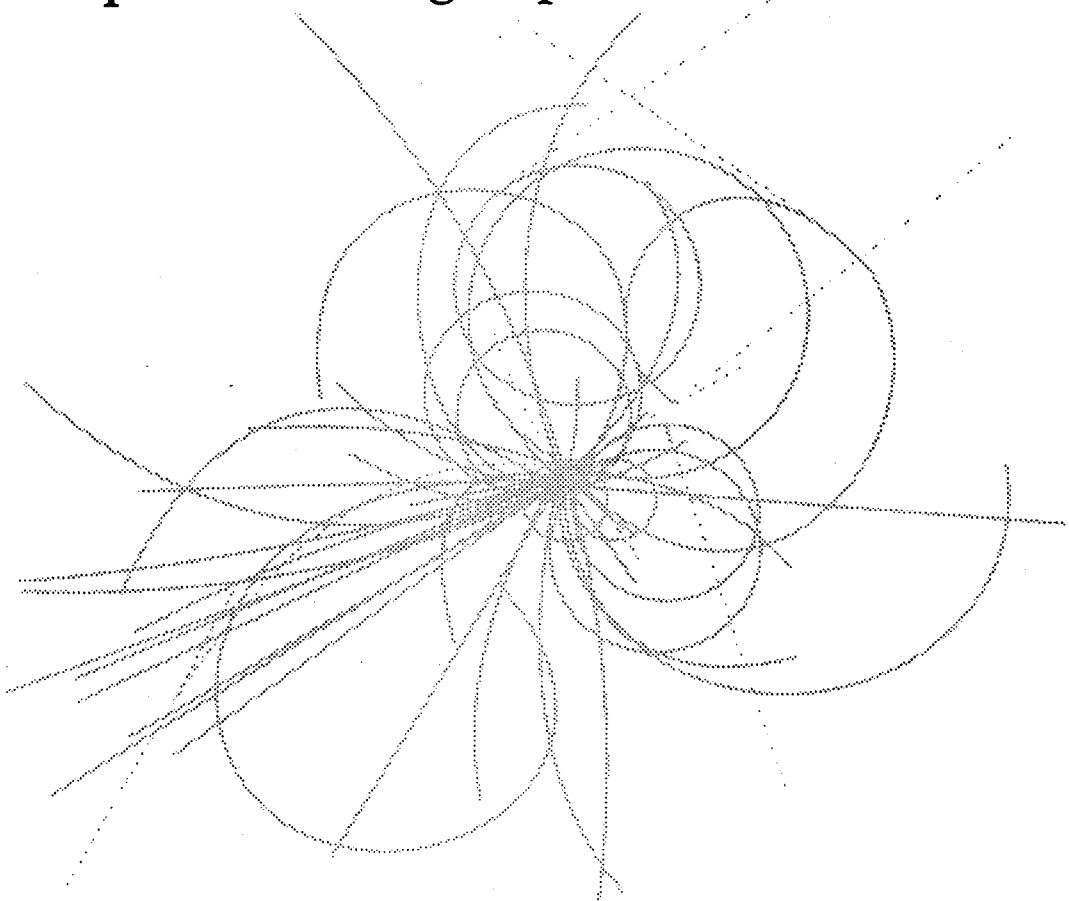

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Abstract

A large amount of supercomputer CPU time has been used for tracking particles in the Superconducting Super Collider (SSC) using a vectorized, multi-tasked post-Teapot tracking program called "Ztrack." Typically, hundreds of particles with appropriate initial displacements (relative to the closed orbits) are tracked for a hundred thousand turns. One then simply makes a survival plot (turn at which particle is lost versus initial displacements) to determine the dynamic aperture. Occasionally, particles are tracked to a million turns for very selective cases. These numerical studies aid in determining the best aperture for the SSC.

