LATEST IMPROVEMENTS OF OPAL

Ch. Metzger-Kraus*, B. Kuske, M. Abo-Bakr, Helmholtz-Zentrum Berlin, Berlin, Germany
A. Adelmann, Paul Scherrer Institut, Villigen, Switzerland

Abstract

OPAL (Object Oriented Parallel Accelerator Library) is an open source, C++ based tool for charged particle tracking in large accelerator structures and beam lines including 3D space charge, particle matter interaction and FFAG capabilities. The careful parallel design makes it possible to tackle large and complex problems, in a reasonable time frame. The current code status and latest program improvements and upgrades are introduced. One of the provided flavors, OPAL-T, was, so-far, used for relatively simple lattices and was not well suited for more complicated arrangements of elements. One of the major upgrades is the possibility to place elements in 3D space, giving the user a better control in absolute element positioning. The old input format with relative positioning is still supported. We show results of the bERLinPro lattice and compare it with results obtained with elegant.

INTRODUCTION

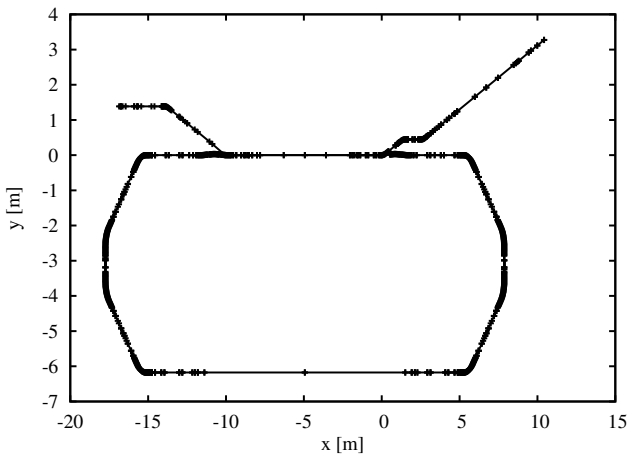

Figure 1: Overview of the bERLinPro accelerator with the gun in the upper right and the dump in the upper left corner.

For the simulation of the bERLinPro accelerator [1, 2], a single-pass energy recovery linac currently under construction at Helmholtz-Zentrum Berlin, we use ASTRA [3] / elegant [4] and OPAL-T [5]. For an overview of the lattice of bERLinPro see Figure 1. The beam is accelerated to 6.5 MeV by the gun in the upper right corner in Figure 1 and the subsequent booster modules before it is merged into the recirculator. The beam is then accelerated to 50 MeV by the linac. The beam is brought back for deceleration after one passage through the recirculator. It is decelerated to 6.5 MeV and then sent to the dump in the upper left in Figure 1.

* christof.metzger-kraus@helmholtz-berlin.de

The current version of OPAL-T provides everything that we needed for a start-to-end simulation:

- models for all electromagnetic elements
- a fast 3D space charge solver and
- 1D CSR wake field model.

Results of elegant and OPAL-T for the recirculator match well when no element is misaligned. A comparison is shown in Figure 2. However one of the motivations to use OPAL

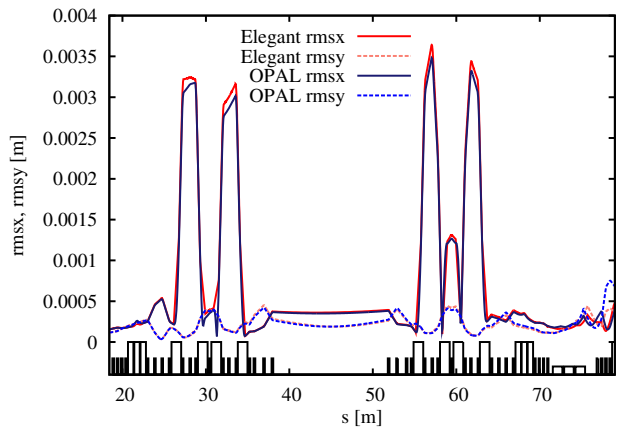

Figure 2: Comparison of results for the recirculator produced with elegant and OPAL v 1.4.0 without space charge effects.

in addition to the combination ASTRA / elegant was to use it for trajectory correction studies [6] with a single code. Soon it became apparent that the model for the dipoles in the current version of OPAL-T (1.4.0) could not handle beams that are off-axis or have a momentum which is not tangential to design path. Furthermore it was not evident how the model could be extended easily.

