12th Int. Particle Acc. Conf. IPAC2021, Campinas, SP, Brazil JACoW Publishing
ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-TUPAB209

THE PARTICLE TRACKING CODE FIXFIELD

J.-B. Lagrange*, STFC/RAL, UK

Abstract

FixField is a code developed to track particles in Fixed Field alternating gradient Accelerators (FFAs). This paper discusses the structure and features of the code.

INTRODUCTION

FixField is a fork of KUT code [1], initially used to model and design scaling FFA (circular and straight), crosschecked with the straight scaling FFA experiment [2]. Other types of fixed field magnetic configuration were later also implemented. A review of the code is presented in this paper.

CODE STRUCTURE

FixField is a step-wise tracking code written in C using Runge Kutta 4 integration. The exact equations of motion integrated in the code are expressed in Cartesian coordinates (x, y, z), x for the initial horizontal direction, y the initial longitudinal direction and z the vertical direction:

$$\begin{cases} \frac{\mathrm{d}u_x}{\mathrm{d}s} = \frac{(u_y B_z - u_z B_y)}{B\rho} \\ \frac{\mathrm{d}u_y}{\mathrm{d}s} = \frac{(u_z B_x - u_x B_z)}{B\rho} \\ \frac{\mathrm{d}u_z}{\mathrm{d}s} = \frac{(u_x B_y - u_y B_x)}{B\rho} \\ \frac{\mathrm{d}x}{\mathrm{d}s} = u_x \\ \frac{\mathrm{d}y}{\mathrm{d}s} = u_y \\ \frac{\mathrm{d}z}{\mathrm{d}s} = u_z \end{cases}, \tag{1}$$

where s is the longitudinal abscissa measured along the orbit of the particle (Frenet-Serret framework), and $B\rho$ is the magnetic rigidity of the particle, also given by:

$$B\rho = \frac{p}{q}, \tag{2}$$

with p the momentum and q the charge of the particle. The magnetic field is $\vec{B} = (B_x, B_y, B_z)$, and $\vec{u} = (u_x, u_y, u_z)$ is a unit vector defined as:

$$\vec{u} = \frac{\vec{p}}{p}. \tag{3}$$

Polar coordinates (r, θ) are often used in circular cells, with $r = \sqrt{x^2 + y^2}$ and $\theta = \arctan(y/x)$.

The lattice is composed of independent cells, where the magnetic field is computed by superposition of the contribution of each magnet of the cell. Since the cells are independent of each other, artificial elements can be added in the cell outside of its physical boundary to model the effect of the neighbouring cells. Thin RF gaps are used to model acceleration.

The rotating convention used here is the trigonometric convention, so the vertical field of an F magnet for a proton is negative. Tracking is done with a fixed step size until the longitudinal boundary of the cell (maximum angle θ_{max} for circular cells, or maximum distance y_{max} for straight cells) is reached, i.e. when the coordinates of the particles exceeds the longitudinal boundary of the cell. A mirror symmetry is then assumed to put back the particle in the cell, and a procedure of iterative tracking with reduced step size is used until the particle is at a distance less than 10^{-12} m of the boundary. Horizontal and vertical collimators are set in the cell to create an allowed range beyond that particle tracking is stopped.

Different types of cells can be concatenated to create complex FFA lattices, like the nuSTORM racetrack decay ring [3]. An example of such a lattice is presented in Fig. 1.

The input of the code is done through text files and hard coded functions. The output of the code can be done either through terminal or output.

FUNCTIONALITIES

Several high level functions can be used in the code, such as

- search for closed orbits,
- linear transfer matrices computation up to the first and second order,
- tunes and phase advances,
- beta-functions and dispersion computation.

4D transfer matrices can also be decoupled with Parzen algorithm. A function to estimate how Maxwellian the magnetic field is by computing the divergence and curl of the field in the cell is available. Dynamic aperture search can be done via implemented functions that track single particles with increasing amplitude over a number of times until the particle is lost on collimators. Plots are realised using Gnuplot with integrated scripts.