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1.0 INTRODUCTION

Critical to the successful performance of the SSC is injection when the proton beams coast for about 40 minutes. A key issue is the aperture, or the cross-sectional area in which the proton motion is stable. If this cross section area is large (relative to the size of the proton beam emerging from the injector), the proton beams will have longer lifetimes. Clearly it is desirable to have as large an aperture as possible, given cost constraints. The aperture depends on the choice of FODO cell characteristics, as well as on the field uniformity in the magnets. Magnets with larger coil diameter have a larger uniform field region, but are more expensive. In this letter, we show a typical long-term tracking result from our recent studies of the dependence of dynamic aperture on magnet coil diameter.

As long-term tracking for the SSC was started in 1988, all the tracking codes available to us were only optimized for scalar computation. Tracking a hundred particles up to ten-thousand turns in the SSC had been a very difficult task. Therefore, "Ztrack"[1] was developed to take advantage of the computational speed of supercomputers (half a year later, another tracking code "SSCTRK"[2] was also developed at the SSC Laboratory as a parallel tool to the program Ztrack for long-term tracking of the SSC). "Ztrack" is an element-by-element post-Teapot[3] tracking program. It is vectorized and multi-tasked. The user needs to prepare two input files for "Ztrack": (a) a machine file "Zfile" provided by the systematic program "Teapot," which describes the non-linear lattice to be studied; and (b) a name list command file "Zcmd" which tells how the tracking is to be performed, such as how many particles, how particle coordinates are initialized, how particles are handled once they get lost, etc. Usually hundreds of particles with well distributed initial displacement amplitudes are tracked, simultaneously, element-by-element for a hundred-thousand turns or more. A survival plot (turn at which particles are lost versus initial displacements) is then obtained for dynamic aperture study.

2.0 NUMERICAL DESCRIPTION

In the following, we give a brief description of the steps which were used to create the machines which were subsequently tracked using Ztrack.

Step 1. Preparation of the Linear Lattice

The machine files are prepared with the program Teapot. A standard "MAD"[4] input that describes a thin-lens representation of the SSC injection linear lattice[5] is first prepared. Teapot then reads in the

input and converts all thick elements to thin ones. Note that all the correctors are included in the lattice.

Step 2. Addition and Correction of Random and Systematic Multipole Errors

Once the linear lattice is defined, random and systematic multipole errors are added to the dipoles in the lattice. Here as an example, two sets of random and systematic errors representing the 4 cm and the 5 cm coil-diameter dipoles are presented in Table 1. In this study, there are no corrections other than the use of chromaticity sextupoles and tune quadrupoles to correct the systematic b_2 and the working tunes (Note that also the normal and skew b_1 and a_1 are set to zero with the assumption of decoupling).

Step 3. Addition of Misalignments and Correction of Orbit

After the random and systematic multipole errors are added to the lattice and the chromaticities and the tunes are adjusted to the desired values, the next step is the addition of random errors due to misalignments (see Table 1). These errors include: (1) random steering errors (σ_{a_0} and σ_{b_0}); (2) rotations (σ_θ); and (3) displacements (σ_x and σ_y). After the addition of errors due to misalignments, the orbit is distorted and corrected to an rms orbit deviation of 1 mm in both the horizontal and vertical planes with respect to the reference orbit. In some other cases not shown here, decoupling is simultaneously performed between the horizontal and vertical planes. The above numerical steps are all performed on a SUN workstation.

Step 4. Retuning

Once the orbit is corrected to a desired value of rms orbit deviation, a machine file is written and transfered to a Cray computer at DOE National Energy Research Supercomputer Center (NERSC) where Teapot reads in the machine file and readjusts the chromaticities and the working tunes. After the chromaticities and the working tunes are well adjusted, a machine file "Zfile" that is suitable for the program Ztrack is written.

