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COMPARISONS BETWEEN AT AND ELEGANT TRACKING*

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Abstract

The simulation codes elegant [1] and Accelerator Toolbox (AT) [2] are both in common use for the study of particle accelerators and light sources. They use different software platforms and have different capabilities, so there is a strong motivation to be able to switch from one version to another to achieve different goals. In addition, it is useful to directly compare results for benchmarking studies. We discuss differences in tracking methods and results for various elements, and explore the impact on simulations performed with lattices designed for the ALS-U. In addition to single-particle tracking, global properties such as chromaticity, dynamics aperture, momentum aperture and beam lifetime are also investigated. We have also developed scripts to translate AT lattices into elegant lattice files to facilitate comparisons.

INTRODUCTION

The simulations codes Accelerator Toolbox (AT) and elegant are often used for modeling light sources and other accelerators. Many ALS-U studies are performed using AT, along with specialized tools such as the Simulated Commissioning toolbox (SC) [3] which are also written for MATLAB with AT installed. At the same time, there are differences and specialized features in elegant which make it desirable to perform calculations on the exact same lattice. The ability to translate with good fidelity a lattice "developed" in AT into elegant would be useful for this purpose, as well as helping with benchmarking studies.

TRANSLATION TOOL

A translation tool, SC2elegant, has been written in MATLAB which takes a ring stored in memory after running AT and converts it to elegant lattice files. This guarantees that the source of the translation is exactly the same as that which was analyzed through AT code, and it is easier to process as the data structures are already in memory. In elegant, a "parameters" file can be written which outputs the final beamline, and there are translation tools, so the reverse translation could also be done. The script takes advantage of metadata produced by SC, which is used alongside AT to create the lattices studied in this work. Without this metadata, it is more challenging and less robust to deconvolve the beamline errors into specific strength and alignment perturbations. The translation tool can still be used for beamlines generated in plain AT, but with reduced functionality and accuracy.

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Recently, there has been work by developers of elegant and SC to implement consistent models for misalignments based on concepts from [4], which has facilitated the translation tool. This work also relies on previous comparisons, for example [5], which includes work by X. Huang to implement tracking in AT that is more accurate and similar to that of elegant. However, this code is not yet in the standard AT repository and is not included in the results shown below.

TRACKING COMPARISONS

Single-particle tracking for particles with moderate amplitudes and energy offsets are used for the comparison. The examples shown below do not include radiation damping or RF cavities, in order to highlight the motion in phase space along invariant surfaces.

An example combining different categories of errors is shown in Fig. 1. Only orbit correction is applied, in particular the LOCO correction chain has not been included. Thus the performance of the ring is quite poor. The turn-by-turn traces in the two codes cover similar regions in phase space, with shifts on the order of 1 micron, or about 1% of the width of the orbit. After one turn around the ring, the particle locations are separated by roughly 1 micron. Over many passes, the maximum disagreement grows linearly by roughly 50 nm per turn. The beta functions and closed orbit are shown in Figs. 2 and 3. The closed orbits agree very well, however the maximum and minimum beta functions are noticeably different.

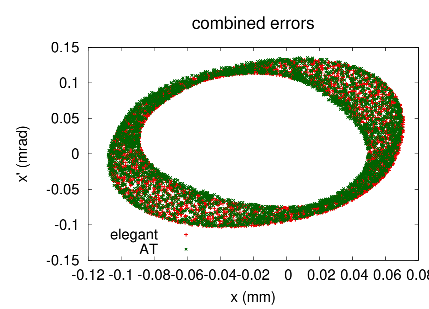

Figure 1: Comparison of turn-by-turn particle trace in AT and elegant, in phase space, for several error types combined.