AVAILABLE MAGNETIC COMPONENTS

Circular radial scaling FFA magnetic component is available with different fringe field model: hard edge, linear fringe field with first order extrapolation off the median plane, tanh fringe field with 4^{th} order extrapolation off the median plane.

Circular spiral scaling FFA magnetic component can be used with hard edge, linear fringe field with first order extrapolation off the median plane, tanh fringe field with 12^{th}

* jean-baptiste.lagrange@stfc.ac.uk

ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-TUPAB209

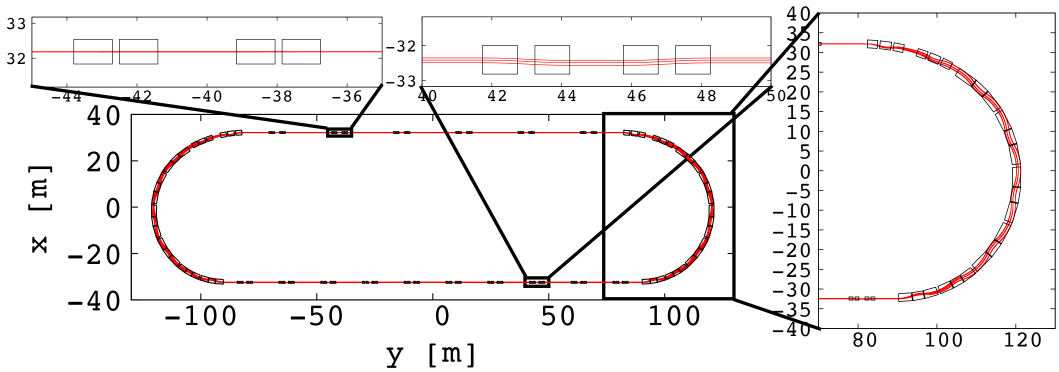

Figure 1: Schematic of the nuSTORM decay ring, designed in FixField, with normal quadrupoles (top straight part), circular scaling FFA (arc parts) and straight scaling FFA cells (bottom straight part).

order extrapolation off the median plane. We note that a radial case can be modelled with this function while setting the spiral angle to 0.

Straight scaling FFA magnetic component is also implemented. Different fringe field model are available: hard edge, linear fringe field with first order extrapolation off the median plane, tanh fringe field with 4th order extrapolation off the median plane.

Straight tilted scaling FFA magnetic component is implemented with hard edge model or linear fringe field model with first order extrapolation off the median plane.

Rectangular scaling VFFA magnetic components have been recently added with linear fringe field (first order extrapolation off the median plane), tanh fringe field model (16th order extrapolation off the median plane) or arctan fringe field model (16th order extrapolation off the median plane).

Separated function magnetic components are also available (dipole, normal quadrupole, normal sextupole, normal octopole) with hard edge model or linear fringe field model.

Tracking in 3D circular and straight field maps can also be done with trilinear interpolation. The grid can be either cylindrical or cartesian.

SUMMARY

FixField is a single particle tracking code used mainly to design scaling FFAs, either horizontal, vertical, circular and straight. Several high level functions can be used to estimate the performance of a lattice.

REFERENCES

[1] T. Planche, "Study of zero-chromatic ffag synchrotron for muon acceleration", Ph.D. thesis, Kyoto University, Japan, 2010.

[2] J.B. Lagrange, "Straight scaling FFAG line", *J. Phys. Conf. Ser.*, vol. 408, p. 012067, 2013. doi:10.1088/1742-6596/408/1/012067

[3] J.B. Lagrange, "Racetrack FFAG muon decay ring for nuSTORM with triplet focusing", *J. Instrum.*, vol. 13, no. 9, p. 09013, 2018. doi:10.1103/physrevstab.14.111002