Table 1. Random, Systematic, and Orbit Errors and Their Corrections

Case	4 cm	5 cm
Half Cell Length	90 m	90 m
Injection Energy	2 TeV	2 TeV
Dipole Coil Diameter	4 cm	5 cm
Random Errors	$\sigma_{b_2} = 0.4$ $\sigma_{b_3} = 0.3$ $\sigma_{b_4} = 0.7$ $\sigma_{a_2} = 0.6$ $\sigma_{a_3} = 0.7$ $\sigma_{a_4} = 0.2$	$\sigma_{b_2} = 0.272$ $\sigma_{b_3} = 0.18$ $\sigma_{b_3} = 0.35$ $\sigma_{a_2} = 0.41$ $\sigma_{a_3} = 0.41$ $\sigma_{a_4} = 0.1$
Systematic Errors	$b_2 = -3.0$ $b_3 = 0$ $b_4 = 0.2$ $b_6 = -0.05$	$b_2 = -1.9$ $b_3 = 0$ $b_4 = 0.09$ $b_6 = -0.017$
Misalignment Errors	$\sigma_{a_0} = 0.000834$ $\sigma_{b_0} = 0.0012$ $\sigma_\theta = 0.0005$ rad (dipole) $^*\sigma_x = \sigma_y = 0.001$ m	$\sigma_{a_0} = 0.000834$ $\sigma_{b_0} = 0.0012$ $\sigma_\theta = 0.0005$ rad (dipole) $^*\sigma_x = \sigma_y = 0.001$ m
Corrections	Use only chromaticity sextupoles to correct the systematic b_2. σ_{b_2} reduced to 0.4	Use only chromaticity sextupoles to correct the systematic b_2. σ_{b_2} reduced to 0.272
Tunes	(0.285, 0.265)	(0.285, 0.265)
RMS orbit distortion	1 mm	1 mm

*For dipoles, quadrupoles, and beam monitors.

Step 5. Tracking

Ztrack was used to track particles. Based on the command input file "Zcmd," Ztrack adds an rf cavity if synchrotron oscillations are required. A TOPDRAWER[5] file is written for the survival plot at the end of the tracking. For protection from loss of tracking information due to unexpected computer problems, for retrieving information during the tracking, and for continuing for longer turn tracking after the requested turns of tracking has been performed, a restart file is written every "ntsave" turns and at the end of tracking.

3.0 A TYPICAL LONG-TERM TRACKING RESULT

While referring interested readers to the "SCDR"[6] for more long-term tracking results, presented here is a typical result obtained from "Ztrack" long-term tracking for the SSC aperture study (magnet and orbit errors are shown in Table 1).

Figure 1 shows survival plots for 100 00 turn tracking from Ztrack. We studied two 2-TeV injection lattices, one with 4-cm coil-diameter dipoles and the other with 5-cm coil-diameter dipoles. The two lattices have the same random seed. The only difference between the two lattices is in the multipole content due to the different size of magnet aperture. The rf cavity system was turned on to maintain bunching. All particles tracked are initiated with a same synchrotron oscillation amplitude of 3 $\sigma_{\rm rms}$ ($\sigma_{\rm rms}$: rms half bunch length) but with an appropriate distribution on initial horizontal (x-axis) and vertical (y-axis) displacements ($y/\sqrt{\beta_y} = x/\sqrt{\beta_x}$ and $P_x = P_y = 0$ at injection, which is at the middle of a horizontal focusing quadrupole).

While many of the particles with higher displacement amplitudes were lost in the earlier turns, all of the particles with initial x displacement amplitudes lower than 5.3 mm for the 4-cm coil-diameter dipole case and lower than 8.1 mm for the 5-cm coil-diameter dipole case survived. The dynamic apertures for a hundred-thousand turns are thus about 5.3 mm and 8.1 mm in radius for the 4-cm coil-diameter dipole case and the 5-cm coil-diameter dipole case respectively.

Based on the survival plots shown in Figure 1, it is doubtful that dynamic apertures beyond a hundred-thousand turns would decrease significantly. Indeed, tracking had been extended to a million turns for the 4-cm coil-diameter dipole case and shows negligible decrease in dynamic aperture.[1]

4.0 SUMMARY

A fast post-Teapot tracking code "Ztrack" was developed to take advantage of the modern supercomputer architecture for long-term element-by-element tracking up to a million turns for the SSC. Survival plots were made that led to an easier understanding of the dynamic aperture.

