PyZgoubi SIMULATIONS OF THE CBETA LATTICE*

S. Tygier†, University of Manchester, UK
F. Meot, N. Tsoupas, Brookhaven National Laboratory, New York, USA
C. Mayes, Cornell University, New York, USA

Abstract

The Cornell-BNL Electron Test Accelerator, CBETA, is a 4 pass up, 4 pass down Energy Recovery Linac (ERL) using Fixed-Field Alternating-Gradient (FFAG) recirculation arcs with a top energy of 150 MeV. We present lattice implemented in the tracking code PyZgoubi, with both hard edge and field map magnet versions. We also describe the recent developments in PyZgoubi such as importing lattice tables from other tracking codes.

INTRODUCTION

CBETA [1, 2] will be the first recirculating ERL with FFAG return arcs. This allows transporting the beam at each of the four energies in a single channel. The Non-Scaling FFAG provides a compact solution with small magnets, saving space and cost.

CBETA will demonstrate the combination of these existing technologies which maybe used in future accelerators such as eRHIC (Election and Relativistic Heavy Ion Collider) upgrade at Brookhaven National Laboratory [3].

PyZgoubi AND Zgoubi

PyZgoubi [4, 5] is a accelerator design framework build around the Zgoubi [6, 7] tracking code. It provides a Python interface to Zgoubi and a set of useful tools for modelling, designing and optimising accelerators.

Zgoubi is a widely used code for modelling FFAG accelerators. It uses a stepwise ray-tracing method that gives accurate tracking of particles through complex magnets, both analytic and field maps, even away from the magnet axis.

PyZgoubi presents Zgoubi as an object oriented library, the input file is a Python script. Lattice elements are classes that get added to a Line object. To perform tracking PyZgoubi writes an input file that is passed to the Zgoubi executable, it then reads in the tracks and other outputs to allow further processing. A set of high level tools is provided to manipulate and analyse lattices. PyZgoubi takes advantage of Python's scientific libraries for data analysis, optimisation and plotting.

As the input file is written in a full general purpose language, is it possible to perform advanced tasks such as reading a lattice from an arbitrary source at run time. In the case of CBETA we read the lattice from an ASCII lattice table generated with Bmad [8].

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† sam.tygier@manchester.ac.uk

CBETA LATTICE

The CBETA ring consists of several sections. The injector (IN), the linac (LA), the splitter (SX) and recombiner (RX) sections, the arcs (FA and FB), matching sections (TA and TB) and the straight section (ZA and ZB) and finally the beam dump (DU). The layout is shown in Fig. 1.

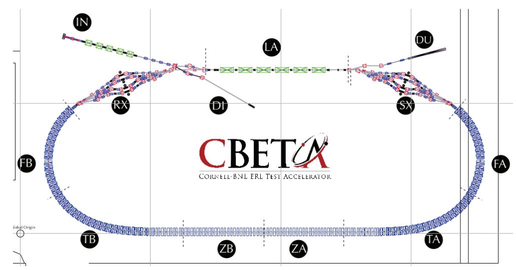

Figure 1: CBETA Lattice Layout.

The lattice is designed with the code Bmad, from which a flat lattice table containing the elements and their parameters can be exported.

To import the lattice table into PyZgoubi an interpreter was written. It reads the table and creates Zgoubi elements for each line. For example on reading the Bmad element `PIPE` it will create a PyZgoubi element `DRIFT`, with the length converted from metres to centimetres. It can also read a subset of the line, for example just the first splitter section S1, which is useful for debugging. Table 1 lists the Bmad elements and the corresponding Zgoubi elements used.

Table 1: Bmad to Zgoubi Element Names

Bmad	Zgoubi
PIPE	DRIFT
SBEND	MULTIPOL
QUADRUPOLE	MULTIPOL
LCAVITY	CAVITE
PATCH	CHANGREF
MARKER	MARKER

A few elements used in the CBETA lattice present additional complications. CBETA makes significant use of `PATCH` elements to adjust the position and angle of the reference frame, in the splitter/combiner regions and to offset quadupoles in the arcs, these must be correctly converted in to PyZgoubi's reference change (`CHANGREF`) element. CBETA uses rectangular dipoles in 3 arrangements, with the reference orbit symmetric, normal to the entrance face or normal to the exit face. In the lattice table these dipoles

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are specified as an SBEND with entrance or exit angles used to make the faces parallel. For PyZgoubi we translate the magnets to rectangular MULTIPOL elements, adjusting the length from the chord to the straight, with a CHANGREF to correct the reference orbit.

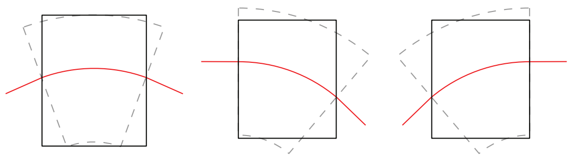

Figure 2: Rectangular bends with reference orbit symmetric, normal to entrance and normal to exit. Solid line shows the actual magnet, and the dashed line shows the sector bend used to model it.