For the case of smaller errors that are only offsets in position, the lattice performs similar to the expected realistic lattice, even without applying corrections. Then the codes agree more closely, however this could be due to the specific type of error which is considered. The turn-by-turn trace, shown in Fig. 4 for both horizontal phase space and coordinate space, is very regular with clear patterns of motion. However, the motion of the particle in the two codes disagree, with a significant difference of tune. In addition,

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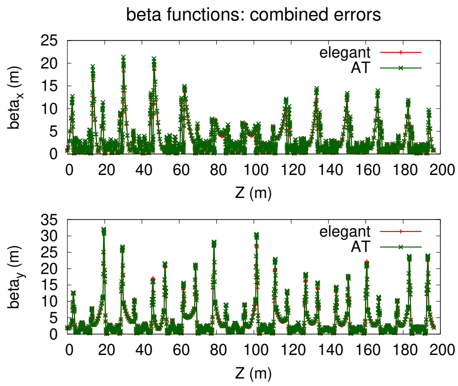

Figure 2: Comparison of beta functions in AT and elegant, for several error types combined.

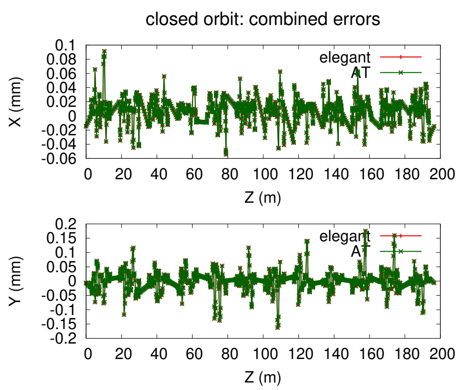

Figure 3: Comparison of closed orbit in AT and elegant, for several error types combined.

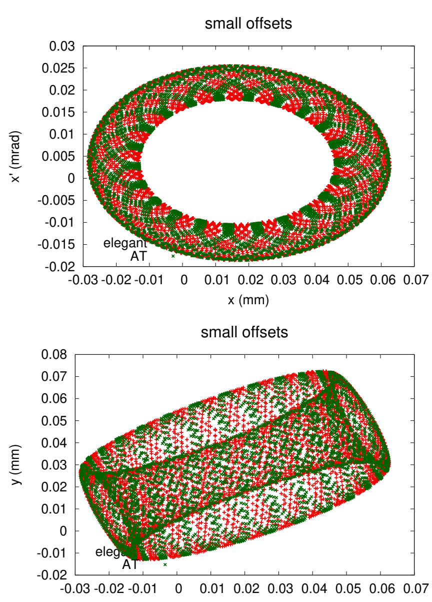

Figure 4: Comparison of turn-by-turn particle trace in AT and elegant, for small offset errors, in phase space (top) and coordinate space (bottom).

the boundaries of the orbit disagree by 50 nm. The rate of growth of the disagreement between the two codes is also much smaller, at about 2.5 nm per turn. In fact, the disagreement over many turns is much less than would be expected based on the discrepancy in tune alone, which suggests that the tune difference and orbit distortion are correlated.

GLOBAL PARAMETERS

Global ring properties such as the tunes, chromaticity and dynamic aperture are especially important, and are in many ways more significant than specific single-particle trajectories. These quantities are shown in Table 1 for an ideal lattice, the lattice with small offsets as shown above, and the lattice with a combination of error types, also shown previously. Unlike the single-particle orbits, for these results the computations in AT and elegant include damping and RF cavities. The RF frequencies are scaled to account for the fact that AT approximates $v = c$, but this is a tiny effect.

The tunes agree to about 0.001 for well-behaved lattices, the one with large uncorrected errors has an order of magnitude larger disagreement. It is currently unclear what drives the difference in tunes. A similar pattern holds for the chromaticities and predicted equilibrium emittance. The area of the dynamic aperture (DA) corresponds fairly well in all three examples, with up to 20% errors. The detailed DA for the same example lattices are shown in Fig. 5. The results are noisy, but qualitatively they match well.

