RECENT ENHANCEMENTS TO THE ORBIT CODE*

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Abstract

At an age of twelve years, the collective beam dynamics particle tracking code, ORBIT, is considered mature. Even so, we continue to enhance ORBIT's capabilities. Two such enhancements are reported here. The first enhancement allows for the use of time-dependent waveforms for the field strengths of all magnetic elements, a capability that previously was limited to kickers and to RF cavities. This capability should prove very useful for applications to synchrotrons, in which tunes are often manipulated during acceleration. The second enhancement provides an internal calculation of the lattice functions. Previously, it was necessary to read them from an external file, but given the capability of dynamically programming the lattice magnet strengths, it is extremely useful to be able to calculate the lattice functions on demand. Examples illustrating these new ORBIT capabilities are presented.

INTRODUCTION

The ORBIT code [1] was originally designed for particle tracking in rings. Because it was written at the Spallation Neutron Source (SNS), much of the physics development went into the creation of models appropriate to high intensity accumulator rings. Detailed models were developed for collective effects, including space charge [2] and transverse and longitudinal impedances [3]. Later, a self-consistent model for electron cloud effects was created [4]. All these models use particle-in-cell methods. ORBIT was conceived to be a "practical" code, one that could be applied to detailed accelerator design and analysis of experiments. Models were developed for stripper foil injection, RF accelerating and focusing cavities, apertures and collimation [5], magnet alignment and field errors and their correction [6], feedback stabilization, and Lorentz tracking [7]. In order to analyze simulations and to compare with experimental measurements, an extensive set of diagnostic routines was written.

Initially, the single particle transport model used first or second order transport matrices taken from the MAD code [8]. The matrices and lattice functions were parsed into ORBIT by reading MAD output and twiss files. Later, symplectic tracking routines were written to replace the MAD matrix approach. However, it remained necessary to parse MAD twiss files to provide the lattice functions. Also, in all the single particle transport models it was not possible to alter the magnet focusing strengths during a simulation. The only lattice-related quantities that could be varied were kicker strengths and RF accelerating and focusing parameters. This limitation is not important in

the SNS accumulator ring, but in many synchrotrons the ability to vary these strengths with time is important. We have now remedied this limitation by providing the capability of controlling magnet strengths in a time-dependent fashion.

The specification of magnetic field strengths in ORBIT is similar to that in MAD. Bend magnets are specified by arc length L in meters and bend angle θ in radians. Quadrupoles are given by length L in meters and focusing strength k in units of meter^{-2}. Multipoles are specified by length L, which can be zero for thin lenses, pole number n and type (normal or skew), and multipole strength k×L, where k is given in units of meters^{-n}. When additional harmonics are included in bends, quadrupoles, or multipoles, they are specified using the multipole convention. The field strength in solenoids is given by specifying the solenoid field B divided by the reference curvature times magnetic field $\rho \times B_0$, and has units of meter^{-1}.

Given time-dependent magnet strengths, the lattice functions, tunes, and chromaticities also depend on time. Because of this, we have developed the capability to calculate the lattice functions on demand, and with this new capability we no longer need to parse MAD twiss files. Because ORBIT is frequently used for calculations in transport lines, as well as in rings, the lattice function calculator can be used for lines or rings. Periodic boundary conditions are used for rings, but the user must provide the entrance twiss parameters when the lattice functions are calculated for a line.

NEW ORBIT CAPABILITIES

The ability to specify time-varying focusing strengths was added to the multipole, quadrupole, and solenoid magnet classes, both for single harmonic and multiple harmonic magnets. This was not done for dipole magnets because a constant bending radius is assumed. These changes were made in the symplectic tracking module, but not in the MAD matrix transport routines, which we regard as obsolete. For each element of one of the above types, the user provides a strength coefficient as a function of time. This coefficient multiplies the magnet strength specified in the lattice input file to give the time-dependent strength. If the value of the coefficient is 1.0, then the element's field strengths are those in the input file. A coefficient of 0.0 results in a drift. The default value is unity. For elements with multiple harmonics, each harmonic is multiplied by the same coefficient value, namely that of the element.