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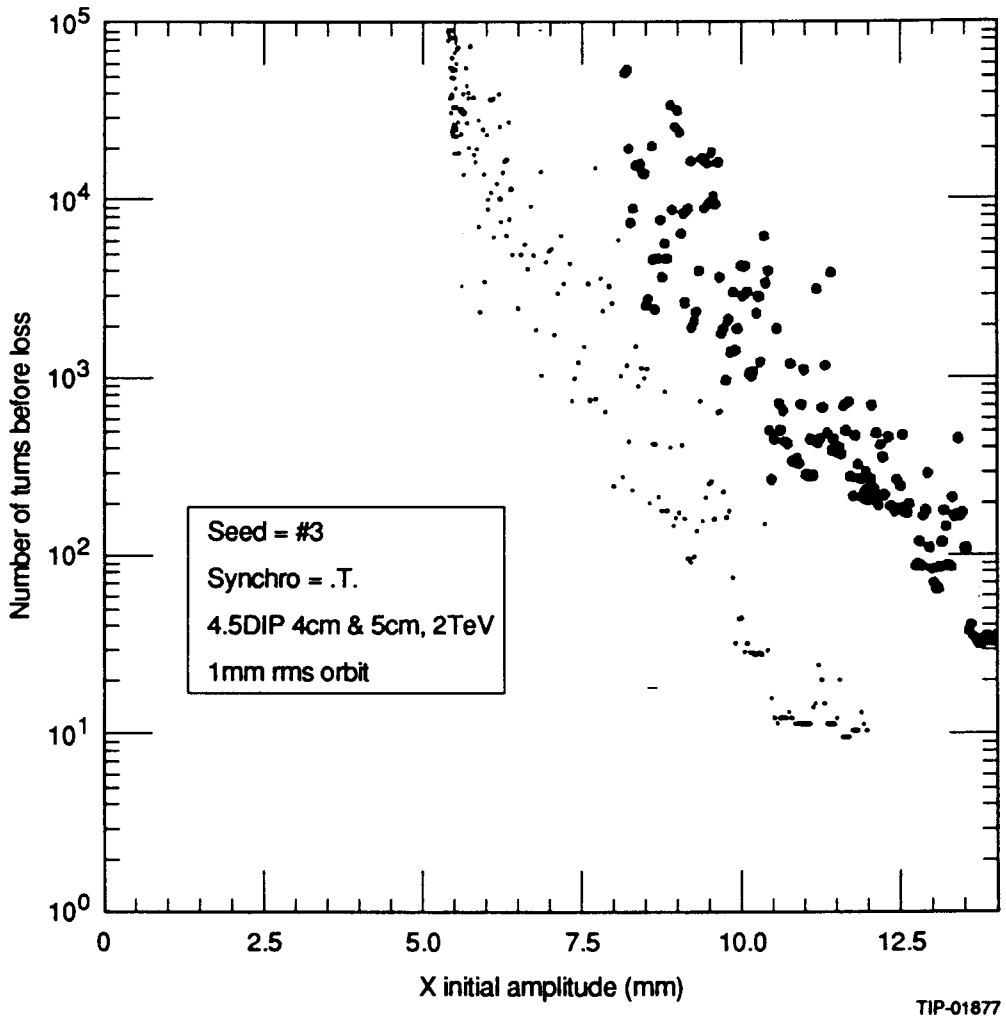

Figure 1. Hundred-thousand-turn survival plots for two 2-TeV SSC injection lattices, comparing the dynamic aperture for two different magnet apertures, one with 4-cm coil-diameter dipoles (shown in '.' symbol) and the other with 5-cm coil-diameter dipoles (shown in '*' symbol). With the 4-cm coil-diameter dipoles, no particles with initial x displacement amplitude of less than 5.3 mm were lost. With the 5-cm coil-diameter dipoles, no particles with initial x displacement amplitude of less than 8.1 mm were lost. By increasing the magnet aperture, the dynamic aperture for 100 000 turns enlarges from about 5.3 mm to about 8.1 mm in radius, which increases the machine's linearity. This plot shows only the protons that were lost before 100 000 turns are reached.

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