The interpreter also allows adding additional rules that can match by name and/or element type, for example to provide additional parameters such as fringe field extents not given in the lattice table.

Figure 3 shows the layout of the first pass of the splitter region (S1) as plotted by PyZgoubi. This demonstrates that the lattice table has been correctly interpreted.

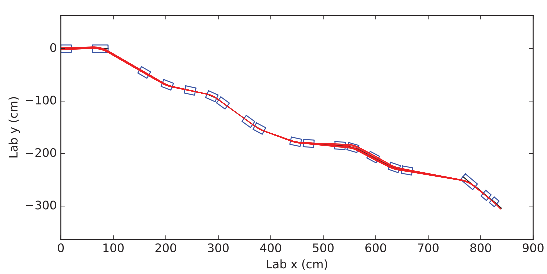

Figure 3: Layout of magnets on the first pass of the splitter line, with exaggerated beam envelope shown in red.

TRACKING

Once the lattice is loaded into PyZgoubi we can perform tracking and optics calculations to ensure that the interpretation of the Bmad file is accurate and to validate the performance of PyZGoubi.

Figure 4 shows the horizontal and vertical beta, alpha and dispersion functions in the S1 section. We see a very close agreement.

Figure 5 shows the layout for the four passes though the splitter section overlaid. We are still investigating a small layout discrepancy that results in four lines not arriving back at the same location.

The matching sections TA (and TB) continue the lattice structure from the arc, but gradually vary the doublet parameters to match into the straight section. Figure 6 shows the change in the beta functions and closed orbit along the TA section, again with good agreement to Bmad.

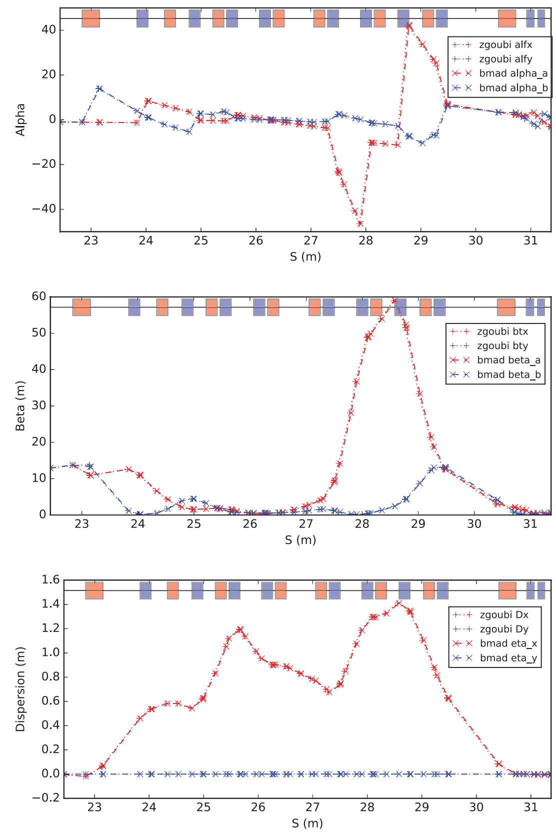

Figure 4: Comparison of the beta, alpha and dispersion functions in S1 between Bmad in dashed and PyZgoubi in dotted line.

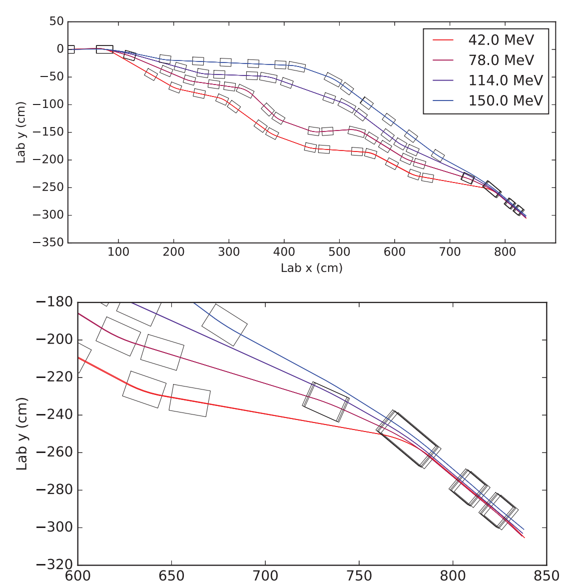

Figure 5: Layout of magnets for all four passes.