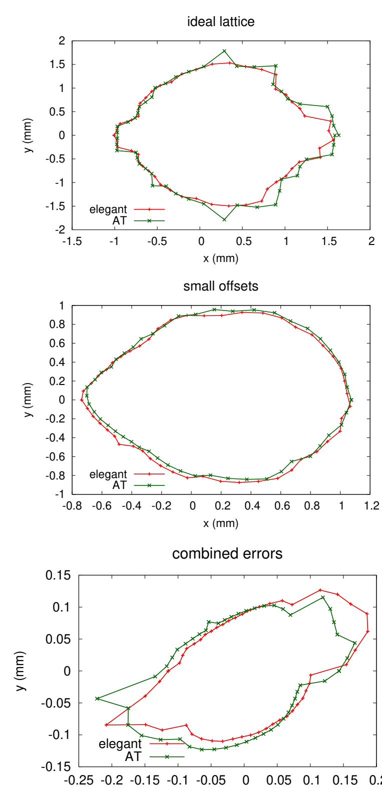

Figure 5: Dynamic aperture in AT and elegant, for three lattices with varying error models.

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Table 1: Comparison of Global Parameters between Elegant and AT for Different Lattices

Parameter	**Ideal lattice** AT:elegant	**Small offsets** AT:elegant	**Combined errors** AT:elegant
Horizontal tune	41.3583:41.3590	41.3573:41.3580	41.4461:41.4546
Vertical tune	20.3533:20.3543	20.3510:20.3528	20.3612:20.3664
Horizontal chromaticity	1.8760:1.8813	1.8579:1.8560	1.3205:1.9963
Vertical chromaticity	1.0923:1.2072	1.1076:1.2172	-1.8052:-1.7535
Equilibrium emittance (pm)	128.0:117.2	86.7:85.7	233.4:362.8
Dynamics aperture area (mm^2)	5.426:4.984	2.315:2.314	0.049:0.040

The momentum apertures (MA) are shown for the same three lattices in Fig. 6. Here, there is significant disagreement between AT and elegant even for the ideal lattice, although the lattice with small offsets has fairly close agreement. Overall, MA results from elegant are more conservative than those from AT, and it seems likely that the algorithms used are an important source of the disagreement. The MA is important because it is a key component of calculating the beam lifetime.

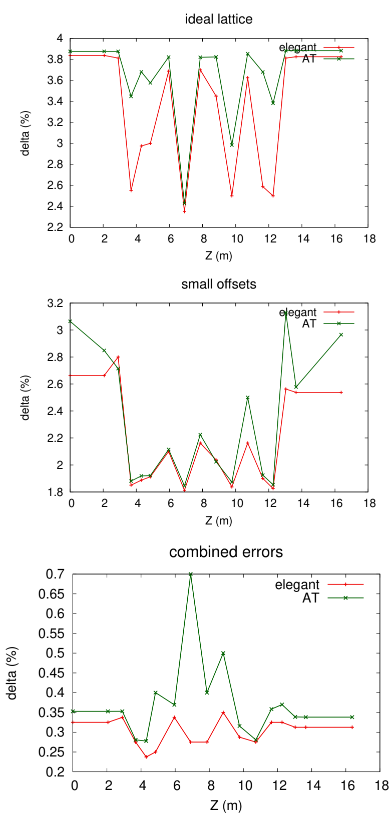

Figure 6: Momentum aperture in AT and elegant, for three lattices with varying error models.

CONCLUSION

A tool has been developed to translate lattices in AT, with general errors, into a format that can be read into elegant. The goal is to facilitate code benchmarking, and to allow groups who rely heavily on one of these codes to make use of capabilities in the other and be confident that the same lattice is in fact being modelled in both codes.

Much of the disagreement between the codes seems to derive from different estimates of the orbit tunes, which may be related to the visible difference in peak beta functions. For the lattice with the most severe errors, the amplitude of the particle orbit considered in the tracking is not far from the edge of the DA. Thus, differences will be magnified by trajectories which have high sensitivity to initial conditions, possibly including chaotic motion.

There do not appear to be any major discrepancies indicating a mistake in how the elements are translated. However, that does not rule out more subtle issues with options or flags being chosen in elegant which are not the best correspondence to how calculations are performed in AT. Single-element comparisons should yield bounds on how much of the discrepancy can be assigned to fundamental difference in how tracking is performed in the two codes. The methods used here seem ready to be used in practical applications.

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