Another issue with version 1.4.0 is that no electromagnetic field may overlap with the field of a dipole. In the case of bERLinPro we have quadrupoles that overlap with the fringe field of some dipoles. To work around this issue we cut the extend of the fringe fields such that there is no overlap.

To solve these two problems it was decided to rewrite essential parts of OPAL-T. The user should be able to place the elements of a machine in three-dimensional space. This would enable to calculate the impact of the earth's magnetic field on the dynamics of the injector. Henceforth in this paper we'll call this new version OPAL-T3D.

In the current version an element is placed at a given path length along the design path. The elements are then concatenated in beamlines. Groups of elements can be placed in sub-beamlines. For a smooth transition the user of OPAL-T3D may place the elements in the same manner as with the current version. The correct position in space is then

ISBN 978-3-95450-147-2

calculated from the path length from the origin of the beamline and the deflection angle of the dipoles. The position of the origin of a beamline and its initial orientation can be provided.

The input file for bERLinPro, i.e. the special case of a recirculated beam, needed some adjustments. Since the beam has to pass twice the linac some of the elements occur twice in the input file for the current version of OPAL. In the input file for OPAL-T3D they should be included only once, otherwise there action would be doubled.

Another adjustment is, that an aperture has to be provided for some elements. Every element has a default aperture of circular shape with a radius of 1 m. All elements in the merger and in the splitter and some in the recirculator need a smaller aperture to prevent an unwanted overlap with elements of the recirculator and vice versa.

Finally a colimator which stops all particles is added to the input file to model the dump. OPAL-T finishes when the reference particle is stopped.

With these changes we get results that again match well the results from elegant, see Figure 3. Only after the chicane of the merger we observe a deviation. The origin of this difference is currently investigated.

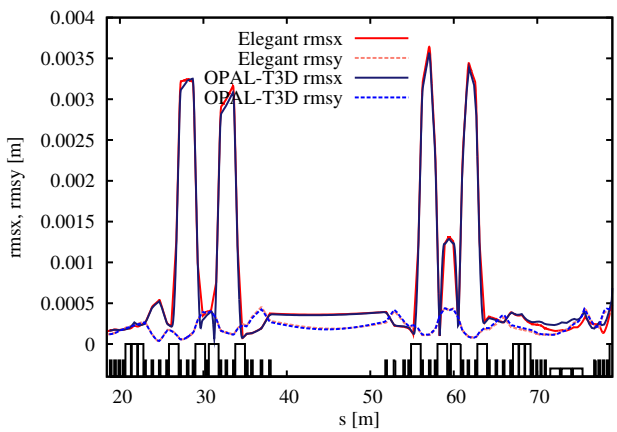

Figure 3: Comparison of results for the recirculator produced with elegant and OPAL-T3D without space charge effects.

With OPAL-T3D we can now also conduct misalignment and trajectory correction studies.

CHALLENGES

In order to make a tracker work using elements that are placed in three-dimensional space, one has to find solutions for some challenges.

Order of Traversal

One of these challenges is the lack of order. With the old approach the position of the particles relative to the elements followed from the covered distance of the bunch. Therefore the electromagnetic field of a few elements only in the vicinty have to be computed. However with OPAL-T3D one doesn't know a-priori in which order the elements are traversed. The simplest but much too time consuming approach is to query for every particle in the bunch the electromagnetic field of every element. This approach is too time consuming since the fields have to be queried every time step.

We chose to establish this order of the elements in a first step by traversing the machine with a single particle. This particle is our reference particle that is emitted at $t = 0$. To query the fields of all elements at every time step with a single particle is done quickly. Furthermore we can use this first traversal to find the initial phases of the cavities. In the end of this procedure we receive a map containing ranges of s-coordinates (path length from cathode) and elements present in these ranges. To query the field during the simulation we now first query the map at the mean s-coordinate of the bunch (including some margins around) to get a set of elements. In a second step we then query the electromagnetic field of these elements at the positions of the particles.

Coordinate Systems

With the current version of OPAL-T both particles and fields are stored in beam coordinates. With the new approach we have to introduce four different coordinate systems for the particles and electromagnetic fields. The first coordinate system is the floor coordinate system, K_f. We place all elements in this coordinate system.

The electromagnetic fields are calculated in coordinate systems, $K_{l,n}$, that are local to the elements. At the start of the simulation we have to compute the coordinate transformation from the floor coordinate system to the local coordinate systems of the elements.

The positions and momenta of the particles are stored in the beam coordinates. The origin of the beam coordinate system, K_b, coincides with the position of the reference particle. Its z-axis is tangential to the path of the reference particle.