The new routine to calculate lattice functions, tunes, and chromaticities works with the symplectic tracking

module and can be called on demand during a simulation. For rings, it is not necessary to input any physical information. However, for transport lines, the entrance values of the twiss parameters $\beta_{x,y}$, $\alpha_{x,y}$, and horizontal dispersion functions η_x, and η'_x must be provided.

At present, the lattice function calculator makes several simplifying assumptions: Magnet alignment and field errors are ignored, as are inter-element coordinate transformations. Lattice curvature is assumed to be horizontal, so dispersion is calculated only in the horizontal direction. Coordinate coupling is not considered, so the analysis of the horizontal and vertical planes is carried out separately. Because of this, skew elements are treated as drifts. Also, the chromaticity calculation neglects the effects of sextupoles, so only natural chromaticities are reported. These inaccuracies will be addressed in future enhancements.

The quantities provided by the lattice function calculator include the tunes ν (or total phase advances in units of betatron periods for lines) and the chromaticities for the complete lattice. The twiss parameters β, α, and γ, the phase advances $\phi/2\pi$, and the dispersion functions η and η' are calculated after each element in the larttice. Except for the dispersion functions, which are horizontal, all quantities are calculated for both the horizontal and vertical planes. The calculations are performed using standard matrix methods, where the transport matrices are defined using the current values of the magnet strengths.

EXAMPLES

In order to illustrate the time-dependent lattice functions we consider some simple examples using the SNS accumulator ring and ring to target beam transport line (RTBT). It should be stressed that SNS is not operated with time-dependent magnet strengths, and that these cases are only intended to illustrate the new models. Because these examples are for illustration only, we neglect collective effects, foil scattering, magnet errors, and RF focusing. Thus, the beam is modeled entirely by single-particle dynamics. In all calculations, we use an initially matched mono-energetic KV coasting beam distribution. We use a "black" model for collimation, in which all particles passing outside the specified machine apertures are immediately lost. The chromatic sextupoles are activated in the ring lattice, so that the chromaticities of the tracked particles are corrected to near zero, at least at their initial settings. However, as stated above, the lattice function calculator reports the natural chromaticities. In the first calculation, we transport the KV beam around the lattice for 100 turns with constant magnet strengths, and then to the entrance of the RTBT line. We use the design SNS settings, so that the tunes are $\nu_x = 6.23$ and $\nu_y = 6.20$. The ORBIT lattice function calculator obtains tunes of $\nu_x = 6.230$ and $\nu_y = 6.199$, while MAD gives $\nu_x = 6.230$ and $\nu_y = 6.198$. For the chromaticities, ORBIT gives $C_x = -9.40$ and $C_y = -7.32$, in reasonable agreement with the MAD values of $C_x = -9.14$ and $C_y = -7.70$. Figure 1 shows the horizontal and vertical

beta functions, calculated by ORBIT's lattice function calculator (lines) and independently from the beam moments (points) using ORBIT's statistical lattice function diagnostic. The agreement is very good, as is the agreement with the MAD lattice functions.
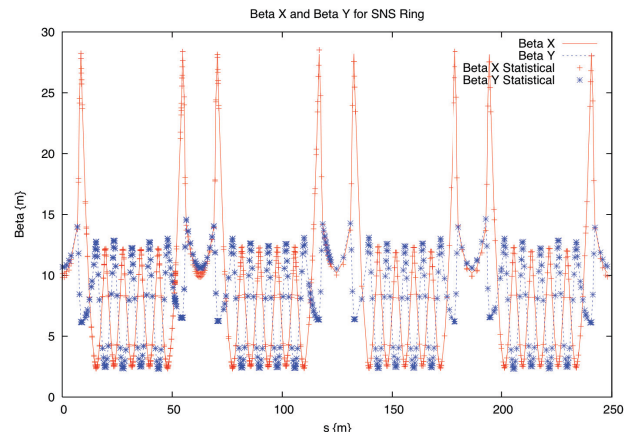

Figure 1. Beta functions in SNS ring as calculated by ORBIT lattice function calculator (lines) and from beam moments (points).