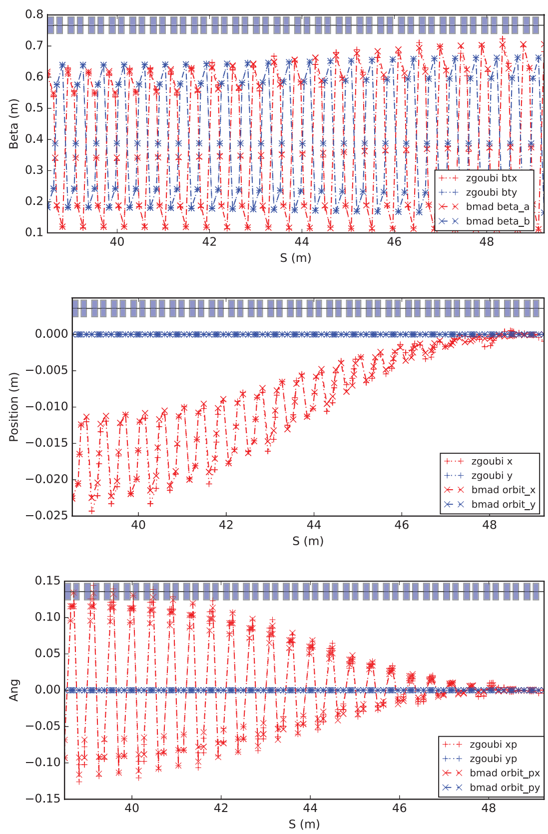

Figure 6: Comparison of the beta functions, closed orbit position and angle in the in TA pass 1 between Bmad in dashed and PyZgoubi in dotted line.

FIELD MAPS

The Zgoubi input data file for the arc cell, using field maps of the QF and BD magnets, is the following sequence:

```
'DRIFT'  HD2
6.
'DRIFT'                  ! excess length of the map
-18.35
'TOSCA'   QF
0 0
-9.69871600E-04  1.00000000E+00  1.00000000E+00  1.00000000E+00
HEADER_8  ZroBXY
501 83 27 15.1  1.
QF_v6_fieldMap           ! Field map name
0 0 0 0
2
.2
2   0.00000000E+00  0.00000000E+00  0.00000000E+00
'DRIFT'                  ! excess length of the map
-18.35
'DRIFT'    ED1
1.2
'CHANGREF'    CORNER
ZR  -2.50000000
'DRIFT'    BPM
4.2
'CHANGREF'    CORNER
ZR  -2.50000000
'DRIFT'    ED1
1.2
'DRIFT'                  ! excess length of the map
-18.9
'TOSCA'   BD
0  0
-9.69871600E-04  1.00000000E+00  1.00000000E+00  1.00000000E+00
HEADER_8  ZroBXY
501 83 27  15.1  1.0
BD_v6_fieldMap           ! Field map name
0 0 0 0
2
.2
2   0.00000000E+00  1.21927873E-01  0.00000000E+00
'DRIFT'                  ! excess length of the map
-18.9
'DRIFT'  HD2
6.
```

It uses a 3D field map for each magnet, or possibly a single field map for the complete cell (not addressed here). The field at particle location is interpolated from the map data. It is based on the TOSCA element name, just an additional one to those appearing in Tab. 1. The field map is positioned using the CHANGREF procedure as addressed earlier. Trajectory computation is performed using a Taylor series method for ODE solving [7]. Closed orbit finding, similar to the method used in matrix codes, allows deriving periodic conditions, for instance cell tunes over the energy range of the ERL. The example of the latest CBETA cell, 'version 6', is shown in Fig. 7. A numerical study of the cell is given in a companion paper [9]. This sequence, or part of it, can replace QF, or BD, or both in any part of the return ERL loop. A similar method can be used for the splitter/combner magnets. The Zgoubi method yields very high accuracy in field maps [7], precision in an ERL beam line, based on field maps, is thus straightforward and essentially depends on the accuracy of the magnetic field.

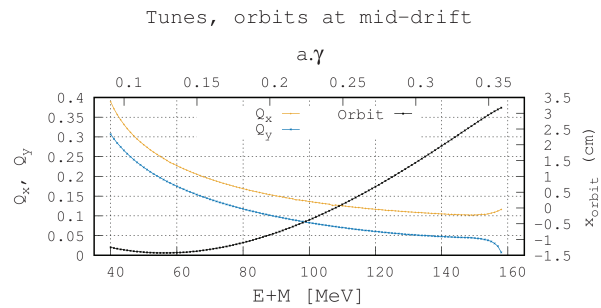

Figure 7: Energy dependence of the tunes in a CBETA cell defined using QF and BD 3D field maps, to replace the usual SBEND or MULTIPOLE optical elements.

CONCLUSION

PyZgoubi is capable of modelling the CBETA lattice, including the complexities of the splitter/combiner sections, the FFAG arcs and the graduated doublets in the matching section. It uses the well established tracking code Zgoubi, which gives confidence to the results. The agreement with the existing modelling in Bmad is good.

PyZgoubi offers the possibility of tracking with field maps, which has been found to be especially important in FFAG accelerators.

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