Finally the space charge field is computed in a coordinate system, K_{sc} in which the mean position of the particles is located at the origin. The z-axis of K_{sc} is parallel to the mean momentum. This choice of coordinate system simplifies the computation of the space charge field, because the transformation of the positions of the particles to the co-moving coordinate system reduces to stretching in z-direction.

The algorithm that is implemented is depicted in Figure 4. To perform the transformation from the beam coordinate system to the local coordinate systems of the elements we have to know the transformation from the beam coordinate system to the floor coordinate system. As the reference particle propagates along the design path one has simply to update this transformation.

Overall we have to apply many coordinate system transformations when placing the elements in the three-dimensional space. We assumed wrongly that this would increase the time to solution compared to the current version. But while rewriting OPAL-T we also rewrote the computation of the Enge function in the fringe field of dipoles. Now the Enge function and its derivatives are computed on a equidistant grid first. During the simulation the field at a given posi-

ISBN 978-3-95450-147-2

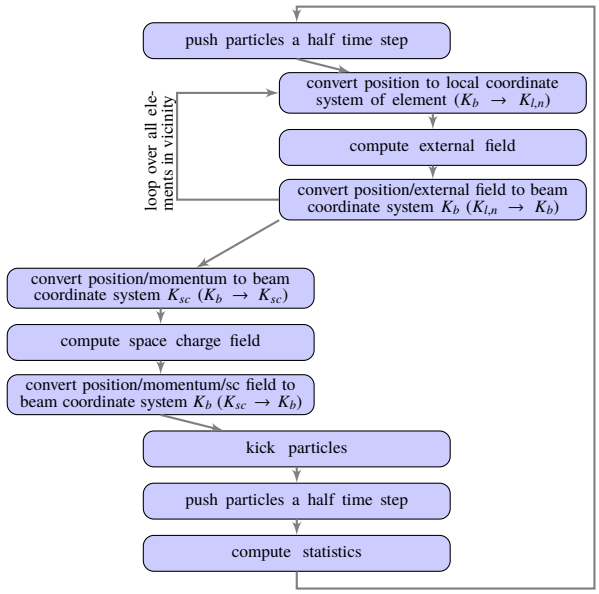

Figure 4: Schematic algorithm of OPAL-T3D's execution model.

tion is then interpolated from the grid. This accelerates the computation of the fringe field consierably.

Furthermore we could remove some communication between compute nodes improving time to solution when running in parallel. A considerable speed-up can especially be observed when neglecting space charge forces. For the case of the recirculator of bERLinPro we observe a speed-up of a factor 9 compared to OPAL-T. Beside the two improvements mentioned this speed-up is also due to a more uniform distribution of the particles among the nodes when no space charge effects have to be considered.

CURRENT ISSUES

Using a single particle as reference is not satisfying. The reference particle should coincide with the centroid of the bunch if both the initial particle distribution and the alignment of the elements is perfect. However a single particle can't replicate the acceleration of the centroid. The kinetic energies after a cavity in particular differ. The consequence is that the trajectories are different.

OUTLOOK

A lot of work is still need until this OPAL-T3D can be released. Currently neither CSR nor other wake fields can be computed. The relevant code still needs to be ported. This is also valid for the particle-matter interaction capabilities available in the current version of OPAL.

In addition to these capabilities we also intend to add the option of using 3D field maps for the fringe fields in dipoles. Furthermore adding fringe fields to quadrupoles and higher order multipoles is on the list of future improvements.

REFERENCES

[1] B. Kuske, N. Paulick, A. Jankowiak, J. Knobloch (edit), "Conceptual Design Report B*ERL*inPro", 2012, HZB

[2] M. Abo-Bakr et al., "Status Report of the Berlin Energy Recovery Linac Project B*ERL*inPro", presented at the 7th Int. Particle Accelerator Conf. (IPAC'16), Busan, Korea, May 2016, paper TUPOW034, this conference.

[3] K. Floettmann, "A Space Charge Tracking Algorithm", 1997-2016, DESY

[4] M. Borland, "elegant: A Flexible SDDS-Compliant Code for Accelerator Simulation", Advanced Photon Source LS-287, September 2000

[5] A. Adelmann *et al.*, "The OPAL (Object Oriented Parallel Accelerator Library) Framework, User' Reference Manual", 2008-2016, PSI

[6] B. Kuske, C. Metzger-Kraus, "Start-to-End Calculations and Trajectory Correction for B*ERL*inPro", presented at the 7th Int. Particle Accelerator Conf. (IPAC'16), Busan, Korea, May 2016, paper THOBA03, this conference.