Comparable agreement between the ORBIT lattice function calculator, the statistical lattice function calculator, and MAD was obtained for the transport of the final KV beam above through the RTBT to the target. The agreement between ORBIT and MAD was exact to four places in the phase advances, and to 3×10^{-3} in the beta functions at the end of the line (target). We conclude that the lattice function diagnostic works for lines as well as for rings.
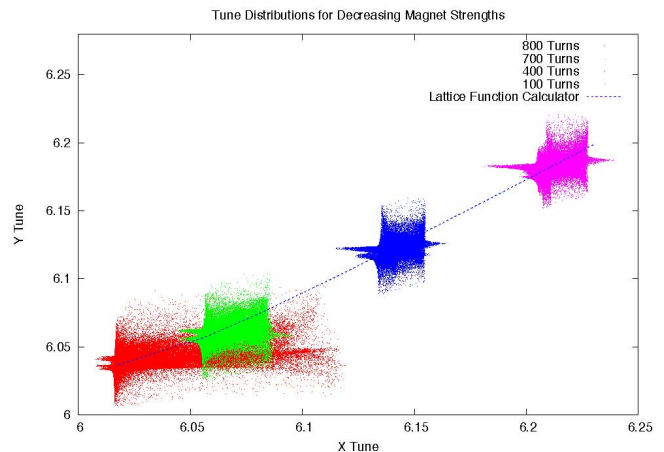

Figure 2. Tune footprints at several times for the case of decreasing magnet strengths. The line shows the tune trajectory from ORBIT's lattice function calculator.

To test the time-dependence of the lattice functions, two further cases were considered. In the first, the beam was transported for 1000 turns as the magnet strengths were decreased linearly in time, starting from the design values. In the other case the beam was again stored for 1000 turns, but the magnet strengths were increased

linearly in time. In the first case, the tunes decreased linearly in time in accordance with the changing magnet strengths. Figure 2 shows tune footprints at 100, 400, 700, and 800 turns along with the ORBIT's calculated tune trajectory from 0→800 turns. Between 800 and 900 turns, the tunes approach the integer resonance at 6.0, and the beam is lost.

For the case of increasing magnet strengths, the tunes increase linearly in time from their initial values of $\nu_x = 6.23$ and $\nu_y = 6.20$ to final values of $\nu_x = 6.63$ and $\nu_y = 6.54$. The horizontal tune crosses the half integer resonance of 6.5 at about 700 turns and the vertical tune crosses 6.5 at about 900 turns. Figure 3 shows the evolution of the horizontal and vertical beam emittances during the calculation. There is significant growth of both emittances between 700 and 800 turns, or after the horizontal tune crosses the half integer resonance. This is followed by another round of vertical emittance growth at 900 turns, when the vertical tune crosses 6.5. These calculations illustrate ORBIT's capability to vary the magnet strengths with time and to calculate the corresponding lattice functions on demand.
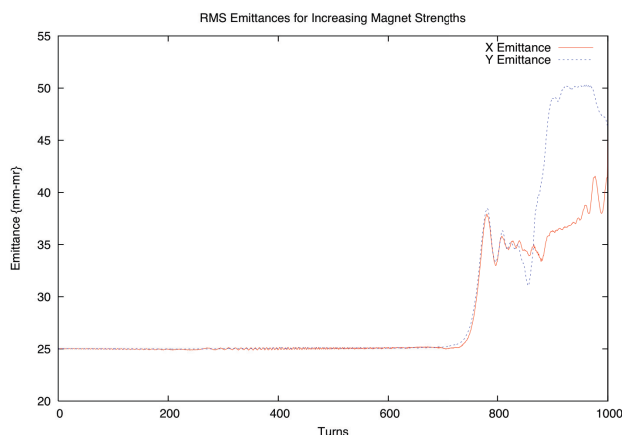

Figure 3. Time evolution of RMS emittances for the case of increasing magnet strengths.

CONCLUSIONS

This paper has described and demonstrated two enhancements of the ORBIT code. The first enhancement allows for the use of time-dependent waveforms for the field strengths of all magnetic elements, a capability that previously was limited to kickers and to RF cavities. This capability should prove very useful for applications to synchrotrons, in which tunes are often manipulated during acceleration. The second enhancement provides an internal calculation of the lattice functions. Previously, it was necessary to read them from an external file, but given the capability of dynamically programming the lattice magnet strengths, it is extremely useful to be able

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